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WEIZMANN INSTITUTE OF SCIENCE

Science Tips

Publications and Media Relations Department, Rehovot, Israel 76100 Tel: 972-8-934-3852 / 56 Fax: 972-8-934-4132
http://wis-wander.weizmann.ac.il news@weizmann.ac.il
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Weizmann Institute Scientists Show

Quantum Systems Could Flout Physics Law

Scientists in the Weizmann Institute's Faculty of Chemistry, together with colleagues in Germany, have made a startling prediction: Simply "taking the temperature" of certain quantum systems at frequent intervals might cause them to disobey a hard and fast rule of thermodynamics.

Thermodynamics tell us that the interaction between a large heat source (a heat bath) and an ensemble of much smaller systems must bring them – at least on average – progressively closer to thermal equilibrium. Now Prof. Gershon Kurizki, Dr. Noam Erez and doctoral student Goren Gordon of the Chemical Physics Department, in collaboration with Dr. Mathias Nest of Potsdam University, Germany, have shown that ensembles of quantum systems in thermal contact with a heat bath could present a drastic departure from this allegedly universal trend, a prediction they recently reported in *Nature*.

With complete disregard for this physical rule, the ensemble may, remarkably, heat up even when it is hotter than the bath or cool down when it is colder. The scientists showed that if the energy of these systems is measured repeatedly, both systems and bath will undergo temperature increase or decrease, and this change depends only on the rate of measurement – not on the actual results of these measurements.

How can these effects of quantum measurements be explained? As opposed to classical measurement, which may be completely nonintrusive, measuring quantum systems decouples them from their heat bath. This decoupling, followed by recoupling of the two when measurement ceases, introduces energy (at the expense of the measuring apparatus) into the systems and the bath alike, and thus heats them up. When this happens over a very short time interval, the systems cannot be discriminated from the bath. For longer time intervals, the systems and bath start exchanging energy as coupled oscillators (analogous to connected springs). This energy exchange will cause the quantum systems to lose energy to the bath, thus lowering the temperature of the ensembles. Depending on whether the measurements are repeated at short or long intervals, it should be possible to heat up or cool down the systems.

The predicted effects may be the key to developing novel heating and cooling schemes for atomic, molecular and solid-state devices. Such schemes might allow ultrafast temperature control by optical measurements performed at an extremely high rate. ▮

Weizmann Institute Scientists Find

New "Quasiparticles"

Weizmann Institute physicists have demonstrated, for the first time, the existence of "quasiparticles" with one quarter the charge of an electron. This finding could be a first step toward creating exotic types of quantum computers that might be powerful, yet highly stable.

Fractional electron charges were first predicted over 20 years ago under conditions existing in the so-called quantum Hall effect, and were found by the Weizmann group some ten years ago. Although electrons are indivisible, if they are confined to a two-dimensional layer inside a semiconductor, chilled down to a fraction of a degree above absolute zero and exposed to a strong magnetic field that is perpendicular to the layer, they effectively behave as independent particles, called quasiparticles, with charges smaller than that of an electron. But until now, these charges had always been fractions with odd denominators: one third of an electron, one fifth, etc.

The experiment done by research student Merav Dolev in Prof. Moty Heiblum's group, in collaboration with Drs. Vladimir Umansky and Diana Mahalu, and Prof. Ady Stern, all of the Condensed Matter Physics Department, owes the finding of quarter-charge quasiparticles to an extremely precise setup and unique material properties: The gallium arsenide material they produced for the semiconductor was some of the purest in the world. The scientists tuned the electron density in the two-dimensional layer – in which about three billion electrons were confined in the space of a square millimeter – such that there were five electrons for every two magnetic field fluxes. The device they created is shaped like a flattened hourglass, with a narrow "waist" in the middle that allows only a small number of charge-carrying particles to pass through at a time. The "shot noise" produced when some passed through and others bounced back caused fluctuations in the current that are proportional to the passing charges, thus allowing the scientists to accurately measure the quasiparticles' charge.

Quarter-charge quasiparticles should act quite differently from odd fractionally charged particles, and this is why they have been sought as the basis of the theoretical "topographical quantum computer." When particles such as electrons, photons, or even those with odd fractional charges change places with one another, there is little overall effect. In contrast, quarter-charge particle exchanges might weave a "braid" that preserves information on the particles' history. To be useful for topologically-based quantum computers, the quarter-charge particles must be shown to have "non-Abelian" properties – that is the order of the braiding must be significant. These subtle properties are extremely difficult to observe. Heiblum and his team are now working on devising experimental setups to test for these properties. ❚

Prof. Moty Heiblum's research is supported by the Joseph H. and Belle R. Braun Center for Submicron Research. Prof. Heiblum is the incumbent of the Alex and Ida Sussman Professorial Chair in Submicron Electronics.

Weizmann Institute Scientists Develop

A New Approach to Treating Autoimmune Disease

In autoimmune diseases, the immune system turns against the body's own tissues and organs, wreaking havoc and destruction for no apparent reason. Partly because the origins of these diseases are so obscure, no effective treatment exists, and the suffering they inflict is enormous. Now Weizmann Institute scientists have developed a method that in the future may make it possible to treat autoimmune diseases effectively without necessarily knowing their exact cause. Their approach is equivalent to sending a police force to suppress a riot without seeking out the individuals who instigated the unrest.

In healthy people, a small but crucial group of immune cells called regulatory T cells, or T-regs, keeps autoimmunity in check, but in people with inflammatory bowel disease (IBD), one of the most common autoimmune disorders, too few of these cells appear in the diseased intestine, and the ones that do fail to function properly. The new Weizmann Institute approach consists of delivering highly selective, genetically engineered functioning T-regs to the intestine. The study was conducted by Dr. Eran Elinav, a physician from Tel Aviv Sourasky Medical Center's gastroenterology institute who is working toward his Ph.D. at the Weizmann Institute, and lab assistant Tova Waks, in the laboratory of Prof. Zelig Eshhar of the Immunology Department.

Relying on Eshhar's earlier work in which he equipped a different type of T cell to zero in on cancerous tumors, the team genetically engineered T-regs, outfitting these cells with a modular receptor consisting of three units. One of these units directed the cells to the intestine while the other two made sure they became duly activated. As reported in the journal *Gastroenterology*, the approach proved effective in laboratory mice with a disease that simulates human IBD: Most of the mice treated with the genetically-engineered T-regs developed only mild inflammation or no inflammation at all.

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The cells produced what the scientists called a "bystander" effect: They were directed to the diseased tissue using neighboring, or "bystander" markers that identified the area as a site of inflammation, and suppressed the inflammatory cells in the vicinity by secreting soluble suppressive substances.

The scientists are currently experimenting with human T-regs for curing ulcerative colitis and believe that in addition to IBD, their "bystander" approach could work in other autoimmune disorders, even if their causes remain unknown. They also think the method could be valuable in suppressing unwanted inflammation in diseases unrelated to autoimmunity, as well as in preventing graft rejection and certain complications in bone marrow and organ transplantation, in which inflammation is believed to play a major role. ❚

Prof. Zelig Eshhar's research is supported by the M.D. Moross Institute for Cancer Research; the Phyllis and Joseph Gurwin Fund for Scientific Advancement; and the Friends of Assaf Harofeh Medical Center. Prof. Eshhar is the incumbent of the Marshall and Renette Ezralow Professorial Chair of Chemical and Cellular Immunology.