Temperature

H. Tracy Hall
Brigham Young U.

FARB H61 0106

RECEIVED
MAY 29 1961

Polytechnic Institute of Brooklyn
Microwave Research Institute

Networks and Waveguide Group

Memorandum 51

May 9, 1961

PIBMRI-915-61

The Fourth Symposium on Temperature, Its Measurement and Control in Science and Industry

By

Professor H. Farber

The Fourth Symposium on Temperature, its Measurement and Control was held in Columbus, Ohio. It was sponsored by the American Institute of Physics; Instrument Society of America and the National Bureau of Standards. Some of the vital statistics may be summarized as follows: The first session was officially started at 10:30 AM on March 27 and a final session terminated at approximately 5PM March 31, 1961. Two hundred twenty eight scheduled papers were presented and more than 30 post deadline papers were added. A total of 41 sessions were held, some occurring on Monday and Tuesday evenings. The sessions were divided into five catagories which were:

a) Plenary sessions during which background and tutorial type papers were presented. These papers were allotted 45 minutes.

b) Definitions of temperature and the establishment of temperature scales. Most of these papers were 30 minutes long.

c) Principles and Applications of instruments

d) Applications of Measurements in various fields and

e) Temperature and heat considerations in Biophysics.

The positive temperatures that were discussed ranged from several millidegrees to several million degrees Kelvin. Dr. Ramsey discussed negative temperatures which are hotter than positive temperatures.

The work reported in this memorandum was performed in connection with Contract No. AF-18(600)-1505 with the U. S. Army Signal Research and Development Laboratory, The Office of Naval Research and the Air Force Office of Scientific Research.

No attempt will be made to discuss any paper in detail but mention will be made of some of the many highlights that were reported and discussed. A list of the scheduled papers that were presented is appended. The American Institute of Physics has published the abstracts of each of these papers. A 3 volume compilation of the proceedings, edited by Dr. Herzfeld of N. B. S. will be published by Rheinhold Publishing Company.

After the introductory remarks and welcome by Dr. Astin, Dr. Lindsay presented the first paper of the conference in which he discussed the concepts of a thermodynamic system. One of the most important variables which characterizes a thermodynamic system in equilibrium is temperature. He also discussed how temperature may be defined on the basis of the zeroth law of thermodynamics and on the statistical foundation which defines temperature as being proportional to the modulus of the statistical distribution.

Dr. Ramsey then extended the temperature scale to negative values during his discussion of thermodynamic systems where the preferred energy state is the higher state. These have the analogous characteristics of "normal" thermodynamic systems in equilibria. The temperatures of these systems are negative quantities and are "hotter" than any temperature in the positive scale. The usual formulation of the 2nd law of thermodynamics must be altered slightly, to include these additional systems, as follows: It is impossible to construct a heat engine that will operate in a closed cycle and provide no other effect than 1) the extraction of heat from a positive temperature reservoir with the performance of an equivalent amount of work or 2) the rejection of heat into a negative temperature reservoir with corresponding work being done on the engine. Some systems that were referred to as having negative temperatures include masers, lasers and negative resistances; and negative temperature systems in general act as amplifiers whereas positive resistance networks act as attenuators.

Our cryogenic laboratory at M. R. I. is largely concerned with phenomena occuring at temperatures below $90^{\circ}K$ and with the measurements of temperature. in this region. This was the deciding factor whenever there was a choice among a number of sessions, which occured almost at each session period. At the moment there is no International Temperature Scale below the boiling point of oxygen ($90^{\circ}K$). Thus there were a number of sessions devoted to this and allied problems. Gas thermometers are used by most laboratories as the primary standard in this region. These are based on the gas law $PV = RT(1 + \frac{B(T)}{v} + \frac{C(T)}{v^2} + \ldots)$ where B(T) and C(T) are the virial coefficients. (For an ideal gas these are zero). Other types of gas thermometers, which may be used for very high temperatures were discussed in a session devoted exclusively to this type of thermometer. Dr. Moessen described the

Pennsylvania State University Thermodynamic Scale which is based on a constant volume gas thermometer. To maintain a constant volume the mercury level in the monometer arm that is connected to the temperature sensing bulb is maintained at a constant level. A precision of approximately $.001^{\circ}$ is claimed and agreement with the N. B. S. scale in the region is better than $.015^{\circ}$. Dr. Barber described another type of constant volume gas thermometer used at the National Physical Laboratories. The constant volume in this thermometer is maintained by sealing the capillary to the gas bulb with a diaphragm. Two gas cylinders, one with helium under pressure and the other one evacuated, are used to counterbalance the pressure produced in the gas bulb. A capacitance probe determines the zero position of the diaphragm. (The diaphragm is at room temperature and is connected to the gas bulb by a long capillary tube). The probable long term precision is in the order of $.001-.003^{\circ}K$. Members of the Committee of Standards, Measures and Measuring Instruments of the Council of Ministers of the USSR in the course of their discussion of platinum resistance thermometry described their constant volume gas thermometer which also has a diaphragm to seal the gas bulb. However the diaphragm is adjacent to the gas bulb and thus almost no capillary dead space exists. However, the diaphragm must be able to function at temperatures as low as $10^{\circ}K$. Dr. M. Holland of Raytheon in a post deadline paper described a gas thermometer system where neither the pressure nor the volume were maintained constant. However, since the accuracies that he required for his work were of the order of .1 $.01^{\circ}K$ we cannot readily compare his system with the others. It should be noted that many of the factors that contributed to the lower accuracy were not related to the inherent inaccuracies of the thermometry system, e. g. he used a relatively inexpensive cathetometer to read the height of the mercury column.

An alternate thermodynamic thermometer may be based on the velocity of sound in a gas. For an ideal gas the velocity of sound is proportional to the square root of temperature, for a non ideal gas the virial coefficients must be included in the equation. Dr. Plumb (N. B. S.) discussed an acoustical interferometer for temperatures in the liquid helium range. The current unit that was tested gave temperature readings which differed only by 10 millidegrees from temperatures derived from vapor pressure measurements. Attempts at N. B. S., will be made to improve on the design and construction materials used to reduce the differential in the derived temperatures. In addition to its importance as another type of thermodynamic thermometer it should be much more convenient to use than the cumbersome gas thermometer.

For temperatures from $90^{\circ}K$ to $630^{\circ}C$ the platinum resistance thermometer (P. R. T.) may be used to determine the International Practical Temperature Scale by using 3 defining fixed points to calibrate it. Accuracies in the order of $.0001^{\circ}$ may be attained readily. However, below 90°K there is no simple equation relating resistivity and temperature for platinum wire. Thus for a comparison of the gas thermometers used by different laboratories, the gas thermometer scale is transfered to a special PRT scale point by point. Comparing gas thermometers in this manner agreement of better than .01°K were reported by many laboratories.

Dr. Corruccini (N. B. S.) suggested a three point calibration technique (below 90°K) for interpolating between the calibration points. Other speakers indicated possible equations that may be useful for deriving a resistance - temperature curve for resistance thermometers made of very pure platinum where $\frac{R \text{ at } 100^\circ}{R \text{ at } 0^\circ} = 1.3925$ or greater.

On Tuesday evening a Panel Discussion on Calibration was held. The panel consisted of members of the N. B. S. staff who answered questions raised by the attendees. These questions dealt with calibration techniques, probable accuracies that are obtainable with different types of thermometers and for different temperature ranges, and such non-technical topics as how long it takes the Bureau to calibrate thermometers and what back-log exists. Aside from questions dealing directly with calibration techniques (the answers to these may be found usually in one of the Bureaus publications) several interesting observations were made by the panelists. For a calibrated, standard instrument whose accuracy is to be maintained to the same degree that it was calibrated at the N. B. S. it should be hand carried from the Bureau instead of being shipped by common carrier. This is done with all standards that are used for comparisons with international standards or among the national standards laboratories.

Dr. Herzfeld, chairman of the Panel reiterated that the Bureau welcomes requests for standardization of measuring equipment even when it is not set up to carry out the measurements. To receive an appropriation from Congress for establishing a calibration facility the Bureau has to demonstrate a need for the facility. This is best done by having received numerous and repeated requests for the service.

Several problems that may occur when calibrating thermometers using the fixed defined points were also noted. It usually takes several days for sulfur baths to reach equilibrium. In addition since the sulfur point is a boiling point measurement, the vapor pressure must be very accurately measured also. Thus it is recommended that the zinc melting point be used instead. Similarly for calibrations using the triple point of water, approximately 24 hours may be needed for equilibrium to be reached.

For low temperature measurements (2°- 20°K) several semi conductor resistance thermometers have been used extensively. These are usually made of carbon or doped germanium.

The work of Dr. Plumb, Edlow and Cataland indicated that after appreciable thermal cycling carbon resistors were not satisfactory as secondary precision thermometers. However germanium resistance thermometers were very stable and could be used as secondary precision thermometers. The disadvantages of the germanium thermometers are that they require individual point by point calibration and they exhibit a large anisotropic magneto resistance. Aside from these shortcomings germanium thermometers are suitable for use as accurate reproducible reference thermometers in the range of 1 to 35°K. These results were confirmed in the papers presented by Dr. Kunzler (Bell Laboratories), by Mr. M. H. Edlow (N. B. S.) and by Dr. P. Lindenfeld (Rutgers University). (Currently two industrial concerns are selling germanium thermometers for low temperature measurements.)

In addition to the three aforementioned resistance thermometers thermistors were also the subject of some discussion. Advantages of these elements are their large negative temperature coefficient, small volume which implies fast response and they exhibit no magnetoresistive effects. However, for low temperature work these units are still only in the developmental stages.

Of the many methods for measuring resistance either a bridge method or a potentiometric method is being used for precision work. Evans (N. B. S.) described the details of his refinements on a Mueller resistance bridge described by Stimson in his 1954 Symposium paper.

A novel potentiometric circuit was described by Dr. Dauphinee. A capacitor is switched periodically between the known and unknown resistor which are in series. A null indication on a galvanometer in another branch (which is also in series with one of the positions of the capacitor) indicates when the two resistors are equal. A d. p. d. t. electromechanical chopper is used to switch the capacitor. Thus a direct comparison of the two resistors may be made using only a single balance. The chief advantages of the potentiometric methods are retained. (These are insensitivity to magnitude and variation of lead resistances and ability to cover wide range of resistances without loss of significant figures.) Several variations of the basic idea were presented including a direct dial reading unit (in °C) for the range of -50° to 700°C to .001°C for the standard 25.5 ohm platinum resistance thermometer.

In the range from 0.3° to 4.2°K vapor pressure measurements are being used for calibration and for precision measurements. He^4 is used for 2 to 4.2°K and He^3 may be used in the range 0.3 to 3.2°K. For very precise measurements it was recommended that a separate thermometer bulb be used and the section of the thermometer stem which passes thru the liquid surface should be isolated (by a vacuum jacket) from contact with the liquid (Cataland of N. B. S.). If less accurate measurements (less accurate than $\pm$ .001°K) are required than one may measure the vapor pressure of the helium gas above the liquid.

For temperatures below 1°K the thermodynamic temperature scale is based on the magnetic thermometer i. e. the measurement of the magnetic susceptibility of materials such as cerous magnesium nitrate. (Paper A. 3. 1 by Dr. Hudson of N. B. S.) This material obeys the Curie Law accurately to .01°K ($X = CT^{-1} + \alpha$). In practice the magnetic thermometer is calibrated against the He^4 thermometer in the 1-4°K range and then measurements of X can be related to temperatures below 1°K.

Dr. R. D. Taylor of Los Alamos suggested using the Mossbauer effect as the basis for a thermometer. In this region the populations of nuclear spin sub levels at very low temperatures is a function of temperature and the relative populations are given by $e^{-\frac{\Delta E}{kt}}$. Excellent agreement between theory and measured results were reported in the temperature range between .85 4°K. Modification of the present set-up is expected to produce accurate and detailed measurements to as low as .3°K. Some of the suggested advantages of this method are direct metal-metal contacts for relatively high thermal conductivity, ease of source preparation and applicability of method to lower temperatures. Although this method does not appear to be as convenient as others in this range it is desirable as an alternate thermodynamic thermometer.. Thermocouples are very useful laboratory thermometers which may cover a wide range of temperatures and where the precision of some of the previously discussed methods are not required. Although the specially developed gold-cobalt vs. copper gives a relatively high thermoelectric e. m. f. the inhomogeneities along the wires and the deviations between different lots makes it less desirable than copper-constantan. (Dr. Powell of N. B. S.)

The papers mentioned above represent but a sampling of those presented which dealt with temperature measurements below 90°K and with some of the basic concepts of temperature and thermometry. The others of equal significance and interest have been left unmentioned since multiple simultaneous sessions, at times as many as five only permitted the attendance at selected sessions. The papers on physiological response to heat and cold for example should have been of interest even to the layman in the field. Preprints for some of the papers were made available by their authors, However the volumes containing the proceedings of the symposium will be eagerly awaited as a valuable reference for any type of temperature measurement.