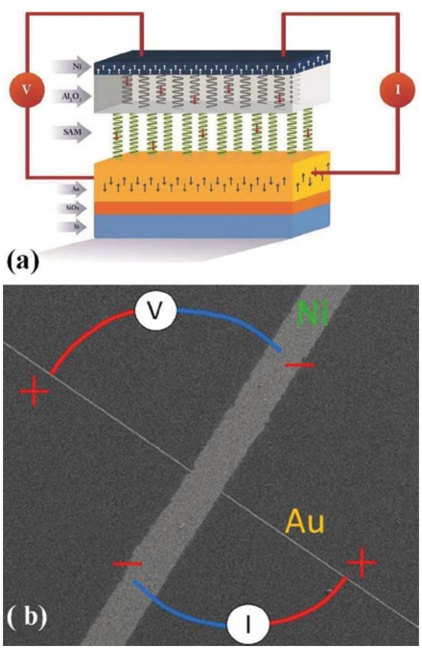
The recent discovery of the Chiral Induced Spin Selectivity (CISS) Effect marks a new stage in our understanding of how electrons travel through chiral molecules. This opens up new possibilities in the application of chiral molecules, and could also lead to new insights into electron transfer processes in biological systems, as **Professor Ron Naaman** explains

Unravelling the secrets of the CISS effect

The recent discovery of the Chiral Induced Spin Selectivity (CISS) effect, where researchers found that electron transmission yield through chiral molecules depends on the spin orientation of the electron, opens up a range of research opportunities. Based at the Weizmann Institute of Science in Israel, Professor Ron Naaman is the Principal Investigator of the CISS project, an initiative which is investigating the effect, building on existing knowledge of biomolecules. "All biomolecules have what is called a chiral (hand in Greek) character. Namely there are two types of molecules with exactly the same chemical properties; however, they are a mirror image of each other. In biology, molecules have a specific type of chirality, and that's why the electron transfer properties through these molecules are so important," he outlines.



Above: (a) Scheme of the device and of the four-probe measurement. The Au/SAM/Al2O3/Ni device is constructed on a Si/SiOx substrate. The chiral SAM/Al2O3 tunneling barrier polarizes the spin distribution of transmitted electrons, and it is probed by the magnetic field dependence of the resistivity through the Ni layer. (b) A SEM image (top view) of the device with a thin (1 micrometer wide) gold trace and a wide (50 micrometer) nickel trace perpendicular to it.

The CISS effect relates to how electrons travel through these chiral molecules. "Electrons have two key properties: one is that they are negatively charged, and the second is spin. You can think about it as electrons rotating clockwise or counter-clockwise – these are the two states of the spin," continues Professor Naaman. "We've found that where electrons go through chiral molecules, one state of spin is preferred over the other. That's very interesting, because typically you get this spin selection only with ferromagnetic materials. Chiral molecules are not a magnetic material, yet still only one state of spin can be transmitted through them."

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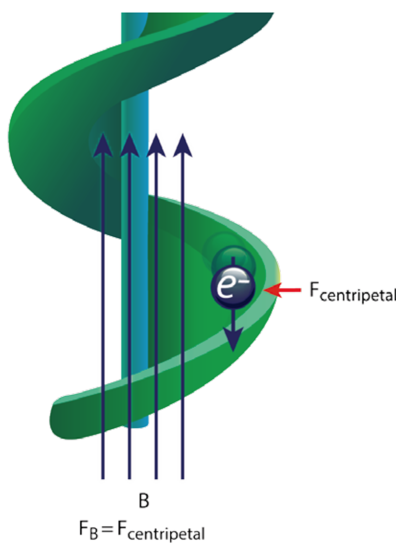
A combination of experimental methods are being used in the project to investigate the CISS effect, including photoelectron spectroscopy, single molecule conduction and spin-specific conduction. One initial goal was to establish the parameters that affect the magnitude of the CISS effect. "One key parameter is of course the molecular length. If we think of chiral molecules as a helix (coil) other parameters that affect the CISS effect are the radius of the coil and its pitch," explains Professor Naaman. This work is combined with investigating the role of the CISS effect in electron transfer in biology-related systems. "We tried to understand, first of all, to what extent spin polarization helps in electron transfer and makes it more efficient," says Professor Naaman.

The project is both pursuing fundamental research into the CISS effect and also exploring potential commercial applications. This work is set to have a significant impact on many fields of research, including biology. "In biology, it's known that electron transfer is very efficient over relatively long distances. The question was why? Now that we understand it better we know that it's related to the CISS effect," says Professor Naaman. Researchers have established that because one state of spin is preferred over the other, the electron can move over longer distances. "Think about a bullet after it's been fired out of a rifle – because it rotates, that bullet moves forward in a more stable way and for a longer time than if it doesn't rotate," explains Professor Naaman.



A model describing electron transport through chiral molecules. A centripetal force is acting on the electron keeping it bound to the molecule. In the rest frame of the electron this force is represented as a magnetic field acting along the axis of the molecule. This effective magnetic field is responsible to the spin selectivity of the electron transmission.

Industrial applications

These findings hold real importance in terms of potential industrial applications. The CISS effect represents a change in the established paradigm, opening up innovative new approaches to technical development. “We can make electronics where, instead of measuring the charge of the electrons, we measure the spin of them. The advantage there is that we can make electronic devices which consume less energy,” explains Professor Naaman. This field of technology is called spintronics; previously researchers had to use magnetic materials to define and to measure the electrons’ spin in spintronics devices. The project’s research will result in the establishment of chiral organic molecules as a new substrate for spintronics applications. “We are building devices that, instead of using ferromagnets – which are complicated and difficult to handle – use chiral molecules. So we can change the material,” continues Professor Naaman.

The use of chiral molecules could make it much easier to produce spin valve devices, which are used in all hard discs. These devices could be made much smaller with chiral molecules, which Professor Naaman believes will bring some significant benefits. “The advantage will be that we can read information on the hard disc at a much higher resolution, which means we can put more information per area,” he says. This holds real importance given the trend towards miniaturisation in the technology sector, and consumer demand for ever-higher levels of performance, underlining the wider relevance of the project’s work.

There are also other potential industrial applications for this research. For example, many people have tried to artifically produce hydrogen as a means of generating energy, but Professor Naaman says there is room for improvement in this regard. “So far, efforts to artificially produce hydrogen have been very inefficient, but it’s not clear why,” he outlines. Researchers have found that if they can control the process in which electrons are transferred in such a way that only one spin state is transferred, then efficiency improves dramatically, while Professor Naaman says there are many other implications arising from the project’s work. “We have also observed that when electrons are transferred in photosynthesis for example, only one spin is transferred,” he outlines.

This work in investigating the role of the CISS effect in biology will form an important part of Professor Naaman’s future research agenda. Along with establishing the role of the CISS effect in biology, Professor Naaman is also looking towards further development of specific devices. “We are trying to build different devices, such as magnetic memory devices and spin filter devices, that are based on the CISS effect,” he says. This work is of real interest to the commercial sector, in particular high-tech industries, and their feedback is helping to guide the project’s research. “There is feedback from industry – we are in contact with several companies, and we are trying to respond to the needs of industry,” says Professor Naaman.

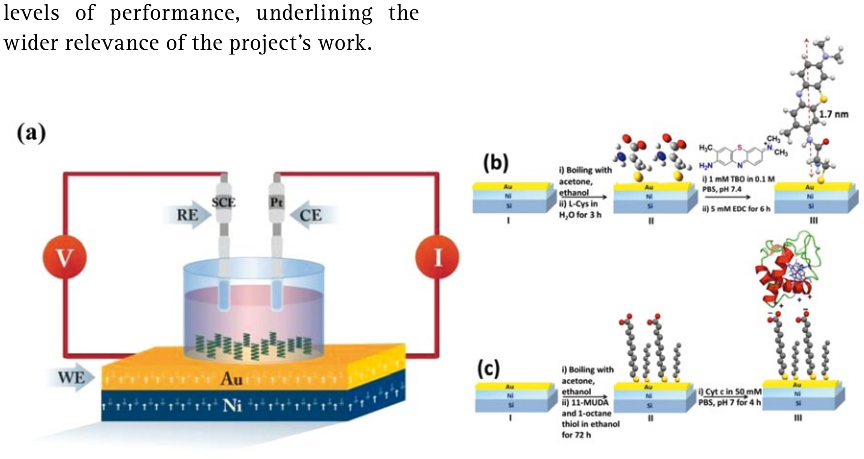


Figure Above: Panel (a) shows a schematic diagram that illustrates the electrochemistry setup, in which a gold-coated Ni film is the working electrode (WE), a platinum wire is the counter electrode (CE), and a Saturated Calomel Electrode (SCE) is the reference (RE) electrode. The Ni electrode is magnetized with an external magnetic field (H) that is applied by placing a permanent magnet below the Ni electrode, with its magnetic dipole pointing up or down (white and yellow arrows, respectively). Panel (b) illustrates the protocol for covalently tethering TBO to the working electrode via a cysteine (L or D) linker. Panel (c) illustrates the protocol for preparing a mixed monolayer of 11-mercaptoundecanoic acid and 1-octanethiol and immobilizing cytochrome c on it.

At a glance

Full Project Title
Chiral Induced Spin Selectivity (CISS)

Project Objectives
1. Verifying the parameters that affect the spin selectivity of electrons transport through chiral molecules.
2. Constructing spintronics devices that are based on the CISS effect
3. Investigating the role of the effect in electron transfer through bio-molecules and bio-systems.

Project Funding
The research has received funding from the European Research Council under the European Union’s Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement n° 338720.

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Professor Ron Naaman

Professor Ron Naaman is a full Professor in the Department of Chemical Physics at the Weizmann Institute of Science. A Fellow of the American Physical Society. Ron Naaman was a Postdoctoral Fellow at Stanford University in California before moving on to becoming a lecturer and research associate at Harvard. His research and lecturing activities then took him to Weizmann as well as visiting positions at the Joint Institute for Laboratory Astrophysics (JILA) at Boulder Colorado, the University of Pittsburg, University of California Santa Barbara, EPFL in Lausanne Switzerland, and the Technical University in Dresden, Germany. Ron Naaman main research interests are in electronic properties of nano devices and interfaces.