Detection of the magnetic field of the heart

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The electromotive forces of the heart set up currents in the torso which in turn produce magnetic fields. These fields are exceedingly small, having peak values less than one millionth of the strength of the earth field. Nevertheless, they may be detected, as is shown by the magnetocardiogram in Fig. 1.

This record was obtained using a specially designed assembly of two coils, each containing two million turns, and wound on a dumbbell-shaped core of magnetic material (ferrite) approximately a foot in length. The coils were oriented as shown in Fig. 2. The output voltage of these coils (of the order of 30 microvolts) was magnified by an amplifier of exceedingly low noise level and high input impedance, and passed through a filter especially designed to suppress 60-cycle interference without significant distortion to the wave form of the signal. Because the coil is sensitive to the rate of change of magnetic field, rather than the field itself, the record in Fig. 1 is actually a derivative of the magnetic field of the heart. It may easily be integrated to give the signal itself.

The record was obtained in an isolated location several dozen yards from the nearest source of interference. The ragged appearance of the baseline is due to noise generated in the coils and amplifier, rather than to external disturbances. A program

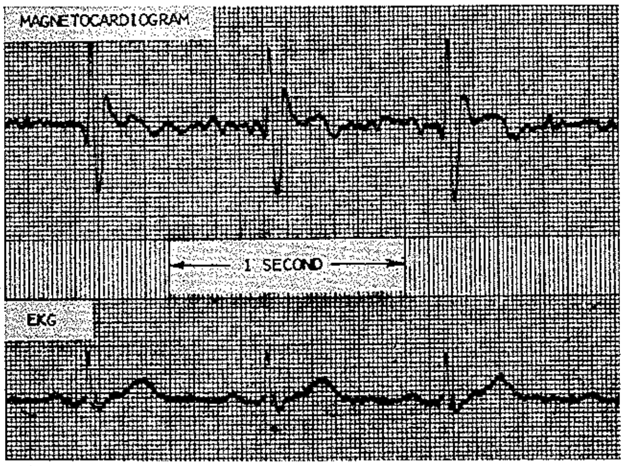

Fig. *1.* Magnetocardiogram taken with coil placement shown in Fig. 2. An electrocardiogram taken simultaneously is also shown. The high noise level in the electrocardiogram is due to the long cable which extends to the subject.

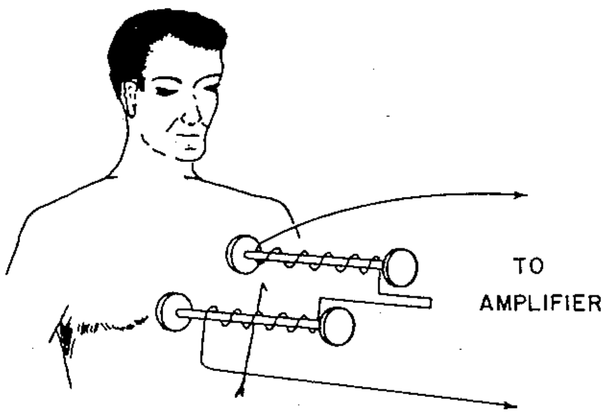

Fig. *2.* Magnetocardiograph pickup coils.

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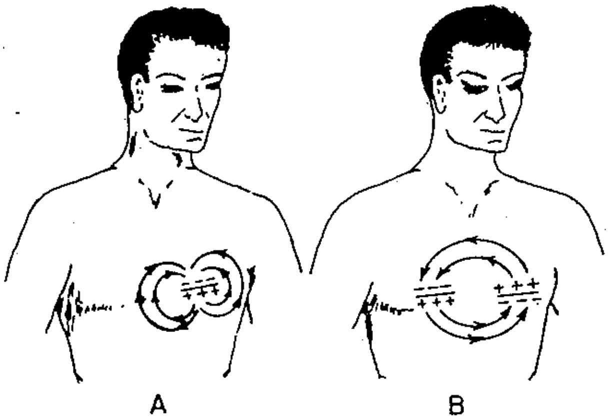

Fig. *3*. Flow lines of currents within the torso giving rise to magnetic fields. *A*, Dipolar electromotive force. *B*, Quadripolar electromotive force.

is now underway to design shielding which will permit the apparatus to be operated under normal laboratory conditions. Various improvements which will further reduce amplifier noise level are also being worked out.

The pickup assembly is extremely sensitive to vibration of the coil assembly in the earth field. To prevent this, the coils are fastened to a heavy mount of great rigidity. Care is taken to see that vibrations are not transmitted to the coils from pulsations of the chest. Motion of magnetic material in the vicinity of the coils also gives rise to disturbances. A cancellation arrangement, in which the output of two identical coils side by side are subtracted from each other, gives considerable immunity to magnetic disturbances which do not arise in the immediate vicinity of the coils.

The magnitude and direction of the field is essentially the same as that predicted from the estimated distribution of current in the chest, which must be associated with an electrical field in a volume conductor. It also agrees with measurements of magnetic fields made with a current dipole in a tank filled with saline solution which simulates the body.

This attempt to measure the magnetic field of the heart has been motivated by the hope that certain electrocardiographic anomalies will be more evident on such a record than on electrocardiographic records. The primary reason for this hypothesis is shown in Fig. 3. In *A* of Fig. 3 the flow lines of current which result from a dipolar electromotive force within the heart are sketched. Such a flow of current produces a tangentially oriented field on the chest over the heart. In *B* of Fig. 3 the flow of current which results from a "quadripolar" combination of electromotive forces is shown. This current produces a magnetic field over the heart which is perpendicular to the chest. The electromotive forces in Fig. 3,*B* are nearly silent in ordinary electrocardiographic records despite the fact that a strong circulating current is produced in and around the heart. Such currents will, however, set up detectable magnetic fields; thus, the magnetocardiograph offers the potentiality of detecting otherwise "silent" components of the electromotive forces of the heart. We have not as yet detected such circulating currents in normal subjects.

In normal subjects the magnetic field of the heart is maximum on the chest directly above the heart and dies away rapidly above, below, and to the sides. At a point on the chest directly above the heart it is greatest in a direction tangential to the surface of the chest and oriented more or less toward the left arm. The component of the field at right angles to this direction is small. Differences exist from subject to subject.