

1355 This Week in *Science*

Editorial

1357 Phenomena at Interfaces

Letters

1360 Creative Deception: M. E. BITTERMAN; R. LEWIN ■ The IPPNW: A Single-Issue Organization: H. L. ABRAMS; C. HOLDEN ■ Animal Rights: R. B. ECKHARDT; J. D. SINCLAIR ■ "Macho" Hours: A. C. LOPO

News & Comment

1364 The (Private) University of NIH?
1366 Costa Rica's Campaign for Conservation ■ Swapping Debt for Nature ■ Guanacaste Paves the Way
1369 Big Science Falters at First Hurdle
1370 Human Experiment Roils French Medicine
1371 *Briefing: Psychology Today* Sold ■ University Labs Find a Place in the Trade Bill ■ Triage of Earth Science Departments in Britain ■ A Plea from Social Sciences

Research News

1372 Comet Source: Close to Neptune
1373 Fermat's Theorem Proved?
1374 Checking the Pulse of PitCon '88: Probing the Authenticity of Antiquities with High-Tech Attacks on a Microscale ■ Surfaces: Up Close and Personal ■ Robot War Weeds Out Competitors ■ Ductless Fume Hood Reaches the U.S. ■ Capillary Electrophoresis: Anticipating the State of the Art at an Early Stage ■ Automated Analyzer Seeks Out Sulfur

Articles

1381 Brain Imaging: Applications in Psychiatry: N. C. ANDREASEN
1389 Performance Assessment of Radioactive Waste Repositories: J. E. CAMPBELL AND R. M. CRANWELL
1393 Parallel Supercomputers for Lattice Gauge Theory: F. R. BROWN AND N. H. CHRIST

Research Articles

1400 Activation of Cell-Specific Expression of Rat Growth Hormone and Prolactin Genes by a Common Transcription Factor: C. NELSON, V. R. ALBERT, H. P. ELSHOLTZ, L. I.-W. LU, M. G. ROSENFELD

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COVER A front view of the 1-gigaflop 64-node Columbia Parallel processor showing the edges of the processor boards and the cables connecting them. The cables form a mesh shaped as a doughnut folded twice onto itself. Each wide, multicolored cable is made up of 20 twisted pairs, carrying 16 data bits and parity at a sustained transfer rate of 16 megabytes per second. See page 1393. [Norman H. Christ, Department of Physics, Columbia University, New York, NY 10027]

Reports

- 1406 Gas Bubbles in Fossil Amber as Possible Indicators of the Major Gas Composition of Ancient Air: R. A. BERNER AND G. P. LANDIS
- 1409 The 1987 Whittier Narrows Earthquake in the Los Angeles Metropolitan Area, California: E. HAUSSON, L. M. JONES, T. L. DAVIS, L. K. HUTTON, A. G. BRADY, P. A. REASENBERG, A. J. MICHAEL, R. F. YERKES *et al.*
- 1412 RNA as an RNA Polymerase: Net Elongation of an RNA Primer Catalyzed by the *Tetrahymena* Ribozyme: M. D. BEEN AND T. R. CECH
- 1416 Expression of the Murine Duchenne Muscular Dystrophy Gene in Muscle and Brain: J. S. CHAMBERLAIN, J. A. PEARLMAN, D. M. MUZNY, R. A. GIBBS, J. E. RANIER, A. A. REEVES, C. T. CASKEY
- 1418 Duchenne Muscular Dystrophy Gene Expression in Normal and Diseased Human Muscle: M. O. SCOTT, J. E. SYLVESTER, T. HEIMAN-PATTERSON, Y.-J. SHI, W. FIELES, H. STEDMAN, A. BURGHEES, P. RAY, R. WORTON, K. H. FISCHBECK
- 1420 Human Immunodeficiency Virus May Encode a Novel Protein on the Genomic DNA Plus Strand: R. H. MILLER
- 1422 Localized Dispersal and Recruitment in Great Barrier Reef Corals: The Helix Experiment: P. W. SAMMARCO AND J. C. ANDREWS
- 1425 Anaerobic Dormancy Quantified in *Artemia* Embryos: A Calorimetric Test of the Control Mechanism: S. C. HAND AND E. GNAIGER
- 1428 Lithium Blocks a Phosphoinositide-Mediated Cholinergic Response in Hippocampal Slices: P. F. WORLEY, W. A. HELLER, S. H. SNYDER, J. M. BARABAN

AAAS Meetings

- 1431 *Thirteenth Annual AAAS Colloquium on R&E Policy*: Preliminary Program ■ Advance Registration Form and Hotel Reservation Form

Book Reviews

- 1434 Contemporary Marriage, *reviewed by* F. F. FURSTENBERG, JR. ■ The Paperclip Conspiracy, P. HAYES ■ Inventing American Broadcasting, 1899–1922, G. WISE ■ Reprints of Books Previously Reviewed ■ Books Received

Products & Materials

- 1439 Programmable Fraction Collector ■ X-ray Fluorescence Software ■ Mobile Modem ■ Microspectrophotometer ■ HPLC Column for Proteins, Peptides ■ Reference Software ■ Antibodies ■ Literature

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Phenomena at Interfaces

Research opportunities created by the scanning tunneling microscope (STM) and the atomic force microscope (AFM) are being addressed by an expanding number of scientists. As of 1 March 1988, about 400 papers had appeared that dealt with their design or use in studying hitherto unapproachable phenomena. These instruments are capable of lateral resolutions of 1 to 2 angstroms and can measure vertical dimensions to better than 0.05 Å. (Atomic dimensions are of the order of 2 Å.) Initially the STM was employed in studies of objects in high vacuum. But more recently atomic resolution has been obtained with both STM and AFM of solids in air and of solids covered by cryogenic fluids, polar and nonpolar solvents, conductive aqueous solutions, oils, and greases.* These observations demonstrate potential for investigating processes that occur at solid-liquid interfaces. Possible applications include lithography, catalysis, corrosion, electrochemistry, and molecular biology.

Most of the measurements have been made with STM. These studies have revealed many interesting phenomena, including mobility of atoms on surfaces and the reactivity of the dangling bonds that are present at crystalline surfaces. In one type of experiment, a fresh graphite surface in high vacuum was exposed to an amount of silver atoms sufficient to provide a small fraction of a monolayer. Subsequent observation with STM revealed islands of silver atoms on the graphite. It was as if the silver atoms had galloped over the surface to be with their friends. An experiment with crystalline gold testified to mobility of gold atoms near the surface after a crater in the gold three atom layers deep and displacing about 3200 atoms was created. The third level of the crater (25 atoms) was filled with gold atoms in 8 minutes. After 130 minutes, the second level of the crater (900 atoms) was filled. All this occurred at room temperature.

It has long been known that the arrangement of atoms at the surface of a crystal differs from that in the interior. The atoms at the interior are surrounded. Those at the surface are not. As a result, spacing of atoms at the surface is different from that in the bulk. A much noted example is that of silicon (111) which has a 7 by 7 unit cell at the surface each having 19 dangling bonds (dbs) which apparently are quite reactive. When a tiny amount of ammonia is introduced into the vacuum, H and NH₂ are preferentially attached to some particular db but to others more slowly.† Again, this is reactivity at room temperatures.

The STM involves a flow of electricity to or from a sharp tip poised about 10 Å above the conducting surface of a solid. The STM is not readily applicable to insulators or directly useful for mobile biological substances. However, for studies involving conductors, STM is the instrument of choice. It can be made rugged and dependable, and it is already being used in the United States on the shop floor to monitor a production process where precise control of tiny dimensions is paramount to achieving quality of output. It is manufactured commercially with various models costing about \$30,000 to \$60,000. On the order of 100 instruments have been sold, many of them to the Japanese. In a number of universities, home-made variants have been assembled for as little as a few thousand dollars.

Ultimately, because of its potential versatility, the AFM, invented in 1985, will probably come into broad use, but at present completely satisfactory models are not available. The AFM senses the force between the end of a sharp tip and the atom being observed. The tiny force causes a very small motion in a spring attached to the tip. At present, the typical forces involved when AFM is employed in monitoring are in the range of 10⁻⁸ newton. (A force of 10⁻⁸ N is equivalent to the weight of 10⁻⁶ g.) However, G. Binnig and C. F. Quate have suggested that an apparatus could be developed that would detect a force as small as 10⁻¹⁸ N. They point out that already displacements of 10⁻⁴ Å to 10⁻⁶ Å have been measured. A displacement of 10⁻⁶ Å corresponds to about 1 percent of the nuclear diameter.

Behind the success of STM, as well as a good potential future for AFM, is the ability to measure, record, and control displacements of small fractions of an angstrom. This ability is likely to be exploited further in the development of other instruments capable of exploring phenomena at the atomic level.—PHILIP H. ABELSON

*A good sample of activities in STM and AFM will appear in the March–April issue of the *Journal of Vacuum Science and Technology*. †R. Wolkow and Ph. Avouris, *Phys. Rev. Lett.*, in press.