orient with respect to a source of ultrasonic pulses.

The method has many possibilities. A second thermistor pair could be placed in the vertical plane to register tendencies to climb and dive. The signal generated by the anemometer suggests arrangements employing feedback, thus permitting study of the actual orientation of insects in stationary flight to sources of optic, acoustic, and other stimuli.

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References and Notes

1. K. D. Roeder, *Anim. Behav.* **10**, 300 (1962).
2. ——— and A. E. Treat, *Proc. Int. Congr. Entomol. 11th* **3**, 1 (1960) .
3. K. D. Roeder and A. E. Treat, *J. Exp. Zool.* **134**, 127 (1957); K. D. Roeder, *J. Insect Physiol.* **10**, 529 (1964); ———, *ibid.*, in press; R. S. Payne, K. D. Roeder, J. Wallman, *J. Exp. Biol.* **44**, 17 (1966); K. D. Roeder, *Science*, in press.
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25 July 1966

Pacemaker Synchronization

Abstract. *A method using the standard radio-frequency receiver was developed to telemeter biopotentials across the intact body wall; it can be employed to program a stimulus to the heart at any phase of the cardiac cycle. The small variations of potential across the electrodes of the implanted cardiac pacemaker change the natural resonant frequency of the receiver in direct relation to the electrical activity of the heart.*

By a new method one can telemeter cardiac electrical activity with the implantable radio-frequency cardiac pacemaker receiver heretofore employed only to forward electrical impulses to the heart for pacemaking (Fig. 1; *1*); an advantage is that one can now synchronize electrical events in the heart with electrical pacemaking, with no modification of the implanted apparatus—only of the external transmitter to change its type of impulse.

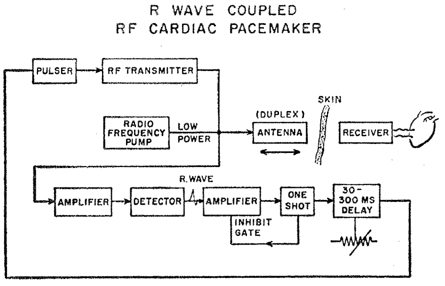

Fig. 1. Schematic diagram of the equipment.

Experiments were performed on dogs under nembutal anesthesia and endotracheal respiration. The cardiac electrodes attached to the radio-frequency receiver were of unipolar or bipolar configuration. Several sites on the ventricular surface were tested, and in some instances the polarity was reversed. The radio-frequency receiver was either located external to the body or implanted in the subcutaneous tissue; in one experiment several recordings were obtained with a direct transcutaneous wire.

Tests were also conducted with a cardiac-voltage simulator generating up to 10 mv which was applied to the electrode leads (Fig. 2). To detect frequency changes in the implanted circuit from signals arising in the heart, we employed Pound's marginal oscillating detector (*2*) to force a current of 5 to 10 μa at approximately 2 Mc/sec through the receiver's diode; when the cardiac signal influenced the diode's elecrical capacity there was an increase in the marginal oscillator's frequency; typically a shift of 21 cy/mv was obtained. Simultaneous recordings, made of the simulator's output, from a frequency-modulation receiver, tuned to 2 Mc/sec, demonstrated excellent correlation with the cardiac-voltage simulator's direct output. When the diode was intentionally short-circuited, no shift in frequency was observed.

When the cardiac-voltage simulator was replaced by a variable resistor, only a small change obtained. Thus our "RF-electrogram" is mainly the result of potentials generated by the heart—not the result of changes in its resistance. A small audio amplifier that demonstrated the electrogram was useful in determining the sites on the cardiac surface from which best to record.

Good electrographic recordings of the P-QRS-T complex were obtained when one electrode was implanted in the ventricle wall within 0.5 cm of the atrium, or when one was implanted in the outer atrial wall. Figure 3A shows direct epicardiac potentials telemetered from an implanted standard radio-frequency receiver whose electrodes were attached to each ventricle (*RF-EG*). The activity recorded, as expected, clearly precedes both the strain-gauge deflection (representing ventricular contraction) and the electromagnetic-flowmeter deflection, representing aortic arch flow.

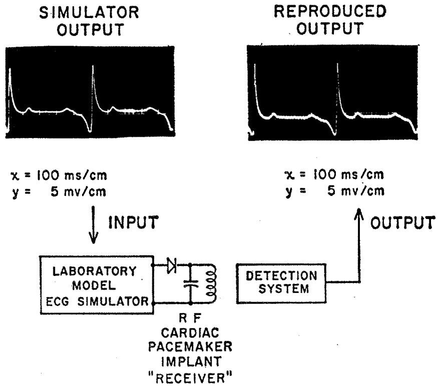

Fig. 2. Results with the output (up to 10 mv) of a cardiac-voltage simulator applied to the electrode leads.

Figure 3B shows delayed pacemaker synchronization with the R wave, resulting in coupled pacing; one may see that when the "delay" was adjusted to 180 msec immediate coupling followed, the rate decreased from 160 to 80 per minute, and there was a concomitant 10 percent increase in left ventricular pressure.

Two distinct problems remain: first, external signal interference preventing establishment of an isoelectric base line; second, the difficulty in determining the best sites for the electrodes, to insure

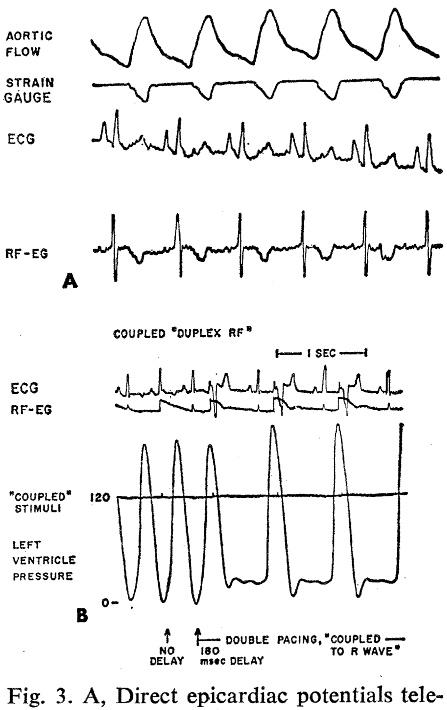

Fig. 3. A, Direct epicardiac potentials telemetered from an implanted radio-frequency receiver whose electrodes were attached to each ventricle (*RF–EG*). B, Delayed pacemaker synchronization with the R wave, resulting in coupled pacing.

sufficiently high P-wave levels for detection purposes to permit atrioventricular synchronous pacing.

The method of "duplexing" the function of the implantable receiver may be applied to various other biologic events as well as to implanted mechanical apparatus capable of generating electrical signals within the body.

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References

1. W. W. L. Glenn *et al.*, *Ann. Surg.* **160**, 338 (1964); L. Eisenberg, A. Mauro, W. W. L. Glenn, J. H. Hageman, *Science* **147**, 578 (1965).
2. R. V. Pound, *Phys. Rev.* **69**, 37 (1946).

12 May 1966

Calcium and Bromide Contents of Natural Waters

Abstract. *The linear relation observed in a log Ca^{++} versus log Br^- plot for subsurface Cl^- waters is attributed to ultrafiltration by shale of sea water and fresh water that have passed through sedimentary rocks since their formation. Reactions between these solutions and sedimentary minerals, particularly dolomitization, must have contributed additional Ca^{++} to solution.*

The Ca^{++} and Br^- contents of subsurface Cl^- waters in marine sedimentary basins are proportional over a wide range of concentration. The values plotted in Fig. 1 are for waters from saline springs and from oil wells, except for waters from the surface sources mentioned. Most of the subsurface data are from Illinois, Michigan, California, Alabama, Mississippi, Alberta, and the Irkutsk area of the U.S.S.R.

Determination of Br^-, especially at the lower end of the concentration range of Fig. 1, is still a difficult analysis; some scatter should be expected in Fig. 1 because of the different analysts and techniques involved. In particular, the very low Br^- concentrations must be viewed with caution, even though they were determined by a highly sensitive catalytic method (*1*) that is more reliable than conventional techniques. However, excellent linear relations are shown by some groups of samples from single areas, such as the six from Michigan and the seven from the Dead Sea area, through which the straight line of Fig. 1 has been drawn. The equation of the line is

$$\log Ca^{++}\,[g/10^6\ g\ (\text{solution})] = 1.263 + 1.406 \log Br^-\,[g/10^6\ g\ (\text{solution})]$$

In other words, there is one Br^- ion to every 36 Ca^{++} ions at the lowest salinity represented in Fig. 1 and 1 : 53 at the highest.

The proportionality shown in Fig. 1 is not repeated in graphs involving Na^+ or Cl^-. Thus, if Na^+ is plotted against Br^-, most of the points concentrate in the log interval of highest Na^+ concentration and show a high degree of scatter, particularly for the Michigan samples. In a graph of Ca^{++} versus Cl^-, scatter in the interval between 10^3 and 10^4 g Ca^{++} per 10^6 g of solution is greater than in Fig. 1, and there is a marked break toward reduced slope above 10^4 g Ca^{++} per 10^6 g of solution because Cl^- concentration becomes nearly constant.

The highly concentrated Cl^- waters found at depth in sedimentary basins contain Ca^{++} as a principal cation, sometimes exceeding even Na^+ in abundance. It has recently been argued that this accumulation of Ca^{++} results from the operation of shale ultrafilters that retain Ca^{++} and Cl^- but pass Na^+ balanced by HCO_3^- equivalent in amount to ($HCO_3^- + SO_4^{--}$ in the original surface waters (*2, 3*). A variant of this mechanism, in which ion transport through the ultrafilters takes place by means of neutral complexes, appears to be favored by the conclusion (*4*) that considerable amounts of the SO_4^{--}, HCO_3^-, and CO_2^{--} in sea water are complexed, but essentially none of the Cl^- is.

Because even the most-concentrated subsurface brine is far from saturation in calcium chloride, all the Ca^{++} and Br^- contained in fresh water and sea water, that have passed through the system since deposition of sediment, could have been retained in solution behind ultrafilters. Part of the Ca^{++} now in solution has probably been derived from the dolomitization reaction

$$2\,CaCO_3 + Mg^{++} \rightleftharpoons CaMg(CO_3)_2 + Ca^{++}$$

No doubt some Mg^{++} has gone into regrading and diagenetic formation of chlorite and other silicates, but presumably little Ca is returned to solution (*2*) because exchange positions of these silicates, originally formed in marine environments, should be Na-saturated.

One plausible explanation of the increase in $Ca^{++}:Br^-$ ratio along the line in Fig. 1 is that the dolomitization reaction proceeds more nearly to completion in more concentrated brines; such brines typically occur at greater

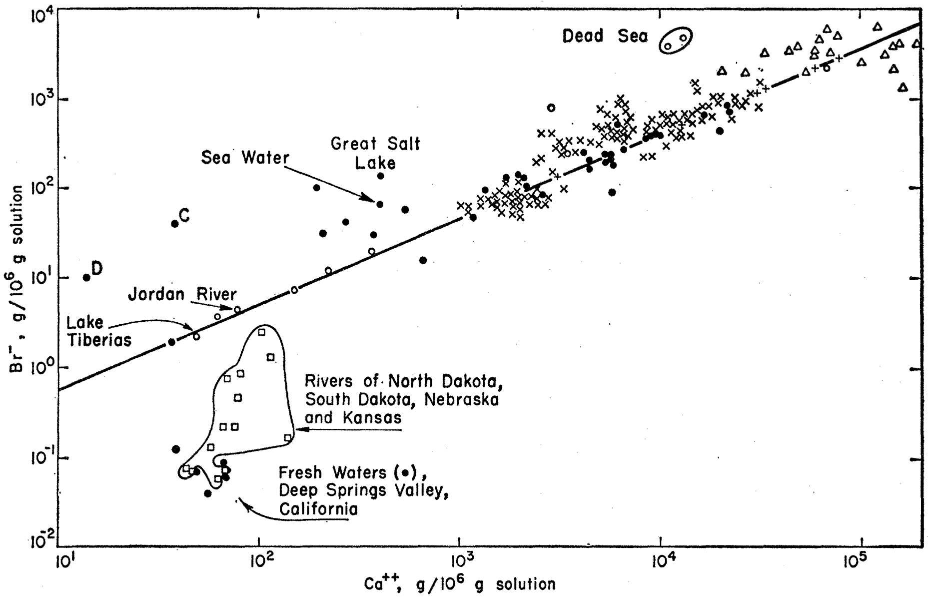

Fig. 1. The Ca^{++} and Br^- contents of a group of natural waters. Samples shown by plus signs (Michigan), open circles (Dead Sea region), and dots (Alberta; various U.S. localities) are tabulated in table 6 and appendix II of (*2*); by triangles (Irkutsk region), in table 2 of (*5*); and by crosses (Alabama and Mississippi), in (*8, 9*). All samples not otherwise identified in the figure are subsurface brines, sampled from either oil wells or points at which the brines reach the surface as saline springs.