transfer. Since the early 1980s, a well-understood theory has existed for the optimal absorption of energy by WEC arrays of various geometries, for waves oscillating at a single frequency (*11*, *12*). Fundamental limits exist for a WEC's capture width (the lateral width of an incoming wave crest with incident power equal to that being absorbed). Optimal control theory has shown that the capture width can be many times the converter's physical width (i.e., the converter can attract energy propagating on either side of it, in addition to incident energy), and that multiple converters can exploit constructive interference to enhance power absorption.

WECs are typically tuned to extract power from only one frequency. Real waves, however, exhibit random oscillation with available power over a range of frequencies. Mathematically, the optimal manner in which to harvest power from random waves requires knowledge of their future behavior. The use of a statistical estimator to predict future incident waves, and its incorporation into a WEC's power generation control system, therefore has the potential to greatly enhance its capture width in random waves.

The power takeoff and control system form the core of a WEC. They must be supported and protected by a structure that is either founded on the seabed or held on station by a mooring system. The marine environment is aggressive—seawater is corrosive, marine organisms cause fouling, and extreme storms impart very large loads to the WECs. Structural and mooring system designs need to address survivability and reliability, without compromising conversion efficiency.

The wave energy industry faces a number of engineering and economic challenges. More efficient designs often have greater initial costs, so development will necessarily be incremental and will take both time and investment. Beyond power plant design, current needs include investigations of the environmental impacts of WECs, as well as policy and permitting issues. Despite these challenges, wave energy is a large and viable source of renewable power, and its development deserves serious attention.

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APPLIED PHYSICS

Looking Below the Surface

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Scanning tunneling microscopy can now be used to determine electronic properties of bulk materials.

Every once in a while, experiments are reported that apply existing tools to apparently well-understood scientific concepts and come up with tantalizing, novel results. On page 1190 of this issue, such a case is beautifully demonstrated by Weismann *et al.* (*1*). They use scanning tunneling microscopy (STM), a standard surface science technique, to visualize electron flow in the bulk of a piece of copper.

Primarily based on its atomic resolution imaging capability, the STM has had phenomenal success in the field of surface science. How can a truly surface-sensitive technique be used to measure a bulk property? The key trick applied by Weismann *et al.* is to exploit the wave nature of the electrons in copper and study their interference patterns on the surface caused by scattering centers in the bulk of the material. Their technique opens the door to a real-space investigation of electron propagation in materials and to the scattering of electrons at defects well below the surface.

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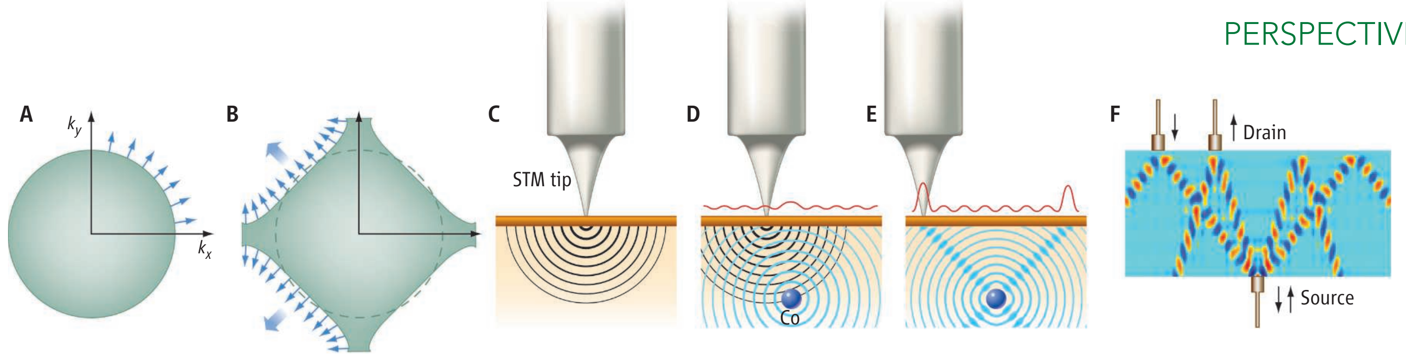
A finite-size piece of copper contains a huge number of atoms and an even larger number of electrons. It might, therefore, seem impossible to understand the behavior of such a complex system. Yet, solid-state physics enables most measurable properties to be characterized by the properties of the Fermi surface—the dividing line between the states occupied by an electron and the empty states. The Fermi surface is most often presented in reciprocal space, where one can characterize a spatially extended state such as an electron wave with a single parameter, its wave number.

The simplest model system for such a solid is the nearly-free-electron gas (*2*), which is spatially homogeneous and, as a result, its Fermi surface is a perfect sphere (see the figure, panel A). Prominent examples of nearly-free-electron gas metals are gold, silver, and copper. The primary deviation from the spherical shape in these materials is an exclusion of allowed states along certain crystal directions (see the figure, panel B). It is this small deviation from the spherical that allows Weismann *et al.* to measure the shape of the bulk Fermi surface.

Most frequently, the shape of a Fermi surface is measured with quantum oscillations and angle-resolved photoemission spectroscopy and calculated with density functional theory. Because only electrons in a small band around the Fermi surface are responsible for electronic transport, the shape of the Fermi surface therefore plays a dominant role in the electrical conductance of solids. It is not surprising, then, that recent years have seen a large body of work measuring the Fermi surface of high-temperature superconductors (*3*) and other advanced materials.

The main reason why the STM can be used to measure these bulk properties is conceptually rather simple: The STM consists of two components, the sample (comprising the surface and the bulk material under the surface) and the tip. The atomic resolution of the STM at the surface stems from the extreme sensitivity of the tunneling current to changes in the overlap of the electron wave function at the tip and the wave functions at the surface. Once an electron has tunneled and arrives in the sample as a hot electron (a state outside of the Fermi surface), it propagates as a wave inside the material and eventually scatters or arrives in the back contact to complete the electrical circuit (see the figure, panel C).



Scattered electrons. (**A**) A nearly-free-electron gas has a spherical Fermi surface. The blue arrows indicate the direction of electron propagation at the Fermi surface. (**B**) In the cartoon model of the Fermi surface of Cu, certain directions become preferred due to the nonspherical shape of the Fermi surface. The thick arrows indicate directions of electron focusing. (**C**) In a typical STM experiment on a metal, an electron tunnels into the surface and becomes a bulk electron wave whose amplitude decays with distance. (**D**) When a scatterer is present under the surface, the electron wave can be reflected. For a spherical Fermi surface, this results in a weak interference pattern at the surface. (**E**) When the Fermi surface is not spherical, electron focusing is observed along certain directions, which can give rise to a pronounced interference pattern observable at the surface. (**F**) Theoretical prediction of separate interference patterns for different spin channels in a magnetic material [from Weismann *et al*. (*1*)].

This wave behavior of the electrons in the bulk of the sample is not visible in most STM images and is thus typically neglected in the analysis of STM experiments.

The situation changes dramatically when a point defect is incorporated under the surface. Such a defect can scatter the electron waves emanating from the tunneling tip. The reflected wave can interfere with the incoming wave, giving rise to a standing-wave pattern that can be seen at the surface. For the case of a spherical Fermi surface, the amplitude of the scattered electron wave decays rapidly, and only a very weak interference pattern can be expected on the surface (see the figure, panel D). Weismann *et al.* see a dramatic increase of this interference pattern at the surface for Co atoms buried several layers underneath (see the figure, panel E), and argue that this can be understood from the shape of the Fermi surface: Along certain spatial directions, the amplitude of the scattered wave decays very slowly (arrows in panel B; see supplementary movies S1 and S2). In essence, the electrons are scattered along beams of electron waves, a phenomenon referred to as electron focusing. When these beams intersect the surface of the material, a strong and characteristically shaped interference pattern is observed. This interference pattern reflects information about the propagation of electrons through the bulk of the material—and hence on the shape of the Fermi surface—and the strength and type of scattering potential below the surface. Weismann *et al.* show that these interference patterns can be accurately calculated by incorporating a very large number of atoms in the sample.

The observation of electron interference patterns on surfaces with STM goes back to the beautiful standing-wave patterns of electrons confined to the inside of a quantum corral on copper (*4*). More recently, the wave nature of electrons in two-dimensional electron gases at surfaces has been used to perform electron holography (*5*) and to study the electron propagation in high-temperature superconductors (*6*). In the latter case, one can deduce a plethora of spatially resolved information on the electron behavior in such partially disordered systems with complex electron-electron interactions.

Weismann *et al.* also use their calculational approach to highlight a wide range of exciting future experiments. They discuss the fact that electrons of different spin character in magnetic materials generally have differing Fermi surfaces. This should enable the observation of separate interference patterns for injecting minority spin versus majority spin electrons (see the figure, panel F). The technique may also be used to study buried interfaces with high spatial resolution. The system used in the present study is a prototypical Kondo system—a single magnetic impurity in a sea of electrons—and one should be able to obtain deeper insights into electron scattering above and below its characteristic magnetic transition temperature. Interpreted correctly, one can therefore judge a book by its cover.

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Supporting Online Material
www.sciencemag.org/cgi/content/full/323/5718/1178/DC1
Movies S1 and S2

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PSYCHOLOGY

From Oral to Moral

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Is moral disgust an elaboration of a food rejection system?

The term "disgusting" is applied to bad tastes, cockroaches, incest, and proposing an unfair division of money in an ultimatum game. Is the emotional response the same in all four cases? On page 1222 of this issue, Chapman *et al*. (*1*) show that there is activation of a muscle central to the facial expression of disgust in response to unfair treatment (divisions of money), and argue that it "elicits the same disgust as disease vectors and bad tastes." What does that mean, and how would you demonstrate it?

One possible model to consider is a temporal analysis of disgust comprising three layers. At the top are the elicitors of disgust. To one degree or another, these trigger a set of mental activities that can be considered a "disgust evaluation system" (see the figure) that appraises the elicitor, generates a sense of offensiveness and revulsion, and leads to thoughts of "contamination." Psychological contamination refers to the feeling or belief that when something offensive touches something else, the offensiveness is transferred to the contacted object (thus, when a

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