Sandoz, Ltd., Basle, for samples of the pure ergot alkaloids.

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[1] Ramstad, Egil, "Modern Pharmacognosy" (McGraw-Hill Book Co., Inc., 1959).
[2] Gröger, D., *Arch. Pharm.*, **292**, 389 (1959).
[3] Feldstein, A., *Experientia*, **12**, 475 (1956).
[4] Saxton, J. E., *Quart. Rev.*, **10**, 108 (1956).
[5] Brady, L. R., and Tyler, jun., V. E., *Planta Medica*, **7**, 225 (1959).
[6] Taber, W. A., and Vining, L. C., *Chem. and Indust.*, 1218 (1959).
[7] Baxter, R. M., Kandel, S. I., and Okany, A., *Nature*, **185**, 241 (1960); *Chem. and Indust.*, 266 (1960).
[8] Gröger, D., Wendt, H. J., Mothes, K., and Weygand, F., *Z. Naturforsch.*, **14**, b, 355 (1959).
[9] Pöhm, M., *Arch. Pharm.*, **291**, 468 (1958).
[10] Jacobs, W. A., and Craig, L. C., *J. Biol. Chem.*, **104**, 547 (1934).

PHYSIOLOGY

Rectifying Properties of Heart Muscle

A FACTOR of likely importance in the genesis of the long-lasting action potentials of vertebrate heart muscle is the influence of membrane potential on the potassium permeability of the fibres. That a difference here exists between cardiac muscle and nerve is evident from Weidmann's[1] demonstration of a low slope conductance during the plateau of the action potential. But little information is so far available on the voltage dependence of the membrane conductance under conditions designed to avoid the generation of action potentials.

To study this point, so far as the technical limitations imposed by the structure of cardiac muscle at present allow, excised Purkinje fibres from sheep ventricles were used. While sharing the essential electrical properties of myocardial tissue, these fibres do not produce a mechanical response on depolarization; they are also insensitive to parasympathomimetic substances so that choline chloride or sucrose may be used as a substitute for extracellular sodium chloride to abolish excitability.

Fig. 1, *A* and *B*, shows how the membrane conductance of a Purkinje fibre in sodium-deficient

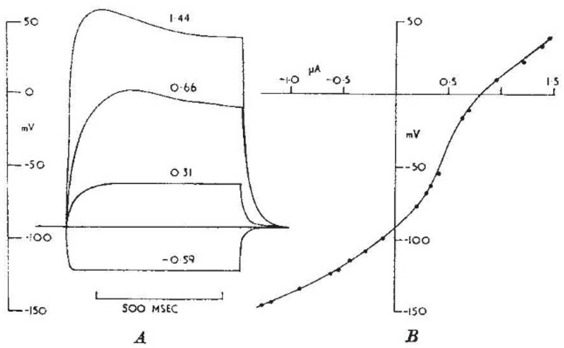

Fig. 1 *A*. Superimposed tracings of electrotonic potentials from a sheep's heart Purkinje fibre. Sodium ions in Ringer's solution replaced by choline. Depolarization is shown in an upward deflexion from a resting potential of −92 mV. Two closely spaced KCl-filled intracellular electrodes were used to record the membrane potential and to pass practically rectangular current pulses of a strength indicated by the figures on each record. *B*, Current-voltage relation for the same preparation. Ordinate, membrane potential at end of current pulse lasting 700 m.sec. Abscissa, total membrane current

solution depends on the direction and magnitude of the polarizing current. An outward current of 0·31 μamp., for example, produced the same voltage deflexion as is caused by nearly twice as great an inward current. Allowing for the cable properties of the fibre, this means that the conductance to a depolarizing current may be about four times less than to a hyperpolarizing current. Since the contribution of chloride ions to the membrane conductance of cardiac muscle is small[2], a decrease in the potassium conductance presumably occurs on depolarization. The direction of the potassium conductance change in Purkinje fibres is thus opposite to the predominant change in nerve[3], but has a parallel in skeletal muscle[4].

With strong depolarizing currents a decline in the electrotonic potentials during the pulse may be observed, suggesting a gradual increase in conductance. This second effect probably accounts for the S-shaped relation between the amplitude of the electrotonic potential at the end of a long pulse and the polarizing current (Fig. 1 *B*), but over the physiological range the conductance remains below its value at the resting potential.

The slope conductance decreases appreciably over the range occupied by the slow diastolic depolarization in spontaneously beating preparations[1]. This alinearity may require consideration in interpreting the resistance changes observed during the pacemaker potential[5].

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[1] Weidmann, S., *J. Physiol.*, **115**, 227 (1951).
[2] Hutter, O. F., and Noble, D., *J. Physiol.*, **147**, 16, *P* (1959).
[3] Cole, K., and Curtis, A. J., *J. Gen. Physiol.*, **24**, 551 (1941). Hodgkin, A. L., and Huxley, A. F., *J. Physiol.*, **116**, 424 (1952).
[4] Katz, B., *Arch. Sci. Physiol.*, **3**, 289 (1949). Hodgkin, A. L., and Horowicz, P., *J. Physiol.*, **148**, 127 (1959). Hutter, O. F., and Noble, D., *J. Physiol.*, **151**, 89 (1960).
[5] Trautwein, W., and Dudel, J., *Pflüg. Arch. ges. Physiol.*, **266**, 653 (1958).

Cardiac Action and Pacemaker Potentials based on the Hodgkin–Huxley Equations

SINCE the equations describing the nerve action potential were formulated by Hodgkin and Huxley[1], the range of phenomena to which they have been shown to apply has been greatly extended. Huxley[2] has applied them to the influence of temperature on the propagated response and to the repetitive firing observed in low calcium concentrations. More recently, Fitzhugh[3] has shown that the long action potentials induced by tetraethylammonium ions in squid nerve may also be reproduced.

The computations described in this communication were carried out with the aim of reconstructing the long-lasting action potential and pacemaker potential of cardiac muscle. Although this work was done independently, the results agree with those of Fitzhugh in showing that action potentials of long duration may be accounted for by Hodgkin and Huxley's formulation of the membrane properties. The description of the potassium current, however, differs from that used by Fitzhugh and provides a better description of the conductance changes.

The equations I have used to describe the sodium current are very similar to Hodgkin and Huxley's,