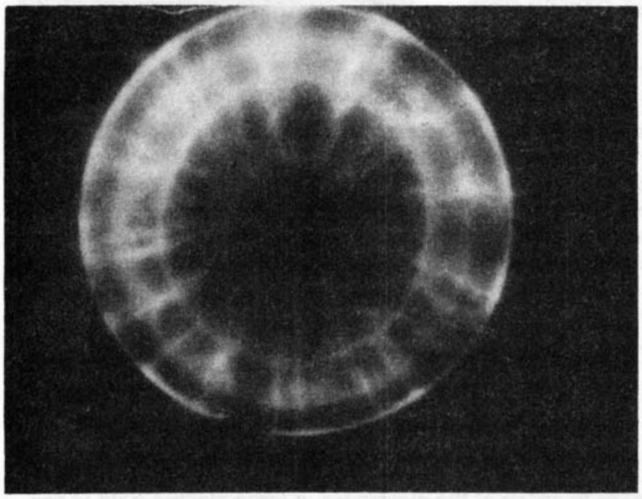
relatively electromagnetically insulated elementary constituents of a solid, liquid, or gas are broken up. With plasma, long-range electrodynamic forces predominate over the short-range chemical bonds and molecular interactions which characterize solids, liquids, and gases. And it is this long-range electrodynamic interaction which is the chief manifestation of the plasma state.

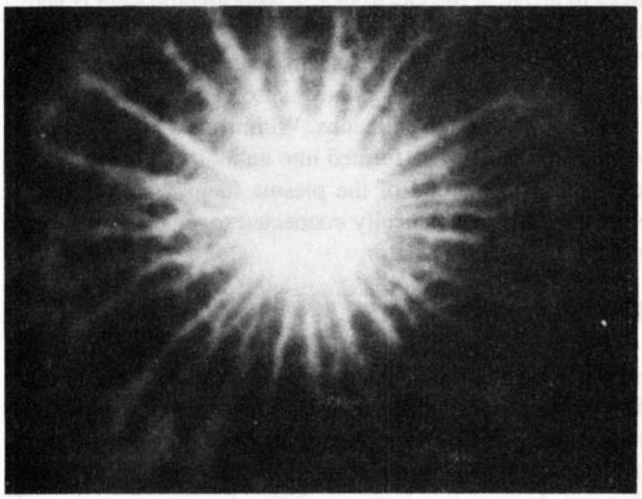
The question arises, therefore: What are the elementary constituents of a plasma? The textbook answer is usually: negatively charged electrons and positively charged ions—the fragments of the atoms and molecules present before "breakdown." But, because of long-range interactions, the dynamics and motion of these individual electrons and ions cannot be accounted for locally. In place of these "elementary constituents," we find that plasmas generate non-particle coherent structures: various types of waves, solitons, vortices, and circulation cells. In place of short-range chemical bonds and van der Walls molecular interactions, the plasma's fundamental constituents are held together by the long-range electric and magnetic fields of the plasma.

While making the plasma far more complicated theoretically and experimentally, this long-range nature of the plasma interaction also makes the plasma potentially far stronger and capable of supporting virtually infinitely greater energy densities.

For example, with solids, the strength of materials is fundamentally delimited by the strength of the short-range chemical bond. Therefore, if a sufficiently intense electric or magnetic field (and/or mechanical stress) is applied to the material, these bonds begin to break down and the material structurally fails—falls apart. But in the plasma, its elementary constituents are held together by the long-range electric and magnetic fields. Therefore, the application of intense electric and magnetic fields can not only be withstood, but these applied fields can further increase the strength and rigidity of the plasma structure. Because of this, plasmas are capable of sustaining virtually unlimited energy densities compared to what ordinary solids and liquids can sustain. And, as we will see with the plasma focus, if given sufficient freedom, plasmas will naturally configure themselves into such dynamically stable structures when an intense field is applied to them.

FIGURE 2
The plasma focus current sheath





Winston Bostick

The inner electrode is located at the circle at the center of the sheath. The outer electrode is located at the circumscribing circle. Barely visible in these photographs, as pairs of radial lines, are pairs of plasma vortex filaments which carry the electric current between the plasma focus electrodes.

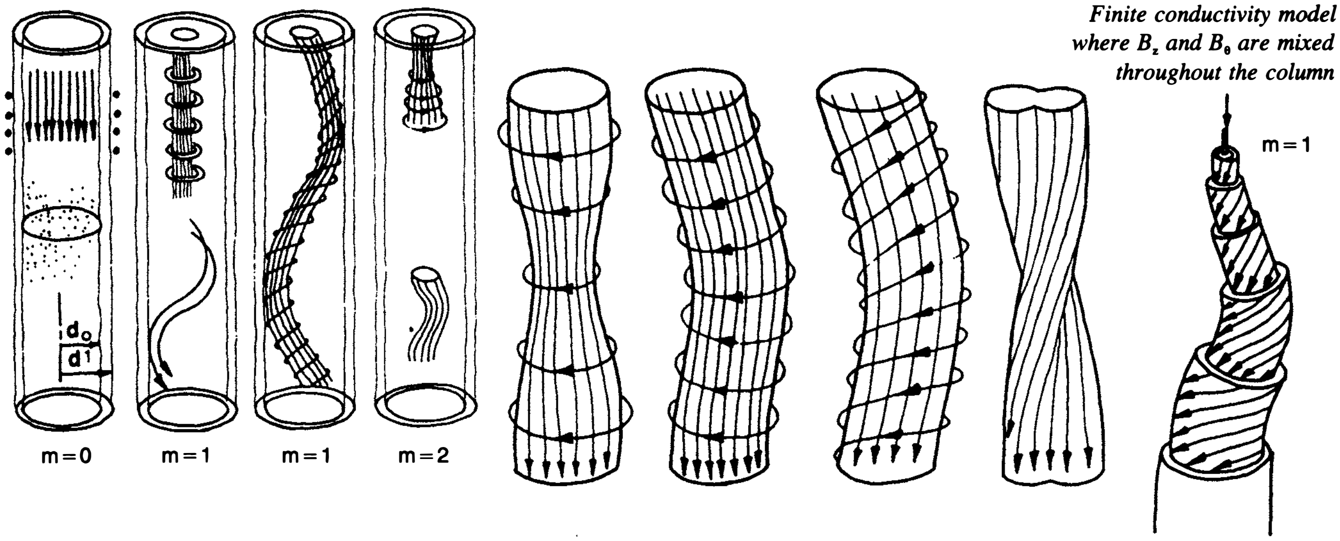
Computerized axial tomography: the CAT scanner

CAT scanners (computerized axial tomography scanners) have revolutionized medical diagnostic techniques. And it is useful to discuss how the CAT scanner works before describing the more advanced positron emission tomography (PET) technique.

Computerized tomography consists of generating an image of a slice—*tomos,* which means slice in Greek—of a three-dimensional object by combining a large number of scans through the object at different angles. For example, ordinary CAT scanners utilize a beam of x-rays to generate a number of scans which are combined to make a three-dimensional slice. Many of these slices can be put together to give a full three-dimensional reconstruction of an object like the brain.

FIGURE 3

Idealized diagram of electric current passing through a column of plasma



The initial conditions are shown in the upper left drawing marked m = 0. The electric current is represented by the arrows. The plasma gas is represented by dots. The azimuthal magnetic field generated by the passage of the electric current is represented by a circle, though such circles extend along the full length of the column. The pinch effect is shown in the next drawing to the right. The azimuthal magnetic field has compressed the plasma column. As indicated in the remaining diagrams, this initial configuration is unstable and the plasma column will undergo magnetohydrodynamic motions to reconfigure itself into a Beltrami configuration shown in the last, lower left drawing.

Source: *International Journal of Fusion Energy*, Vol. 3, No. 1, January 1985.

In contrast, ordinary x-ray exposures have many limitations. They do not provide a three-dimensional image, nor do they distinguish between two body structures that have the same density. The CAT scanner overcomes these limitations through combining directed x-ray beams with computer analysis.

For example, in a CAT scan of the brain, a patient's head is inserted into the "hole" of a special doughnut-shaped scanner. An x-ray beam generating tube rotates along a circular path within the doughnut, always pointing at the patient's head. These x-ray beams pass through the head. The brain tissue absorbs x-rays in proportion to the density of the various brain components that the beam passes through. (White brain matter differs from gray matter, and normal brain tissue has different densities from diseased brain tissue.)

The intensity of the x-ray beam that is not absorbed is recorded by sensitive crystal detectors, or what are termed scintillators, that convert incident x-rays into electronic signals. A computer is then used to carry out elaborate calculations based on the known input intensity and measured output intensity of the x-rays that pass through the brain and the angles at which the x-ray beams pass through the brain. These calculations permit a three-dimensional reconstruction of a slice of the brain.

In general, the way this works can be seen by examining an elongated rectangle, which will represent a side view of the brain slice. An x-ray beam passing through the rectangle along a path parallel to a diagonal goes through more brain material than one going along a path parallel to the rectangle's side. If the density is uniform, more x-rays will be absorbed along the diagonal path. Now, if we place irregularly shaped blobs in the rectangle to represent regions of higher density, we see that when the diagonal path and the side-parallel path both pass through such a blob, they do not usually have the same path lengths. The longer the path through denser materials, the more x-rays will be absorbed and the weaker the beam. By combining many such "cuts" at different angles, it is possible to reconstruct the outlines of the regions of higher and lower density. This principle is simply extended to three dimensions by rotating the rectangle—i.e., rotating the x-ray beam generator in the doughnut.

Positron emission tomography (PET) works on the basis of the same principles. But in this case not only is the brain structure pictured, but the brain activity, too.