Evidently cells in an electric field may show either of 2 types of locomotion: first, electrophoretic movement, which is easily observable at low field strength, forcing the leucocyte toward the anode[2]; second, amoeboid galvanotactic movement in higher field strengths, forcing the leucocyte in the opposite direction toward the cathode.

Whether these 2 factors are of importance in determining the direction of locomotion of leucocytes in an inflammatory area remains to be determined.

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A Thermoelectric Blood Flow Recorder in the Form of a Needle.

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The needle flow recorder described here was primarily designed to measure rate of blood flow through the internal jugular vein of man. Preliminary work on animals has shown that the device possesses certain characteristics that would seem to promise it a sphere of usefulness in a variety of problems where blood flow is an important variable. The advantages of the device are as follows: Its use entails only a minimal trauma. It can be applied to the study of flow through relatively inaccessible structures. The method makes it possible to measure qualitatively the changes in blood flow through a vascular tissue without isolating or cannulizing the afferent or efferent vessels, and thus enables one to study the blood flow through a tissue or organ, the blood supply of which is not capable of being completely isolated. It also makes possible relative determinations of the blood flow through various parts of the same organ or region. This has not been possible by any method previously described. The thermoelectric methods for measurement of volume flow of blood previously reported require cannulization of a vessel and the passing of heparinized blood through a water jacket, the temperature of which is thermoelectrically determined (Bronk and Gesell[1]); or the isolation of a vessel, the heating of the blood therein by means of a high frequency current, and the determination of the temperature gradient along the

[1] Gesell and Bronk, *Am. J. Physiol.*, 1926, **79**, 61.

vessel (Rein[2]); or the insertion of an organ or region into a calorimeter.

The theory upon which the instrument operates is extremely simple. The cooling power of a stream depends, among other things, upon its velocity. If a needle, supplied with a constant amount of heat, is thrust into a vessel or into a tissue through which blood is flowing, the temperature of the needle will vary inversely with the flow of blood. That is, an increased flow of blood will cool the needle, and a decreased flow will allow the needle to heat up. By measuring the temperature of the needle it is possible to obtain an index of the blood flow. The tip of the needle can be supplied with a constant amount of heat by incorporating in it a length of high resistance wire through which a constant electric current is allowed to pass. The temperature of the tip of the needle can be conveniently measured by means of thermojunctions in series with a galvanometer, one junction being mounted in the tip of the needle.

The construction of the needle and the circuits used are shown in Fig. 1. Dimensions of the wires and spacing of the connections varied with the size of the needle and with the particular situation in which the needle was to be employed. One copper lead was usually

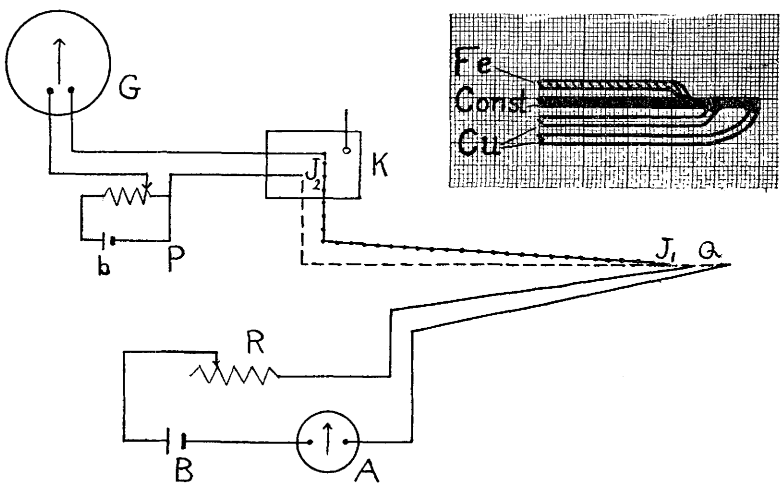

FIG. 1. Wiring diagram of needle blood flow recorder.

Solid line, copper wire; dotted line, iron wire; broken line, constantan wire. J_1 and J_2, thermojunctions; K, constant temperature box; P, potentiometer with b, source of known E. M. F.; G, galvanometer; Q, length of constantan used as heating element; A, milliammeter; B, battery; R, variable resistance. Insert shows large scale drawing of needle tip.

[2] Rein, *Z. f. Biol.*, 1928, **87**, 394.

connected to the constantan wire at the very tip of the needle (see large scale insert in Fig. 1); the second copper lead was soldered to the constantan about 3 mm. behind the first; and the iron wire was soldered to the constantan a millimeter or less behind the second copper lead. Thirty-six gauge copper, iron, and constantan wire were used in making large needles. Wire .02 mm. in diameter was used in making the finest needles. Electrical insulation and heat insulation were obtained by covering the wires with bakelite varnish. The heating current was supplied by a 6 volt storage battery in series with a suitable rheostat and ammeter. A potentiometer, capable of measuring tenths of a millivolt, was employed in conjunction with a sensitive galvanometer to measure the E. M. F. in the thermojunction circuit. Running records of the E. M. F. in the thermojunction circuit were made by recording on a smoked drum the turning of the potentiometer dial (which was manually

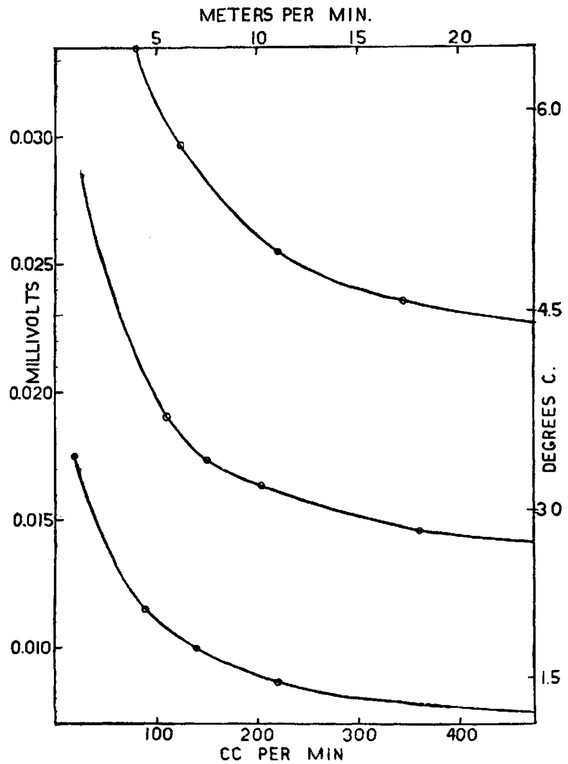

FIG. 2. *In vitro* calibration of needle flow recorder.

The curves give the E. M. F. and the corresponding difference of the temperature of the needle tip compared to that of the unheated blood for different rates of flow (lower scale minute flow, upper scale velocity). The 3 curves were obtained for 3 different strengths of the heating current.

operated) or by partially balancing the thermojunction current with the potentiometer and following the reflected light beam from the galvanometer mirror with a pointer mounted on a carriage under the galvanometer scale, the movement of the pointer being communicated to a writing arm recording on a smoked drum.

When the needle tip was placed in a stream of defibrinated ox blood flowing through a glass tube, the temperature of the needle varied with the flow and with the amount of heat supplied in the manner shown in Fig. 2.

Fig. 3 shows the change that occurs in blood flow through the kidney when adrenalin is injected intravenously. Records of changes in blood flow due to electrical stimulation of vasomotor nerves are shown in Fig. 4.

Experience has indicated that in anesthetized animals changes in body temperature do not introduce a serious source of error. By making alternate readings of the temperature of the needle tip, with the heating current off and with the heating current on, a change in body temperature can be noted and corrected for. In unanesthetized animals violent muscular exertion and emotional excitement produce sudden changes in body temperature. These can be automatically corrected for, if instead of placing the cold junction in a constant temperature box, it is placed in the tissue with the needle. The danger that changes in flow in distant areas may be misinterpreted as occurring at the needle tip can be minimized by using a small amount of heat, and by reducing the heat conductivity of the needle. Satisfactory sensitivity can be obtained without raising the temperature of the needle more than 2°C. above body temperature.

Whenever it is possible to maintain constant the cross section area of the stream being measured, the instrument can be calibrated (preferably *in situ*) so as to yield quantitative data. An example of such a situation is the bony canal that forms the lateral sinus in the dog. When the instrument is calibrated in an ordinary blood vessel, it should be realized that the changing pressures alter the cross section area of the vessel and make an accurate calibration impossible. Rough quantitative data can be obtained if the needle is calibrated in tissue. For example a record may be made of the E. M. F. in the thermojunction circuit with the needle flow recorder in the cortex of a cat's kidney. Various experimental procedures may be carried out and the resulting changes in E. M. F. recorded. At the end of the experiment which may last 2 or 3 hours, during all of which time it is possible to keep a running record of the E. M. F., a stromuhr can be inserted into the renal vein. By plot-

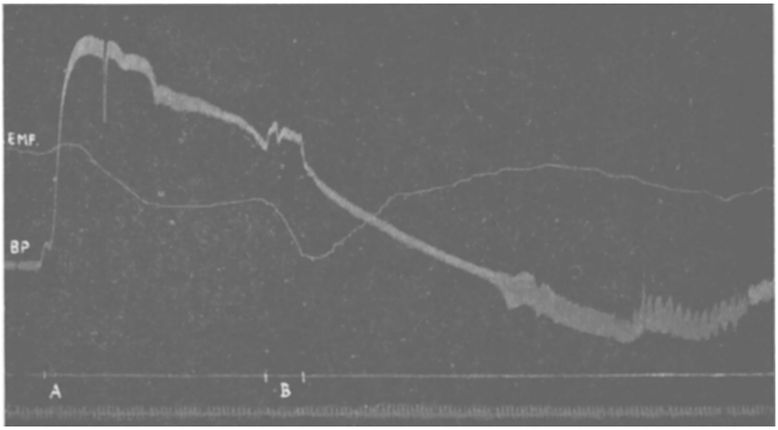

FIG. 3. Change in Blood Flow Through the Kidney Produced by Intravenous Injection of Adrenalin.

Needle flow recorder in cortex of the kidney of a cat anesthetized with sodium amytal. At A 1 cc. of 1:10,000 solution of adrenalin was injected intravenously. At B loose ligature around abdominal aorta above renal artery was pulled upon. Blood pressure tracing taken with cannula in common carotid artery. Time in 5 secs. Rate of blood flow past tip of needle indicated by E. M. F. in galvanometer circuit. Movement of the writing arm toward the base line shows increase of E. M. F. and a decrease in the rate of flow.

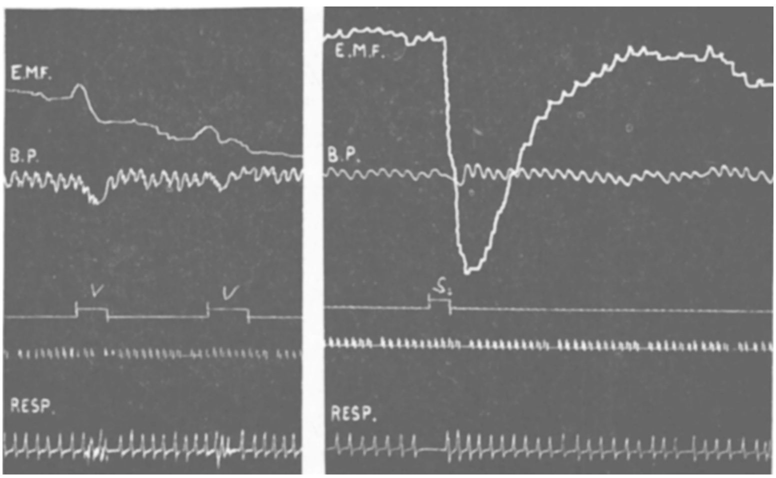

FIG. 4. Change in Blood Flow Through the Temporal Muscle Produced by Stimulation of Vagus and Sympathetic Nerves.

Needle blood flow recorder in muscle of a cat. Sodium amytal anesthesia. At V central end of homolateral vagus nerve stimulated with weak induction shock. At S central end of homolateral cervical sympathetic trunk similarly stimulated. Blood pressure cannula in femoral artery. Records as in Fig. 3.

ting E. M. F. against cc. of blood per min. as measured with the stromuhr, a curve is obtained which makes it possible to interpret the previously obtained record of E. M. F. in terms of flow through the whole kidney. Such a curve is shown in Fig. 3. The most serious source of error in such a procedure lies in the possibility that the relationship between the total flow through the kidney and the fraction of that flow which affects the temperature of the needle may have altered in the course of the experiment.

Though it is thus possible in certain situations, and by taking proper precautions, to obtain data with this instrument that are susceptible of quantitative interpretation, it is most advantageously used when employed as an essentially qualitative instrument. Such an instrument is not without present value in medicine and physiology. There remain important problems relating to blood flow that do not require for their solution knowledge of the actual volume flow per minute, but only require information as to whether the flow is slightly increased, greatly increased, continues unchanged, or is diminished. It was for such problems that this instrument was primarily designed.

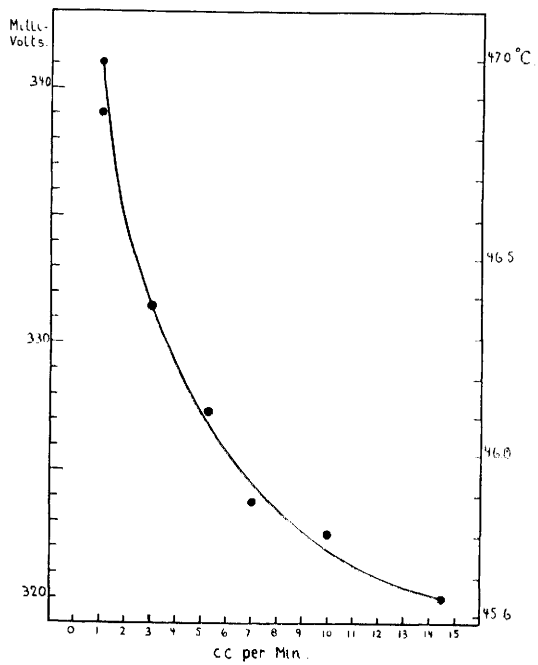

FIG. 5. *In vivo* calibration of needle blood flow recorder in cortex of cat's kidney against stromuhr.

Inserted into renal vein. Amytal anesthesia. Flow through kidney decreased by pulling on loose ligature around renal artery. It will be observed that an excessive amount of heat was supplied to the needle tip. This was an early experiment; later experience showed that satisfactory sensitivity can be obtained without raising the temperature of the needle tip more than 2°C. above body temperature.