Atom detection improves, on the surface

"Interface" is a much-used word nowadays, but as a famous theologian once said, *Abusus non tollit usum*—the abuse of a thing does not cancel the reasons for its proper use. The misuse of the word is probably grounded in its proper use in the field of solid-state electronic devices. It is at interfaces that the things happen that make these devices do what they do, and those things happen through the activity of electrons located on the surfaces of the interfacing elements.

The locations of the electrons on a surface are determined by those of the atoms. "Tell me where the atoms are," says solid-state theorist Marvin Cohen of the University of California at Berkeley, "and I'll tell you where the electrons are." Experimenters now seem pretty well able to tell where the atoms are. Three methods that can fairly accurately locate individual atoms in the surface of a solid were discussed at last week's meeting in San Francisco of the 17th International Conference on the Physics of Semiconductors. With this ability, experimenters are narrowing the choices among the models used to describe the structures of surfaces.

Surface conditions differ from those in the bulk of the crystal, and what physicists know about the interior of a crystal does not apply unmodified at the surface. A surface is characterized by broken chemical bonds. When a surface is made — say by cleaving a crystal of silicon, the element most used in these experiments — bonds in the vertical direction that would have extended above the surface are broken. The atoms adjust in various ways. Unbalanced forces may pull them back, forth or sideways. They may use the broken bonds to link laterally with each other in ways different from the interior of the crystal.

Methods for studying surface structure must be able to probe the first few atomic layers, where the surface effects are concentrated, and not mask or mix these data with information from the interior. These three methods are in part rivals, in part complementary, as each of them is more sensitive to aspects that the others don't see as well. Pierre Petroff of AT&T Bell Labs at Murray Hill, N.J., described a method of surface-sensitive transmission electron microscopy. He and his collaborators take an ultrathin slice of the material, 50 angstroms thick, and irradiate it with a "plane wave" of electrons. Solid-state physics is truly applied quantum mechanics, and this technique uses the quantum mechanical characteristic of electrons—their wave-like behavior.

The pattern of atoms in the surface sets up a varying electric potential, that is, a varying capacity to exert electric forces. This potential affects the electron wave as a grating affects a light wave: It alters its phase and causes diffraction. Either a somewhat gross direct image, a kind of electron shadow graph, can be made, which distinguishes details 30 angstroms apart, or much more detail can be gained by analyzing the interference effects characteristic of the diffraction. In any case they can see single atoms in columns and single surface atoms.

Theorists had calculated that silicon atoms in a surface would use their broken bonds to join each other laterally in two-dimensional cells. There are two main choices: square cells one atom on a side, or square cells seven atoms by seven. Petroff reports evidence for the seven-by-seven configuration. Their latest technical development, he says, is a very narrow electron beam, five angstroms across, that they can center in a unit cell, and so get a much sharper diffraction pattern.

Rudolph Tromp of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., described a method whereby a beam of ions is sent against the surface from the side. The ions are scattered by the atoms of the surface and form shadow cones. Analysis of the intensities and directions of the ions coming out of the sample can determine the sources of the shadow cones and so the locations of the atoms. Tromp says his group also sees evidence for the seven-by-seven unit cells.

Gerd Binnig of the IBM Zurich Research Laboratory in Rüschlikon, Switzerland, reported progress in development of the scanning tunneling microscope first reported about two years ago (SN: 1/30/82, p. 70). This device makes use of another quantum mechanical property of electrons: They can "tunnel" their way through an insulating barrier that they do not have enough energy to surmount in the usual way by arcing or burning out the insulator. The equations just give a probability for some electrons to appear on the far side of the barrier, energy notwithstanding.

Binnig's device uses a tiny probe that hovers over the surface and draws these tunneling electrons to itself. It is particularly sensitive to vertical displacements of the surface atoms, and Binnig says it could see something much smaller than an atom if such a particle could exist on a surface. When his group first reported success with the device two years ago, they used vacuum as the insulator. Now they have made it work with oil, which increases its versatility.

As an example Binnig cited studying the structure of DNA directly, "something you couldn't do before." Exposed in a vacuum, DNA deteriorates rapidly; immersed in oil, it retains its structure and can be studied at some leisure. The next extension is to get the technique to work in water. Water is a conductor, not an insulator, and so presents problems, but Binnig thinks they are surmountable. Others have suggested that this technique might be used to move atoms around in surfaces or to etch them microscopically and so store information, but Binnig passes such suggestions off as matter for future consideration.

—*D. E. Thomsen*

Membrane electrons: Transfers in the dark

A recently developed artificial membrane, which can transfer electrons in complete darkness, may help scientists to simulate more accurately some of the electrical processes that go on within living cells. These processes, which involve chains of electron transfers across membranes enclosing cellular entities such as mitochondria, play an important role in the way cells use energy and convert it from one form into another.

The artificial membrane developed by H. Ti Tien of Michigan State University in East Lansing consists of a double layer of lipid molecules (a mixture of lecithin and oxidized cholesterol). This membrane, less than 100 angstroms thick, is normally an excellent electrical insulator, but its electrical properties change when appropriate compounds are incorporated within the lipid bilayer. The additive in this case is tetracyano-*p*-quinodimethane (TCNQ), which is sometimes described as an "organic metal." Tien and his co-workers saturated the initial lipid solution with TCNQ and came up with an electron-conducting membrane.

To study the reactions that take place in this artificial membrane, Tien used an electrochemical technique called cyclic voltammetry. By measuring how the current changes as the voltage goes repeatedly through a cycle, researchers obtain useful information about reactions that involve the gain or loss of electrons (redox reactions).

When the technique was applied to the TCNQ-modified membrane with a benzoquinone solution on one side of the membrane and hydroquinone on the other, Tien found evidence that the artificial membrane acts just like a platinum electrode in conventional electrochemistry. A redox reaction occurs as a result of the transfer of electrons across the membrane. This reaction is important, Tien reports in the July 15 JOURNAL OF PHYSICAL CHEMISTRY, because similar compounds are known to play vital roles in living cells.

Previous research had already established that lipid bilayers incorporating pigments are capable of light-induced electron-transfer reactions. Tien's work represents one of the first demonstrations that these reactions can occur in the absence of light. — *I. Peterson*