Science's breakthrough of the year: The first quantum machine

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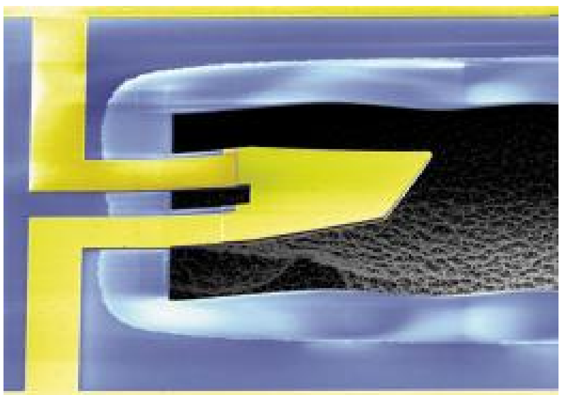

The first quantum machine — a mechanical, vibrating device, which is as long as a hair is wide.

Until this year, all human-made objects have moved according to the laws of classical mechanics. Back in March, however, a group of researchers designed a gadget that moves in ways that can only be described by quantum mechanics -- the set of rules that governs the behavior of tiny things like molecules, atoms, and subatomic particles. In recognition of the conceptual ground their experiment breaks, the ingenuity behind it and its many potential applications, *Science* has called this discovery the most significant scientific advance of 2010.

Physicists Andrew Cleland and John Martinis from the University of California at Santa Barbara and their colleagues designed the machine—a tiny metal paddle of semiconductor, visible to the naked eye—and coaxed it into dancing with a quantum groove. First, they cooled the paddle until it reached its "ground state," or the lowest energy state permitted by the laws of quantum mechanics (a goal long-sought by physicists). Then they raised the widget's energy by a single quantum to produce a purely quantum-mechanical state of motion. They even managed to put the gadget in both states at once, so that it literally vibrated a little and a lot at the same time—a bizarre phenomenon allowed by the weird rules of quantum mechanics.

Science and its publisher, AAAS, the nonprofit science society, have recognized this first quantum machine as the 2010 Breakthrough of the Year. They have also compiled nine other important scientific accomplishments from this past year into a top ten list, appearing in a special news feature in the journal's 17 December 2010 issue. Additionally, *Science* news writers and editors have chosen to spotlight 10 "Insights of the Decade" that have transformed the landscape of science in the 21st Century.

"This year's Breakthrough of the Year represents the first time that scientists have demonstrated quantum effects in the motion of a human-made object," said Adrian Cho, a news writer for *Science*. "On a conceptual level that's cool because it extends quantum mechanics into a whole new realm. On a practical level, it opens up a variety of possibilities ranging from new experiments that meld quantum control over light, electrical currents and motion to, perhaps someday, tests of the bounds of quantum mechanics and our sense of reality."

The quantum machine proves that the principles of quantum mechanics can apply to the motion of macroscopic objects, as well as atomic and subatomic particles. It provides the key first step toward gaining complete control over an object's vibrations at the quantum level. Such control over the motion of an engineered device should allow scientists to manipulate those minuscule movements, much as they now control electrical currents and particles of light. In turn, that capability may lead to new devices to control the quantum states of light, ultra-sensitive force detectors and, ultimately, investigations into the bounds of quantum mechanics and our sense of reality. (This last grand goal might be achieved by trying to put a macroscopic object in a state in which it's literally in two slightly different places at the same time—an experiment that might reveal precisely why something as big as a human can't be in two places at the same time.)

"Mind you, physicists still haven't achieved a two-places-at-once state with a tiny object like this one," said Cho. "But now that they have reached the simplest state of quantum motion, it seems a whole lot more obtainable—more like a matter of 'when' than 'if.'"

Science's list of the nine other groundbreaking achievements from 2010 follows:

Synthetic Biology: In a defining moment for biology and biotechnology, researchers built a synthetic genome and used it to transform the identity of a bacterium. The genome replaced the bacterium's DNA so that it produced a new set of proteins—an achievement that prompted a Congressional hearing on synthetic biology. In the future, researchers envision synthetic genomes that are custom-built to generate biofuels, pharmaceuticals or other useful chemicals.

Neandertal Genome: Researchers sequenced the Neandertal genome from the bones of three female Neandertals who lived in Croatia sometime between 38,000 and 44,000 years ago. New methods of sequencing degraded fragments of DNA allowed scientists to make the first direct comparisons between the modern human genome and that of our Neandertal ancestors.

HIV Prophylaxis: Two HIV prevention trials of different, novel strategies reported unequivocal success: A vaginal gel that contains the anti-HIV drug tenofovir reduced HIV infections in women by 39 percent and an oral pre-exposure prophylaxis led to 43.8 fewer HIV infections in a group of men and transgender women who have sex with men.

Exome Sequencing/Rare Disease Genes: By sequencing just the exons of a genome, or the tiny portion that actually codes for proteins, researchers who study rare inherited diseases caused by a single, flawed gene were able to identify specific mutations underlying at least a dozen diseases.

Molecular Dynamics Simulations: Simulating the gyrations that proteins make as they fold has been a combinatorial nightmare. Now, researchers have harnessed the power of one of the world's most powerful computers to track the motions of atoms in a small, folding protein for a length of time 100 times longer than any previous efforts.

Quantum Simulator: To describe what they see in the lab, physicists cook up theories based on equations. Those equations can be fiendishly hard to solve. This year, though, researchers found a short-cut by making quantum simulators—artificial crystals in which spots of laser light play the role of ions and atoms trapped in the light stand in for electrons. The devices provide quick answers to theoretical problems in condensed matter physics and they might eventually help solve mysteries such as superconductivity.

Next-Generation Genomics: Faster and cheaper sequencing technologies are enabling very large-scale studies of both ancient and modern DNA. The 1,000 Genomes Project, for example, has already identified much of the genome variation that makes us uniquely human—and other projects in the works are set to reveal much more of the genome's function.

RNA Reprogramming: Reprogramming cells—turning back their developmental clocks to make them behave like unspecialized "stem cells" in an embryo—has become a standard lab technique for studying diseases and development. This year, researchers found a way to do it using synthetic RNA. Compared with previous methods, the new technique is twice as fast, 100 times as efficient and potentially safer for therapeutic use.

The Return of the Rat: Mice rule the world of laboratory animals, but for many purposes researchers would rather use rats. Rats are easier to work with and anatomically more similar to human beings; their big drawback is that methods used to make "knockout mice"—animals tailored for research by having specific genes precisely disabled—don't work for rats. A flurry of research this year, however, promises to bring "knockout rats" to labs in a big way.

Finally, to celebrate the end of the current decade, *Science* news reporters and editors have taken a step back from their weekly reporting to take a broader look at 10 of the scientific insights that have changed the face of science since the dawn of the new millennium. A list of these 10 "Insights of the Decade" follows.

The Dark Genome: Genes used to get all the glory. Now, however, researchers recognize that these protein-coding regions of the genome account for just 1.5 percent of the whole. The rest of the genome, including small coding and non-coding RNAs—previously written off as "junk"—is proving to be just as important as the genes.

Precision Cosmology: Over the past decade, researchers have deduced a very precise recipe for the content of the universe, which consists of ordinary matter, dark matter and dark energy; as well as instructions for putting it all together. These advances have transformed cosmology into a precision science with a standard theory that now leaves very little wiggle room for other ideas.

Ancient Biomolecules: The realization that "biomolecules" like ancient DNA and collagen can survive for tens of thousands of years and provide important information about long-dead plants, animals and humans has provided a boon for paleontology. Analysis of these tiny time machines can now reveal anatomical adaptations that skeletal evidence simply can't provide, such as the color of a dinosaur's feathers or how woolly mammoths withstood the cold.

Water on Mars: Half a dozen missions to Mars over the past decade have provided clear evidence that the Red Planet once harbored enough water—either on it or just inside it—to alter rock formations and, possibly, sustain life. This Martian water was probably present around the time that life was beginning to appear on Earth, but there is still enough moisture on Mars today to encourage scientists seeking living, breathing microbes.

Reprogramming Cells: During the past decade, the notion that development is a one-way street has been turned on its head. Now, researchers have figured out how to "reprogram" fully developed cells into so-called pluripotent cells that regain their potential to become any type of cell in the body. This technique has already been used to make cell lines from patients with rare diseases, but ultimately, scientists hope to grow genetically matched replacement cells, tissues and organs.

The Microbiome: A major shift in the way we view the microbes and viruses that call the human body home has led researchers to the concept of the microbiome—or the collective genomes of the host and the other creatures that live on or inside it. Since 90 percent of the cells in our bodies are actually microbial, scientists are beginning to understand how significantly microbial genes can affect how much energy we absorb from our foods and how our immune systems respond to infections.

Exoplanets: In the year 2000, researchers were aware of just 26 planets outside our solar system. By 2010, that number had jumped to 502—and still counting. With emerging technologies, astronomers expect to find abundant Earth-like planets in the universe. But for now, the sizes and orbits of larger planets already discovered are revolutionizing scientists' understanding of how planetary systems form and evolve.

Inflammation: Not long ago, inflammation was known as the simple sidekick to our healing machinery, briefly setting in to help immune cells rebuild tissue damage caused by trauma or infection. Today, however, researchers believe that inflammation is also a driving force behind the chronic diseases that will eventually kill nearly all of us, including cancer, Alzheimer's disease, atherosclerosis, diabetes and obesity.

Metamaterials: By synthesizing materials with unconventional and tunable optical properties, physicists and engineers have pioneered new ways to guide and manipulate light, creating lenses that defy the fundamental limits on resolution. They've even begun constructing "cloaks" that can make an object invisible.

Climate Change: Over the past decade, researchers have solidified some fundamental facts surrounding global climate change: The world is warming, humans are behind the warming and the natural processes of the Earth are not likely to slow that warming. But, the next 10 years will determine how scientists and policymakers proceed with this vital information.

More information: www.sciencemag.org/special/insights2010/

Source: AAAS