

has the weakest chemisorption of the systems for which enhancement is seen. Furthermore, Rowe, Shank, Murray and Zwemer were able to determine, using Auger spectroscopy and low-energy electron diffraction, the thickness of the adsorbed layers in their experiments. They found that at least some lines are enhanced by effects that persist out to more than five molecular layers (about 30 Å).

Models. The difficulty of interpreting the data from the complex electrolyte systems and the rapid rate of accumulating experimental results has made it difficult to construct models to explain the effect. As Joseph Birman, a theorist at City College in New York told us, it was difficult to see what is general for all systems and what is specific. But any model or class of models will have to be able to produce a factor of 10^6 enhancement as a sort of yardstick. Burstein had pointed out that the geometry of the surface must be paramount. Somehow, the roughness produces an enhanced local electromagnetic field; the adsorbed molecules respond to that enhanced field.

In one model, proposed by Van Duyne and his collaborators, the image dipole that is induced in the metal by the polarization of the adsorbed molecule greatly enhances the polarizability of the molecule. Although it is a classical—and more or less heuristic—model, Van Duyne said, it is a useful guide for suggesting experiments. Horia Metiu and Shlomo Efrima (University of California, Santa Barbara) independently proposed a more elaborate model of this type.

Another class of models is based on the resonant Raman effect. Metiu and Efrima, for example, have also suggested that an interaction between the molecule and the substrate causes a shifting and broadening of molecular levels so as to make possible an electronic transition at the exciting frequency.

Burstein and his coworkers have proposed that the enhancement is due to coupling between the molecular excitation and excited electron-hole pairs in the metal. The surface roughness plays the role of an antenna, strengthening the interaction with the radiation field.

Many groups are now working on models that involve coupling of light to surface plasmons (transverse collective electron excitations) via the surface roughness. Among these are Kirtley, S. S. Jha and Tsang; Peter Wolff (MIT); Philip Platzman and Samuel McCall (Bell Labs); Ting-Kuo Lee (Institute for Theoretical Physics, Santa Barbara) and Birman; and Martin Moskovits (University of Toronto).

Most investigators appear to agree with Van Duyne, who believes that no one mechanism is likely to produce the entire enhancement, and that the same causes do not act with the same strength in all systems.

Applications. Surface chemists would

clearly be delighted with an analytic technique that allows one to measure surface properties in complex systems, under "messy" (real world) conditions, without disturbing other processes, at high temperatures and with the ability to give one dynamical and high-speed time-resolved information. It would be useful, for example, for investigating catalysts, corroding surfaces, batteries and other systems.

The enhanced Raman effect shows promise of being just such a tool, once it is understood. Most investigators in the field are interested in more general questions of spectroscopy and surface science, and Heritage suggested that the enhancement may be most useful in helping us sharpen our experimental skills to the point that we can observe Raman

spectra from catalysts or other surfaces in cases without enhancement. —TVF

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Langchow plans heavy-ion facility

The Institute of Modern Physics in Langchow is one of three nuclear-physics institutes in the People's Republic of China and the only one I saw during my recent visit (*PHYSICS TODAY*, March 1980, page 32). The Institute has ambitious plans for a new heavy-ion facility whose first phase, scheduled to operate in 1985, is expected to produce heavy ions from carbon to xenon—with 50 MeV/nucleon for low Z and 6 MeV/nucleon for high Z . The second phase would produce light ions with 100 MeV/nucleon and all ions up to uranium with 10 MeV/nucleon.

The Institute, formally founded in 1963, inherited a Soviet-built cyclotron that was assembled in Langchow. Between 1963 and 1973 the cyclotron was entirely devoted to the measuring of fast-neutron cross sections and studying reactions of very light nuclei, presumably for military applications. Since 1973 the Institute has primarily been doing heavy-ion research, converting the old cyclotron so that it could accelerate carbon, nitrogen and oxygen.

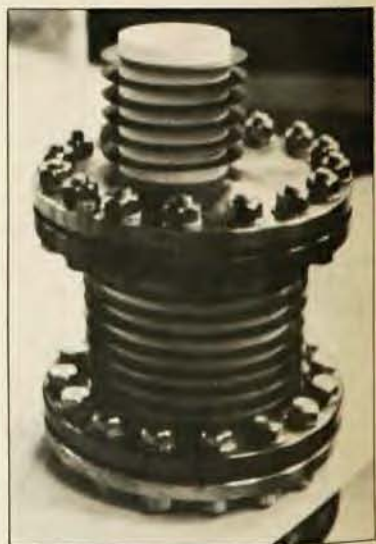
The old cyclotron, which has a 1.5-meter-diameter pole face, is being converted to a 1.7-meter-diameter sector-focusing cyclotron, scheduled for completion in 1982. This sector-focusing cyclotron will then be used as an injector for a separated-sector cyclotron, the first phase of the heavy-ion facility.

During a lab tour, I saw the 1.7-meter pole pieces and a $1/4$ -scale model magnet being tested. In the full-scale version, the field will be 16 kG, and the device will have three sectors.

Construction of a large new building to house the separated-sector cyclotron and experimental areas is underway. The injection radius is to be 0.9 or 1 meter, and the extraction radius will be 3.2 meters; the value for K is 450. The Institute's director, Yang Cheng-chung, told me he

hopes that Phase 1, the separated-sector cyclotron, will operate in 1985, but the timetable depends on various factories in China—one might machine the magnet, another the coils, another the rf generators.

Phase 2 of the Langchow heavy-ion facility would have a 20-MV tandem electrostatic accelerator injecting into the separated-sector cyclotron, thus extending the mass range from about xenon to uranium. Yang feels it is too early to predict when Phase 2 would be completed, but R&D on the tandem is being vigorously pursued now at the Institute of Modern Physics. The Langchow institute is cooperating with the Institute of Nuclear Research in Shanghai, which will have a 6-MV tandem to be built by the



Section of an accelerating tube at the Institute of Modern Physics in Langchow is made of Al_2O_3 with titanium electrodes.

Vanguard Accelerator Factory; the factory is cooperating with some personnel from the Institute of Modern Physics and the Institute for Nuclear Research. The 6-MV tandem will be the first Chinese accelerator to have insulating columns made of a material other than lucite. Yang views the Shanghai tandem as a prototype for the 20-MV Langchow tandem. Meanwhile the Institute of Atomic Energy in Peking is buying an HI-13 tandem from High Voltage Engineering Corp that will have a 13-MV terminal voltage. Buildings to house the facility are under construction. Although the contract was signed last year, delivery is not anticipated for another year and a half, according to Yang.

During a tour of the accelerator development lab, Kuo Chi-ti showed me a complete section of an accelerating tube made of Al_2O_3 with Ti electrodes (resembling the design developed by National Electrostatics Corp); the tube had undergone vacuum and thermal tests. The leak rate was 10^{-8} torr-liters/sec. In operation the vacuum required will be 10^{-8} - 10^{-9} torr. The tube had been heated to 500°C, then immersed in liquid nitrogen and survived the treatment.

Recently the tandem group built a 6-foot high test section of a charging device resembling the Laddertron being built at Daresbury. Both the rods and cylinders are welded stainless steel; the link isolators are cast nylon.

A variety of detectors and electronics were shown to me—some purchased, some locally produced. I saw a Tridac-C multichannel analyzer made by Inter-technique (the Institute's first on-line electronics), one lithium-drifted germanium crystal (made by Schlumberger) and others being developed by the Langchow institute. The Langchow detectors have a sensitive volume of 30 cm³; Schlumberger's has one of 80 cm³. The Langchow-built detector has an energy resolution of 3.3 keV for 1.33-MeV gammas from a Co⁶⁰ source. Ion-implanted semiconductor detectors are being developed—boron implanted in n-type silicon. Another group showed me their locally built scattering chamber and electron channeling tube, which Yang remarked was more or less standard nuclear equipment abroad. A 30 cm × 30 cm multiwire chamber with 50 wires has been built, with a 1-mm gap between wires. The chamber is to be used for beam diagnostics.

What kinds of research are being done? I asked. Langchow experimenters have been doing elastic scattering, transfer reactions and fusion reactions with heavy ions. Yang notes that detailed spectra are difficult for them because the energy resolution of the beam is poor. Experimenters observed deep inelastic collisions of 73-MeV carbon nuclei on gold. Nuclei far from the beta-stability line have been studied; for example, the Langchow ex-

perimenters have measured the most precise value for the lifetime of P^{115} . The Institute also has a small theory group studying fusion reactions, high spin states and nuclei far from the beta-stability line.

The Institute has been doing a number of applied projects. For example, Wang Shu-fen showed me her lab, where Mossbauer analysis is being used to select appropriate metallurgical conditions for

industry. Using Mossbauer spectra, her group analyzes the phase change of iron compounds as a function of temperature or gaseous conditions when an ore is either oxidized or reduced by hydrogen. I saw a strong neutron source— 4×10^{11} neutrons/sec—being used for irradiation of seeds (in cooperation with the Agricultural Research Institute) and for cancer therapy (in cooperation with a local medical facility). —GBL

Radioactive waste bound in crystals

Long-lived products of uranium fission such as strontium-90 and cesium-137, with half lives of about 30 years, cease to be a problem in reactor wastes after a few centuries. But the alpha-active transuranic actinides produced by transmutation in reactor fuel rods live much longer. Neptunium-237, plutonium-239, americium-241 and curium-246 have half lives ranging from five hundred to two million years. Although a waste disposal site would be no more radioactive after 500 years than a natural pitchblende ore deposit, it is widely felt that one should take reasonable precautions to keep these waste actinides out of the biosphere for hundreds of thousands of years.

Lynn Boatner and his colleagues at Oak Ridge have recently reported the successful incorporation of several α -active transuranic isotopes into single crystals of synthetic lanthanide orthophosphates. These ceramics are laboratory analogs of the mineral monazite, which in Nature is known to bind uranium and thorium for more than a billion years. The group has also developed a process for converting the lanthanide and actinide oxides found in reactor waste into compressed pellets of monazite powder.

The idea of binding long-lived radioactive waste species in crystal structures that have proven their stability over geological time spans has become increasingly attractive since Rustum Roy, Gregory McCarthy and their coworkers at Penn State reported two years ago that borosilicate glass was unstable under the action of water or brine at high temperatures and pressures. Such glasses had for the past decade been the leading candidates for the solidification of high-level radioactive wastes. The Penn State group is also investigating synthetic monazite, as part of a multiphase ceramic waste-solidification system that would bind strontium and other hazardous fission products as well as the heavy actinides. As part of a widespread effort to develop suitable synthetic minerals for binding the various radionuclides occurring in nuclear wastes, groups at Livermore, Sandia, Oak Ridge, Argonne and the Australian National University are working with combinations of titanate minerals.

The general scheme for the disposal of very long-lived wastes from reprocessed fuel rods or weapons manufacture is to provide three layers of isolation from the biosphere. First one imbeds the waste in a "solid waste form" such as glass, cement or the synthetic minerals (ceramics) under discussion here. The second line of defense would be a metal or ceramic cladding or canister around the solid waste form. Finally, one isolates the cladded solid waste form geologically, by burying it five hundred to a thousand meters underground.

It is difficult to vouch for the geological stability of an underground isolation site for a million years, not to speak of the integrity of the cladding. So the integrity of the crystalline or amorphous solid imprisoning the radionuclides is the ultimate line of defense against the ground water that threatens to leach them out and carry them to the biosphere.

Borosilicate glass. At a vitrification plant near Avignon, the French have already begun imbedding in borosilicate glass the wastes left over after reprocessing spent reactor rods. This amorphous solid has shown good resistance to leaching by water at moderate temperatures. But the work reported by the Penn State group in 1978 sets limits on the ability of this glass to withstand conditions that it might encounter in a disposal site deep underground.

At the concentration levels generally recommended for glass waste forms before 1978, the heat of radioactive decay would have raised the temperature of the waste deposit and its surroundings as high as 400°C during the first decades after geological isolation. The Penn State group subjected samples of borosilicate glass containing simulated reactor wastes to pressurized water and brine at 300°C. After several weeks the group found that the glass had degenerated severely and that significant quantities of cesium and other hazardous wastes had escaped into solution.

W. Kenneth Davis of the Bechtel Power Corporation, a member of the National Academy of Sciences Radiation Waste Management Committee, has challenged the relevance of the results reported by Roy's group. He told us that one can