SURFACE SCIENCE

Ion-Surface Interactions: From Channeling to Soft-Landing

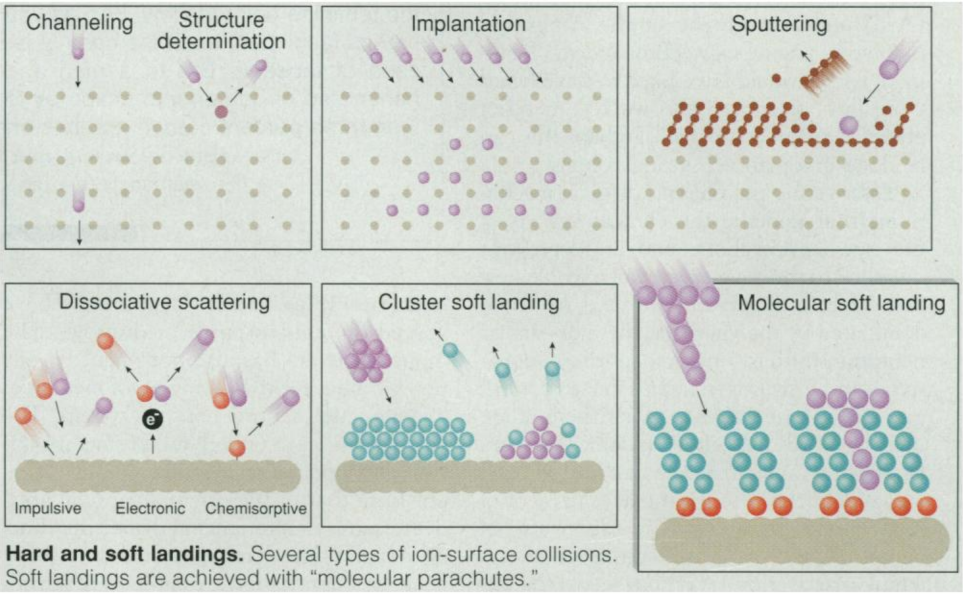
A. W. Kleyn

Collisions of ions with surfaces rarely are gentle but rather are crash landings. This is because of the high energies (kilo- to megaelectron volts) usually used in surface science experiments. The corresponding physical picture is that of a point charge moving in an ordered array of other well-separated point charges. The interaction is determined by Coulomb repulsion between the nuclei. In surface science, fast ions are used in surface crystallography: From the patterns of 0.1- to 1-MeV protons or alpha particles reflected from solids, the structure of the first layers can be determined, for instance, by using the technique of channeling (*1*) (see figure). In addition to scattering from the surface region, implantation into this region is very probable. Thus, the surface and subsurface of a material can be modified by ion implantation with a variety of usually atomic ions (see figure). In all of the processes mentioned so far, the energies involved exceed chemical binding energies; thus, survival of a molecular ion in a collision with the surface is extremely unlikely, and a soft landing of a polyatomic ion would be unheard of; it has never been observed. Drastically different conditions are needed to allow soft landing, an accomplishment reported on page 1447 of this issue by Miller *et al.* (*2*).

A look at other types of ion-surface interactions can put the observation of molecular soft landing in perspective. Implantation will have a side effect: The energy transfer between the incident projectile and atoms at or close to the surface will be so large that the lattice atoms and, for instance, molecules in overlayers get sufficient energy to overcome the surface binding energy and escape. This is the well-known phenomenon of ion sputtering (see figure), used to prepare atomically clean surfaces in ultrahigh vacuum and diagnose the composition of surfaces in the well-established technique of secondary-ion mass spectrometry (*3*). When the energy of the sputtering projectiles is chosen to be sufficiently low, molecules, thermally deposited intact on the surface, can be lifted off intact for analysis in a mass spectrometer (see figure); this is the process that was used by Miller *et al.* (*2*) to verify that soft landing had occurred.

When one wants a fair chance of a polyatomic ion surviving its collision with a surface, the energy of the ions should not exceed the bond dissociation energies of individual bonds in the molecule by much. Therefore, ions with energies in the 10- to 100-eV range are necessary. What is the nature of the molecule-surface interaction in this case? The forces between the ion and the surface are now dominated by the Pauli repulsion between the electrons. This interaction makes the effective repulsive potential felt at a larger distance (see figure). The solid is no longer seen as an ordered gas of point charges but as a continuum. The projectile interacts with more than one surface atom at the same time and can no longer penetrate the surface. This regime is that of surface rainbow scattering (*4*).

Dissociation in molecular ion surface collisions has been studied extensively. A number of mechanisms can be discerned (see figure). An impulsive collision with the corrugated surface can lead to a direct rupture of a bond: The molecule is smashed to pieces. Electron transfer to the ion can yield a neutral that is in an electronically excited state, which leads to direct dissociation. Finally, chemisorption of part of the molecule can also lead to fragmentation (*5*). Dissociation of polyatomic ions in surface collisions is used to elucidate molecular structure in the technique of surface-induced dissociation mass spectrometry (*6*). The impulsive mechanism can be suppressed by lowering the ion energy as much as possible. The latter two mechanisms can be suppressed by using an inert surface. However, the condition of taking an inert surface can lead to a serious problem when attempting to deposit a molecule intact on a surface: It will not stick to it but instead will desorb. So one needs an adsorbing surface, but one without strong chemical forces that would break up the molecule.



Hard and soft landings. Several types of ion-surface collisions. Soft landings are achieved with "molecular parachutes."

Soft landing has been studied by aiming small mass-selected cluster ions at a surface (*7*). It has been demonstrated recently that these clusters can be deposited at the surface intact; that is, the cluster did not lose many atoms. The shape of the cluster was modified by its strong interaction with the surface and by the violent collision of the cluster ion with the surface. In such a collision, a cluster is tremendously heated internally and melts (*8*, *9*). To make a better soft landing, spacer layers of noble gas atoms at cryogenic temperatures were adsorbed at the surface. The softer energy transfer to these layers caused the cluster to lose its integrity more slowly, and allowed it to be chemisorbed intact (*10*). The shape of the cluster changed as a result of the strong chemical interaction (see figure).

So, the deposition of a molecular ion intact on a surface remains a formidable task: We require a low energy to prevent impul-

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sive dissociation, an absorbing layer that removes the kinetic energy of the ion, no charge transfer, and no chemisorption that could lead to dissociation. The group at Purdue has reached this goal in a remarkable way (2): The ion energy is kept low, which is experimentally very tedious, and to avoid chemisorption, the ions are trapped in a fluorocarbon self-assembled monolayer (F-SAM) on an Au substrate. To make sure that the molecules are stopped without hitting the substrate, bulky groups at the end of the molecules act as parachutes (see figure). The F-SAM monolayers have been demonstrated to be remarkably inert. Only when a molecule is locked between the molecules of the F-SAM is it trapped. No molecular deformation and no charge transfer occur. This combination makes it possible to softly land molecules intact at a surface. It is remarkable that the molecule retains even its charge in the layer. The only price one has to pay is that only molecules that are properly oriented can penetrate the chains of the F-SAM. This technique may indeed allow for an entirely novel way of storing information at the nanoscopic level.

References and Notes

1. J. F. VanDerVeen, *Surf. Sci. Rep.* **5**, 199 (1985).
2. S. Miller *et al.*, *Science* **275**, 1447 (1997).
3. B. L. Bentz and W. Odom, Eds., *Int. J. Mass Spectrom. Ion Processes* **143**, 1 (1995).
4. A. W. Kleyn and T. C. M. Horn, *Phys. Rep.* **199**, 191 (1991).
5. W. Heiland, in *Low Energy Ion-Surface Interactions*, J. W. Rabalais, Ed. (Wiley, Chichester, UK, 1994), pp. 313–354.
6. R. G. Cooks, T. Ast, T. Pradeep, V. H. Wysocki, *Acc. Chem. Res.* **27**, 314 (1994).
7. K. Bromann *et al.*, *Science* **274**, 956 (1996).
8. H.-P. Cheng and U. Landman, *ibid.* **260**, 1304 (1993).
9. ______, *J. Phys. Chem.* **98**, 3527 (1994).
10. J. W. Weaver and G. D. Waddill, *Science* **251**, 1444 (1991).

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CELL BIOLOGY

Unresolvable Endings: Defective Telomeres and Failed Separation

R. Scott Hawley

In chess games and mystery novels, the focus is always on the end. A similar captivation with endings has directed the attention of generations of geneticists and cytologists to the ends of chromosomes, the telomeres. The question has always been, Just how are telomeres special, and what are their functions? Two reports (*1*, *2*), one on page 1478 of this issue (*1*), suggest a surprising new significance of telomeres in the processes of meiotic and mitotic chromosome segregation. Both reports point to an unexpected conclusion: Although telomeres themselves may not mediate chromosome segregation, the separation of telomeres during cell division creates a special problem for the segregational system.

The discovery of the structure of DNA, together with our understanding of how DNA replicates during the production of daughter cells, pointed to the first clear function for telomeres (3). Somehow, telomeres must facilitate the replication of the ends of the DNA molecule such that the chromosome does not shorten with each round of replication. Recall that DNA polymerase can only move in one direction (5′ to 3′). Thus, once the RNA primer on the leading strand at the end is removed, there is no way to "back-fill" the missing base pairs. Left unaltered, the next replication event will result in a daughter chromatid that has been shortened by a few base pairs (4).

Telomeres exist in at least two general forms, each of which appears to solve the problem of replicating chromosome ends in a different manner. In most organisms the telomere consists of tandemly repeated copies of a G-rich simple repeat sequence (for example, TTGGGG in *Tetrahymena thermophila*). The ends of the chromosome are prevented from shortening at each replication by the ability of an enzyme, called telomerase, to synthesize more such repeats at each end (3). This de novo synthesis of new telomeric repeats is mediated by a corresponding RNA template within the telomerase holoenzyme.

Curiously, *Drosophila melanogaster*, the organism in which telomeres were first discovered, possesses a very noncanonical telo-

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WEBWATCH

Electronic eruptions

http://volcano.und.nodak.edu/

At any one moment, dozens of volcanoes are active around the world. Volcano World is a prototype Web site supported by NASA to provide remote sensing data on volcanoes to a wide group of users. Data from a variety of sources are available, along with updates on currently active volcanoes, images of eruptions, and maps of volcanic regions. Educational material is the primary offering, with opportunities to learn how volcanoes work and submit questions to the volcanologists on the Web team. Links are also provided to the top volcano observatories and research centers.

Population ecology

http://www.gypsymoth.ento.vt.edu/~sharov/popechome/welcome.html

Groups of organisms that interact give rise to complex dynamical structures, and this is the domain of population ecology. Drawing together many resources, this site at Virginia Polytechnic Institute offers paths to computational models, journals, and online research papers. Extensive links to large data sets useful in ecological modeling are available, along with pointers to important simulations such as SmartForest at the University of Illinois. Links to related areas such as pest management and mathematics are also listed.

Material matters

http://vims.ncsu.edu/cgi/index.acgi

Hypertext is ideal for online textbooks. One of the best in materials science is ViMS, short for Visualizations in Materials Science, created at North Carolina State University. The site is a highly polished presentation of the syllabus of NCSU's introductory materials science course and is supplemented by more than 700 megabytes of downloadable movies, computer graphics, and simulations. Exercises for the student are available in Adobe PDF format and the contents of the site are available on CD-ROM.

Edited by David Voss

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