Research in Progress

Magnetic Monopoles

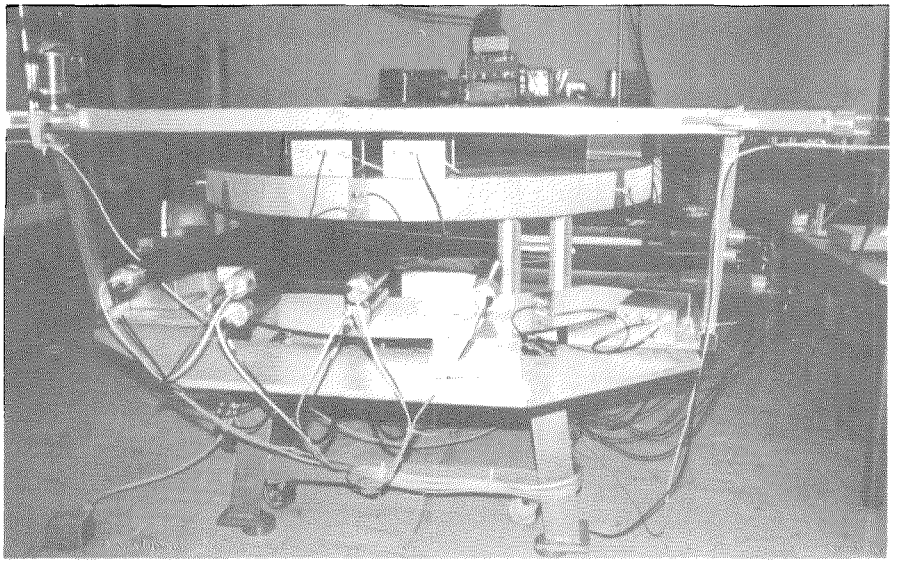
MAGNETIC MONOPOLES, which, as their name implies, are fundamental particles behaving as a single pole of a magnet, have never been observed. But there are enough hints of their existence to whet physicists' appetites to find them. The monopole, or carrier of a single magnetic "charge" corresponding to the electron, was the only lack of symmetry in Maxwell's equations of electric and magnetic fields. Half a century ago, Dirac predicted magnetic monopoles to explain the quantization of electric charge. And just a decade ago, grand unified theories, which seek to unify three of the four basic forces — electromagnetism, the strong force, and the weak force — suggested that magnetic monopoles could have been produced in the extreme high energy collisions of the Big Bang.

This recent prediction set off a new wave of searching, because the monopole's existence would help confirm the theories. One of those looking for the rare and elusive particle is Barry Barish, professor of physics. Or he is, like the other monopole hunters, at least trying to determine the best way to search.

The monopole described by the grand unified theories is extraordinarily massive for a fundamental particle — about as heavy as a speck of dust. It has 10 million billion times the mass of a proton but its volume is far smaller. And it's slow moving — about one-thousandth the speed of light.

No accelerators exist that are capable of the extremely high energies necessary to produce magnetic monopoles. That amount of energy existed only at the time of the Big Bang (in the first 10^{-43} second), so the only possibility of observing a monopole lies in finding one that has been around since then, lurking perhaps in the cosmic rays. How likely is this? How many monopoles might exist, if they exist at all?

Various cosmological calculations have come up with either too many or none at all, says Barish. There is, however, some important guidance from astrophysics. Upper limits on their abundance can be set by assigning monopoles responsibility for all the unseen mass of the universe; greater mass would have caused the universe to collapse. Also, the existence of the galaxy's magnetic field limits the concentration of monopoles that could exist; too many monopoles would have destroyed these magnetic fields. The astrophysical bounds, then, set the scale for a serious experimental search. Just to get below the upper bounds, to have the possibility of finding even a few monopoles in a year, would take a detector at least the size of a football field.



Detectors like this, but greater in size and sensitivity, may someday be listening for monopoles. The acoustic detector consists of two aluminum disks, 2 m in diameter and 10 cm thick, with tiny sensitive microphones attached along the sides to pick up the high-frequency signal of a monopole's ultrasonic shock wave when passing through the disks. Sheets of scintillation material above and between the disks, with cylindrical photocells attached, would provide additional signals to determine the presence of a monopole.

Barish's experimental ionization detectors are not yet that large. One recently dismantled in his laboratory consisted of a stack of sheets of plastic scintillation material 3 meters by 1.5 meters, surrounded by photomultipliers. If the detector is sensitive enough, a monopole passing through the scintillation material would produce a tiny, but detectable, flash of light. Barish is working on some of the fundamental aspects of the detector's design, including determining the optimal type of scintillating material. Eventually an array of such detectors could be constructed on the hypothetical "football field."

One of the practical problems is where to put such a huge, flat array. Physicists aren't likely to commandeer a football stadium anyway, but the main problem is to shield the detector from cosmic rays — from all of them that are not monopoles, that is, all but about 1 in 10^{10} cosmic rays. If the detector is underground, the intervening dirt will screen out most of the unwanted cosmic rays, and the rest could be dispatched with instruments. Barish recently returned from talks in Italy about a possible collaboration there. Italian scientists have acquired access to a 150-meter-

long, underground laboratory space in the Gran Sasso tunnel (an extra little boon from a highway project) and are serious about using it for magnetic monopole experiments. Over the next six months Barish will continue negotiations on joining the Italians in the tunnel.

An alternative to putting the detector underground is to use instrumentation to remove all the cosmic rays from an above-ground detector. This might, however, raise its cost considerably; the cost of the projected large scintillator array is probably at least $10 million. And even though the scintillator is generally considered the most likely technology for finding magnetic monopoles, the monopole's signature in such a detector is "not as unique as we would really like," says Barish. So he is simultaneously pursuing an alternate acoustic technique.

Barish theorizes that monopoles passing through a conductor produce eddy currents that would create an ultrasonic shock wave, detectable by piezoelectric transducers. A stack of aluminum disks with acoustic transducers (very sensitive microphones), attached around the edges to measure the speed of a particle passing through them, would produce an unambiguous signal from a slow-moving monopole. Sheets of scintillator material are mounted between and above the disks of the detector to give further information on the particle. A large-scale version of this system could be significantly cheaper than the scintillator and would identify a monopole more definitely, but Barish still has to make the technique 100 times more sensitive before it has a chance of finding a magnetic monopole.

Other attempts to find magnetic monopoles are under way from such diverse sources as x-ray emission from neutron stars and etched tracks in ancient mica. There have been a couple of false alarms, the most recent being the 1982 preliminary report of a monopole-like signal from a wire-loop apparatus in a Stanford lab. But since no more particles have been recorded on a more sensitive Stanford instrument, though it has run 68 times longer than the first experiment, it appears less and less likely that a magnetic monopole was actually observed. And it seems more and more likely that the first monopole will be seen as a tiny flash of light or heard as a high frequency ping in some giant detector yet to be built. □ — *JD*

Sickle Cell Anemia

AN ABNORMAL HEMOGLOBIN, known as hemoglobin S, characterizes sickle cell anemia, a genetically determined disease that seriously afflicts an estimated one in 600 Americans of African descent. About 8 percent carry the genetic trait for the disease but are asymptomatic.

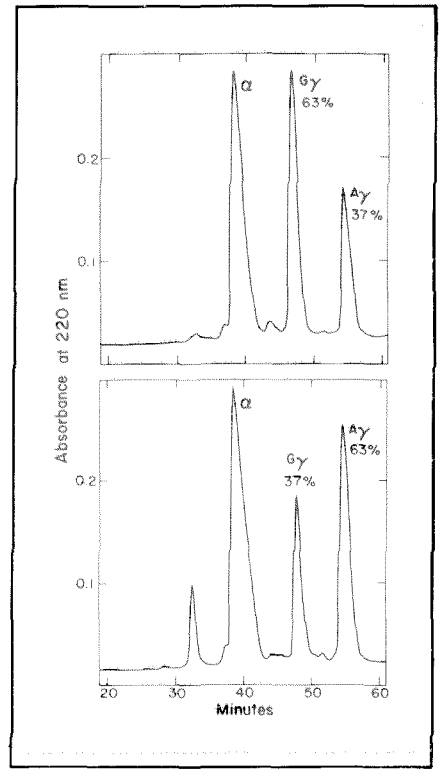
Hemoglobin carries oxygen throughout the body to be used in various metabolic processes. The problem in sickle cell anemia arises when oxygen leaves hemoglobin S. The molecules of hemoglobin S then tend to line up in long fibers, which distort the red cell into a rigid sickled shape that does not pass easily through the capillaries of the circulatory system. Even though much is known about sickle cell anemia and about hemoglobin, no cure or means of alleviating the symptoms of the illness has yet been found.

Walter Schroeder, senior research associate in chemistry, has been studying abnormal hemoglobins (with some lapses) since hemoglobin S was discovered by Linus Pauling and Harvey Itano here at Caltech in 1949. Recently, new, faster, and more sensitive tools for biochemical analysis, as well as current advances in DNA research, have added much information and may lead to the possibility of at least alleviating the severity of sickle cell anemia, as well as other genetic diseases of hemoglobin abnormalities, such as thalassemia.

The problems of sickle cell anemia begin to appear as fetal hemoglobin is replaced by adult hemoglobin (in this case, hemoglobin S; in the normal child this adult hemoglobin is hemoglobin A), a process that begins before birth and is completed by about six months of age. How the switch to adult hemoglobin takes place is a mystery. Fetal and adult hemoglobin differ in one of their two polypeptide chains, which are the products of particular genes. It's in the gene for that different chain, the beta chain, that the sickle cell abnormality is expressed in adult hemoglobin. Fetal hemoglobin has properties that are useful to the developing fetus but it also functions perfectly well in adults; in fact, it would be preferable to hemoglobin S.

Traces of fetal hemoglobin remain in the blood of adults. These traces occur in greater, but variable, amounts in individuals with sickle cell anemia and may have something to do with alleviating the symptoms. For example, Saudi Arabians with sickle cell anemia have rather a lot of fetal hemoglobin, and they are reported to have a generally less severe form of the disease. Consequently, it has long been a goal of many investigators to try to prevent the switch from occurring in infants diagnosed as having sickle cell anemia, or even to reverse the mechanism in adults and switch back to production of fetal hemoglobin. Schroeder thinks that 40-50 percent fetal hemoglobin might be needed to prevent the sickle cell fibers from forming. This conclusion comes from statistical studies with Darleen Powars of USC, which suggest an effective threshhold of 20 percent. In order to find a way to increase this percentage, Schroeder has done extensive analyses of fetal hemoglobin in search of the switch-over mechanism.

With Joseph DeSimone at the University of Illinois, Schroeder has collaborated on studies of baboons, whose hemoglobin synthesis is very similar to that of humans. The scientists have succeeded in treating the baboons chemically, under certain conditions, so that



Analyses of the concentration ratios of polypeptide chains in fetal hemoglobin of two sickle cell anemia patients shows opposite ratios for the two gamma chains (G and A). This ratio may affect the severity of the disease.

the baboons actually do produce large amounts of fetal hemoglobin. The conditions and complexities of this switch are still being investigated.

The Caltech chemist is also concentrating on analysis of the hemoglobin and DNA of sickle cell patients for biochemical factors that determine how severity of the illness varies. Some patients get much less sick than others; is there one piece of genetic information that is likely to tell why? Schroeder's main tool to determine the composition of hemoglobin in these studies is high performance liquid chromatography (HPLC). It's now possible to separate chemically two polypeptide chains that differ by only one methylene group (molecular weight 14) out of a total molecular weight of 16,000. Work that once took three days can be done with HPLC in two hours and with a sample of 0.1 milligram instead of 100.

The particular hemoglobin chains that he's interested in are the two types of gamma chains in fetal hemoglobin. What is called the alpha chain in fetal hemoglobin remains the same in the switchover to the adult form, but the two gamma chains switch to a single beta chain in adult hemoglobin. And it's in the beta chain that the sickle cell and thalassemia abnormalities are expressed.

The two gamma chains (called G-gamma and A-gamma) differ in only one amino acid in a particular position along the chain. The ratio of the concentrations of these chains is different in the hemoglobin of newborn infants than in the trace of fetal hemoglobin present in adults. Adult sickle cell patients, however, may have either ratio. The figure gives examples of HPLC data from two patients who have opposite ratios of the chains.

Similar data had previously been obtained with the old time-consuming methods in collaboration with Titus Huisman of the Medical College of Georgia. Huisman has also been examining fetal hemoglobin of patients in Georgia by HPLC and looking at certain aspects of DNA structure. He is seeing correlations between some properties of fetal hemoglobin and DNA that suggest certain regions of DNA as the control point of the switch. Schroeder is studying patients in southern California to discover whether there's a similar correlation of the ratio of the gamma chains with a difference in the DNA of these patients, whether the ratio of the gamma chains and differences in DNA influences the severity of the illness, and whether these factors are implicated in the switchover to adult hemoglobin.

Correlations of biochemical data with medical information has been aided by the Los Angeles Sickle Cell Center at the USC School of Medicine. Schroeder has been associated with the center since its founding in 1972. Some of his main collaborators at Caltech have been associate chemists Roger Shelton, Joan Shelton, and Lois Kay. □ — *JD*