A strategy to control the spin polarization of electrons using helium

November 2 2021, by Ingrid Fadelli

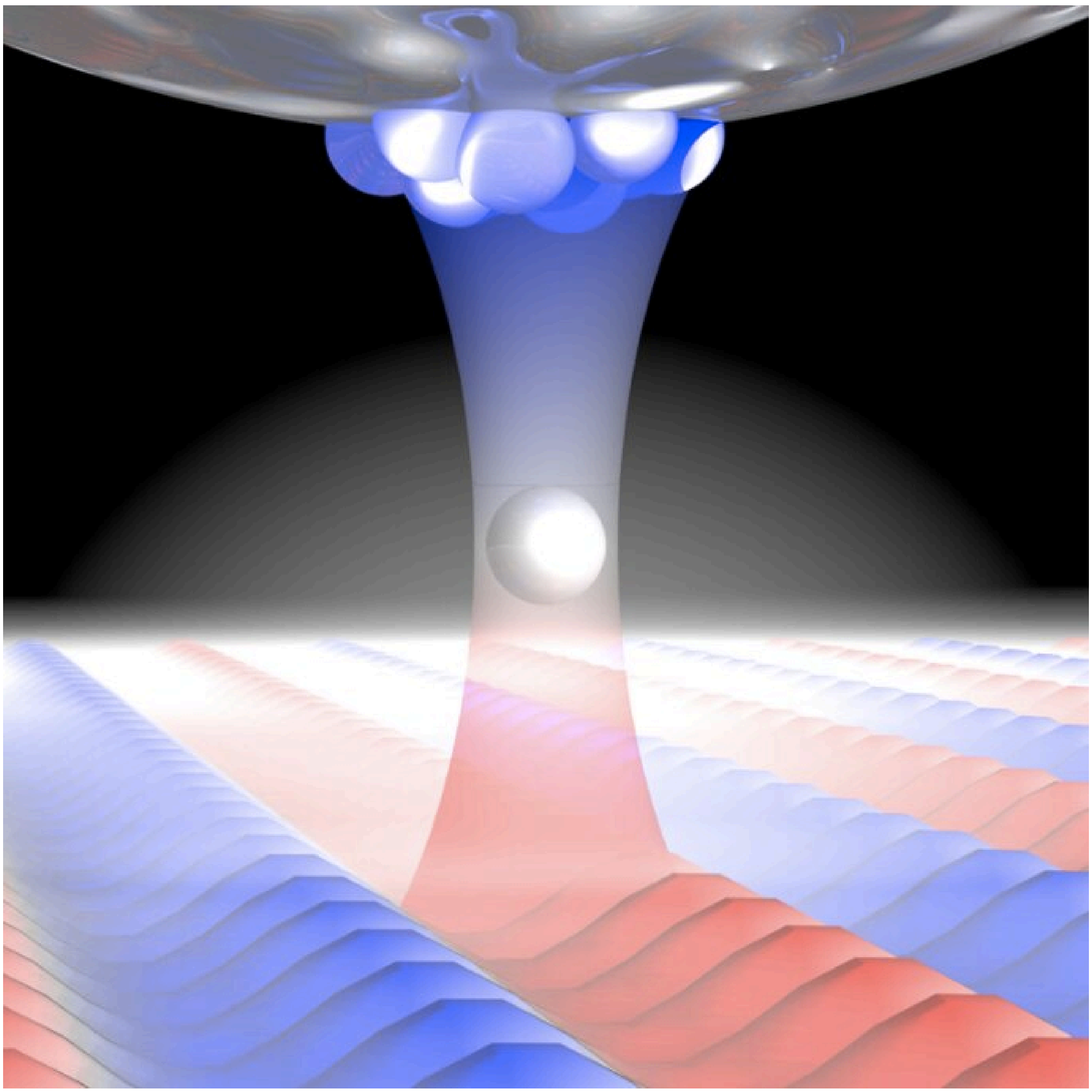


Figure showing a Helium atom trapped between the STM tip and the sample. Credit: Trainer et al.

Spintronics, also known as spin electronics, is a research field that explores how the intrinsic spin of electrons and its magnetic moment can be exploited by devices. Spintronic devices are promising for a wide range of applications, particularly for efficiently storing and transferring data.

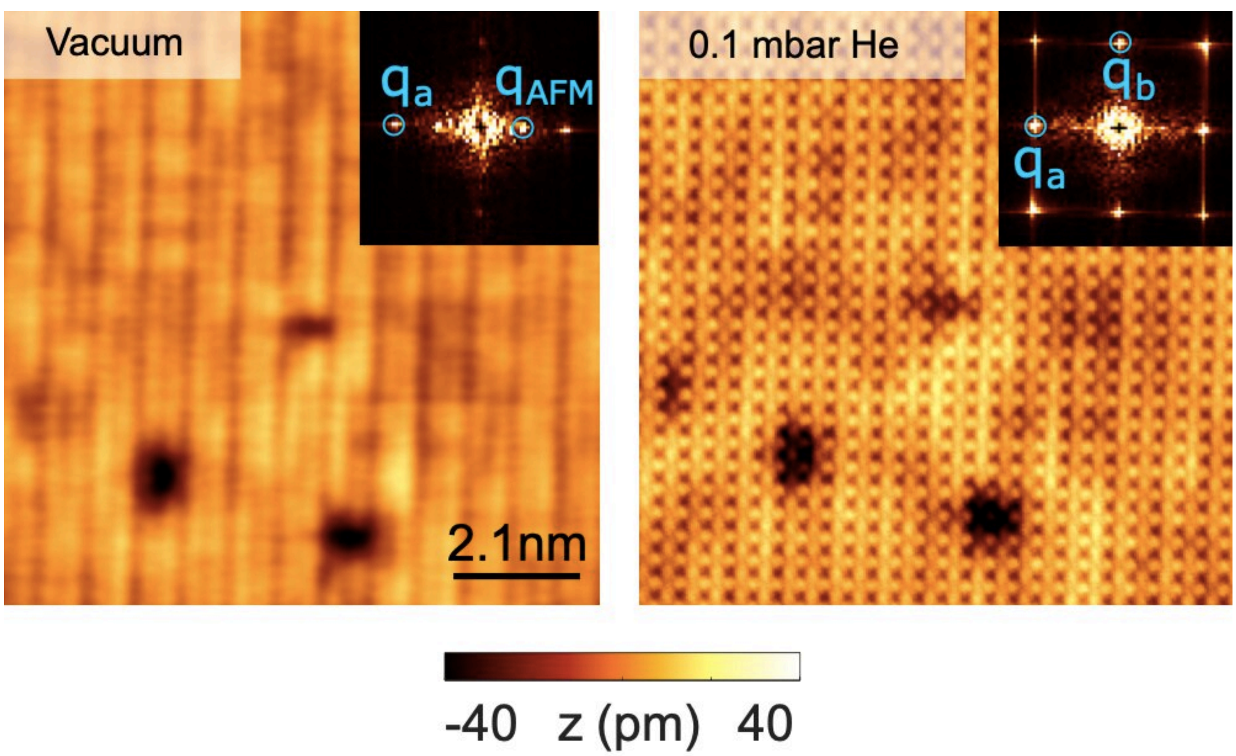
The key requirement for spintronic devices is the ability to control and detect the spin polarization of electrons. The spin polarization is essentially the degree to which the spin (i.e., the intrinsic angular momentum of electrons and other elementary particles) is aligned with a specific direction.

Researchers at University of St Andrews in the U.K. and other institutes worldwide have recently shown that helium can influence the spin polarization of the tunneling current and magnetic contrast of a technique known as spin-polarized scanning tunneling microscopy (SP STM). Their findings, published in *Physical Review Letters*, could have important implications for the development of new electronic devices.

In their previous research, the same research group investigated the magnetic order in the antiferromagnetic material iron telluride. Remarkably, they found that by collecting magnetic material from their sample's surface using an STM tip, they could image the sample's magnetic order.

"As part of my Ph.D. project, I was to set up a new STM in a vector magnet and one of the first measurements I set out to do was reproduce this imaging," Christopher Trainer, one of the researchers who carried out the study, told Phys.org. "I tried hard, but couldn't get it to work. This was a huge puzzle to us because usually, this measurement worked fairly straightforwardly, until we found that the new microscope had a leak in its vacuum seal so that the liquid helium that we used to cool the experiment could enter the measurement chamber."

Based on their previous observations, Trainer and his colleagues set out to test the hypothesis that helium could affect their microscope's ability to image the magnetic order. To do this, they fixed the helium leak and systematically added helium to their microscope's measurement chamber. Their experiments revealed that helium trapped between the STM tip and their sample could completely suppress the microscope's ability to detect the magnetic order.



Scanning tunneling microscope images of the Iron Telluride surface before and after the Helium was added. In the vacuum image the magnetic order shows up as a stripe-like pattern, which disappears once the Helium is added. Credit: Trainer et al.

"We would usually never have deliberately added helium in the vacuum can of our microscope, because it risks destroying the STM head," Peter Wahl, another researcher involved in the study, told Phys.org. "In fact, due to the high voltages required to control the tip position, one can get arc discharges in the wiring, effectively 'burning' the measurement head, the heart of our microscope. In hindsight, the key effect, (i.e., that we become sensitive to exchange interactions once there is a probe particle in the tunneling junction) was probably predictable, but nobody had carried out the measurement."

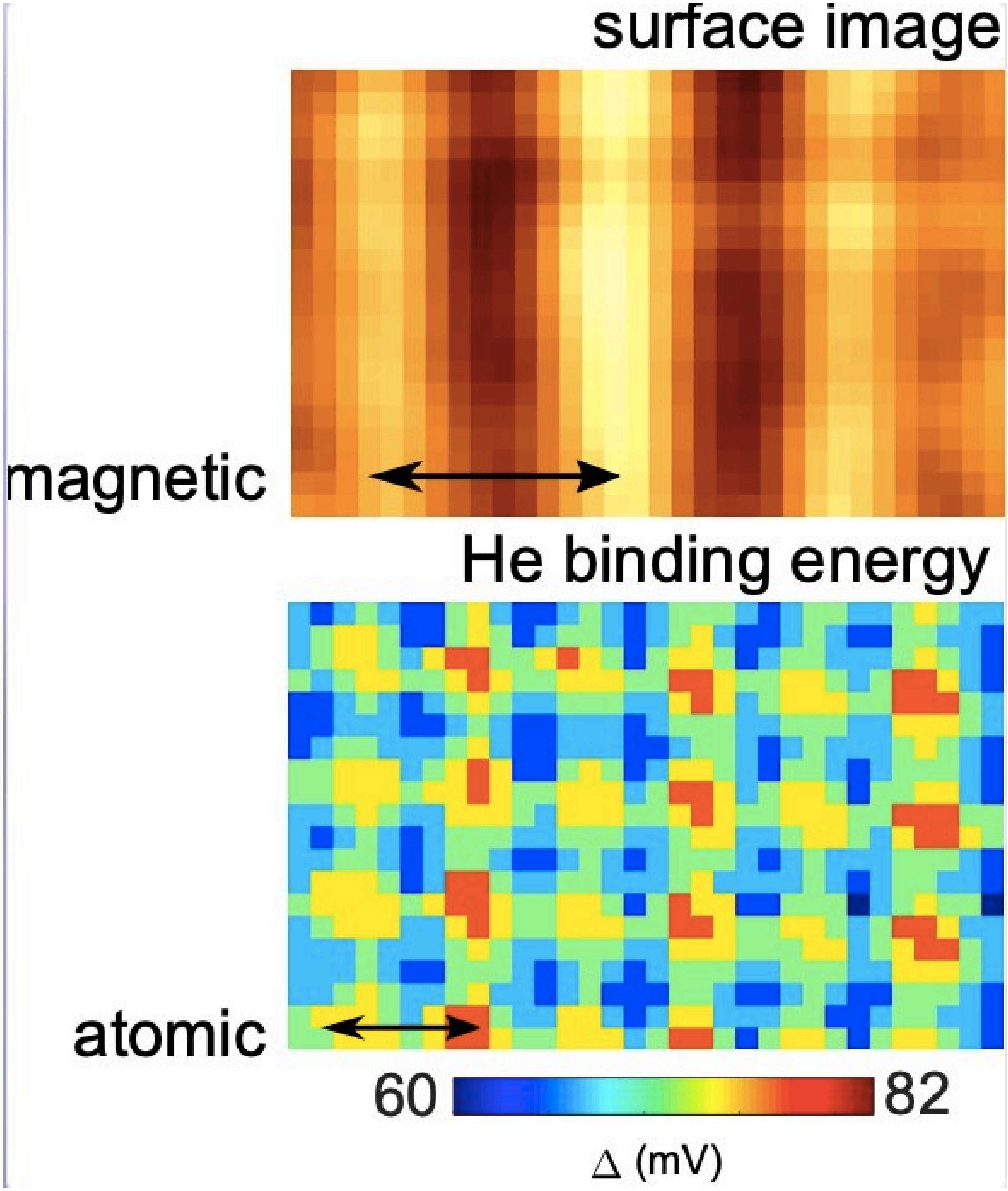
In their recent study, Trainer, Wahl and their colleagues used an STM, a microscope that can be used to image surfaces at the atomic level, to measure a sample of iron telluride that exhibited an unusual antiferromagnetic order. Notably, STM microscopes work by leveraging the ability of electrons to 'quantum tunnel' through potential barriers that they would not typically be able to pass through.

"When bringing an atomically sharp tip extremely close to the surface of a sample (to well within one billionth of a meter) electrons can 'jump' between the tip and the sample," Trainer explained. "By moving the tip across the sample surface, we can use this effect to build up an atomic picture of the sample's surface. The STM is also able to image magnetic order if the probe tip of the microscope is magnetic."

The key objective of the experiments conducted by Trainer, Wahl and their colleagues was to determine what effect helium atoms trapped between this tip and an iron telluride sample would have. By changing the voltage applied between the STM tip and their sample, the team could eject the helium atoms from between the tip and the sample.

"We found that the voltage that is required to kick out the helium gives us access to its binding energy and is dependent on the magnetic interaction between the tip and the sample and so by precisely measuring the voltage required to eject the Helium across the sample surface we could map out the magnetic exchange interaction (or the magnetic force) between the tip and the sample," Trainer explained.

Interestingly, the researchers also found that the presence or absence of helium in the tunneling junction dramatically impacted the spin-polarization of the tunneling electrons. This means that by applying different voltages to the sample and consequently the helium in the tunneling junction one can control the spin-polarization of the tunneling current.



An image showing the iron telluride surface recorded at a voltage when the helium is forced out from between the tip and sample. Bottom: A mapping of the energy necessary to eject the helium atom from the tunnel junction. The energy required can be seen to vary with the underlying magnetic order, providing a way to map the magnetic exchange interaction. Credit: Trainer et al.

"The two key results of our study are that we can control the spin polarization of the electrons that tunnel between the tip and the sample using an applied voltage, as well as measure the exchange interaction between tip and sample without having to undertake a force measurement, as had been done previously," Trainer said.

In the future, the method for controlling the spin polarization of electrons using an applied voltage presented by this team of researchers could enable the development of new spintronic circuits and devices. Meanwhile, Trainer, Wahl and their colleagues plan to conduct further studies aimed at testing the strategy introduced in their recent paper further.

"There are many exotic quantum materials with complex magnetic phases that show interesting physics however disappointingly many of these materials are insulating which means that they cannot be directly studied by a scanning tunneling microscope," Trainer added. "One of our future research plans is to grow thin layers of these insulating magnetic materials on a metallic substrate which would allow the electrons from the microscope to tunnel through the insulating layer."

Ultimately, Trainer and his colleagues hope that by applying a layer of helium to an insulating surface and collecting measurements with a magnetic tip, they will be able to measure the exchange interaction between the tip and the insulating layer. This would in turn allow them to characterize the magnetism of the insulating magnetic materials they examine, which would otherwise be undetectable by STM techniques.

"Our method provides a new way to image quantum magnetism, for example in frustrated magnetic systems," Wahl said. "An interesting open question is how magnetic fluctuations would affect the exchange interaction and whether this method would be sensitive to fluctuating magnetic orders."

More information: C. Trainer et al, Probing Magnetic Exchange Interactions with Helium, *Physical Review Letters* (2021). DOI: 10.1103/PhysRevLett.127.166803