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life, or in its third summer, when the minnow is approximately 75 millimeters total length.

2. This species was found to be almost entirely insectivorous at the time of the collection. Chironomids, ephemerids, and simulids, in their immature stages, comprised most of the food and their proportion in the diet varied according to the age of the fish.

In conclusion, it is hoped that this study has shed some light on several important life history phases of the longnose dace, which will aid an evaluation of the part played by this minnow in the synecology of trout streams.

LITERATURE CITED

Adams, Charles C. and Hankinson, T. L. The Ecology and Economics of Oneida Lake Fish. Bull. N. Y. State Coll. For., Syracuse Univ., *1* (4a) (Roosevelt Wild Life Annals, *1,* No. 3 and 4): 241–548. 1928.

Greely, J. R. The Spawning Habits of Brook, Brown, and Rainbow Trout, and the Problem of Egg Predators. Trans. Amer. Fish. Soc. *62*: 239–248. 1932.

Needham, Paul R. Trout Streams. Ithaca, New York, 233 pages. 1938.

Traver, Jay R. The Habits of the Blacknose Dace *(Rhinichthys atronasus* Mitchel). Jour. Elisha Mitchel Sci. Soc. *45* (1): 101–129. 1929.

APPLICATION OF THERMISTORS TO TEMPERATURE MEASUREMENTS IN EXPERIMENTAL INVESTIGATIONS*

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The thermistor was introduced into our laboratory because we hoped it would permit temperature measurements of living tissues in situ during exposure to microwave diathermy. So far as we know, there is no satisfactory method for measuring such temperatures in the presence of high-frequency alternating currents. Although we failed to achieve the desired goal, the thermistor has proved a very convenient element for temperature measurements in experimental animals. The first equipment which we constructed followed the description given by Drummeter and Fastie.[1] Later models have been modified somewhat according to the particular application. We have been using the thermistor for almost four years, and during this time its usefulness has gradually increased. A report of the applications which we are making may be of general interest to all who measure temperatures in the physiologic laboratory.

The word "thermistor" connotes the phrase "thermally sensitive resistor." Thermistors are made of solid semiconducting materials

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which have a high negative temperature coefficient of resistance; that is, the electrical resistance decreases rapidly with increases in temperature. Some of the materials used in making thermistors are the oxides of manganese, nickel, cobalt, copper and uranium. The composition of a particular thermistor is determined largely by the desired relation between resistance and temperature. During the last fifteen years the thermistor has found multiple uses in various electronic circuits. Becker, Green and Pearson,[2] of the Bell Telephone Laboratories, have spent years in perfecting the thermistor for use in electrical circuits. The thermistor has had interesting applications as a thermometer in military equipment. Meteorologists have used a certain type of thermistor for measuring temperatures at various levels in the atmosphere. The thermistor and auxiliary circuits were sent aloft in balloons. The atmospheric temperatures were transmitted to the ground stations by radio. Thermistors were also used for "seeing" the warmth of a man's body a quarter of a mile away.[3]

Because the electrical resistance decreases markedly with increasing temperatures, the thermistor introduces a new order of sensitivity into the field of resistance thermometry. As with all resistance thermometers, one must design the resistance-measuring circuit carefully so that the heating caused by the measuring current is negligible compared to that produced by the ambient temperature which one wishes to measure. The sensitivity of the thermistor method of measuring temperature may be expected to approach that of the precision platinum thermometer. It is possible to detect temperature changes of 0.000001° C. The small size, flexibility, rapid response, ruggedness, simplicity and sensitivity of the thermistor make it particularly suitable for physiologic thermometry.

Our first important use of the thermistor was in the measurement of cutaneous temperatures of the dog. We think that the thermistor is particularly suitable for recording changes in cutaneous temperatures. It now replaces the thermocouple method which we had employed previously for such measurements. It is interesting to note in a recent publication[4] from England that the thermistor has proved satisfactory also for measuring skin temperatures in experimental animals. Our next application was the measurement of rectal temperatures of the laboratory white rat when we were studying the effect of microwave diathermy on the flow of lymph. The thermistor is a very simple element for continuous recording of rectal temperatures of small animals as well as large animals. These early applications of the thermistor proved so satisfactory and convenient that we extended its use to measurements of intramuscular and subcutaneous temperatures. Recently, with the assistance of our surgical staff, we have succeeded in placing thermistors in bone and bone marrow, permitting them to heal in place. Under these conditions measurements of temperatures can be made over prolonged periods. Such a technic makes possible the study of changes in temperature which are due to various physical or other agents in the trained dog. Our particular problems in which this procedure was used were the study of changes in the temperature of bone and bone marrow caused by microwave diathermy and by ultrasonic vibrations. Another recent application has been the measurement of temperature changes in certain tissues of the rabbit during the investigations on frost bite. The thermistor may be used over a wide range of temperatures. We have measured temperatures ranging from —50° to +50° C. Thermistors have been used, however, in measuring temperatures from —100° to +400° C. The thermistor can be introduced into the vitreous humor and its location can be observed through the lens of the eye of the experimental animal. We have also used the thermistor for observing temperatures produced near the sciatic nerves of the dog when exposed to ultrasonic vibrations.

Thermistors can be procured in various sizes and shapes. Some are in the form of beads, disks, rods, washers and flakes. Other thermistors exist as specks of metallic oxides imbedded in glass beads about the size of a pin head, which in turn may be mounted in a vacuum. We have used the bead type of thermistor most frequently because it can be procured in sizes conveniently small for insertion into polyethylene tubing, which can be introduced through 15 gage needles into the various tissues the temperature of which we wish to measure (fig. 1). The disk type of thermistor has been used ingeniously by Williams and Thompson[5] for recording body temperatures of a human subject. The thermistor is imbedded in a plastic plug molded to the contour of the external ear. This permits continuous recording of temperatures without disturbing the patient. These authors state that the temperature of the auditory canal is about 0.25° C. lower than the sublingual temperature. Hill[6] has used the thermistor to measure "alterations of pressure [in the frog's gastrocnemius muscle] by means of the reversible change of temperature caused by the

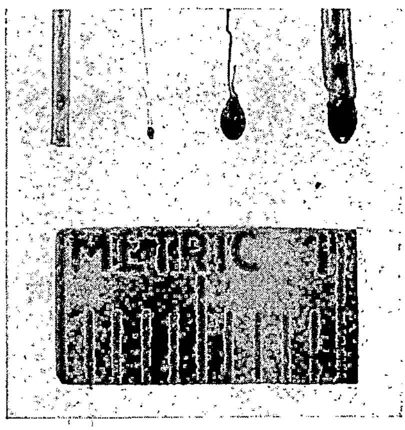

FIGURE 1. Two types of bead-shaped thermistors. The two on the left (one outside and the other inside polyethylene tubing) are type V-597. The two on the right are type V-642. Note that the thermistor V-642 itself is bare except for the enclosure in a glass capsule (not inserted into tubing).

compression of oil." Van Dilla and Gray[7] have described a circuit in which amplification is used. These investigators stated that their "circuit is sensitive to less than 1 ohm in 3000 ohms, or, in terms of temperature, it will respond to a temperature change of less than 0.015° F."

The equipment needed for measuring temperatures, in addition to the thermistor, is any convenient apparatus for recording resistances accurately. The Wheatstone bridge, which is a well-known method for measuring resistance, is the method employed in our laboratory. The thermistor forms one arm of the bridge. The bridge is balanced at some arbitrary temperature, preferably the midtemperature in the range of expected observations. Temperatures on either side of the balancing point may be read quickly after proper calibration. The thermal time constant of the thermistor which we use most frequently is two seconds. The term "thermal time constant" indicates "the time required for the temperature of the thermistor to change 63 per cent of the difference between its initial value and that of the surroundings."[2] Some thermistors have time constants as small as one millisecond. The calibration curve showing the relation between the ambient temperature and the deflection of the meter is a straight line for ranges of temperatures within 10° C. of the balancing point. This allows a range of observations of 20° C. on a linear scale with a zero-centered meter. If larger ranges of temperatures are to be observed, appropriate changes in sensitivity and the balancing point may be made. The meter scale in several of our portable equipments indicates temperature directly, so that the observer does not need to refer to the calibration chart.

For several years we have been interested in a study of the temperature differences between arterial and venous blood at various places in the circulatory system of animals. Such an investigation requires accurate measurements of very small differences in temperature. Some preliminary observations which we have made recently indicate that the thermistor will be satisfactory for such differential measurements. The thermistor placed in the vein forms one arm of a Wheatstone bridge and the thermistor located in the artery forms another arm of the bridge. The meter indicates the difference in temperature between the two thermistors. It is desirable to have two thermistors which are identical. However, we have compensated for differences that exist between any two thermistors by suitable circuit design.

The thermistor lends itself well to remote temperature measurements because the resistance of the lead wires is small compared to the thermosensitive element. Considerable distances may exist between the meter indicating the temperature and the thermosensitive element, the thermistor. If a physician in one part of the hospital wishes to observe the temperature of a patient in another part, he may do so by having the meter at that desired location. As stated previously in this paper, the temperatures may be transmitted by radio. Permanent and continuous records may be made by modern writing systems. Our permanent records are made by the usual photographic method. It is possible to make these measurements in a very few seconds.

We have built a first pocket model of a portable thermistor-thermometer for measuring skin temperatures which the physician may use when making his hospital rounds (fig. 2). This pocket size

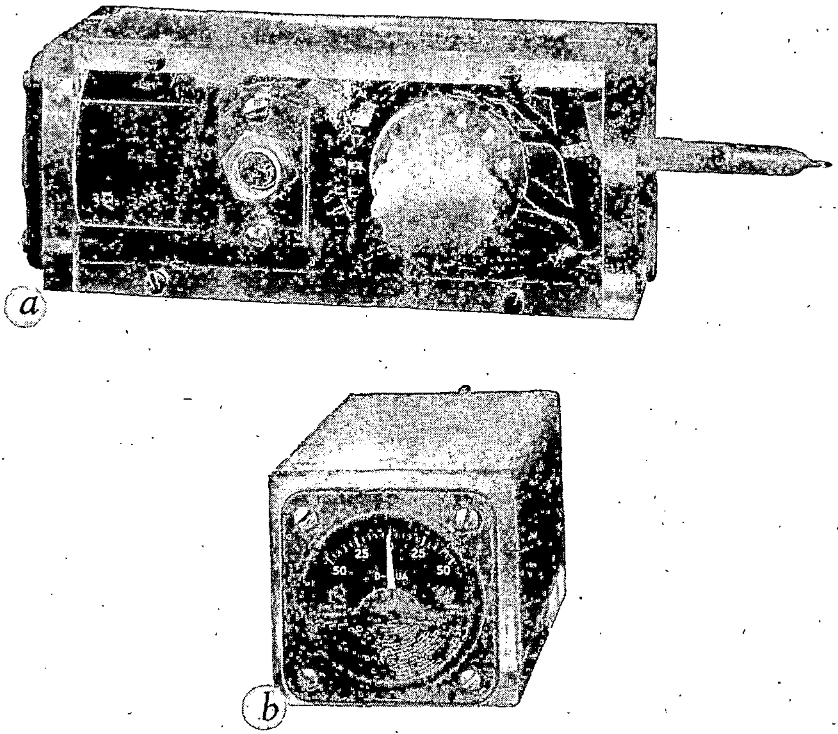

FIGURE 2. Small portable thermistor-thermometer for measuring cutaneous temperatures. *a*. Side view showing circuit components.*b*. End view showing meter.

has been possible through the development of miniature components. Such thermometers need not be limited to the measurement of cutaneous temperatures. By proper changes in the design of mounting the thermistor temperatures may be taken orally, rectally or however the physician prefers. One of our laboratory methods for measuring cutaneous temperature is shown in figure 3.

A comparative study of temperatures by thermocouples and by thermistors has been made. We have found that the two methods are about the same so far as accuracy is concerned. The thermistor has the advantage of being more convenient than the thermocouple in the laboratory, since it does not require a reference junction. In addition it is faster, simpler and more sensitive. The outstanding advantage which the thermistor has in our particular application is that it can be left in situ during microwave diathermy. The

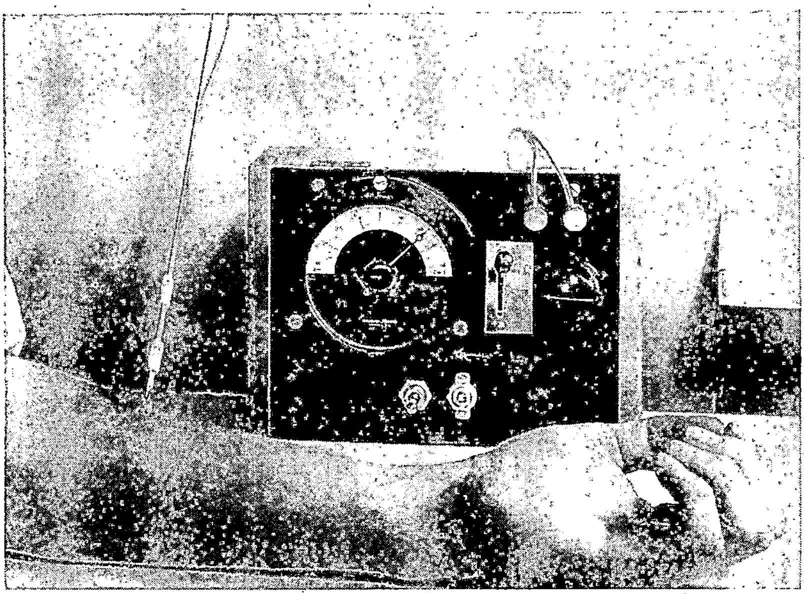

FIGURE 3. The bead-shaped thermistor, type V-642, as used for measuring cutaneous temperature. The method of mounting the thermistor insures suitable and constant pressure on the skin. The box contains the Wheatstone bridge circuit.

thermocouple cannot be left in situ unless it is completely covered by insulating material, thereby increasing the response time. Because the thermistor bead is a semiconductor the electromagnetically induced currents in the insulated lead wires do not "leak off" into the tissues which are immediately adjacent. The thermocouple, being all metal and a good conductor, causes burns in its immediate vicinity. These burns are due to the electromagnetically induced currents which "leak off" from the thermocouple into the tissues. If one is curious about this phenomenon, all he needs to do is hold a thermocouple (or any metal) in his hand while exposing his hand to microwave diathermy. The thermocouple soon becomes too "hot" to hold. The thermistor itself does not become "hot." If the output of the microwave generator is excessive the induced currents may cause direct heating of the thermistor. Under these conditions the thermistor becomes hot.

We were interested in determining whether the thermistor indicated any error in the true temperature of the tissue because it remained in situ during microwave diathermy. In order to answer this question we checked the temperature indicated by the thermistor which had remained in the tissue during microwave diathermy with that indicated by a thermocouple which was inserted immediately after the microwave generator had been turned off. The same thermocouple had been used to obtain control temperatures before microwave diathermy had been applied. All temperatures were recorded photographically (fig. 4). We found that the temperatures indicated by the thermistor were within experimental error

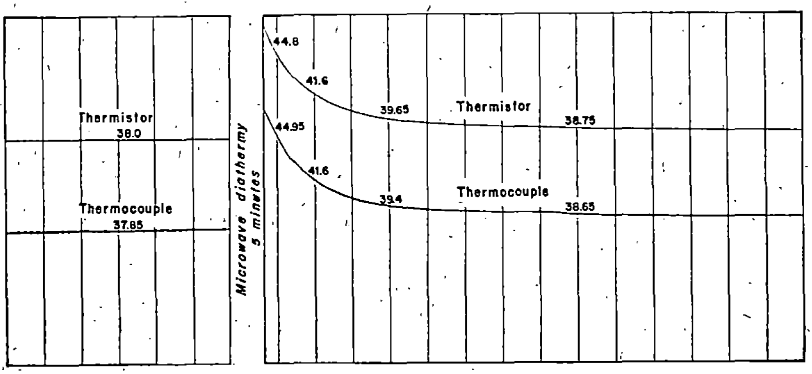

FIGURE 4. Comparison of temperatures indicated by thermistor and thermocouple. Thermistor remained in situ during microwave diathermy treatment. Thermocouple was removed.

of those temperatures indicated by the thermocouple. When one can permit the thermosensitive element to remain in situ during microwave diathermy he can obtain a temperature measurement at any time he wishes merely by turning off the generator for fifteen seconds. This technic enables one to evaluate the temperatures developed for various periods of exposure more efficiently than when the temperature-measuring element must be removed completely from the field of electromagnetic energy.

If one is interested in cutaneous temperatures only, it may be possible to make such measurements in the presence of microwaves. The thermistor may be used in a manner somewhat similar to that in which Hardy [8, 9, 10] and others have used the thermopile and also the resistance bolometer when measuring cutaneous temperatures. Thermistor bolometers have been described by Becker and his associates.[11, 12] A suitable thermistor may be placed at the focus of an elliptical mirror. The radiation from the skin falling on the mirror converges on the thermistor. Actual cutaneous temperatures are obtained by proper calibration of the equipment. The advantages of the thermistor over a thermopile or resistance bolometer are, according to Becker and his associates,[2] its ruggedness, more favorable resistance value and high temperature coefficient of resistance. The very small size of a thermistor, resulting in low heat capacity, permits rapid response (from one millisecond to one second) to temperature changes. Vacuum tube amplifiers or very sensitive meters are required for measuring small temperature changes. Such a setup as that described by Becker and his associates may prove useful when one is measuring temperatures during microwave diathermy, provided the distance between the temperature-measuring equipment and the source of microwave energy is sufficient to produce negligible effect from the electromagnetically induced currents in the circuit.

SUMMARY

The various applications of thermistors to temperature measurements of living tissues in our laboratory have been described. A comparison with the thermocouple method of measuring temperatures has been made. The advantages of the thermistor are its ruggedness, simplicity, quick response and sensitivity.

ACKNOWLEDGMENTS

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REFERENCES

[0] Drummeter, L. F., Jr. and Fastie, W. G. A Simple Resistance Thermometer for Blood-temperature Measurements. Science. n.s. *105*:73–75. 1947.

[2] Becker, J. A., Green, C. B. and Pearson, G. L. Properties and Uses of Thermistors — Thermally Sensitive Resistors. Electrical Engineering. *65*:711–725. 1946.

[3] Bell Telephone Laboratories (Advertisement) Proc. Inst. R. E. *34*:14A. 1946.

[4] Boyle, A. C., Cook, H. F. and Buchanan, T. J. The Effects of Micro-waves: a Preliminary Investigation. Brit. J. Phys. Med. *13*:2–9. 1950.

[5] Williams, R. J. and Thomson, R. C. A Device for Obtaining a Continuous Record of Body Temperature from the External Auditory Canal. Science. n.s. *108*:90–91. 1948.

[6] Hill, A. V. The Pressure Developed in Muscle During Contraction. J. Physiol. *107*:518–526. 1948.

[7] Van Dilla, M. and Gray, T. S. Thermistors, Their Characteristics, Uses and Associated Circuits. Climatic Research Laboratory of the Army Service Forces Quartermaster Corps at Lawrence, Mass. Office of Publication Board Report PB–3407, 1945, Dept. of Commerce, Washington 25, D.C.

[8] Hardy, J. D. Radiation of Heat from the Human Body: I. An Instrument for Measuring the Radiation and Surface Temperature of the Skin. J. Clin. Investigation. *13*:593–605. 1934.

[9] Hardy, J. D., Milhorat, A. T. and DuBois, E. F. Heat Loss and Meat Production in Women Under Basal Conditions at Temperatures from 23° to 35° C. American

Institute of Physics: Temperature; Its Measurement and Control in Science and Industry, Reinhold Publishing Corporation, New York, pp. 529–536. 1941.
[10] Hardy, J. D. Discussion. American Institute of Physics: Temperature; Its Measurement and Control in Science and Industry, Reinhold Publishing Corporation, New York, p. 581. 1941.
[11] Becker, J. A. and Moore, H. R. Thermistor Bolometer Detecting System for Infrared Spectrometers. (Abstr.) J. Optic. Soc. America. *36*:354–355. 1946.
[12] Brattain, W. H. and Becker, J. A. Thermistor Bolometers. J. Optic. Soc. America. *36*:354. 1946.

THE PHYSIOLOGIC EFFECTS OF FREEZING

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FLORAL DEVELOPMENT IN BIRDSFOOT TREFOIL
(Lotus corniculatus L.)

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ABSTRACT

Although *Lotus corniculatus* L., birdsfoot trefoil, has been gaining in popularity as a desirable legume for use as a forage crop and in land renovation, little has been published on the life history of the plant.

The transition from a vegetative to a flowering apex is initiated by a broadening and lobing of the stem tip; each lobe is the primordium of a flower. A whorl of sepals, one of petals and two of stamens arise in acropetal succession. The fifth and final whorl consists of an elongated carpel primordium. The fully developed corolla is of the normal papilionaceous type, consisting of a standard, two alae and two petals which fuse to form a tubular keel surrounding the anthers and style. Growth of the region basal to the stamens brings about an apparent merging of the proximal ends of nine of the filaments; the tenth, the adaxial member of the fourth floral whorl, remains attached separately to the receptacle. The carpel primordium is transformed to a U shaped trough by the meristematic activity of two adaxial regions of cells; continued development of these two regions and their final merging brings about the formation of a tubular carpel.

The tip of each staminal primordium becomes capitate and then four lobed, thus forming an anther. Each lobe consists of a central region of sporogenous cells bounded by a tapetal layer, two rows of parietal cells and an epidermis. The nucleus of each pollen