of CRISPR-Cas genome-editing technology has made it possible to successfully inactivate 62 PERVs in immortalized pig cells (*12*), and now the same group, in Niu *et al.*, inactivated all PERVs in primary cells and used these cells to generate live, healthy, genetically modified pigs (*1*) (see the figure). The pig strain used for this experiment normally carries 25 copies of PERV-A and PERV-B. Using CRISPR-Cas to introduce an inactivating mutation in a highly conserved region in the *pol* gene that encodes reverse transcriptase, all 25 PERVs in the primary cells were inactivated and unable to produce infectious virus particles. Using nuclei from these cells, embryos were produced by somatic cell nuclear transfer and transferred into surrogate sows with no PERV-C and minimal PERV numbers. They produced 37 PERV-inactivated piglets from 17 sows—15 piglets remain alive, and the oldest healthy pigs were four months old at the time of publication. Although it remains unclear whether PERVs can actually infect humans (even though they can infect human cells in culture) and induce diseases that are typical for retroviruses, such as immunodeficiency or cancer, this new achievement will allay fears of PERV infection after xenotransplantation. This is a step forward in the clinical application of xenotransplantation; however, the other problems—immune rejection, physiological compatibility, and the elimination of other potentially zoonotic viruses—have to be solved.

There is another interesting piece of information gained from Niu *et al.*: In numerous species, including humans, the envelope proteins of endogenous retroviruses play an important role in the generation of the placenta (*13*). These proteins, known as syncytins, help generate the syncytiotrophoblast in the placenta and may have immunosuppressive properties (*14*). The fact that the genetically engineered pigs were born healthy indicates either that the disruption of the reverse transcriptase does not affect the function of the envelope proteins or that placentogenesis in pigs does not, after all, require retroviral envelope proteins. ■

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ULTRAFAST OPTICS

Angular momentum can slow down photoemission

Electrons with high angular momentum are the last to emerge from a solid

By **Vladislav S. Yakovlev** *and* **Nicholas Karpowicz**

Photoemission spectroscopy, where the absorption of an energetic photon by a material results in the emission of an electron, is an invaluable source of information about electronic structure. Electrons gain their kinetic energies by interacting with both light and their surroundings. In a solid, for example, this makes it possible to measure band energies, energies and lifetimes of quasiparticles, spectral density of states, surface states, and both elastic and inelastic scattering processes. Since the photoelectric effect was explained by Max Planck and Albert Einstein, the fundamental processes behind photoemission have been thoroughly studied in both experiment and theory, but do we fully understand the dynamics of electron emission? On page 1274 of this issue, Siek *et al.* (*1*) show that the angular momentum of the electron affects which electrons are emitted first from an atom in a solid.

"...the local environment of a bound electron, which is dominated by atomic potentials, leaves measurable signatures in time-resolved photoemission."

When an energetic photon is absorbed by an atom, it takes a very short time for the outgoing electron wave packet to form. The formation time can be roughly estimated as the ratio of the Bohr radius to the electron's final velocity, which gives 2×10^{-17} s (20 as) for a 30-eV electron. Direct access to processes that occur on such short time scales was once unimaginable, but at the beginning of this century, a series of breakthroughs led to what is currently known as attosecond physics (*2*). Its toolbox allows for such measurements, especially attosecond streaking (*3*). In this technique, the electron is set free by a pulse of energetic photons lasting <1 fs. Photoemission takes place in the presence of a laser field that does not ionize on its own, but instead shifts the energy of the electron depending on the moment at which it is emitted. In these measurements, time can be mapped onto electron energy or momentum.

Why is this valuable? Whereas conventional photoemission measurements are only sensitive to real-valued photoemission cross sections, attosecond streaking gives access to complex-valued probability amplitudes of photoemission into a certain direction. In this framework, the electron wave packet emerging from a given energy level is a duplicate of the attosecond pulse, but with its phase shifted by the phase of the responsible transition matrix element. The first derivative of this phase with respect to energy is related to the Eisenbud-Wigner-Smith delay, originally studied in the context of electron scattering (*4*). In a single-electron atomic system, calculating this delay is simple, but for more complex quantum systems, theorists must make approximations, and experimental verification of their predictions puts these models through a new line of scrutiny.

Apart from testing various assumptions and approximations, one of the persisting challenges is explaining these delays in clear physical terms. For atoms, the centrifugal barrier experienced by an electron wave with a nonzero angular momentum was identified as one of the important factors that determine the group delay of an electron wave packet. Does the centrifugal barrier matter in a solid, where electrons are exposed to a complex environment created by a crystal lattice and other electrons? This was the question that Siek *et al.* asked. Solids are much more complex than individual atoms, so the answer was not trivial.

To investigate this question, they performed attosecond streaking measurements on tungsten diselenide, WSe_2 (see the figure). This van der Waals material consists of alternating sheets of W and Se, with the

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topmost layer consisting of Se. For this material, photoelectrons emitted by a 91-eV pulse belong to four easily distinguishable classes. The fastest electrons originate from the valence band, and the slower ones leave vacancies in the 4s and 3d subshells of Se, as well as in the 4f subshell of W. Thus, in a single measurement, it was possible to determine the formation of wave packets emerging from atomic orbitals with zero, two, or three quanta of angular momentum.

In the idealized picture of photoemission from atomic orbitals, the outgoing partial waves would have angular momenta up to four (photoemission with a linearly polarized field changes the angular momentum by one). Each partial wave with a nonzero angular momentum is subject to a repulsive centrifugal potential. This potential is frequently called centrifugal barrier. It is not a barrier in the way of an outgoing electron wave—this barrier keeps an electron away from the nucleus. However, in many-electron atoms with strong electron screening, another potential barrier may form through the combined action of the repulsive centrifugal force and attractive atomic forces. The elastic scattering of a wave packet from centrifugal potential modifies the timing of the wave packet's emission.

Because the electrons originating from states with higher angular momenta see higher effective outward forces, it is counterintuitive that they are the most delayed in the atomic model of the photoemission process. Nevertheless, this idealized picture correctly predicts the order in which wave packets leave the WSe_2 sample: The larger the angular momentum of the atomic orbital that an electron vacates, the longer it takes for the wave packet to begin interacting with the laser field.

This work demonstrates that the local environment of a bound electron, which is dominated by atomic potentials, leaves measurable signatures in time-resolved photoemission. Knowing this is important for taking further steps. Now researchers can ask more detailed questions about how much one can learn about angstrom-scale potential landscapes surrounding initial electronic states. Perhaps we can even learn something about how this landscape changes once an electron begins to move. Here, the relation between the conventional angle-resolved photoemission spectroscopy and attosecond streaking spectroscopy somewhat resembles that between the conventional microscopy and phase-contrast microscopy; the additional phase information may be difficult to obtain, but it reveals otherwise invisible details. The phase information utilized in most attosecond streaking measurements is, at this moment, largely limited to photoemission delays—the first term in a series expansion of the phase information available. As the use of attosecond techniques becomes more widespread, it is likely that photoelectrons will tell us much more than just how late they were. ■

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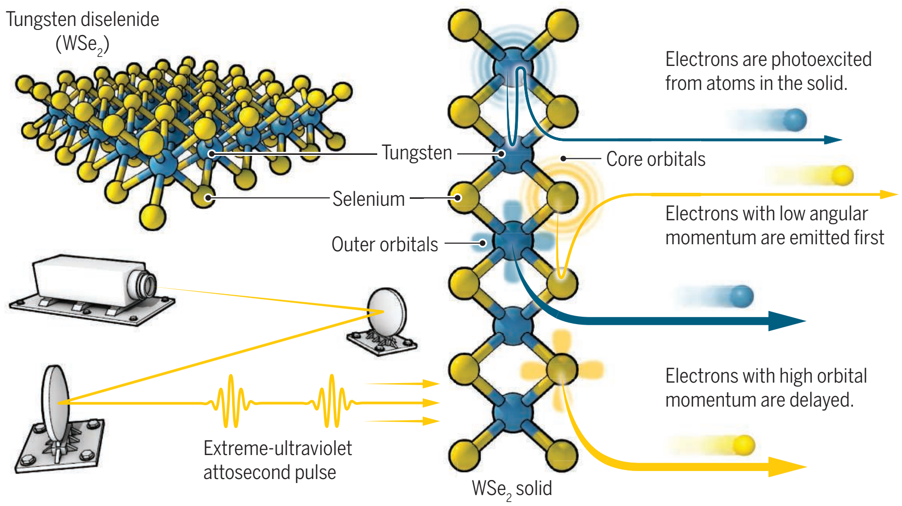
Delayed by angular momentum

Seik *et al*. exposed a WSe_2 surface to an ultrafast light pulse and observed different electron emission times. This effect arises from the centrifugal barrier associated with the electron angular momentum on the photoelectron escape time.



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ASTRONOMY

New angle on cosmic rays

A substantial directional anisotropy is observed for ultrahigh-energy cosmic rays

By **John S. Gallagher III**[1] *and* **Francis Halzen**[2]

Cosmic rays are nuclei that have been accelerated to relativistic velocities by astrophysical sources, arriving at Earth after traversing the space between us and the source. As electrically charged particles, they are deflected by magnetic fields, which scramble their directions in space (*1*). Finding deviations from the highly isotropic angular distribution of high-energy cosmic rays in the sky has long been a prime goal of cosmic-ray researchers. Marginal detections have been reported in the past that failed to hold up. On page 1266 of this issue, The Pierre Auger Collaboration (*2*) report a strong detection of a pronounced anisotropy in the arrival directions of cosmic rays with energies (E) of ≥8 EeV (8×10^{18} electron volts), indicating that they are of extragalactic origin.

Cosmic rays were discovered by V. F. Hess in 1912, and by the mid-20th century, it was clear that the distribution of cosmic rays of moderate energies [in the gigaelectron volt (10^9) range] arriving at Earth was nearly uniform in all directions. This isotropy was shown to be a natural result of the scrambling of cosmic-ray paths by the Galactic magnetic field, a process that is analogous to the scattering of light in a thick fog. Just as light seems to come from all directions because it scatters over short distances in fog, cosmic rays scattered by magnetic fields also appear to arrive uniformly across the sky.

We do not expect the scrambling of cosmic rays to be perfect. The geometry and strength of the magnetic field is one key factor. This operates in tandem with the radius at which cosmic rays gyrate around magnetic field lines that is set by the energy and charge of the cosmic ray and the magnetic field strength. When the cosmic-ray gyro-radii exceed the size scales of inhomogeneities in the

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Science

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