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Superconducting Magnets

by

W. Virgil Winters

Boys and girls are learning that some materials possess a property of attracting or repelling similar materials that are nearby. Iron and some of its alloys represent the more familiar of such materials.

Later they find out that a wire through which an electric current is flowing shows this magnetic property. If this wire is wound into a coil, forming a solenoid, and the same amount of current sent into it, the coil becomes more strongly magnetic, that is, its magnetic field is more intense. If a rod of iron is placed inside this coil, a considerable increase in the magnetic field about the coil can be detected. When the amount of direct current is sent into the coil, the magnetic field increases. This happens also if the amount of core material is increased. If the amount of current is further increased, the wires become warm and even hot so that for large amounts of current forced air on water must be used to reduce the temperature of the wire. Increasing the number of turns and enlarging the core material produce more intense fields and also increase the volume, weight, and cost of the magnet.

How may these disadvantages be reduced? One answer lies in making "super conducting" magnets.

H. Kamerlingh Onnes discovered super conductivity in 1911. He found that at temperatures near absolute zero, 0° Kelvin scale the electrical resistance of some metals disappeared and no energy was required to maintain a current through them after it was started. He attempted to construct a super conducting electro-magnet but was not successful because his materials lost their superconductivity in the presence of magnetic fields of moderate strength.

The maximum magnetic field in which a material remains superconducting is called the "critical field." Its value depends upon the material and temperature. This field is at a maximum at the temperature of 0°K and zero at the critical temperature of the super conductor, the temperature above which the material cannot be super conducting, (up to about 20°K).

The superconductors which Onnes and his immediate successors used had low critical fields of several hundred gauss. Small, toy magnets have fields of this value.

It was also discovered that a high current flowing through a wire could destroy superconductivity in the absence of an external magnetic field.

Through the work of Kurt A. G. Mendelssohn, Heinz London and others, it was found that some super conductors as aluminum, lead, mercury, and tin carried current mainly through a thin surface film while in others as niobium, and niobium-zirconium the current seemed to have been carried by filaments within the material. The first type of superconductors was called "soft" and the latter type "hard."

A three-dimensional network consisting of thin filaments or thin films could be expected to remain superconducting in magnetic fields several times stronger than the critical fields for the corresponding bulk material.

In 1960 Stanley A. Autler operated a superconducting niobium magnet for a solid state microwave maser. This magnet generated a field of 4,300 gauss at a temperature of 402°K. A Bell Telephone group of scientists using a molybdenum-rhenium alloy produced a magnet generating a field of about 15,000 gauss.

In 1954 Matthias and others reported the synthesis of niobium-ten, Nb_3Sn, which was superconducting at 18°K.

In 1961 Kunzler and others showed that this compound satisfied quite well the three essential requirements of a material suitable for constructing super conducting magnets: (1) the material must remain superconducting in an intense magnetic field; Nb_3Sn was found to be thus in a field of 88,000 gauss; (2) the material must sustain a high current density in the intense magnetic field; Nb_3Sn was shown to sustain a current density of over 100,000 amperes per square centimeter at 88,000 gauss; (3) the material, even if refractory, must be capable of being fabricated into a magnet; Nb_3Sn is quite brittle, but it can be formed into a solenoid.

To determine if a material is suitable as a superconductor, a good test is to determine how the critical current density decreases as the applied magnetic field is increased. The sample material is cooled in a bath to the temperature of liquid helium 2° to 4°K, and a transverse magnetic field is applied. Then current is passed through the sample. As the current increases to some value a voltage difference across the sample can be observed. This difference represents resistance of the sample and the end of its super conductivity.

Since niobium-ten is quite brittle, a special process is required to overcome this difficulty. A niobium tube .015 inch in diameter (about #26 B. & S. gauge) is filled with an intimate mixture of powdered niobium and tin; then the open ends of the tube are seated with niobium plugs. The tube is encased in an insulating tube of monel metal. The material is run through dies, which reduce its diameter and then wound on a cylinder to form a solenoid. This coil is heated in a furnace to 1000°C, at which temperature the compound Nb_3Sn is produced. To avoid short circuits when adjacent turns of the monel metal come in contact when the initial current is turned on, the wire is covered with an insulating layer of quartz fiber cloth.

Westinghouse Research Laboratories operate a 70,000 gauss magnet containing coils of niobium-zirconium. Bell Laboratories have tested a 70,000 gauss niobium-tin experimental magnet.

Another promising superconductor is vanadium gallium, V_3Ga. Matthias and associates at Bell Laboratories developed this substance. Preliminary experimental evidence indicates that the critical field of this compound is over 400,000 gauss.

Uses of superconducting magnets are in particle accelerators as cyclotrons, for power generation, magneto-hydro-dynamic devices, and for controlled nuclear fusion.

One of the problems in controlling nuclear fusion is in the confinement of hot ionized gases or plasmas in some sort of container. Since the gases may be at temperatures up to one hundred million degrees centigrade, some means must be employed to prevent these hot gases from coming in contact with the container walls. Intense magnetic fields set up in the container prevent this contact.

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