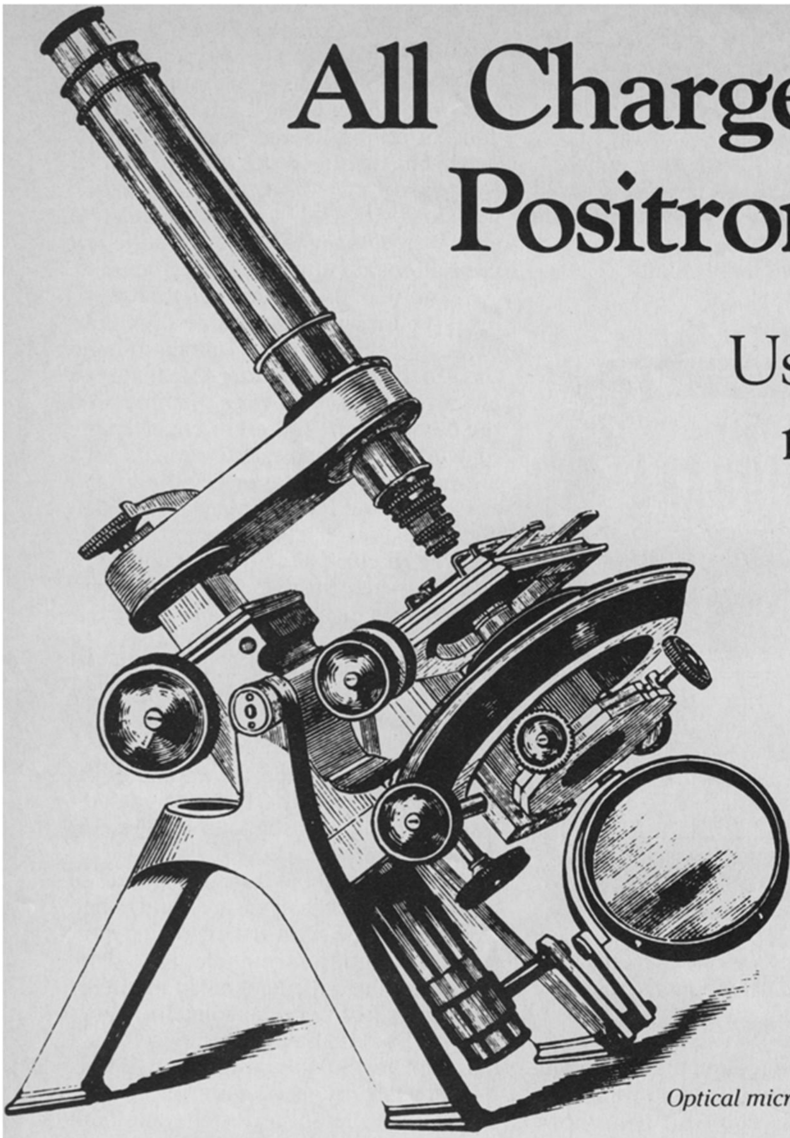
All Charged Up for the Positron Microscope

Using antimatter to make microscopes that matter



Optical microscope of old.

By STEFI WEISBURD

Fifty years ago the first electron microscopes opened a new frontier in the microscopic world. By using electrons instead of light to probe samples, biologists, chemists and materials scientists could explore details 1,000 times finer than what could be seen with optical microscopes.

Now comes the electron microscope's antimatter counterpart: the positron microscope. Encouraged by recent advances in making bright beams of positrons, a number of research groups are developing several kinds of positron instruments. Because positrons – with their positive electric charge and other antimatter properties – interact with matter differently than do negatively charged electrons, positron probing of materials promises to reveal features not previously seen with electrons. Moreover, scientists expect that with one kind of positron microscope, they will be able to image fragile biological molecules without destroying them – a goal that has eluded electron microscopists.

"We're very close to using positrons in ways that will contribute to microscopic studies of matter," says Karl F. Canter, a physicist at Brandeis University in Waltham, Mass.

The first published image from a prototype transmission positron microscope (TPM) appeared in the Jan. 18 Physical Review Letters in a paper by physicists James Van House and Arthur Rich at the University of Michigan in Ann Arbor. Like the transmission electron microscope (TEM), their TPM works by sending a beam of imaging particles (in this case positrons) completely through a thin sample. Electromagnetic interactions with atoms in the target scatter different parts of the beam to produce a final pattern or image of the target.

Constructing a TPM is now possible, says Van House, because in the last four years scientists have devised ways of generating positron beams with enough brightness, or intensity per unit area, to adequately illuminate and magnify samples. Their microscope also benefits from single-particle imaging techniques that had originally been developed as a result of research using an infrared nightscope – an instrument used to see at night – during the Vietnam era. Until now, says Van House, such techniques had not been widely applied to microscopy.

Even with these advances, though, both the resolution and magnification of the prototype TPM fall significantly short of TEM standards. When further improvements are made, Van House expects that scientists will be able to compare TPM and TEM images of the same material to gain greater insight into the material's atomic energy states and composition. TPM images should contain slightly different information from TEM patterns because positrons "see" a target's atomic world of positively charged nuclei shrouded in negative electron clouds differently than electrons do.

While the TPM takes advantage of the different electric charge of the positron as compared to the electron, other kinds of instruments are exploiting other aspects of the positron's antiparticle nature. In general, antiparticles are the counterparts of the elementary particles that make up ordinary matter. While they have the same mass as their "ordinary" cousins, antiparticles have equal and opposite values of some other property, such as electric charge or magnetic moment. A fundamental rule governing the behavior of particles and their antiparticles is that when the two come together, they annihilate.

At Brandeis, Canter and graduate student George Brandes have utilized this last rule in making a scanning positron microprobe to hunt for missing atoms and other defects in silicon crystals. When positrons in their microprobe beam collide with electrons in the sample, the two are destroyed and gamma rays are produced.

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As the researchers move the positron beam across a crystalline sample, they are able to monitor changes in the energy spectrum of the emitted gamma rays to detect defects, grain boundaries and other structural incongruities of the crystal. Such detection is possible because the positrons are readily trapped by defects in the sample. Trapping changes the amount of energy that the positron brings to its annihilating collision with an electron, and this in turn is reflected in the total energy of the escaping gamma rays.

In collaboration with Allen P. Mills Jr. at AT&T Bell Laboratories in Murray Hill, N.J., Canter, Brandes and their Brandeis colleagues describe their microprobe apparatus in the February REVIEW OF SCIENTIFIC INSTRUMENTS. Canter says the resolution of this microprobe is still not up to par, but he believes the positron microscopes his group is making are already superior in resolution and magnification to what the University of Michigan researchers have achieved. He attributes this to the use of a second-generation beam-strengthening technique called brightness enhancement.

Originally proposed by Mills in 1980, this technique increases the brightness by drastically reducing the cross-sectional size of the positron beam while, in the process, losing as few positrons from the beam as possible. By focusing the beam onto small crystals, which then reemit low-energy positrons from a small area, Canter's group has reduced the diameter of the emitting area from 10 millimeters to 0.1 mm, which, with other factors, translates into a 500-fold increase in brightness over conventional positron sources.

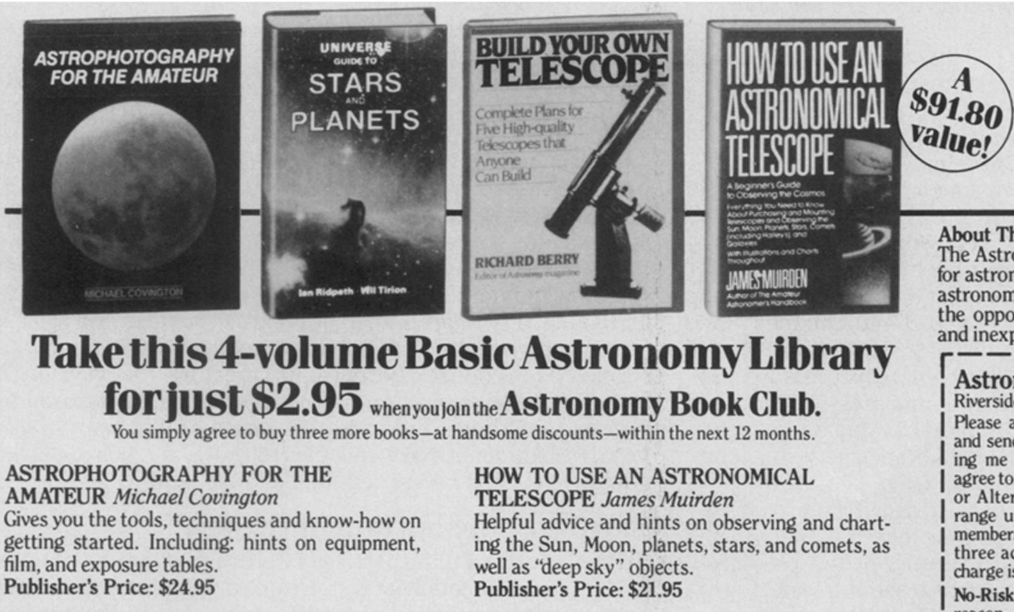
Having demonstrated the feasibility of making bright positron beams, Canter's group now is racing with others to develop a kind of holy grail of positron microscopes: the reemission microscope, an instrument that Canter says will put positrons to their most advantageous use yet. As first proposed several years ago by Lester D. Hulett at Oak Ridge (Tenn.) National Laboratory, positrons in a reemission microscope are focused onto a thin foil where they come to a halt, then slowly diffuse to the other side of the foil and are ejected at low energies. The beauty of positrons is that, unlike electrons, they naturally pop out of materials at low temperatures and don't have to be coaxed out by heating, says Canter.

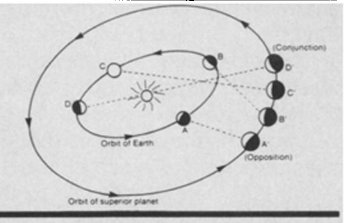
One resulting advantage is that the low-energy positrons have, in a sense, time to smell the roses as they drift through the sample, and so are extremely sensitive to the presence of defects and other structural irregularities. "This is far better than the high-energy transmission microscopes, which send particles tearing through a foil at hundreds of thousands of electron-volts," says Canter.

But what is most exciting to the researchers is that the reemitted positron energies are so low that they could image biological specimens — such as RNA, hemoglobin and other molecules and viruses — without destroying them, something only optical microscopes can do with their much poorer resolution and magnification powers.

Another advantage of the reemission microscope is that the positrons all emerge with roughly the same energy, which makes it relatively easy to see fine details clearly since large spreads in energy can cause blurring. Canter expects that with positrons, researchers may one day be able to benignly image biological details as small as 1 angstrom, a size that is more than a 100 times smaller than most viruses and a distance comparable to the resolution of electron microscopes. To get to this resolution, however, Canter says that higher fluxes of positrons will eventually be required.

For now, though, with brightness enhancement, the positron reemission microscope is clearly within reach. "It's just a matter of time, of how fast we can tighten bolts and put things together," Canter says. "I would be amazed if it doesn't appear within a year." □





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