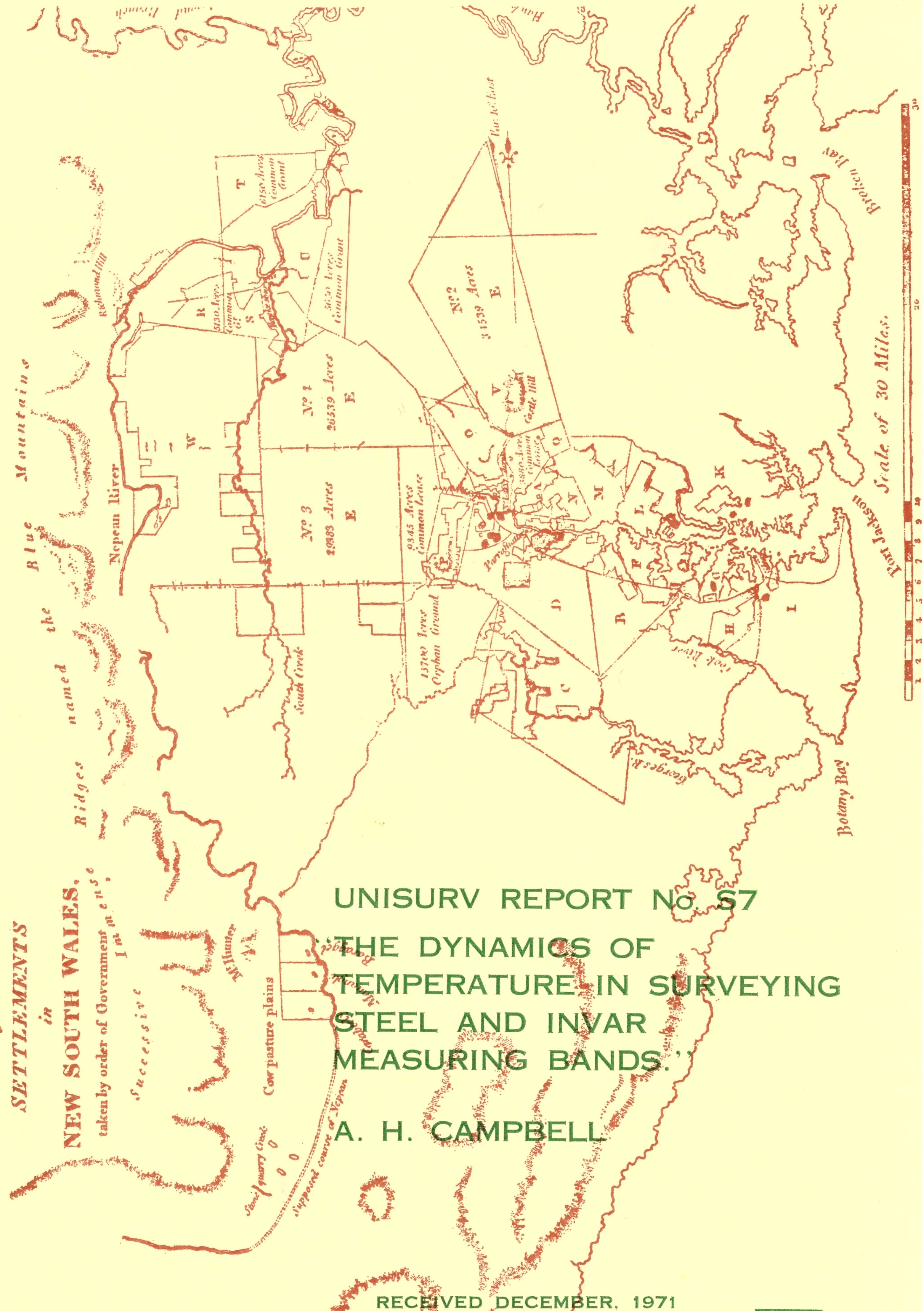

UNISURV REPORT No. 57

"THE DYNAMICS OF TEMPERATURE IN SURVEYING STEEL AND INVAR MEASURING BANDS."

A. H. CAMPBELL

RECEIVED DECEMBER, 1971

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"THE DYNAMICS OF TEMPERATURE IN SURVEYING STEEL AND INVAR MEASURING BANDS"

A.H. CAMPBELL

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SUMMARY

During the period of May 1970 to January 1971 a number of different experiments were conducted at the University of New South Wales aimed at developing better techniques for the temperature measurement of surveying tapes.

These experiments covered the following aspects:

(i) the application of thermocouples and thermistors to the temperature measurement of surveying tapes.

(ii) characteristics of mercury thermometers - size; type of casing; material and surface quality of casing; holding position at the time of reading.

(iii) width, material and surface quality of survey tapes and the influence of these on the temperature behaviour of the tape.

(iv) the application of modern resistance measuring instruments to the determination of the temperature correction.

(v) the general behaviour of a range of tapes under a variety of field conditions.

The mercury thermometers used in the experiments were representative of those commonly used by Australian surveyors as were the tapes (see figures 6.1, 7.1).

The investigations indicated that the use of mercury thermometers for the accurate determination of the temperature of a survey tape requires a knowledge of the temperature behaviour of both the tape and the thermometer. It was further shown that the inappropriate use of the thermometer could result in large errors in the temperature determination. The error could be as large as 10°C in extreme cases.

Thermocouples and thermistors, although requiring further development in their detailed application, deserve consideration for temperature measurement of surveying tapes. The thermocouple meter unit would need to be placed in an insulated container for best results. The thermocouple wires are easily attached to an auxiliary length of tape identical to the one in use. The thermistor thermometer is relatively simple to construct, however selection of the correct thermistor and its proper attachment to the tapes present some difficulties.

Modern Kelvin bridge instruments provide a means of determining the change of length of the tape by means of resistance measurement. The bridge units may be obtained in compact versions and could be used to measure the resistance of the actual measuring tape or an auxiliary tape.

It is felt that with the necessary knowledge and careful use the mercury thermometer provides, for the majority of instances, an adequate instrument for the determination of the temperature of the survey tapes commonly used by Australian surveyors (i.e. 1/12" to 1/8" steel tapes). However it is felt that it is not the best instrument for this type of temperature measurement. Thermocouples and thermistors offer a more appropriate means of making the temperature measurement. Further, compact Kelvin bridge instruments provide a means of determining the temperature correction where high accuracy is required.

PREFACE

The measurement of the temperature of steel and invar surveying tapes is a problem. The difficulty is caused by the lack of a convenient and reliable instrument to measure the tape temperature.

For practical purposes the temperature of the tape has been assumed to be that of the surrounding air. A mercury thermometer has generally been used to measure the air temperature.

There are two main factors making the use of thermometers for the measurement of tape temperature unsatisfactory -

(i) The particular characteristics of a thermometer have a bearing on its measurement of temperature under field conditions. A thermometer is designed to determine temperature by means of partial or total immersion in an homogoneous liquid or gas. Hence the thermometer is not being used in the manner it was designed to be used.

(ii) The "temperature characteristics" of a tape will also escape detection by a mercury thermometer. If the tape and thermometer do not have identical heat capacities, they will reach different temperatures.

The use of invar tapes rather than steel tapes lessens the temperature problem to a large degree. However invar has a number of negative properties. The microstructure of invar is not stable and the material kinks very easily. The effect of these kinks on the measurement is hard to determine.

Various approaches have been adopted to overcome this problem. Valuable work was carried out in the 1930's under the guidance of the Surveyor Generals in Rhodesia and the Gold Coast in Africa and in Ceylon. Most of their work centred around the use of thermometers for the temperature determination. A number of "synthetic" thermometers were made and used with some degree of success. *

* Clendinning, 1935
Thornhill, 1935
Jackson. 1935.

More recent developments involve the measurement of resistance of the tape rather than the temperature. Although the method had been proposed as early as 1891 by Campbell of the Massachusetts Institute of Technology it was not put into practice until the late 1930's. Captain Fitzgerald *(Fitzgerald, 1939)* applied resistance measurement successfully in the measurement of the Jondaryan and Somerton baselines in Australia in 1939 by using a Kelvin bridge and attached a second tape of the same properties for the return lead.

Further developments by Clark and Johnson *(Clark & Johnson 1951)* in the 1950's emplo... ...iliary tapes for the resistance measurement.

The advent of e.d.m. equipment in the late 1950's drew attention ...y from the steel and invar tapes. Undoubtedly e.d.m. instruments have taken over much of the measurement previously conducted with tapes. However, with the introduction of Integrated Surveys into this country, more surveyors will have to conduct surveys of a higher precision. For some years to come the majority of these surveyors will use tapes as the measuring instrument.

Although in time e.d.m. equipment will be used more universally for the tasks in which a tape is presently used, it is hard to foresee the complete extinction of the tape. There will always be situations where the tape is more convenient and where the tape provides a more direct means of measurement. It is important therefore that comparable precision, relatively easily obtained with e.d.m. instruments, can be achieved universally and simply with tapes.

Further, it is likely that tapes will continue to play a role in the calibration of e.d.m. in the field, partic ularly for the determination of index error.

ACKNOWLEDGEMENTS

I wish to acknowledge my gratitude to the following persons - Messrs. J. Connelly and J. McAllam from the C.S.I.R.O. for adivce; Mr. J. Reizes from the School of Mechanical and Industrial Engineering (U.N.S.W.) also for advice, and particularly to Associate Professor G. Johnson from the School of Electrical Engineering (U.N.S.W.) and his staff for their assistance with equipment and technical aid. Further I would like to acknowledge my gratitude to Messrs. I. Lloyd and G. Meers for their assistance with the earlier practical work.

Finally I would sincerely like to thank my Supervisor, Mr. A. P. H. Werner. Mr. Werner was the instigator of the research having had an interest in this matter for a number of years. He had conducted a number of experiments on the use of thermometers during the period 1960 - 1962 and the experience he gained from this was invaluable in this research.

Mr. Werner has assisted me with the field and laboratory work as well as the preparation of this report and I am deeply indebted to him for this.

Andrew Campbell
August, 1971.

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CHAPTER 1.

RELEVANT HEAT LAWS & TERMS

1. GUIDE TO NOTATION

1. Symbols

Symbols	Units in this report	S.I. Units
a_λ = absorptive power	not specified *	
α = coefficient of thermal expansion	$/^oF$, $/^oC$	$^oC^{-1}$
c_p = specific heat	Cal/(gm) (^oC)	J/kg
e_λ = emissive power	not specified	
i = current (amperes)	amperes	A
k = thermal conductivity	(Kcal/Sec)/(metre^2) (C^o/metre)	W/(m-k)
λ = wavelength	not specified	
L = length	Ft, metre, (m)	m
M = mass	lbs	kg
Q = quantity of heat (calories)	Calories	J
R = resistance	ohm	Ω
σ = Stefan-Boltzmann constant	erg.sec^{-1}cm^{-2}Adeg^{-4}	-
t = time	second	s
T = degrees Kelvin	^oK	K

* units not discussed in relation to this quantity.

1.2 HEAT LAWS

1.2.1 General

The following facts on heat laws and terminology come largely from Curnow 1963, Resnick & Halliday 1960.

Heat is defined as that form of energy which is transferred between a system and its surroundings as a result of temperature differences only.

The unit of heat in the c.g.s. system of units is the caloric (or small caloric or gram calorie: abrev. cal.) which is defined as the amount of heat required to raise the temperature of 1 gram of water from 14.5 to 15.5^{o}C.

Other substances require different quantities of heat per unit mass per unit temperature rise, hence to each substance is given a value of a thermal property called specific heat.

The specific heat is usually denoted by Cp. Thus the quantity of heat Q(calories) necessary to raise the temperature of a mass M from T1 to T2 is given by

$$Q = M\ Cp(T1 - T2) \ldots\ldots.(1)$$

or more particularly

$$Q = M\int_{T_1}^{T2} c_p dT \qquad \ldots\ldots.(1a)$$

(Curnow)

Further the thermal capacity of particular bodies is defined as the product of its mass and the specific heat of the material.

$$\text{Thermal capacity} = MC_p \ldots\ldots\ldots\ldots.(2)$$

1.2.2 Transference of heat

It is usual to distinguish three methods of transference of heat

(i) Convection

In this case heat is transferred by mass movement of a fluid (liquid or gas) due to pressure differences set up by local thermal expansions accompanying local changes of temperature.

(ii) Conduction

Here the energy is transferred from molecule to molecule without the latter changing their mean positions. For a solid, the mean position of atoms are fixed but oscillations can take place about these fixed positions. If one end of a metal bar is heated the thermal energy is transferred to kinetic energy of the atoms. Owing to the binding forces holding the atoms in position as the energy of one atom is increased there is a change in the energy of neighbouring atoms and so the energy passes along the bar. Conduction takes place in fluids but, owing to the relatively small binding forces in such materials, conduction is a slow process and it is actually masked by the convection processes.

Consider a slab of material of cross-sectional area A and thickness Δx, see Figure 1.1, whose faces are kept at different temperatures. We measure the heat Q that flows perpendicular to the faces for a time t. Experiment shows that Q is proportional to the time t and to the cross-sectional area A for a given temperature difference ΔT, and that Q is proportional to $\Delta T/\Delta x$ for a given t and A, providing both ΔT and Δx are small, that is,

$$\frac{Q}{t} \propto \frac{A\Delta T}{\Delta x} \quad \text{approximately}$$

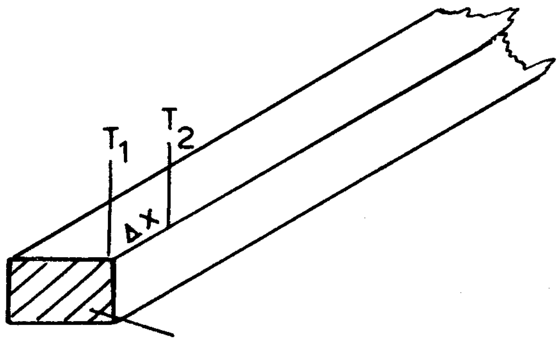

T1
T2
ΔX
Cross sectional
area A

FIG. 1·1

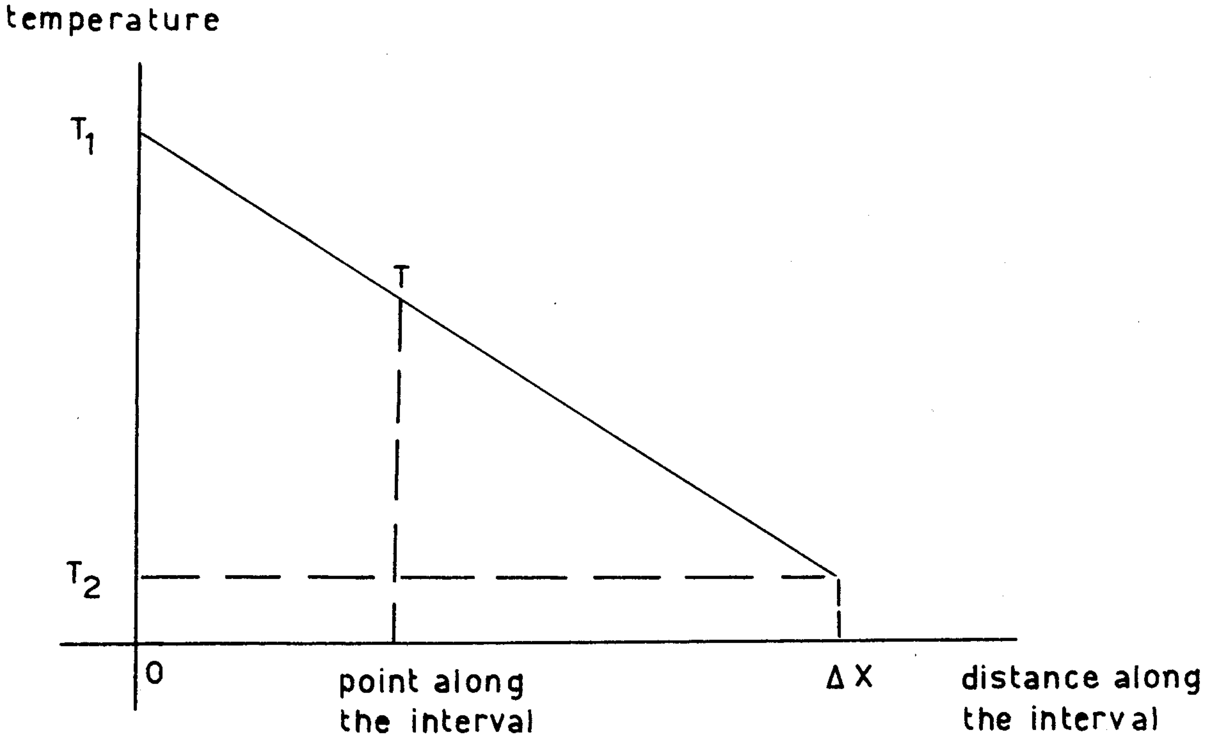

temperature
T1
T
T2
0
point along
the interval
ΔX
distance along
the interval

FIG.1·2

In the limit of a slab of infinitesimal thickness dx, across which there is a temperature difference dT, we obtain the fundamental law of heat conduction

$$\frac{dQ}{dt} = \frac{-kAdT}{dx} \quad \ldots\ldots\ldots\ldots \quad (3)$$

Here $\frac{dQ}{dt}$ is the time rate of heat transfer, $\frac{dT}{dx}$ is called the temperature gradient, and k is a constant of proportionality called the *Thermal Conductivity*. A substance with a large thermal conductivity k is called a good heat conductor and one with a small thermal conductivity k is a poor heat conductor or a good insulator. The value of k is temperature dependent but may be regarded as being constant for all practical purposes.

Table 1-1 shows values of k for some substances

TABLE 1-1

Thermal conductivities, $(KCAL/SEC)/(M^2)(C^o/M)$

Metals	
Aluminium	4.9×10^{-2}
Brass	2.6×10^{-2}
Copper	9.2×10^{-2}
Lead	8.3×10^{-3}
Silver	9.9×10^{-2}
Steel	1.1×10^{-2}
Gases	
Air	5.7×10^{-6}
Hydrogen	3.3×10^{-5}
Oxygen	5.6×10^{-6}

Others

Asbestos	2×10^{-5}	
Concrete	2×10^{-4}	
Cork	4×10^{-5}	
Glass	2×10^{-4}	
Ice	4×10^{-4}	
Wood	2×10^{-5}	(Resnick & Halliday Page 472)

Thermal resistance

The equation for thermal and electrical conduction are formally the same:

$$\text{Thermal} \qquad \frac{dQ}{dt} = \frac{kA(T1-T2)}{L} \qquad \ldots\ldots\ldots\ldots (4)$$

$$\text{Electrical} \qquad \frac{dQ}{dt} = \frac{A(V2-V1)}{\rho L} \qquad \ldots\ldots\ldots\ldots (5)$$

The term "thermal resistance" $R = \frac{L}{kA}$ can be introduced to correspond to the electrical resistance $R = \frac{\rho L}{A}$. The theory of electrical circuits may be applied to thermal conduction where the conductors consist of one or more materials in series or in parallel paths.

(iii) Radiation

In any material at any temperature, charged particles (electrons and nuclei) are in constant motion. When such particles accelerate they emit energy in the form of electromagnetic waves. At ordinary temperatures the motions are relatively slow and the radiation emitted is of very long wavelength (low frequency). As the temperature rises, the velocities and accelerations increase and the wavelength of the emitted radiation decreases. Up to about $600^{\circ}C$ the radiations are emitted mainly in the region of the infra-red part of the spectrum, as the temperature is increased to about 700° some of the radiation occurs in the red portion of the visible spectrum and the body is said to be "RED HOT". At still higher temperatures, radiations in other parts of the visible spectrum are noticeable. At the temperature of the sun, "white" light is emitted as well as ultra-violet and infra-red rays.

These radiations are emitted throughout the material but that from atoms within the body is usually reabsorbed by the other atoms before reaching the surface of the body. Thus thermal radiation is characteristic of the state of the surface of the body and its temperature.

This thermal radiation can travel through vacuum or through certain materials or it may be reflected from a surface. When absorbed, the energy is transformed into kinetic energy (or potential energy) within the atoms of the body and a result is a rise in temperature.

1.2.3 Prevost's theory of exchanges

Suppose that we have three bodies A, B, C such that temperature of A > than the temperature of B > temperature of C. If A is placed near B, the temperature of B rises and we say that heat radiation from A has been absorbed by B. When B is placed near C, B radiates heat and it is reasonable to assume that B was radiating in the case when it was placed near A.

Prevost *(Curnow, 1963)* first pointed out that when a body such as B increases in temperature due to radiation exchange, the effect is due to a net absorption. Thus when B is placed near A, B radiates to the surroundings but it absorbs a greater amount of energy from A and so its temperature rises. Thus we have Prevost's Theory of Exchange:-

> "All objects are continually radiating energy to the surroundings at all temperatures. If a body is in thermal equilibrium with its surroundings, it is absorbing energy at the same rate as it is emitting energy. If its rate of absorption is greater than its rate of emission its temperature will rise."

1.2.4 The Effect of Surface Quality on Emmission & Radiation of Heat.

Leslie *(Curnow, 1963)* examined the rate of cooling of bodies and the dependence of this rate on the state of the surface. If a container (say an enclosed metal can filled with water) has its surface blackened and it is then placed in a definite position in cooler surroundings, it will cool by radiation, conduction and convection. If a similar can with similar contents has its surface polished and is placed in the position of the first can, it will not cool as quickly as the blackened one. Since convection and conduction are the same in both cases, the blackened surface must radiate heat more rapidly than the polished one.

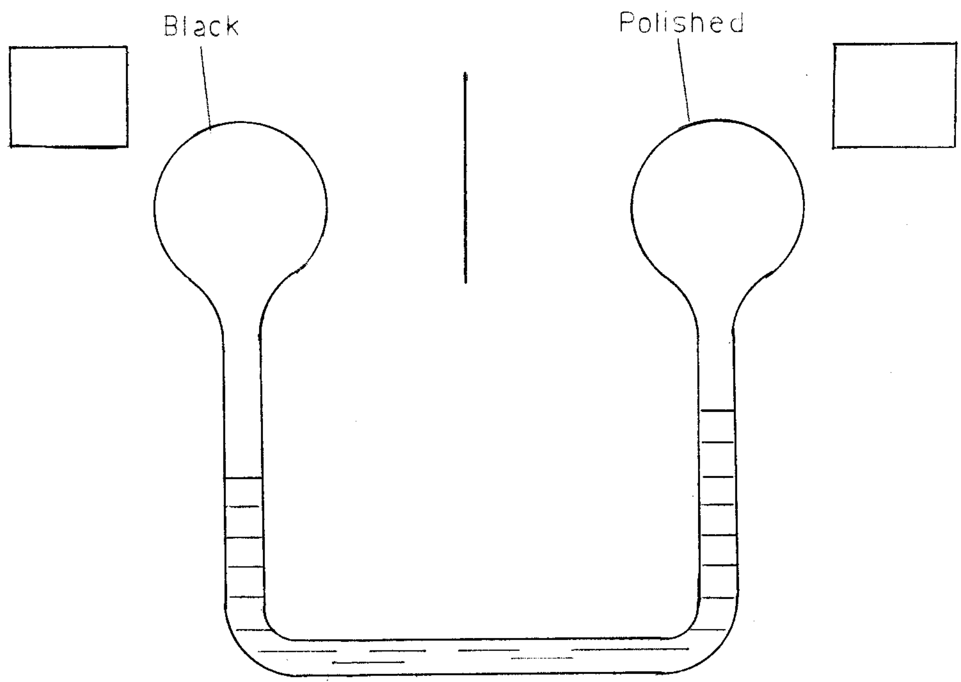


FIG. 1·3 (Curnow 1963)

If now two similar vessels (containing say hot water) are placed, as shown in Figure 1.3, near the bulbs of a differential air thermometer, the blackened bulb of the instrument will absorb more energy than does the polished one. The temperature of the air inside the black bulb will rise more and the liquid level on that side will fall.

Such experiments indicate that some surfaces absorb radiant energy better than others do. A blackened surface will both emit and absorb radiant energy better than a polished one.

If a series of materials are used for the surfaces of a body the order of these based on their efficiency as radiators will be the same as the order based on their efficiency as absorbers. Hence *good emitters are also good absorbers of radiation.*

A visible black body is one that absorbs all visible radiation falling on it (e.g. a surface coated with lamp black). The term "black body" is used in relation to any radiation and a black body is one that absorbs all incident radiation. Such a surface will emit this radiation better than any other kind of material at the same temperature.

Note Glass is transparent to visible radiation but is not transparent to ultra-violet radiation or infra-red radiation. In the same way a lamp-black surface is black to visible radiation but is not black with respect to all radiation.

1.2.5 Emissive Power and Absorptive Power.

Introducing the following terms -

(i) Emissive power

If a body emits radiation, we can plot a curve of energy emitted against wavelength λ. For thermal radiation it is usual to plot the curve so that the area under the curve between any two ordinates, corresponding to wavelength λ_1 and λ_2, represents the energy in this wavelength interval. The energy in the wavelength between λ and $\lambda+d\lambda$ is expressed as $e_\lambda d_\lambda$ where e_λ is called the emissive power for this radiator for this wavelength for this temperature.

(ii) Absorptive Power

If energy of wavelength λ to $\lambda+d\lambda$ is incident on a surface then the absorptive power, a_λ, for this surface for this wavelength for this temperature is the fraction of this energy absorbed by the surface. The fraction $1-a_\lambda$ is reflected from the surface.

Consider an enclosure at a constant temperature T^oK with part of the wall of the material of emissive power $e_{1\lambda}$ and absorptive power $a_{1\lambda}$ while another part of the wall has the values $e_{2\lambda}$ and $a_{2\lambda}$ for the same range λ to $\lambda+d\lambda$. The walls of such an enclosure are found to take up and keep a constant temperature. It can be deduced that the radiation within this enclosure is the same in intensity at all points in all directions for all wavelengths, (otherwise: If the flow in one direction is greater than in another direction, radiation of this wavelength would continually build up at one end of the enclosure).

For this wavelength the band λ to $\lambda+d\lambda$ suppose that the energy incident on unit area is $E_\lambda d_\lambda$.

For the first surface, $e_{1\lambda}d_\lambda$ is emitted and $a_{1\lambda}E_\lambda d_\lambda$ is absorbed so that $(1-a_{1\lambda})E_\lambda d_\lambda$ is reflected. Thus the radiation incident on the surface per unit is $E_\lambda d_\lambda$ while that returned to the enclosure is $e_{1\lambda}d_\lambda+(1-a_{1\lambda})E_\lambda d_\lambda$. Thus we have for equilibrium condition

$$e_{1\lambda}d_\lambda+(1-a_{1\lambda})E_\lambda d_\lambda = a_{1\lambda}E_\lambda d_\lambda$$

$$\text{or} \quad e_{1\lambda} = a_{1\lambda}E_\lambda$$

$$\text{or} \quad \frac{e_{1\lambda}}{a_{1\lambda}} = E\lambda = \text{constant} = \frac{e_{2\lambda}}{a_{1\lambda}} \qquad \dots\dots \quad (6)$$

Thus the ratio of the emissive power to the absorptive power for each wavelength is constant. This is Kirchhoff's law.

If one portion of the walls of such an enclosure is a black body for wavelength λ to $\lambda+d\lambda$, then all radiation incident is absorbed so that the incident radiation is equal to that emitted i.e. $e_\lambda d_\lambda = E_\lambda d_\lambda$ or, the energy within the enclosure is equal to the energy emitted by a black body portion of the surface.

If a small hole is made in the side of the enclosure without altering the temperature of the enclosure, the radiation $E_\lambda d_\lambda$ from the interior will be emitted through the hole. But this is equal to the radiation emitted from a black body part of the surface of the interior. Thus the enclosure emits radiation at all wavelengths of the same value as that emitted by a perfectly black body. We call this radiation total or black-body radiation for this temperature and it is the maximum possible for any body to emit at that temperature.

In the case of a small hole in a body, if radiation is incident from outside and passes through the hole, it will in general suffer many reflections before the rays finally emerge from this hole. At each reflection some of the energy is absorbed so that the final emergent rays are of negligible energy. Thus the hole acts as an area of a perfect absorber for all wavelengths. Such a system of a furnace with a small door gives an experimental perfect or black body radiator and the emission of energy from this is taken as a standard or maximum with which other radiators may be compared.

1.2.6 Laws of Black-Body Radiation

Stefan-Boltzmann Law

The total energy emitted per unit area per unit time from a black-body (for all wavelengths in all directions) is proportional to the fourth power of the absolute temperature of the body.

If A is the area of the emitting surface, t the time and T the absolute temperature of the surface, then the total energy E emitted is given by:

$$E = \sigma.A.t.T^4 \qquad \ldots\ldots\ldots \quad (7)$$

where σ is called the Stefan-Boltzmann constant and has the value $\sigma = 5.735 \times 10^{-5}$ erg sec^{-1} $cm^{-2}Adeg^{-4}$.

1.2.7 Newton's Law of Cooling

Newton's Law of Cooling states that the time rate of loss of heat from a heated body to its surroundings is proportional to the difference in temperature between the body and its surroundings.

It is an approximate emperical result for small temperature differences and includes the effect of convection, conduction and radiation.

If T is the temperature of the body (e.g. a calorimeter) at time t and T_s is the constant temperature of the surroundings then the time rate of loss of heat is given by -

$$-b(T-T_s)$$

where b is called the radiation constant for the body. But if M is the mass of the body and Cp is its specific heat, the rate of loss of heat $= \frac{d}{dt}(MCpT) = MCp\frac{dT}{dt}$

Thus we may express Newton's Law in the form:

$$M.Cp.\frac{dT}{dt} = -b(T-T_s) \qquad \ldots\ldots\ldots \quad (8)$$

separating variables,

$$\frac{dT}{T-T_s} = \frac{-b}{MCp}.dt$$

integrating

$$\log_e(T-T_s) = \frac{-bt}{MCp} + \text{constant } K$$

If the initial temperature of the body is T_o then

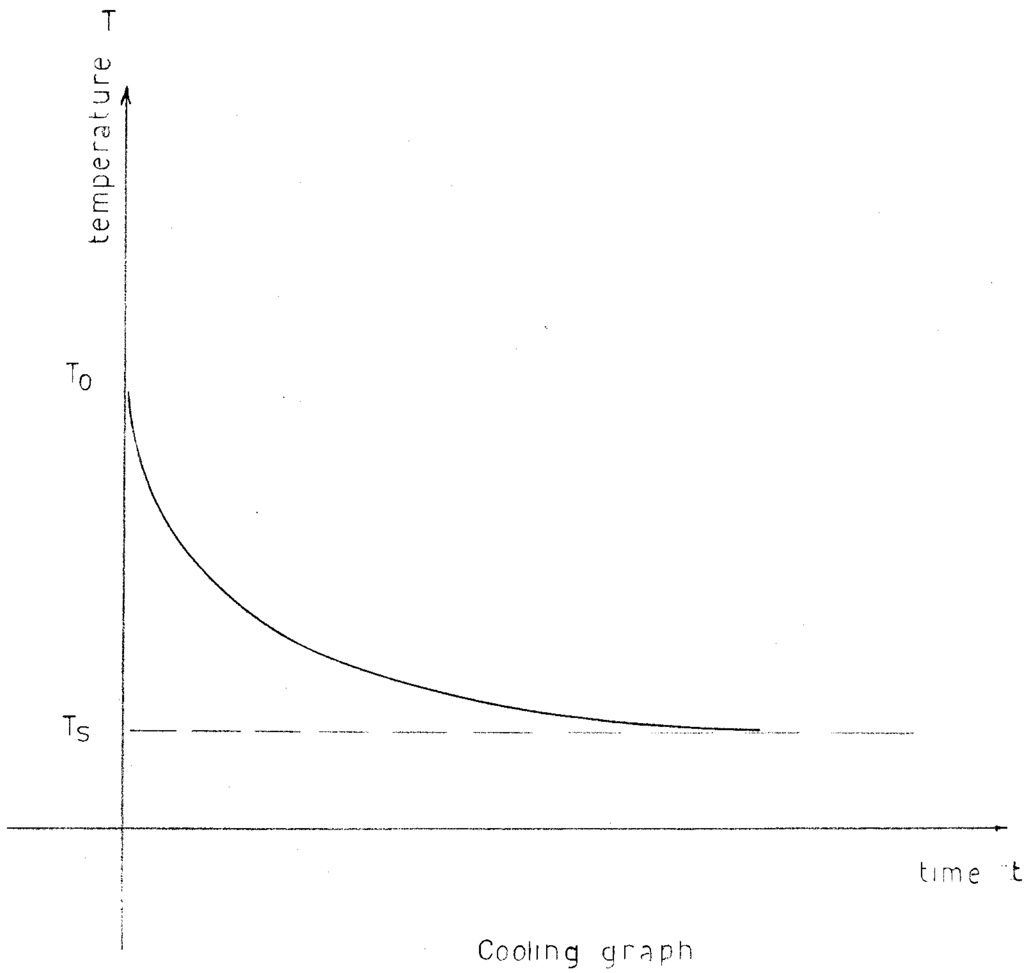
$$\log_e(T_o - T_s) = K \text{ and we have}$$

$$\log_e\left(\frac{T-T_s}{T_o-T_s}\right) = \frac{-bt}{MCp}$$

Taking antilogs

$$T-T_s = (T_o-T_s)e^{-bt/MCp} \qquad \ldots\ldots\ (9)$$

Thus the temperature difference between the body and its surroundings decreases exponentially, as shown in Figure 1.4.



Cooling graph

FIG. 1·4

1.2.8 Summary

The Relevant heat laws regarding radiation and transfer of heat may be summarized as follows:-

(a) All substances require a different amount of heat to raise the temperature of a given mass. The term that describes this characteristic is known as the specific heat.

(b) The thermal conductivity describes the ability of a material to transfer heat within itself. In general the thermal conductivity of metals is high. However steel has one of the lower thermal conductivities of the metals.

(c) The amount of heat absorbed per unit time per unit area of surface depends, among other things, on the nature of the surface. Bright, polished surfaces tend to reflect radiant heat, while dark rough surfaces tend to absorb it.

(d) Also the amount of heat absorbed by any surface is proportional to the area of the surface exposed to the radiation and to the cosine of the ange between the direction of the incident radiation and the normal to the surface.

(e) Bodies which are good "absorbers" of radiant heat are also good "radiators". The radiation emitted by them is of exactly the same kind as received.

(f) All objects are contually radiating energy to the surroundings at all temperatures. If a body is in thermal equilibrium with its surroundings, it is absorbing energy at the same rate as it is emitting energy. If its rate of absorption is greater than its rate of emission its temperature will rise.

(g) Flow of heat by transfer can only occur between bodies at different temperatures.

1.3 THERMAL EXPANSION OF METALS

1.3.1 Linear Expansion

The linear dimension of a solid (e.g. the length on the diameter of a rod, the length of a straight or curved line marked on a solid), is found to increase as the temperature of the solid is increased. Over moderate ranges of temperature the increase in linear dimension is proportional to the original length and to the increase in temperature so that we may write increase in length

$$\Delta L = L\alpha\Delta T \qquad \ldots\ldots\ (10)$$

where ΔT is the increase in temperature and α is a constant for the material of the solid. "α" is called the coefficient of linear expansion of the material and is defined as the fractional change in length per unit temperature change. The units of α are : C deg^{-1}.

Our linear expansion equation may be written in one of the following ways:

(i) Length at $T^{o}C = L_t = L_o(1+\alpha T)$

where L_o is the length at $0^{o}C$

(ii) If we write L_1, L_2 for the lengths at temperatures T_1 , T_2 ^{o}C respectively

$$L_2 = L_o(1+\alpha T_2) \text{ and } L_1 = L_o(1+\alpha T_1)$$

so that

$$\frac{L_2}{L_1} = \frac{L_o(1+\alpha T_2)}{L_o(1+\alpha T_1)} = (1+\alpha T_2)(1+\alpha T_1)^{-1}$$

$$= 1+\alpha(T_2-T_1)$$

where we neglect terms in α^2 and higher powers.

i.e. $L_2 = L_1(1+\alpha(T_2+T_1))$ .... (11)

(iii) If ΔL is the change in length for a temperature change of ΔT, then

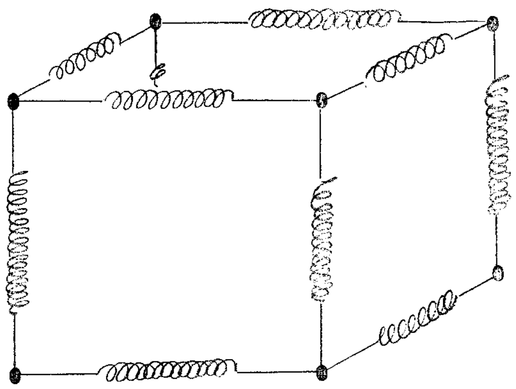
$$\Delta L = L\alpha\Delta T$$

For more accurate work, particularly for large ranges of temperature, the expansion equation may be written

$$L_t = L_o(1+\alpha T+\beta T^2+\psi T^3+.......) \qquad .... (12)$$

where the expansion constants α, β, ψ .... may be determined experimentally.

To gain a picture of what happens a solid can be visualised diagrammatically as a microscopic bedspring in which the molecules are held together by elastic forces (see Figure 1.5).



(Resnick & Halliday p. 459)

FIG 1·5

TABLE 1-2

Coefficients of Linear Expansion

Substance	$\bar{\alpha}$ (per C^{o})	Substance	α(per ^{o}C)
Aluminium	23×10^{-6}	Hard Rubber	80×10^{-6}
Brass	19×10^{-6}	Ice	51×10^{-6}
Copper	17×10^{-6}	Invar	0.7×10^{-6}
Glass (ordinary)	9×10^{-6}	Lead	29×10^{-6}
Glass (pyrex)	3.2×10^{-6}	Steel	10.8×10^{-6}

(Resnick & Halliday
Page 459)

CHAPTER 2

THERMOMETRY

2.1 Temperature *(Curnow 1963)*

From our everyday experience we talk of supplying heat to a body and we say that its temperature rises as a result of this process. We say that two bodies are at the same temperature when, if placed in contact, heat does not pass from one to the other. We say that a body A is at a higher temperature than body B if heat flows from A to B if the two bodies are placed in contact.

As heat is supplied to a body and its temperature increases certain changes are experienced. For example, the dimensions of the solid body may change, the volume of the fluid body may change, there may be a change in state (e.g. melting or vaporization), there may be a change of colour of the body, there may be a change of electrical resistance of the body (say in the form of a wire). We use such physical changes in a suitable body to develop a "scale of temperature".

The construction of a suitable temperature scale requires

(i) The selection of standard, "fixed" or reference points to which standard values of temperature are assigned.

(ii) The choice of a thermometric property and a suitable material to show this property (quantitatively) and to allow numbers to be given to intervals of temperature change.

For everyday use the fundamental fixed points are the *ICE POINT* and the *STEAM POINT*. The ice point is the temperature of pure water in contact with pure ice at Standard Pressure (Standard Pressure is the pressure due to column of ice cold mercury of vertical height 760mm at latitude 45° at M.S.L.). Ice Point is given the value 0° Celsius or 32° Fahrenheit. The steam point is the boiling point of pure water at standard pressure and it is given the value 100° Celsius or 212° Fahrenheit.

We define temperature intermediate to these fixed points in terms of some convenient property X (e.g. the level of mercury in a suitable container, the length of a metal rod, the resistance of a wire) and we say that the temperature changes above the ice point is proportional to the change in the property X from its value X_o at the ice point. Thus our basic definition of temperature becomes

$$\frac{T}{100} = \frac{X-X_o}{X_{100}-X_o} \qquad \ldots\ldots\ (1)$$

where X is the value of the property at $T^{\circ}C$

X_o, X_{100} are the values of the property at $0^{\circ}C$, $100^{\circ}C$

Slightly different values of T are obtained if X is the length of a solid, the volume of a liquid, the volume of a gas, the electrical resistance of a wire.

There is a theoretical scale of temperature (called the thermodynamic scale) which is independent of the properties of any special body and this scale can be shown to be identical with the scale obtained by taking X as a measure of the expansion of a "perfect gas" (e.g. X is the pressure of a perfect gas at a constant volume).

We often refer to this as the *Kelvin Scale* of temperature on this scale we take the ice point to be 273.15°K and the steam point to be 373.15°K where we denote temperature on this scale by the symbol $^{\circ}$K.

Temperature measurements (in degrees Kelvin) are difficult experimentally and are usually made with a constant volume gas thermometer.

2.2. THERMOMETERS IN USE *(Considine, 1957)*

In most forms of temperature measurement, the variation of some property of a substance with temperature is studied, and a mathematical relationship established between the variation of the property and the temperature.

For example, the variation of resistance of a platinum resistance thermometer at temperatures between $0^{o}C.$ and $630.5^{0}C.$ is given by

$$R_t = R_o(1+At+Bt^2) \qquad \ldots\ldots\ldots \quad (2)$$

where the unknown constants can be found. If the resistance R_t at some unknown temperature T in this range, is found, then the temperature may be calculated by substitution in the formula.

In order to use the platinum thermometer for measuring temperature, the bulb must be brought to the same temperature as the body whose temperature is required. This may be relatively simple when the substance whose temperature is being measured is a liquid or a gas. It is much more difficult when the substance is a solid. This difficulty is also experienced when using any other bulb. The circumstances in which a thermometer is used should be carefully considered before it can be assumed that the reading on the thermometer is a true indication of the temperature of the tested body. Thus, if thermometers are used out-of-doors to measure air temperature, the reading of a thermometer in the sun will be higher than in the shade, even if the temperature of the surrounding air is the same in both cases. This is because the thermometer in the direct sunlight will be receiving radiant heat from the sun, while that in the shade will not. The radiant heat will be absorbed by the thermometer, raising its temperature above that of the surrounding air. Hence its reading will be too high.

When a thermometer is used to find the temperature of a body, sufficient time must be allowed for the thermometer to reach the same temperature as the body. If the temperature of a hot body is changing continuously, then the thermometer will 'drag'.

The time taken for the thermometer to reach the temperature of the hot body can be reduced by making the thermal capacity of the thermometer as small as possible, and ensuring that the contact between the hot body and the thermometer is as close as possible.

Close thermal contact between thermometer and tested body is particularly difficult to achieve when a refractory sheath is being used to protect the thermometer. This is because the thermal conductivity of the sheath is low. A sheath of mild steel (0.1 per cent C)* would transmit 330 times as much heat as a sheath of identical dimensions of silica, and a similar copper sheath would transmit 3,000 times as much. Where copper or mild steel sheaths are used due allowance must be made for temperature difference owing to heat which is conducted to, or from, the thermometer bulb along the sheath. The fact that a thermometer bulb takes a certain time to reach the temperature of the tested body must be taken into account. However it is probably more important to obtain consistant results than ones which are absolutley accurate.

In the succeeding section thermocouples and thermistors are introduced, mercury-in-glass and bi-metal thermometers are discussed in general terms and the background to resistance thermometry is given.

In succeeding chapters the advantages and disadvantages of these various devices is discussed in the light of the preamble above.

* 0.1% Carbon

2.3 LIQUID IN GLASS THERMOMETERS *(Considine 1957)*

The liquid in glass thermometer has been in use for over two hundred years. Although it is not generally used today for high precision measurements, it is the most widely used device for temperature measurement.

There are three basic forms of liquid in glass thermometers:-

(i) All-glass (etched stem or enclosed scale)

(ii) Tube and scale

(iii) Industrial

Representative instruments in classes (i) and (ii) are described here, together with a summary of the technology of glass thermometry. These three classes are summarized in Table 2-1.

2.3.1 Thermometers for Total and Partial Immersion

The liquid in the column of a liquid-in-glass thermometer is part of the total thermally responsive system and is affected by the temperature along its length. For this reason thermometers are divided into two types:

1. *Partial Immersion Thermometers:* These instruments have a line etched around the stem to indicate the exact immersion depth for maximum accuracy.

2. *Total Immersion Thermometers:* The term total immersion does not mean that the entire thermometer must be immersed but rather that the entire bulb and all or nearly all of the liquid column be immersed.

2.3.2 Thermometer Fillings

Almost any liquid can be used. However, the following materials are most commonly used: (1) mercury; (2) mercury-thallium; (3) gallium; (4) alcohol; (5) toluol; (6) pentane; and (7) silicone.

TABLE 2-1

Characteristics of Liquid-in-Glass Thermometers

Class and type	Range		Accuracy
	°F	°C	
All glass:			
Einchluss	-328 to +680	-201 to +360	Usually 1 scale division
Beckmann	-22 to +392	-30 to +200	± 0.002 to ± 0.005°C
Clinical	+96 to +106	+35 to +41	± 0.2°F (0.1°C)
Laboratory or chemical	-328 to +1200	-201 to +648	Usually 1 scale division.
Max. or min. registering	-40 to +400	-40 to +204	1 to 2 scale division
Tube and scale:			
Cup case	-30 to +500	-22 to +260	Usually 1 scale division
Tin copper or stainless-steel case	-40 to +400	-40 to +204	Usually 1 scale division
Industrial:			
Spirit filled	-150 to +120	-100 to +50	Usually 1 scale division
Mercury filled	-40 to +1200	-40 to +648	

(Considine Page 2-88)

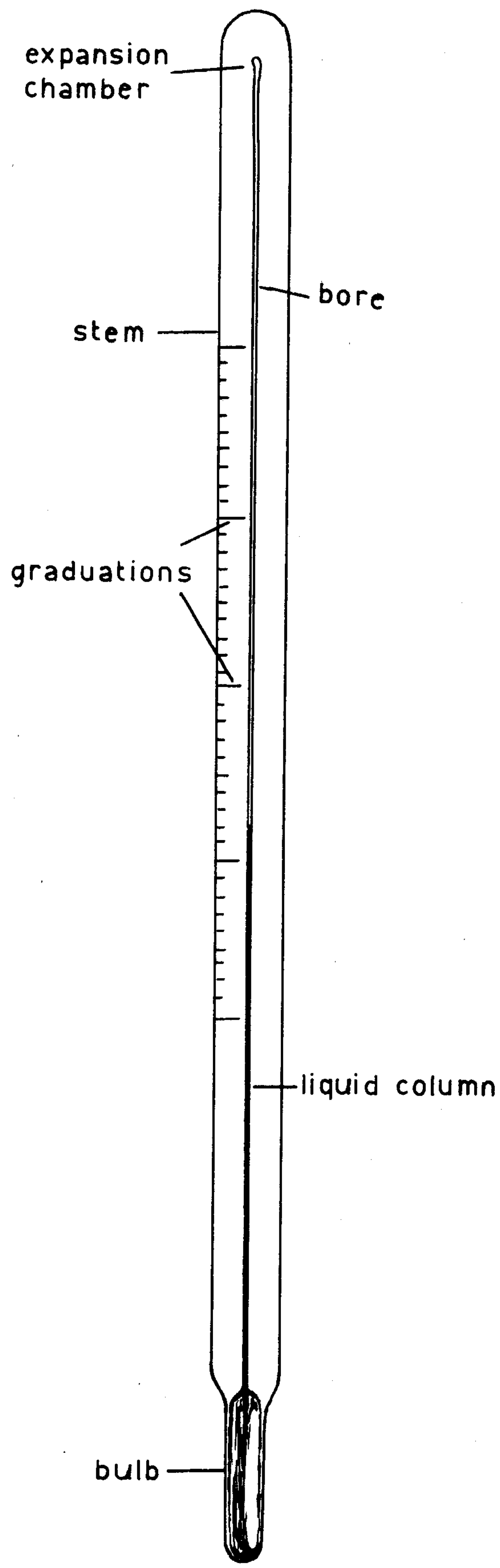

expansion
chamber
bore
stem
graduations
liquid column
bulb

FIG. 2·1

2.3.3 Gas-Filled Thermometers

Better grades of thermometers with metallic fillings have an inert gas above the liquid column. Nitrogen, argon, or carbon dioxide is generally used above mercury, nitrogen is used above mercury-thallium.

Electric contact-making thermometers usually contain hydrogen.

2.3.4 Capillary Bores

Capillary bores are usually round or elliptical, the latter sometimes being called a flat bore. Sections of the bore are sometimes purposely deformed.

2.3.5 Expansion Chamber

Most thermometers have an expansion chamber at the top of the bore. This acts as an overflow reservoir to prevent damage due to overheating.

2.3.6 The various types of all-glass thermometers

Basically as shown in Figure 2.1 the all-glass thermometer comprises a glass bulb to which is joined a glass stem or capillary tube. A calibrated scale is etched on the stem. Various styles of all-glass themometers are shown in Figure 2.2.

(i) *Einchluss Thermometer*. The Einchluss or enclosed scale thermometer is widely used in Europe. The graduations are printed on a separate scale which is fastened to the stem. The entire unit is then sealed in a glass tube for protection (see Figure 2.2).

(ii) *Beckmann Thermometer*. This instrument, shown in Figure 2.2 incorporates a large-volume bulb which feeds into an extemely small bore, resulting in a very sensitive device. It is set to the required temperature by means of a large overflow chamber at the top, into which excess mercury is forced by heating the bulb end. The excess mercury is forced in this chamber, shortening the mercury column. When the setting is changed, a setting factor must be applied to the reading to convert them to true temperature differences.

(iii) *Armored Thermometers.* When a liquid in glass thermometer is to be subjected to rough handling, it be supplied in a protective metal sleeve or armour (see Figure 2.2).

(iv) *All-Glass Thermometer with Electric Contacts.* Instruments which use metallic fillings can be made with wire contacts which are fused through the wall and penetrate into the capillary bore. An electric current will flow from one contact through the column to the other contact when the liquid touches it.

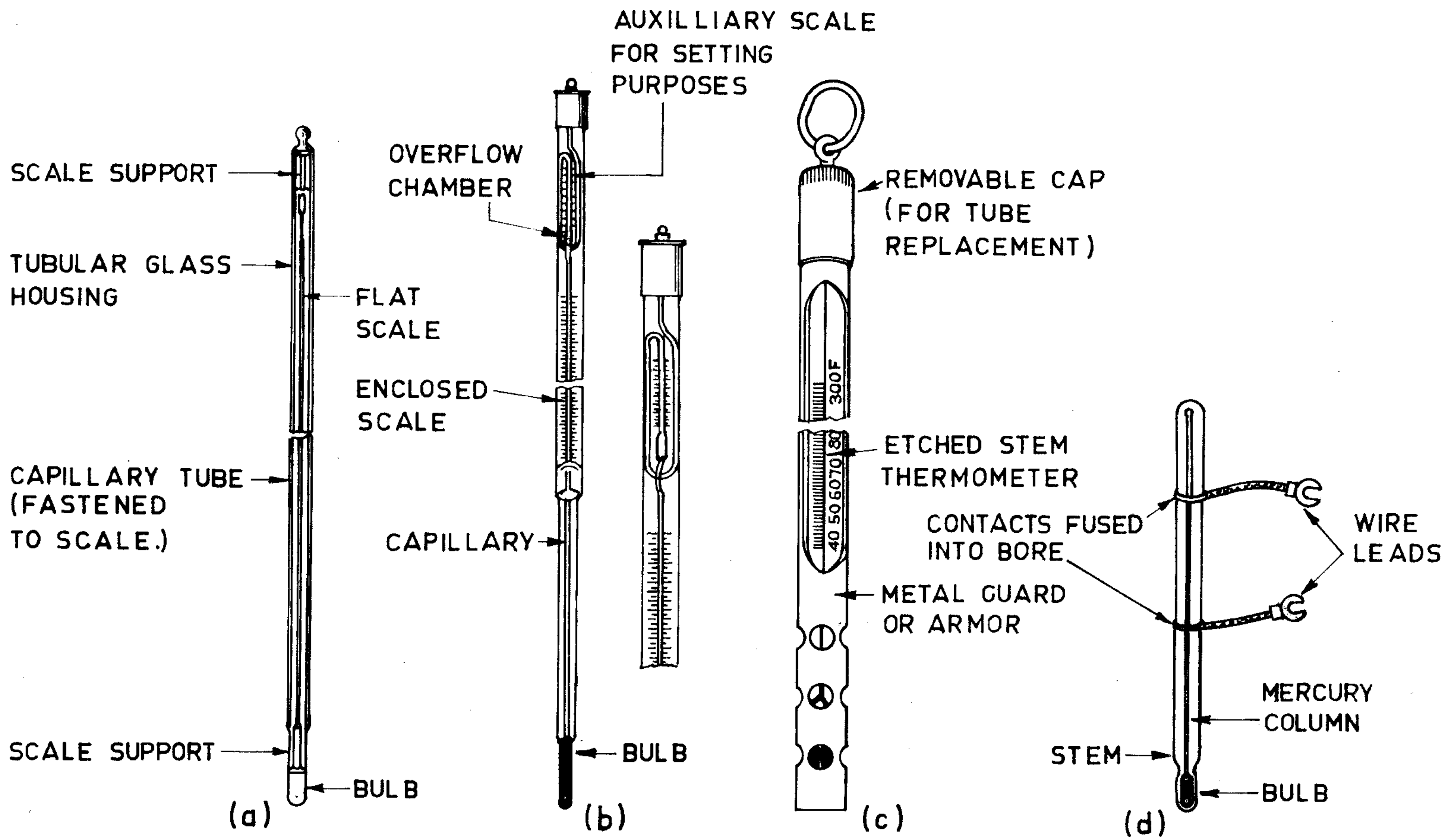


Fig.2-2 (a) Einchluss or enclosed scale thermometer. (b) Beckmann or metastatic thermometer. (c) Armored thermometer. (d) Electrical-contact thermometer. Considine p. 2-90

2.4 BIMETAL THERMOMETERS *(Considine 1957)*

2.4.1 General

The bimetal thermometer, although widely used today, was not acceptable for industrial and laboratory use before about 1935. The fact that bimetal elements bend with temperature changes was observed over a century ago. These elements were then used for temperature correction in chronometers.

Thermostatic bimetal can be defined as a composite material, made up of strips of two metals fastened together, which, because of the different expansion rates of the components tend to change its curvature when subjected to a change in temperature.

With one end of a straight strip fixed, the other end deflects in direct proportion to the temperature change and the square of the length, and inversely to the thickness, throughout the linear portion of the deflection characteristic curve.

If a strip of bimetal is wound into a helix or a spiral and one end is fixed, the other end will rotate when heat is applied. The angular deflection varies directly with the temperature change and the length of the strip, and inversely with the thickness of the material, over the linear section of the deflection curve.

Bimetals show uniform deflection only over part of the deflection characteristic curve (see Figure 2.3). Therefore, for a thermometer with uniform scale divisions a bimetal must have linear deflection over the desired temperature range.

2.4.2. Types of Elements

The three types of elements most commonly used in thermometers, the flat spiral, the single helix and the multiple helix, are shown in Figure 2.4.

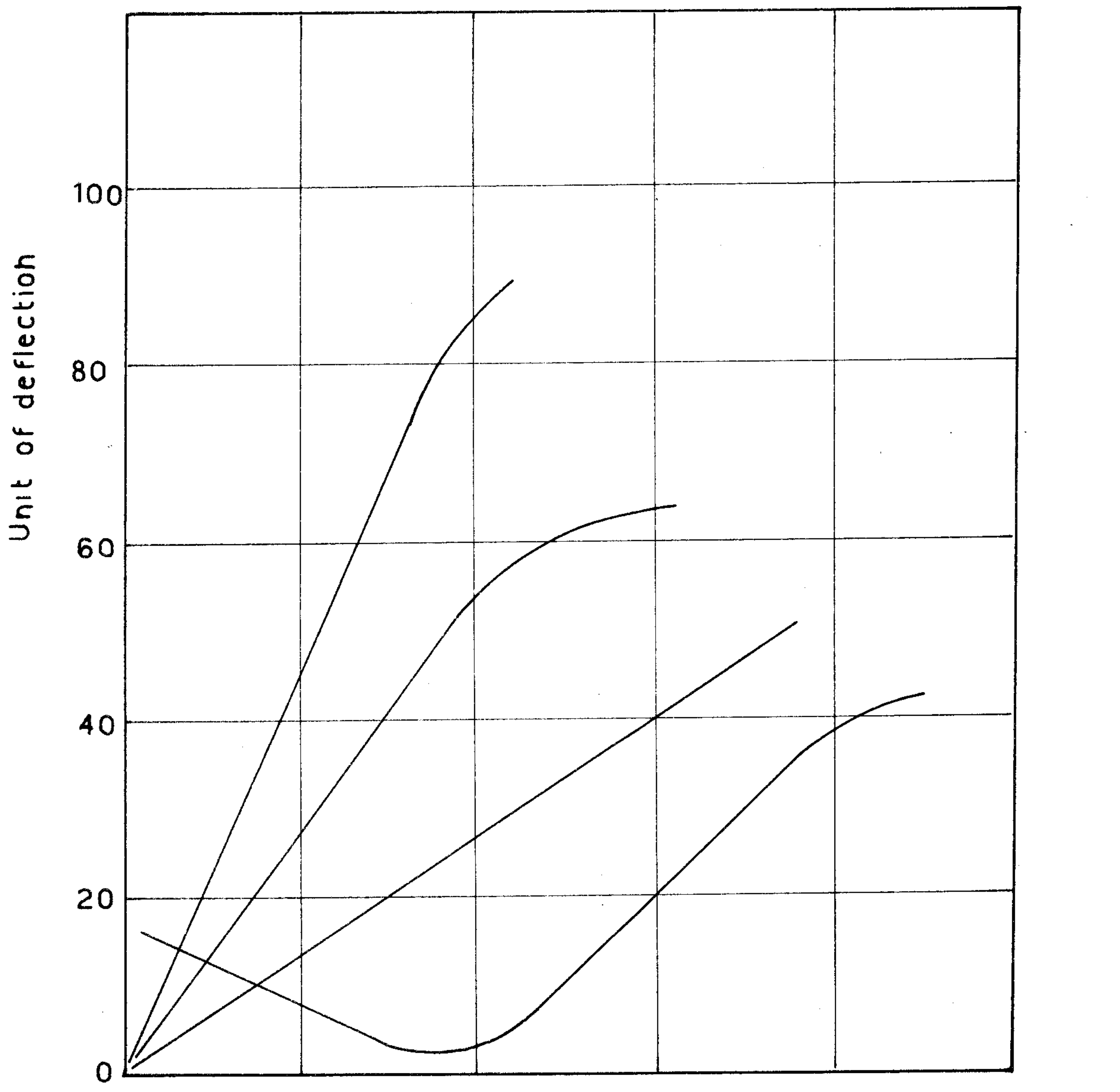


FIG. 2·3 Deflection characteristics of various bimetals

(Considine 2-85)

2.4.3 Construction of the Bimetal Thermometer

The construction of the general industrial thermometer is shown in Figure 2.5. Motion of the helical element is transmitted to the pointer by a staff or shaft. Precision made bearings and guides centre the shaft with minimum friction. Construction is simple. There are few moving parts, and maintenance is low.

Bimetal thermometers are also made with the dial face parallel to the stem. This has been done in Europe with precision bevel gears. There is backlash in the gears and high torque is needed to eliminate friction errors. More simply, the right-angle transmission today is accomplished by a long edge-wound helical spring which eliminates backlash and requires little torque.

2.4.4 Accuracy

Good bimetal thermometers will retain their accuracy indefinitely. Usually industrial bimetal thermometers are guaranteed to be within 1% of the scale range at any point on the scale.

The smaller laboratory or general purpose types are guaranteed to be within one-half of one percent of the scale range. Better accuracy is possible if each scale is hand drawn to match the element, but high cost makes this impractical. To get maximum accuracy, the section of the stem containing the element must be completely immersed.

2.4.5 Types of Bimetal Thermometers

Bimetal thermometers are made in a large variety of forms from 1-in. head diameter to 6-in. and larger. In general they are divided into two classes: (1) the larger sizes with pipe-threaded connections, for industrial use, and (2) the smaller sizes with smaller stems and no threaded connections, for general use and laboratory work. All sizes, however, can be obtained with or without threads. Also available are pointed and screw or gimlet-ended stems for use in hard substances. These ends are integral with the regular stem and are in contact with the bimetal element, permitting quick heat transfer.

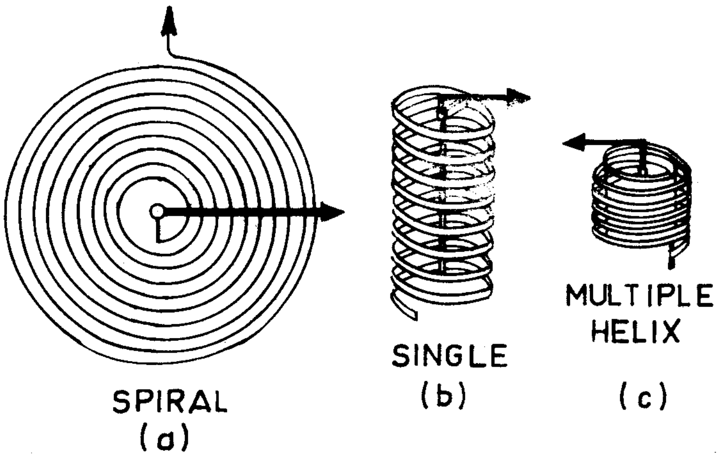


Fig. 2·4 Principal types of elements used in bimetal thermometers: (a) flat spiral (b) single helix (c) multiple helix. Considine p. 2-86

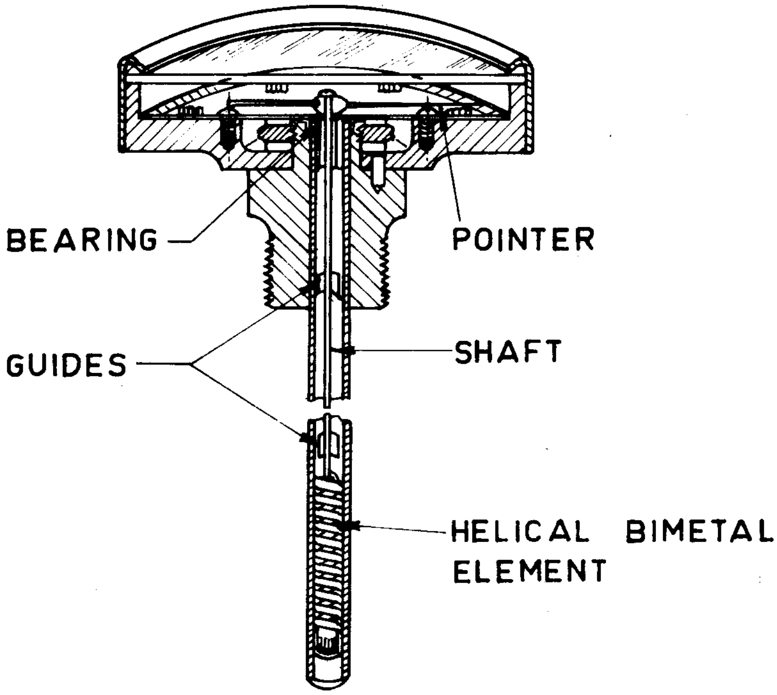


Fig. 2·5: Sectional view of industrial thermometer using helical-type bimetal element

Considine p2-86

2.4.6 Thermal Response

The speeds of response of bimetal thermometers, as shown in Figure 2.6 are in general similar to comparable liquid-in-glass thermometers.

Response speeds of various types of bimetal thermometer (in water bath)

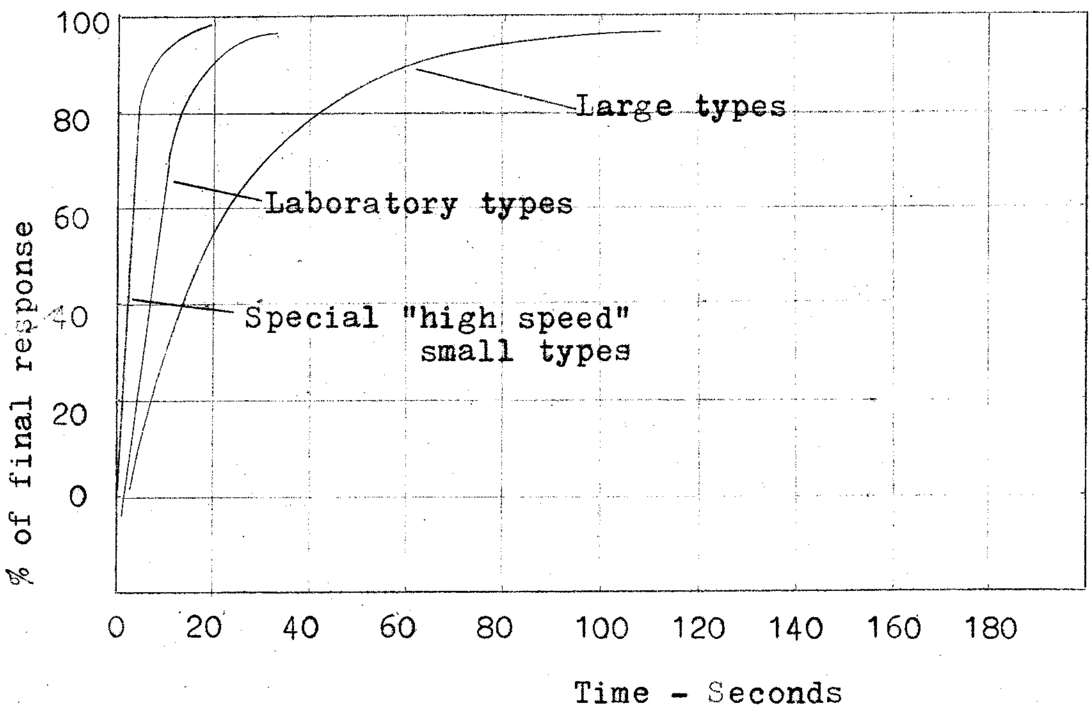


FIG. 2·6

2.5 THERMOCOUPLES *

2.5.1 General

A thermocouple is formed by the junction of two dissimilar metals to form a circuit as shown in Figure 2.9. To introduce something of the basic theory some knowledge of atomic physics will be assumed. The valency electrons in a conductor constitute an "electric gas" which wander randomly.

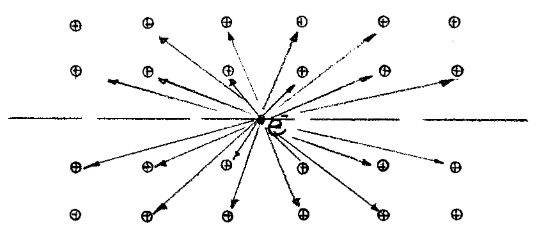


Fig. 2.7 - Similar Metals

In Fig. 2.7 the metals abutting are identical and therefore the forces in an electron balance out.

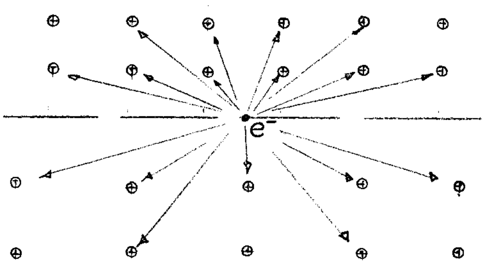


Fig. 2.8 - Dissimilar Metals

* 1. *Considine 1957*
2. *Jones 1970*
3. *Finch 1963*

In Figure 2.8 where the metals abutting are dissimilar the forces of attraction on an electron are out of balance due to the denser lattice structure of metal A relative to metal B. At high temperatures much thermal agitation occurs and electrons move easily across the surface into metal A.

If a circuit is formed by the two metals which are, say iron and copper.

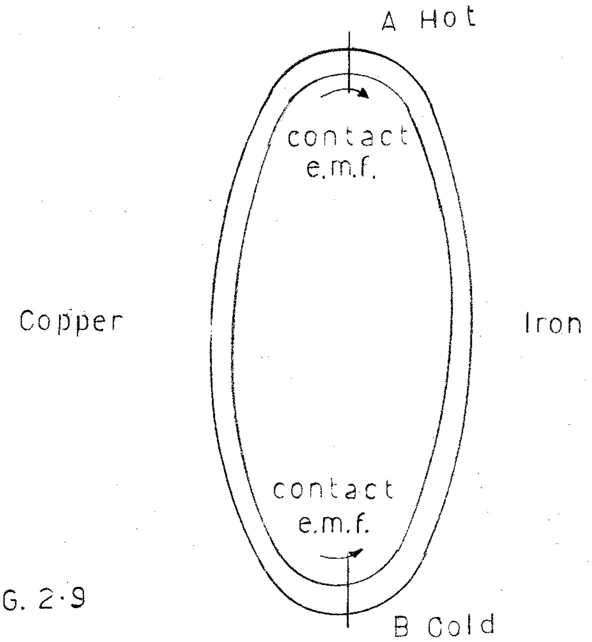


FIG. 2·9

Electrons travel from iron to copper which constitutes a current from copper to iron, and is known as the e.m.f. in that direction. If the junctions are at the same temperature the two e.m.f.'s are equal and opposite so that no current flows. If the junctions are at different temperatures then the transfer of electrons at the hot junction will exceed that at the cold junction. There is therefore an e.m.f. acting around the circuit in the direction of copper to iron at the hot junction. This e.m.f. is called a themoelectric force. This phenomenon was first observed by Seebeck in 1821 and hence is known as the Seebeck effect.

This phenomenon discovered by Seebeck *(Finch 1963)* is the important or over-riding principle of the thermocouple. In the 1830's Peltier and Thompson demonstrated other factors, showing how the Seebeck effect works. Consequently laws were compiled setting out the workings of the thermocouple in all circumstances.

The behaviour of the thermocouple is described by the following effects:-

(i) The Seebeck effect

(ii) The Peltier effect

(iii) The Thompson effect.

2.5.2 Thermoelectric laws

The laws governing the behaviour of the thermocouple can be summarized by the following:-

(i) The law of intermediate metals

(ii) The law of homogeneous circuit

(iii) The law of combination of e.m.f.

(iv) The law of intermediate temperatures.

2.5.3 Thermoelectric power

The rate of change of e.m.f. with temperature is called the "thermoelectric power" of the thermocouple. For a given combination of metals, the e.m.f. of a thermocouple plotted against a large range of temperatures varies approximately according to a parabolic law (see Figure 2.10).

If the cold junction is kept at $0^{o}C$ then for any temperature T of the hot junction

$$E = P_{AB}T+\tfrac{1}{2}Q_{AB}T^2 \qquad \ldots\ldots\ldots \quad (3)$$

where E is the e.m.f. in micro-volts, P_{AB} and Q_{AB} are coefficients for metals A and B, T is the temperature of the hot junction.

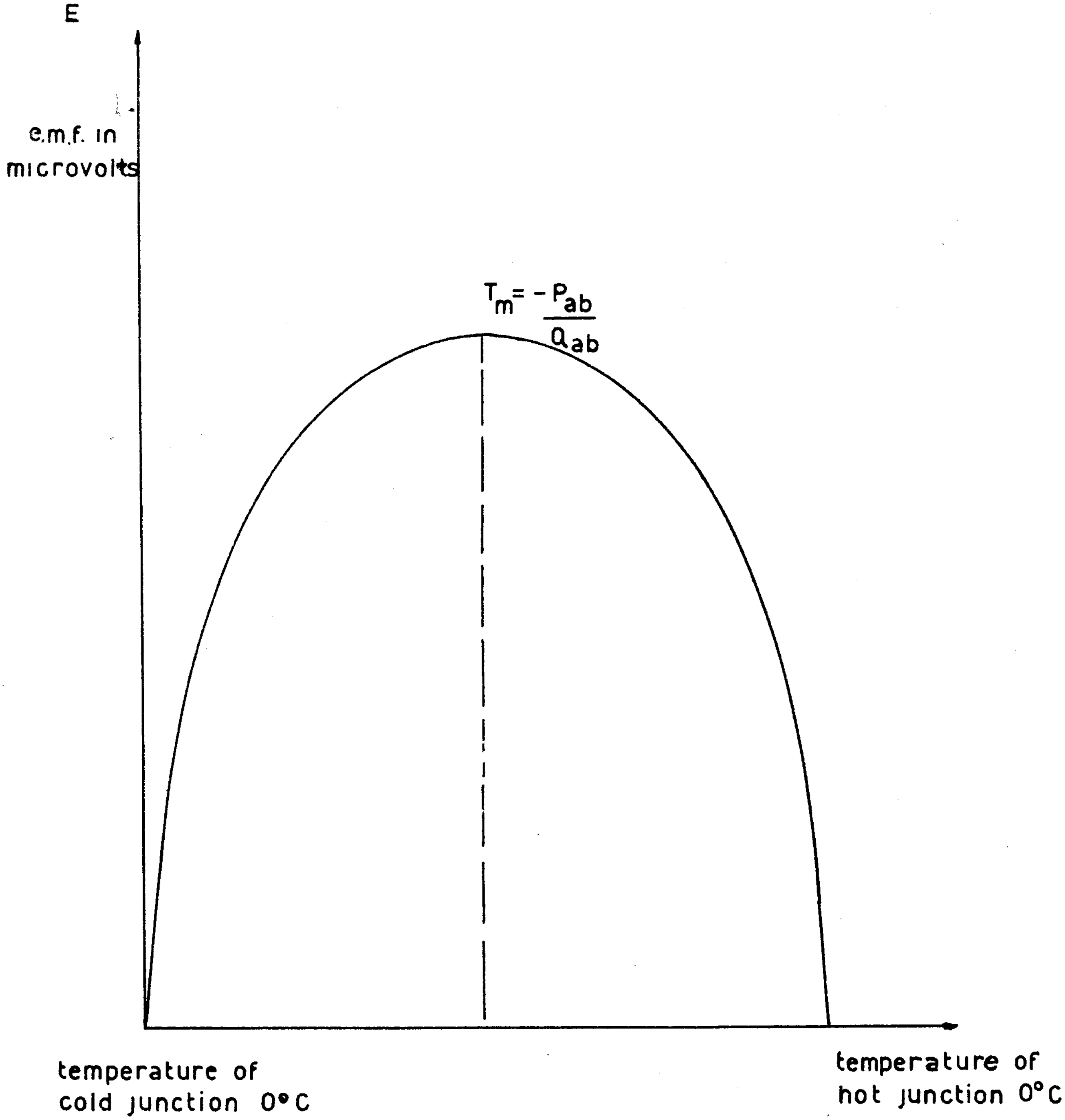

E
e.m.f. in microvolts
$T_m = -\frac{P_{ab}}{Q_{ab}}$
temperature of cold junction 0°C
temperature of hot junction 0°C

FIG. 2·10

2.5.4 Common Thermocouples

The most commonly used metal combinations in practice and their operating range are:-

	Type	Operating temperatures
1.	Platinum-Platinum 10% Rhodium	0-1450 °C
2.	Platinum-Platinum 15% Rhodium	0-1450 °C
3.	Chromel-Alumel	0-1100 °C
4.	Iron-Constantin	0-900 °C
5.	Copper-Constantin	190-350 °C
6.	Chromel-Constantin	0-900 °C

2.5.5 Thermocouple measurement in the classical form

In a classical form a thermocouple temperature measuring system would be as shown in Figure 2.11.

In this case the reference junction is kept at 0°C by immersion in ice. The e.m.f. is determined from a potentiometer circuit. This obviously is far too cumbersome for the usual surveying application.

Thermocouple units sold commercially would generally use ambient temperature as the reference junction temperature. The more recent instruments would also be fitted with automatic reference junction compensation.

Section 3.2 of this thesis gives a description of the thermocouple unit used in the experimental work for this thesis.

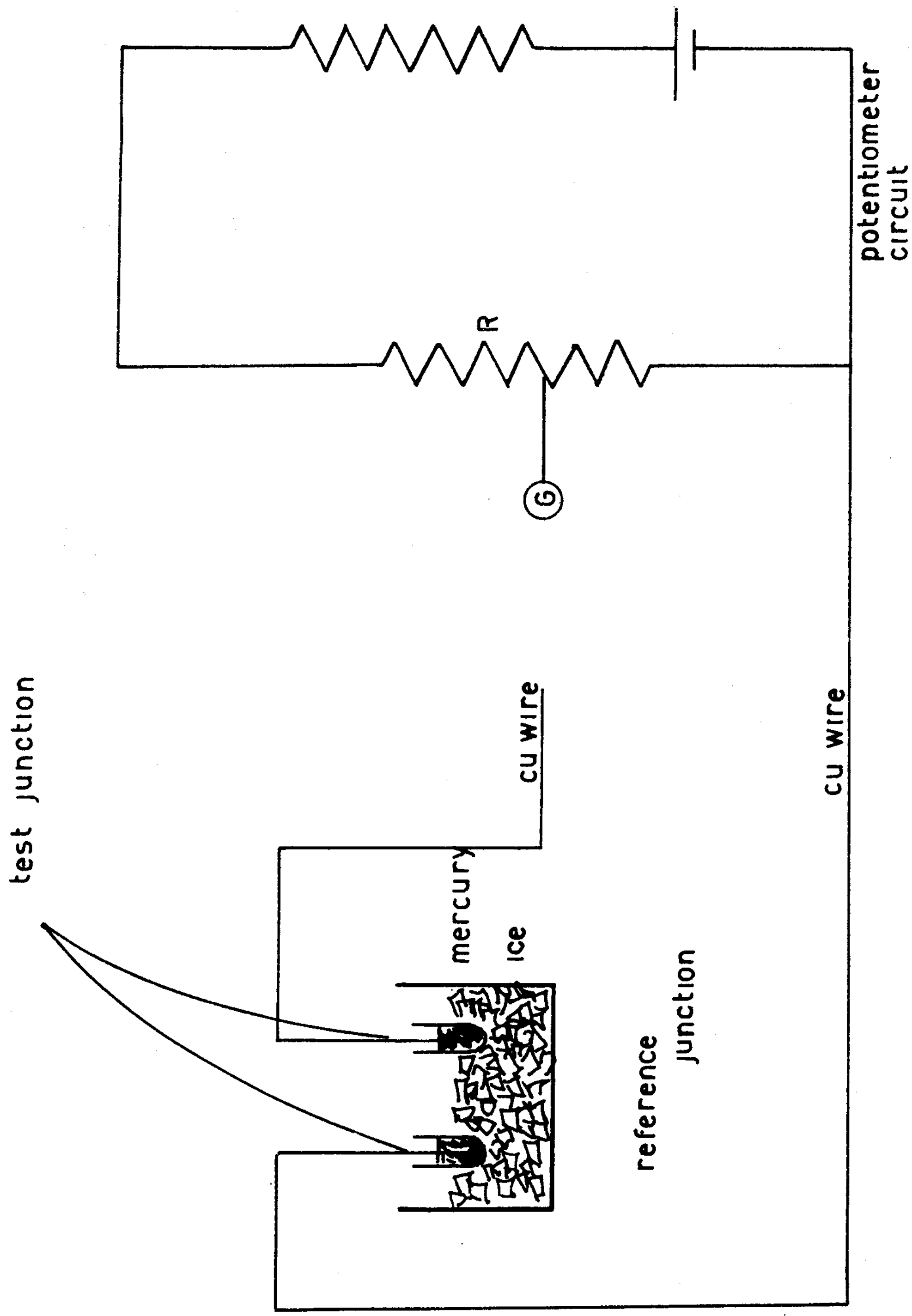

test junction
mercury
ice
cu wire
reference junction
cu wire
R
G
potentiometer circuit

FIG 2·11

2.6 THERMISTORS AS TEMPERATURE ELEMENTS *(Considine 1957)*

2.6.1 General

The property possessed by some substances of changing electrical resistance markedly with temperature has been known since 1835, the time Faraday's work with silver sulphide. Since about 1835 reproducibility and stability of characteristics of certain of these materials have been brought into practical bounds and usable electrical devices depending upon this property have become available. Known as thermistors, they have been used since about 1940 in industrial and communications applications in moderately large quantities, in both America and Europe.

A thermistor is an electrical device made of a solid semiconductor with a high temperature coefficient of resistivity, which would exhibit a linear voltage-current characteristic if its temperature were held strictly constant. The applications of the thermistor can be divided into two broad categories for the purpose of classification. In one of these by design, very little power is dissipated in the thermistor, as in bridge and potentiometer methods of measuring resistance, usually used for measuring temperature and control applications. The other major class, which is beyond the scope of this section, is based on the nonlinear voltage-current characteristics resulting from temperature rise in the thermistor itself when significant amounts of power are dissipated in it.

When a thermistor is used as a temperature-sensing element, the relationship between its electrical resistance and its temperature is of primary concern. The approximate relationship applying to most thermistors is

$$R = R_o \exp B(T^{-1} - T_o^{-1}) \qquad \ldots\ldots\ldots \quad (4)$$

(Considine 1957)

where R_o = resistance value at reference temperature T_o

R = resistance at any temperature T, ^oK

B is approximately a constant over moderate temperature ranges and depends upon composition and process of manufacture.

The temperature coefficient commonly expressed as a percent change in resistance per degree temperature change is approximately related to B by the formula

$$\alpha = -BT_o^{-2} \qquad \ldots\ldots\ldots \quad (5)$$

(Considine 1957)

where T_o is in degrees Kelvin.

The value of α at room temperature is approximately ten times that of the metals of which resistance thermometers are constructed. In consequence of the large coefficient thermistors are several times more sensitive than thermometers with metallic elements up to about 400^oC, assuming the same power-dissipating capability.

However they are not readily manufactureable to the same degree of uniformity and are not ordinarily commercially available with resistance-temperature calibrations. In addition they do not thus far compete generally with precision thermometers because their calibrations are not stable over long periods of time. The research and development work being done on semiconductors makes it reasonable to expect continuing improvements in thermistor stability and uniformity.

The selection of a thermistor for a particular application in thermometry or temperature control requires consideration of several factors in addition to the resistance temperature characteristic. These include response time and compatibility with the associated resistance-measuring apparatus. Among these compatibility factors are the thermal-dissipation factor of the termistor and convenient magnitude at the extremities of the working temperature range. Suitable dimensions and mechanical qualities are also important. The response time or thermal time constant is the time required for the temperature of the thermistor to change 63 percent of the difference between its initial value and that of the surroundings when no electric power is being dissipated in it. The termal dissipation factor is the proportionality C in the relation.

$$P = C\Delta T \qquad \ldots\ldots\ldots\ldots \quad (6)$$

(Considine 1957)

where P = power dissipated

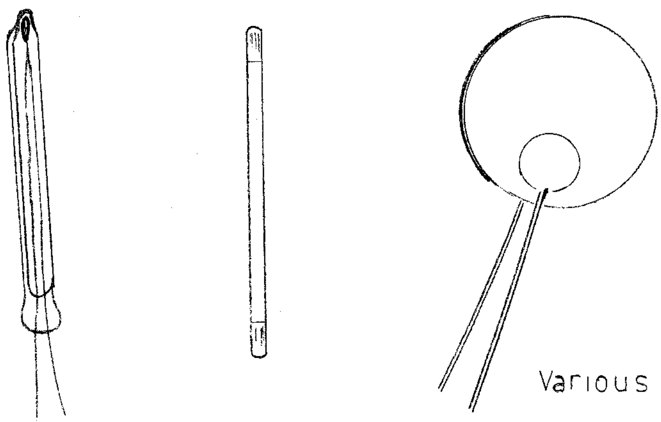
ΔT = steady-state temperature rise resulting from this power dissipation in the thermistor.

C depends upon the thermal coupling to the surroundings.

The relationship as given holds exactly for conductive heat losses and approximately for convection and radiation losses where the temperature difference is small.

2.6.2 Construction of thermistors

Among the semiconducting materials of which thermistors are made are a number of metal oxides and their mixtures, including the oxides of cobalt, copper, iron, manganese magnesium, nickel, tin, titanium, uranium, and zinc.



Various forms of thermistor

FIG. 2·12

(Considine 2-61)

The oxides, usually compressed into desired shapes from powders, are heat treated to recrystallize them, resulting in a dense ceramic body. Electric contact is made by various means - wires embedded before firing the material, plating or metal-ceramic coatings baked on (see Figure 2.12).

Forms in general use are beads as small as 0.015 in. in diameter, disks ranging from 0.2 to 1.0 in. in diameter and rods from 0.03 to 0.25 in. in diameter and up to 2 in. in length. Flakes a few microns thick are employed as infra-red detectors or bolometers. Various methods of mounting are used. Beads are suspended from wire leads or embedded in probes disks are mounted in spring-loaded stacks with or without heat-dissipating fins., other disks and rods are pigtail mounted. Beads and small disks may be covered with a thin adherent coat of glass to reduce composition changes of the thermistor at high temperature. They may be mounted by their leads in evacuated or gas-filled bulbs to minimize or control the degree of thermal coupling to the surroundings. Some types have associated heaters to control the thermistor resistance for various purposes.

2.6.3 Characteristics of Thermistors

(i) Resistivity

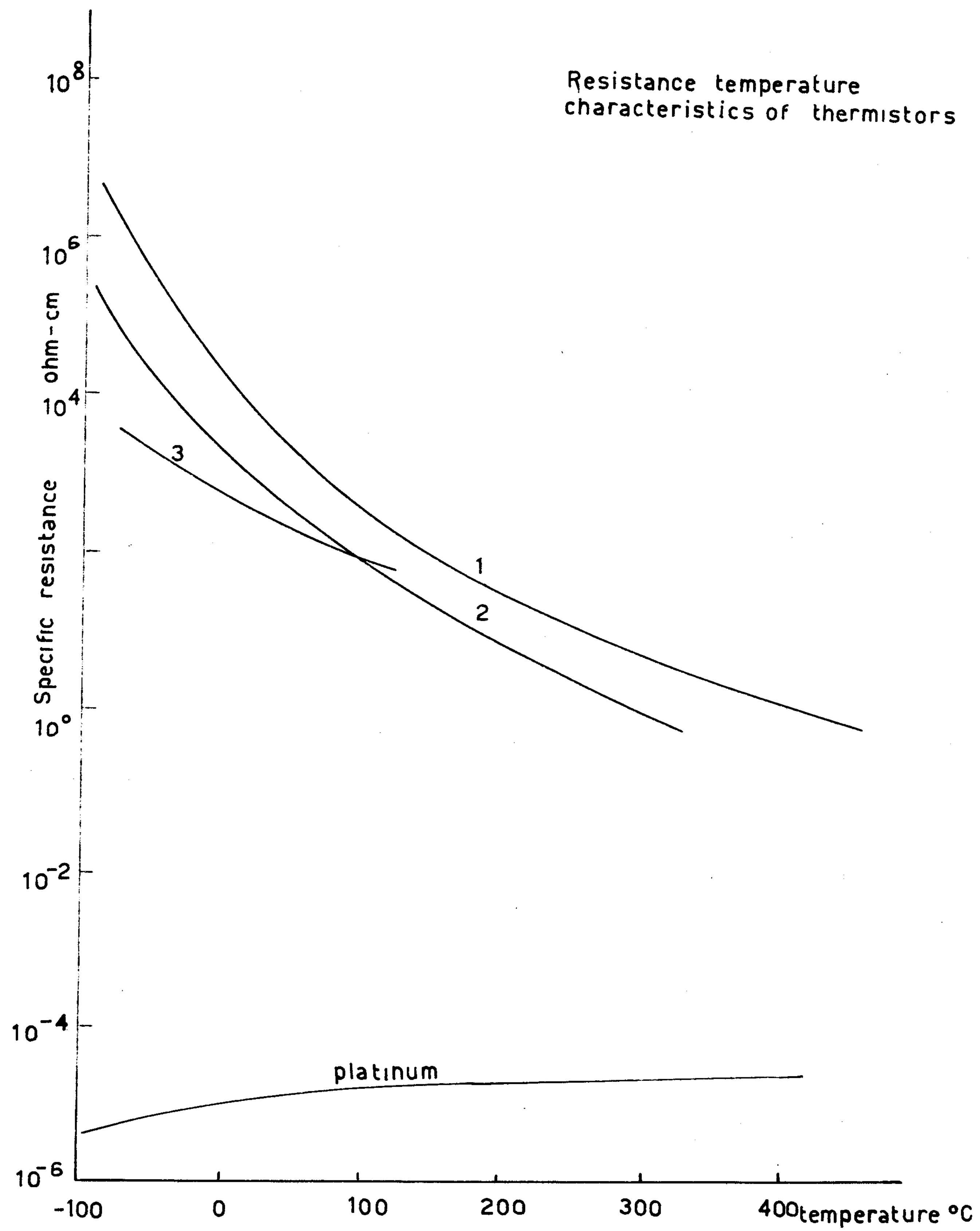
Figure 2.13 shows how the logarithm of the specific resistance varies with temperature for three typical thermistor materials and for a metal. The specific resistance of the thermistor represented by curve 1 decreases by a factor of 50 as the temperature is increased from 0 to 100^{o}C. Over this same temperature range, the resistivity of a typical metal will increase by a factor of 1.4.

(ii) Terminal Resistance

Thermistors range in terminal resistance at room temperature from about 1 ohm to the order of 10^8 ohms, depending upon composition, shape and size. Within a given type, they commonly vary 10 to 30 per cent in resistance from the nominal at room temperature. Some types can be adjusted mechanically by grinding off part of the contact area to bring resistance values within closer limits.

(iii) Temperature Coefficients

All practical types of thermistors have negative temperature coefficients of resistance, values ranging from 1 to 5 per cent per degree centigrade near room temperature. These values increase with decreasing temperature, doubling at about -60^{o}C. They are halved at approximately 150^{o}C. Within a given type individual thermistors may have a temperature coefficient varying from the nominal about 0.5 per cent for compositions best in this respect or as much as 5 per cent where composition and process are not optimized for this factor.



(Considine p.62)

FIG 2·13

(iv) Dissipation Factor

The range in power-dissipation factor is from about 10^{-5} watts to several watts per centigrade degree of resultant rise in temperature. This varies inversely with the degree of thermal isolation of the thermistor element.

(v) Thermal Time Constant

This factor varies from a few tenths of a second to the order of several minutes among the general-purpose types. The shorter times are associated with the smaller beads. The time constant varies directly with the thermal capacity of the thermistor and inversely with the dissipation factor.

(vi) Calibration Stability

The stability with time of the resistance-temperature relation depends upon the thermistor construction and use conditions. Changes may occur in the resistivity of the semiconductor or in the contact medium and its relation with the semiconductor. Resistivity may change through chemical changes in composition, caused by decomposition or diffusion processes which are generally accelerated at higher temperatures. Certain oxide compositions are inherently more stable than others. Thermistors enclosed in a glass covering with sintered-in noble-metal electrodes exhibit better stability with time, especially at temperatures of several hundred degrees centigrade, than not so constructed. Silver-ceramic electrodes, commonly used on disks and rods, diffuse to some extent at 150°C and higher, resulting in resistance drift. If subjected to cycling involving a high temperature, some types of thermistors may exhibit a behavior characteristic of relaxation. The resistance change may be as much as several percent following the temperature change, with a recovery time of a few hours. In this respect such thermistors behave somewhat like mercury-in-glass thermometers. When thermistors are held at a fixed temperature with negligible current flow, resistance changes of the order of one percent per year are typical. Figure 2.14, for example shows aging characteristics at 105°C of disk thermistors made of manganese-nickel oxide (material 1) and manganese-nickel-cobalt oxide (material 2). In certain glass enclosed types smaller aging rates are observed at even higher temperatures, being of the order of few tenths of a percent in resistance per year. This corresponds to a calibration change of 0.1°C or less in resistance per year.

The upper operating temperature limit is set by physical changes, such as solder melting point where solder is involved or by calibration change considerations. This limit will depend upon the construction of the thermistor and the degree of precision required of it and usually ranges from the order of 100 to 400°C. In a few types, it may even be higher. The low-temperature operating limit is usually determined by the resistance reaching such a high value as to preclude convenient measurement of it.

2.6.4 The Method of Application of Thermistors to Thermometry

The application of thermistors to the measurement of temperature follows the usual principles of resistance thermometry. Conventional bridge or other resistance-measuring circuits are commonly employed. The high temperature coefficient of thermistors results in their having a greater available sensitivity as temperature-sensing elements than metal resistance thermometers or common thermocouples.

To illustrate, the use of thermistors permits the adaptation of conventional temperature recorders to the measurement of 1°C spans, which is not feasible with ordinary resistance-thermometer or thermocouple elements.

The resistance-temperature calibrations for thermistor elements are decidedly non-linear for extensive temperature spans. They can be straightened if required by the use of a resistance shunt, at the cost of sensitivity.

As with any resistance thermometer, consideration must be given to keeping the measuring current small enough to avoid significant heating in order that the element resistance shall be dependent upon the temperature of the surroundings alone. The average power dissipation can be reduced without sacrificing sensitivity by energizing the thermistor element with pulses of measuring power.

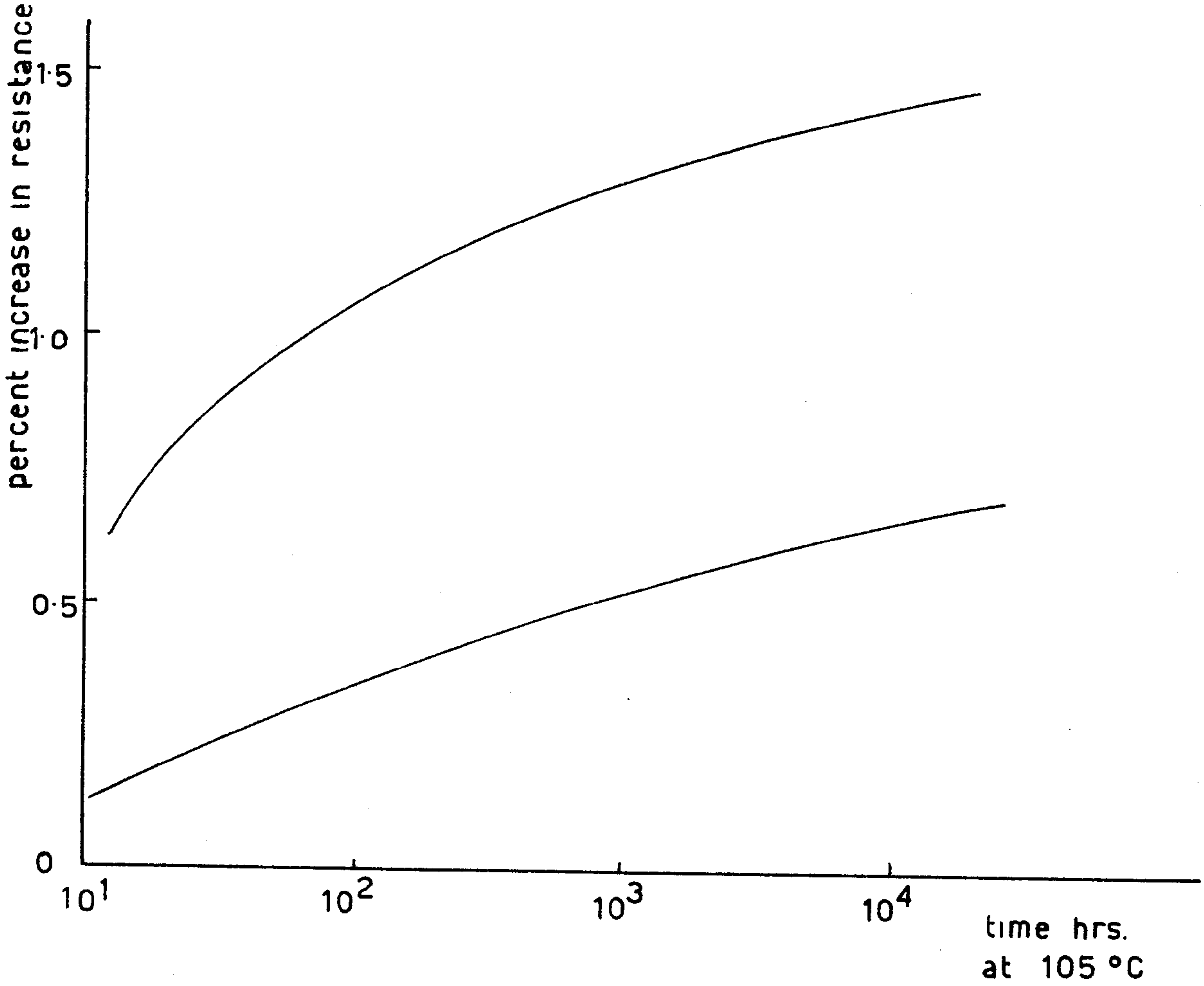
Thermistors are readily designed for sufficiently high resistance values to make lead resistance errors negligible. Hence, thermistors primary elements, unlike metallic resistance thermometers and thermocouples, can be located remotely from their measuring circuits. This permits greater flexibility in application. The availability of thermistors in small sizes and their mechanical simplicity give them advantages over sensing elements such as mercury thermometers and conventional resistance thermometers.

Several thermistors which have been used for thermometry are shown in Figure 2.15; included in the group are types which are suitable for such diverse applications as intravenous blood thermometry and high-altitude meteorological observations.

The temperature of objects which are inaccessible, in motion, or too hot for contact thermometry can be determined by permitting radiation from them to be focussed on a suitable thermistor by optical means. Such a thermistor takes the form of a thin semiconductor flake attached to a solid support. Its advantage against the thermopile (a bank of thermocouples) and resistance bolometer are its more favourable resistance value, its ruggedness, and its high temperature coefficient of resistance. It can be made small to reduce its heat capacity so as to follow rapidly changing temperatures.

Flake thermistors have been made with time constants ranging from a few milliseconds to 1 sec. Since the amount of radiant energy falling on the thermistor may be quite small, sensitive meters or vacuum-tube amplifiers are required to measure the small changes in the flake resistance. Where rapidly varying temperatures are not involved, thermistor types with longer time constants can be utilized.

The usage of thermistors as temperature-sensing elements in industrial and laboratory fields is increasing rapidly. For some time they have been in use in large numbers as thermometers in automobile engines and weather balloons. Widespread but not large-scale use has been made of them in biological and physiological research.



Change in thermistor resistance versus time at 105°C

Considine p. 2.63

FIG. 2·14

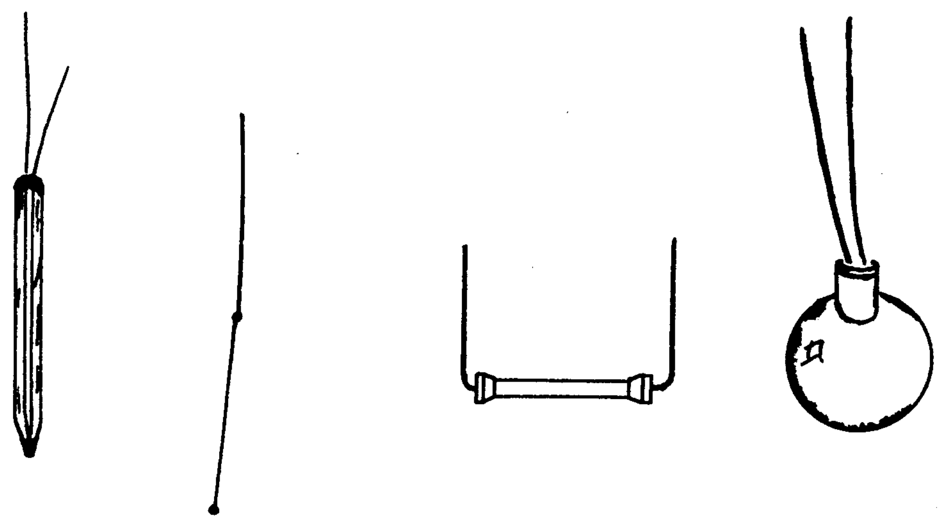


FIG. 2·15 Forms of thermistors used as thermometers

Considine p. 2-64

2.7 RESISTANCE METHODS OF MEASURING TEMPERATURE

2.7.1 General

Most of the work in connection with electrical resistance thermometry involves a knowledge of OHM's law. Ohm's law states that:-

"When a current is flowing in a conductor, the potential difference between the ends of the conductor divided by the current flowing through the conductor is a constant quantity provided the physical condition of the conductor does not change. This constant quantity is called the *'Resistance'* of the conductor, and if the potential difference is measured in volts and the current in amperes, then the resistance will be given in ohms."

This law is extremely useful in calculations involving conductors, for if two of the three quantities, potential difference, current and resistance, are known, the third can always be found. For:-

$$\text{Volts} = \text{Amps.Ohms},\ \text{Amps} = \text{Volts.Ohms}^{-1},$$
$$\text{Volts.Amps}^{-1} = \text{Ohms}.$$

Laboratory standards are established, for the international ohm and ampere are defined in terms of reproducible quantities, and the volt defined in terms of the ohm and ampere, as follows:-

The International Ohm. The international ohm is defined as the resistance of a column of mercury of mass 14.4521 gram and length 106.300 centimetre, having a constant cross-sectional area, and at the temperature of melting ice.

The International Ampere. This is the unvarying current which, when passed through an aqueous solution of silver nitrate, deposits silver at the rate of 0.001118 grams per second.

The International Volt. This is the potential difference which, when applied across a resistance of one international ohm, produces a current of one international ampere. By the application of Ohm's law, the measurement of one electrical variable enables the value of another to be determined. Thus, with standard resistances and a standard cell, both amp-meters and voltmeters may be calibrated by the use of a potentiometer.

A potentiometer, in its simples form, consists of a length of wire of uniform shape AB, usually fixed over a scale of length. The resistance per unit length of the wire may be regarded as being constant, so that when a current flows, the voltage drop along the wire is uniform. The wire is connected with an accumulator, as shown in Figure 2.16. If a standard cell is connected in series with a large resistance and a galvanometer, a point C may be found in AB such that no current flows through the galvanometer when it is connected to C. The high resistance, R, is for the protection of the standard cell, which must never be permitted to give an appreciable current as this will alter its e.m.f.

The cell gradually recovers its e.m.f. when it ceases to give a current. When the point C has been found it is known that the potential drop between A and C is equal to the e.m.f., or electromotive force, of the standard cell (E)

$E = Kl_1$, where K is a constant and $l_1 = AC$.

If now another source of potential difference is connected to A and the galvanometer, and a new point C_1 is found such that there again is no deflection of the galvanometer then:-

Applied potential difference $= Kl_2$ where $l_2 = AC_1$

$$\frac{\text{Applied potential difference}}{E} = \frac{l_2}{l_1}$$

This enables any applied P.D. to be measured. To measure current, the P.D. across a standard resistance may be measured when the current is flowing.

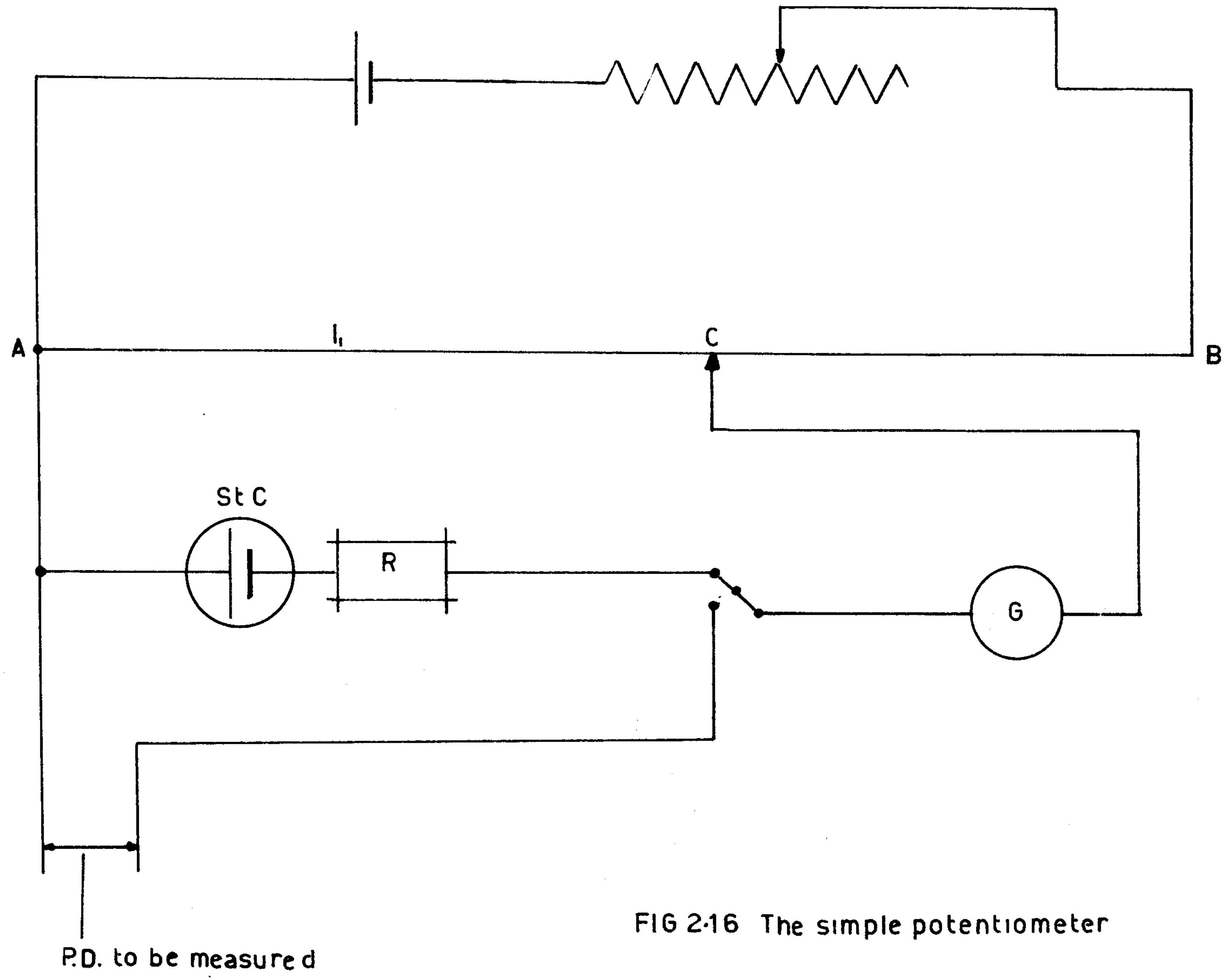


FIG 2·16 The simple potentiometer

The P.D., V volts, across the resistance, R ohms, when a current, I amps, is flowing is then given by:-

$$V = IR \text{ volts, or } I = \frac{V}{R} \text{ amperes}$$

Resistances may be compared by placing them in series and passing a current through them. The ratio of the potential difference across them, as measured by means of the potentiometer, will be the same as the ratio of the resistance.

In industrial instruments, the potentiometer is always more complicated than this simple version but the principle is the same.

2.7.2 Resistance and Temperature

It is found that the resistance of pure metallic conductors increase with temperature. In practical thermometry, the metals used are platinum, nickel and copper because they can be reproduced with a high degree of purity. Copper has the disadvantage that it has a low specific resistance (resistance between the faces of a cube of the metal having all edges 1 cm. long) but is has a similar temperature coefficient to platinum and it is relatively inexpensive. Elements made of copper have a usuable temperature range of -50° to $+250^{\circ}$C., but copper is readily oxidized so that adequate steps must be taken to protect the element from oxidation. Nickel provides an inexpensive substitute for platinum at temperatures between -200 and $+350^{\circ}$C., is not readily oxidized and has a temperature coefficient which is about 1½ times that of copper or platinum.

Platinum is the standard material used for the resistance thermometer that defines the *International Scale of Temperature* not because it has a particularly high temperature coefficient of resistance, but because it has high stability in use. In fact, a high temperature coefficient of resistance is not, in general, necessary for a resistance thermometer material as resistance values can be determined with a degree of accuracy using suitable equipment and taking adequate precautions.

Platinum, having the highest possible coefficient of resistance, is considered the best material for the construction of thermometers as a high value of this function is an indication that the platinum is of high purity. The presence of impurities in resistance thermometer material is undesirable, as in service, diffusion, segregation and evaporation may occur resulting in a lack of stability of the thermometer. The temperature coefficient of resistance is also sensitive to internal strains so that it is essential that the platinum should be annealed at a temperature higher than the maximum temperature of serve. The combination of purity and adequate annealing is shown by a high value of the ratio of the resistances at the steam and ice points. To comply with the requirements of the International Temperature Scale of 1948 this ratio must exceed 1.391 0 but wire having a ratio well above 1.392 is readily available.

It is essential that the platinum element is mounted in such a way that it is not subject to stress in service. Platinum is used for resistance thermometry in industry for temperatures up to 600^{o}C. It does not oxidize, but must be protected from contamination. The commonest cause of contamination of platinum resistance thermometers is contact with silica, or silica bearing refractories, in a reducing atmosphere.

At temperatures approaching the *Absolute Zero*, leaded phophor-bronze resistance thermometers are found to be more suitable.

If the temperature can be regarded as being a constant relationship to the resistance, the temperature may be expressed in terms of a 'platinum scale' of temperature. This scale approximates to, but is not identical with, the gas scale over the range 0-100^{o}C. If the rate of increase of resistance of platinum wire is regarded as being uniform between 0^{o}C and 100^{o}C, the resistance R_T at a temperature T, within this range, is given in terms of the resistance, R_0, at 0^{o}C by the equation:-

$$R_T = R_0(1 + \alpha T) \qquad \text{........(7)} \quad \textit{(Considine, 1957)}$$

where α is the mean temperature coefficient of resistance of platinum between 0^{o}C and 100^{o}C, i.e.

$$\alpha = \frac{R_{100} - R_0}{100R_0} \qquad \text{........(8)}$$

The values of R_0 and α may be found by determining the resistance of the wire at the ice point, 0^oC, and the steam point, 100^oC. The difference between the resistance at 0^oC and 100^oC is called the *Fundamental Interval* for the thermometer.

The temperature T_p as measured on the platinum resistance scale may be determined by measuring the resistance R_T at the required temperature when:-

$$T_p = \frac{R_T - R_0}{R_{100} - R_0}$$

Temperatures above 100^oC as measured on the platinum scale will be less than those given by the gas scale. In the range 0-630.5^oC, the resistance is best represented by the quadratic equation -

$$R_T = R_0(1 + AT + BT^2) \qquad \text{........(9)}$$ *(Considine, 1957)*

The value of the third unknown is determined by measuring the resistance of the platinum wire at the sulphur point (444.60^oC), in addition to the ice point and steam point.

The above relates mainly to resistance thermometry where the resistance of a small (relatively) element usually made of platinum, is measured and related to temperature using equations (7) and (9). In surveying practice, however, it is the resistance of the measuring tape that is measured. These measurements can then be treated as before for conversion to temperature.

The usual methods of measuring the tape resistance is to employ one of the following instruments:-

(i) A Wheatstone Bridge
(ii) A Kelvin Bridge
(iii) A Potentiometer

To introduce something of the theory behind each of these instruments we will look at them individually.

2.7.3 The Wheatstone Bridge.

The Wheatstone Bridge is perhaps the best known method of measuring the tape resistance. It is perhaps not the most accurate method of determining the resistance but has the advantage of simplicity.

Referring to figure 2.17, R_1, R_2, R_3, R_4, are connected to form a bridge network as shown. The points A and C are connected to a battery and key, while B and D are connected to a galvanometer. The values of the arms of the bridge are adjusted until no current flows through the galvanometer.

When this is so, the values of the currents and resistances are as shown, then:-

Potential at B = potential at D

i.e. potential drop in AB = potential drop in AD

$$i_1R_1 = i_2R_3 \qquad \text{.........(10)}$$

Also, potential drop in BC = potential drop in DC

$$i_1R_2 = i_2R_4 \qquad \text{.........(11)}$$

Dividing equation (10) by equation (11)

$$\frac{i_1R_1}{i_1R_2} = \frac{i_2R_3}{i_2R_4}\text{, or, } \frac{R_1}{R_2} = \frac{R_3}{R_4} \qquad \text{.........(12)}$$

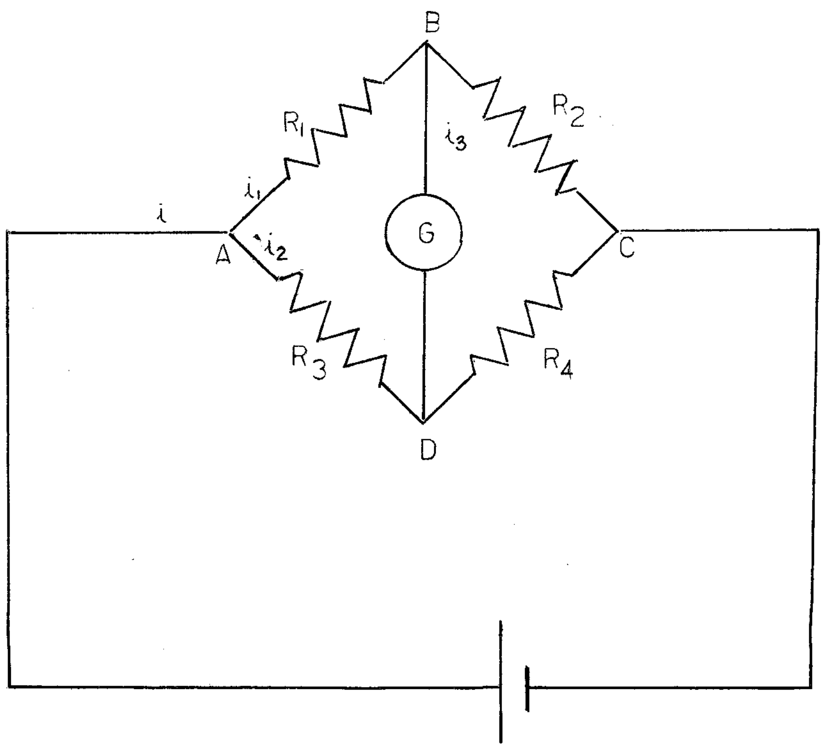


FIG 2·17

2.7.4 The Kelvin Bridge *(Johnson 1971)*

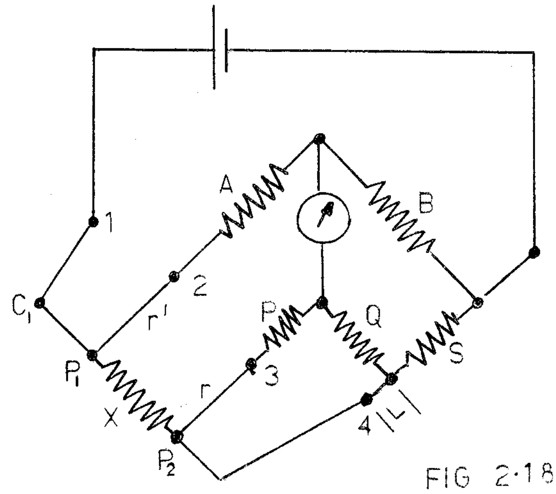


FIG 2·18 Johnson 1971

The exact condition for the balance of the bridge in Figure 2.18 is

$$X = \frac{A+r^1}{B} S + \frac{Q(L+l)}{(P+r+Q+L+l)} \left(\frac{A+r^1}{B} - \frac{P+r}{Q} \right) \qquad ....(13)$$

In many applications of the Kelvin bridge r, r^1 may be made sufficiently small to be ignored whilst A/B is made equal to P/Q (and usually also A=P, B=Q) so that equation (13) reduces to the standard Wheatstone bridge condition X=AS/B. For the use of the Kelvin bridge for surveying application the correction terms in (13) must be considered. The result of some algebraic manipulations of (13) is to give

$$X = \frac{A}{B} S \left[1 + \frac{r^1}{A} - \frac{Q(L+l)}{(P+r+Q+L+l)S} \left(\frac{r}{P} + \alpha + \beta - \frac{r^1}{A} \right) \right] \qquad ....(14)$$

where P = A(1±α), Q = B(1±β) and the worst combination of signs has been used in (14) and second order terms have been neglected.

If X is about 4 ohms corresponding to about 100 ft. of steel tape r,l could readily be made about 1 ohm whilst L,r^1 could be made less than 10 milliohms. Typical values for S, A, B, P, Q could be 10, 40, 100, 40, 100 ohms respectively. Inserting these values gives

$$X = \frac{A}{B} S\ (1-\theta) \qquad ....(15)$$

where θ = 3/1000 and where α,β have each been assumed to be 10^{-2}. Consequently, if the bridge is used without any corrections for the leads, an error of about 3/1000 would arise in the measurement of absolute resistance. However for temperature-rise measurements resistance change is important so that only changes in θ contribute to the error in the determination of temperature-rise. Specifically if the resistance of the tape is X_o at a reference temperature T_o and X_1 at a temperature T_1 then it may be shown that

$$\frac{X_1-X_o}{X_o} = \frac{A_1-A_o}{A_o} \; \frac{1-\frac{A_1\theta_1-A_o\theta_o}{A_1-A_o}}{1-\theta_o} \qquad \text{........(16)}$$

The departure from unity of the term inside the brackets is the fractional error in temperature-rise deduced from the uncorrected bridge readings. For a 10 °C temperature rise this departure from unity is less than $1/10^8$ for the values previously quoted, assuming a temperature coefficient of resistance of the leads of $4/10^3$ per °C.

<u>2.7.5 The Potentiometer</u> *(Resnick & Halliday 1960)*

The potentiometer is basically an instrument for measuring an unknown e.m.f. E_x. Referring to figure 2.19 the currents and e.m.f.'s are as shown. Applying the loop theorem to loop abcda yields

$$-E_x-ir+(i_o-i)R = 0 \qquad \text{..........(17)}$$ *(Resnick & Halliday)*

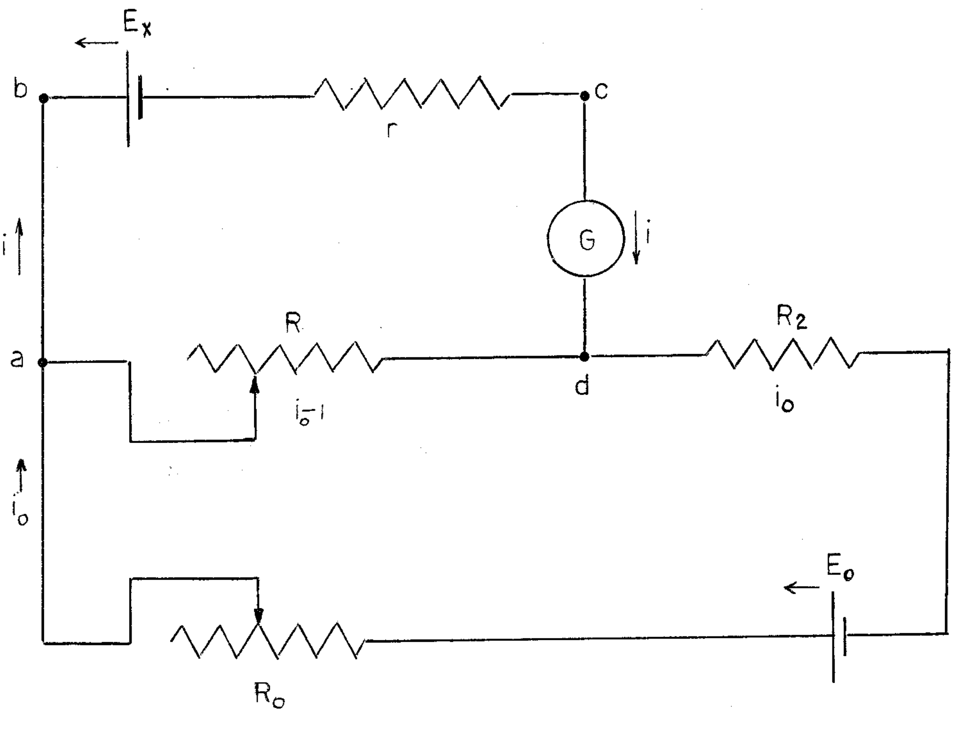


FIG 2·19 Resnick & Halliday p. 684

where $i_o - i$, by application of the junction theorem at a, is the current in resistor R. Solving for i yields

$$i = \frac{i_o R - E_x}{R + r} \qquad \text{..........(18)}$$

in which R is a variable resistor. This relation shows that if R is adjusted to have the value R_x where

$$i_o R_x = E_x, \qquad \text{..........(19)}$$

the current i in the branch abcd becomes zero. To balance the potentiometer in this way, R must be adjusted manually until the sensitive meter G reads zero.

The e.m.f. can be obtained from Eq. (19) if the current i is known. However, it is standard practice to replace E_x by a known standard e.m.f. E_s, and once again to adjust R to the zero-current condition. This yields, assuming the current i_o remains unchanged,

$$i_o R_s = E_s \qquad \text{..........(20)}$$

Combining the last two equations yields

$$E_x = E_s \frac{R_x}{R_s} \qquad \text{..........(21)}$$

(Resnick & Halliday)

which allows us to compare e.m.f.'s with precision. Note that the internal resistance r of the e.m.f. plays no role. In practice, potentiometers are conveniently packaged units, containing a standard cell which, after calibration at the National Bureau of Standards or elsewhere, serves as a convenient known standard seat of e.m.f. E_s. Switching arranging for replacing the unknown e.m.f. by the standard and arrangements for ascertaining that the current i_o remains constant are also incorporated.

C H A P T E R   3

A brief description of the thermocouple, thermistor and wheatstone bridge units.

3.1 General

As part of the aim of the project was to investigate means of temperature measurement of the tape, a thermocouple thermometer and a thermistor thermometer were acquired.

The background theory to the thermocouple and thermistor have been given in some detail in Chapter 2 .

This has not been the first application of thermocouples and thermistors to surveying. *Major Richards (1967)* used thermistors for remote temperature measurement in E.D.M. *Professor Angus-Leppan (1962, 1964, 1968)* also used the thermistor in determining the temperature gradient in his refraction studies. *Postnikov and Gushchin (1964)* applied thermistors to measurement of tape temperatures in 1964. The thermocouple has had a smaller application, however *Brown (1968)* used thermocouples for a similar purpose as *Angus Leppan.*

The particular instruments used in the project do not represent the best available for this particular application and for future work better instruments would need to be acquired.

As well as the thermocouple and thermistor units a Wheatstone bridge was used as a field standard. The particular bridge used was made up from borrowed components and again for future work a more satisfactory bridge preferably a Kelvin bridge would need to be obtained.

The notes below on each of the instruments set out only the basic facts of each instrument. Further comments on their usage will be given in chapters 6, 7 & 8.

3.2 The Comark Type 160C Thermocouple Thermometer

Figure (3.1) shows the Comark Type 160C thermocouple thermometer together with a Type 163 selector unit which allows ten thermocouples to be monitored by the one meter unit. Figure (3.2) shows the thermocouple attached to the tape by means of solder.

The reference junction of this particular thermocouple unit is subjected to ambient conditions. For accurate work it is necessary to ensure that the meter unit together with the reference junctions are maintained under stable conditions. A control is provided in order to set the ambient temperature into the meter unit. This must be periodically checked together with the ambient temperature itself which is determined by thermometer. It was found with use, that as long as the conditions remained stable, little adjustment was required. More recent versions of this instrument have an inbuilt automatic reference junction compensation device. This eliminates the necessity to set and subsequently re-check the ambient temperature.

The instrument reads out directly in temperature units. To facilitate a wide usage however a number of ranges are provided, viz.

0-30°C
0-100°C
0-300°C
0-1000°C

As well as the above facilities the instrument has the ability to use several different metal combinations of thermocouple. The particular combination used for this project being Chromel-Alumel which together with Copper-Constantin represents the best combinations for this type of work in this temperature range.

Figure (3.3) shows the unit in an insulating box with remote control for the selector switch.

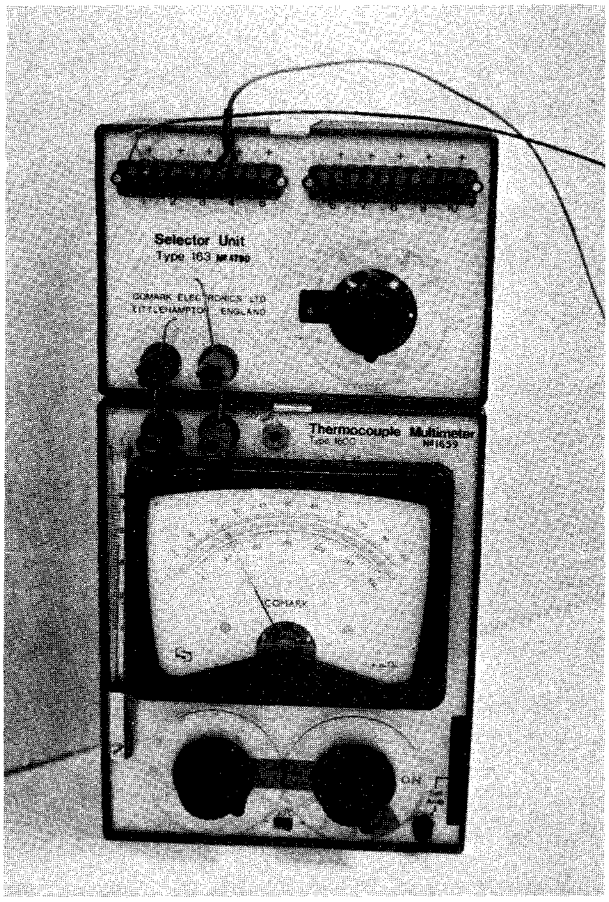


FIG. 3·1

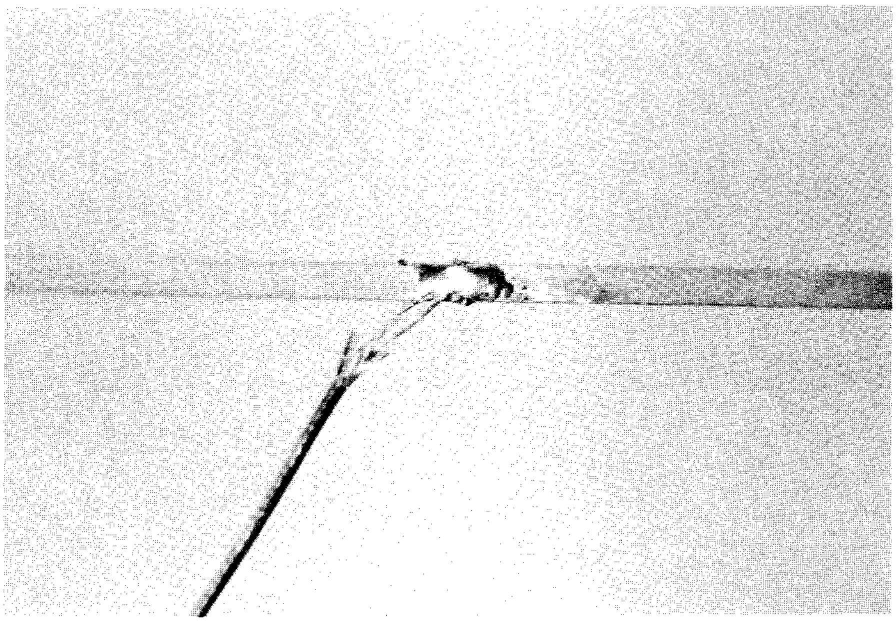


FIG. 3·2

3.3. The Thermistor Unit

Unlike the thermocouple unit which was a standard unit, the thermistor unit was built in the university workshops. Using as a basic a design given for a similar type of unit *(Horsfield & Watson 1968)* the unit was built to serve the particular needs.

Six thermistors can be monitored by the one meter.

Figure 3.4 shows the main features of the unit. The six plugs aonlg the top of the instrument facilitate the use of six thermistors, a particular thermistor being selected by the selector switch. The lead to the thermistor element is ordinary "figure of eight" copper lead and may be of any reasonable length.

The parameters governing the behaviour of each thermistor vary from one thermistor to another and hence each thermistor must be calibrated individually. Facility is made for this by means of two calibration settings on the main switch (see Figure 3.4). The instrument has two ranges each covering 20^{o}C. The first being from 10^{o}C to 30^{o}C and the second from 30^{o}C to 50^{o}C. The range being selected by means of the main switch.

The meter scale is divided into twenty but is labelled only from 0 to 10. Care should therefore be exercised when reading the instrument.

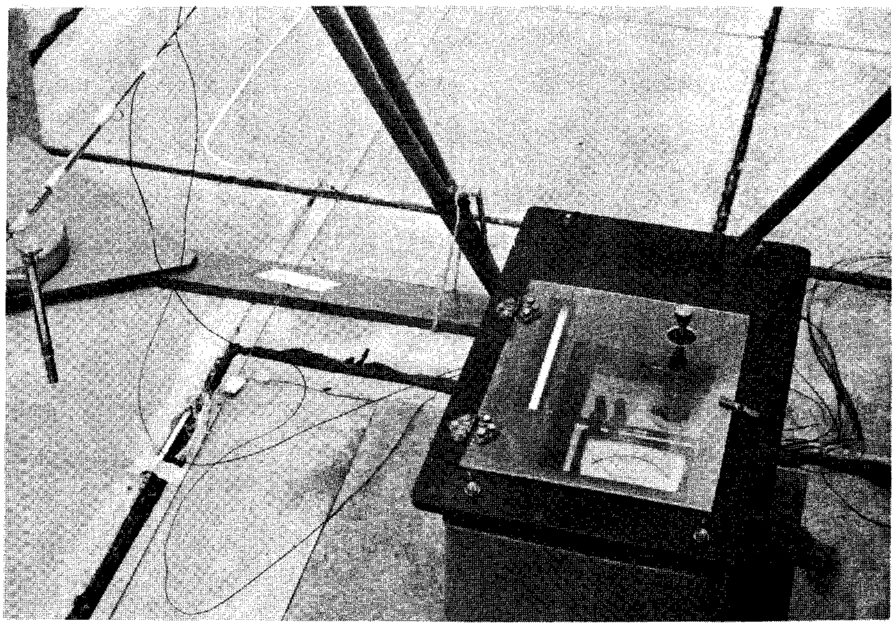


FIG. 3·3

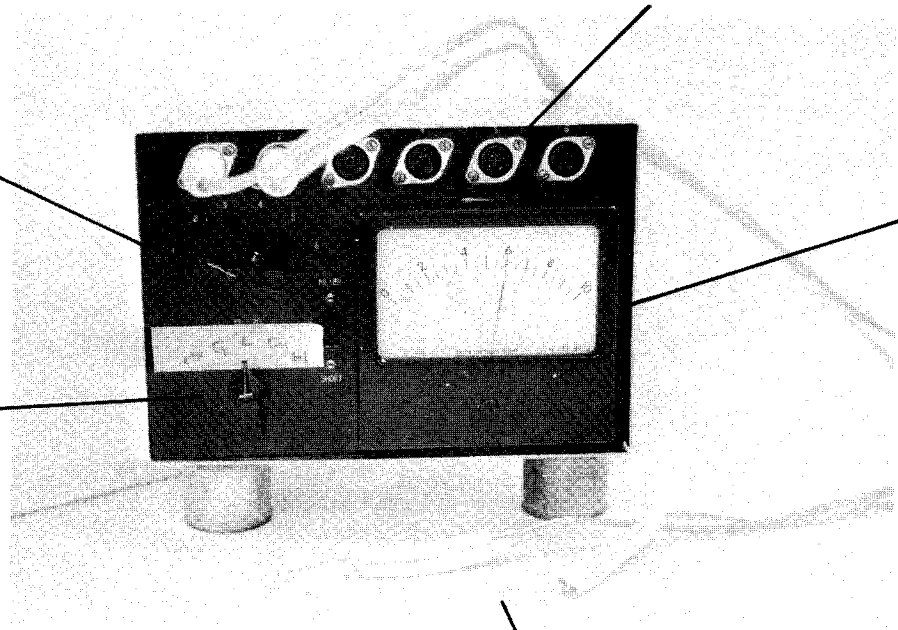

plugs
selector switch
meter °C
main switch
thermistor element

FIG. 3·4

Figure 3.5 shows the thermistor element. It is a miniature NTC thermistor (code No. 232263411332). The element is essentially a small bead semiconductor approximately 1 mm. in diameter enclosed in a glass sheath.

Figure 3.6 shows a commercially made electronic thermometer employing a thermistor as the sensing element. It is essentially the same as described above. It has one element held in a brass sheath.

Full details of the design of the thermistor thermometer together with the temperature characteristics of the thermistor element are given in Appendix A.

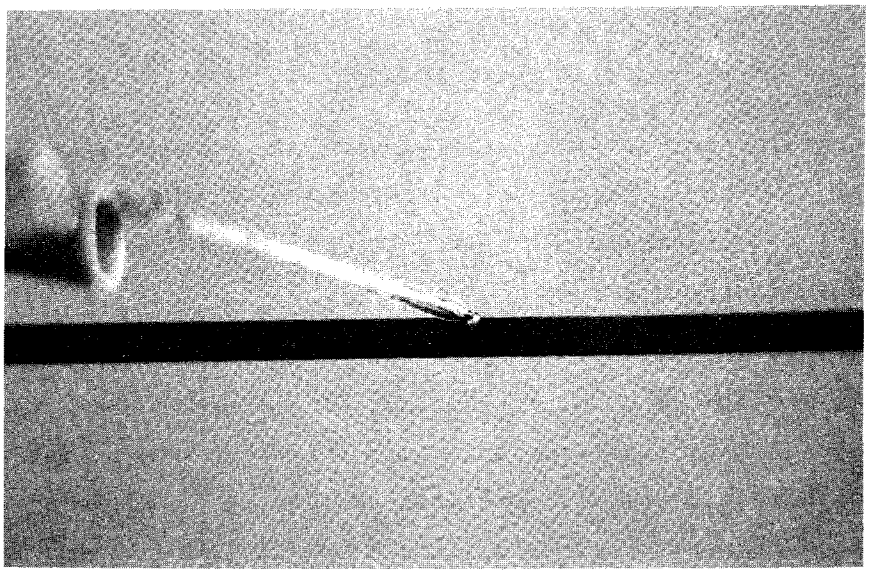


FIG. 3·5

FIG. 3·6

3.4 THE WHEATSTONE BRIDGE

3.4.1 General

As long ago as 1891 G. A. Campbell, of the Massachusetts Institute of Technology, *(Clark & Johnson 1951)*, suggested and discussed a method of determining the expansion of a steel tape by measurement of its electrical resistance.

In 1923-24 investigations were initiated at the National Physics Laboratory in England by S. W. Attwell *(Clark & Johnson 1951)* to see if it were possible to standardise and use surveying steel tapes by reference to their electrical resistance instead of in terms of their estimated temperatures. The circuit used by Attwell was adopted for the purposes of this project.

3.4.2 The Circuit

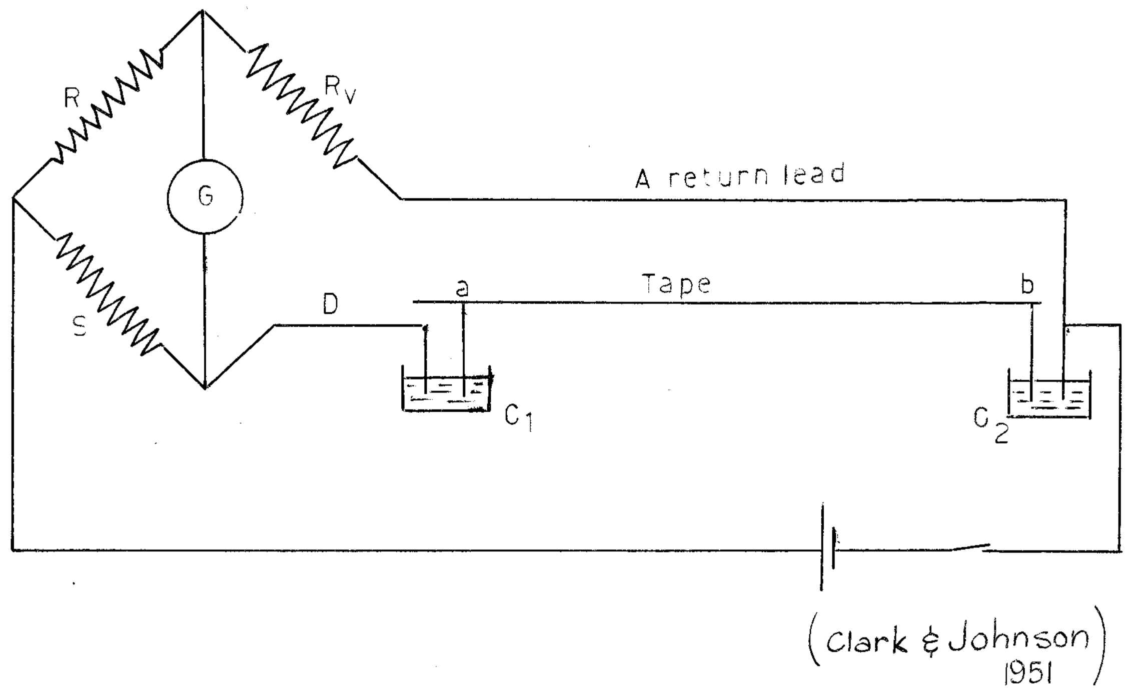


FIG. 3·7

The circuit shown in Figure 3.7 involves the use of a return lead of copper of known resistance A to connect the remote end of the tape to the variable resistance of the bridge. The battery leads also had to extend to the remote end of the tape, and a short length of copper wire of known resistance D connected the near end of the tape to complete the bridge circuit. Attwell made the connections to the tape by means of short lengths of copper wire of negligible resistance dipping into cups C_1 and C_2.

When the bridge was balanced the resistance of the tape between the clamps is given by

$$(R_v+A)S/R-D \qquad \ldots\ldots\ldots\ldots(22)$$

(Clark & Johnson 1951)

Where S was a standard resistance made from manganin of .125 ohm resistance. R was a constant resistance of 1000 ohms whilst the variable resistance R_v was read using a decade box with five dials ranging up to 100,000 ohms. The point of balance of the bridge was determined using a sensitive spot galvanometer.

Figure 3.8 shows the components assembled for use. A two volt power supply was provided by using one cell of a larger voltage battery. A reversal switch was also incorporated into the circuit. The reversal of current usually resulted in a small variation in resistance reading and it was the practice to read in both directions and to take the mean.

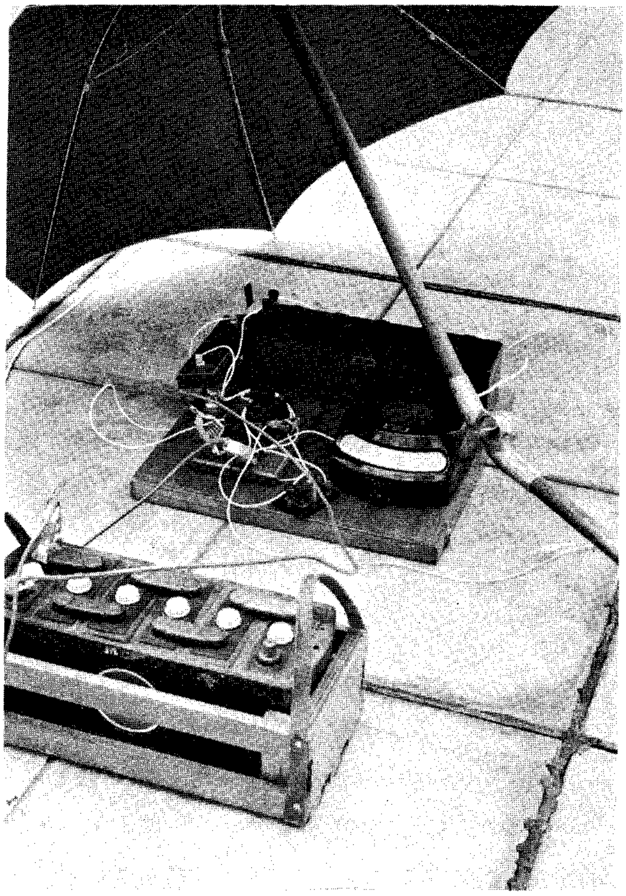


FIG. 3·8

CHAPTER 4

*A Short Resume on Microclimatology.**

4.1 General

As most measurements made with a steel or invar tape are made either on the ground surface or within the first few metres of the atmosphere above the ground surface, some knowledge of the factors affecting the climate of this region is important.

As much has been written on the climate extending to approximately 100 m above ground level, it is necessary to limit this chapter to a short statement of the important factors involved.

To gain a proper knowledge of the factors affecting the microclimate a detailed knowledge of the motion of air near a solid or liquid boundary of variable shape and changing temperature is required. A knowledge of heat transfer and diffusion is necessary in order to understand the heating affects in the regions from radiation.

Of most interest to the surveyor however, is the temperature structure of the region.

* *Geiger* *1965*
Sutton *1953*

4.2 THE HEAT BUDGET OF THE EARTH'S SURFACE

Radiation drives the atmospheric circulation, the only means of exchange of energy between the earth and the rest of the univers.

Heat can be transferred in the atmosphere in four different ways.

(i) Conduction.

(ii) Convection.

(iii) Change of state.

(iv) Radiation.

Conduction is a well known phenomena as is convection. Convection involves mass exchange and is characteristic of both liquids and gases, being almost always present under atmospheric conditions. Convection plays a much greater part in minimizing temperature differences than does true heat conduction.

Evaporating water extracts about 580 cal. of heat from the earth's surface for every gram released as vapour. This heat becomes available to the air when the water vapour condenses in the upper atmosphere to form clouds. In this case heat is transported by means of the change of state of the water.

Thermal radiation in contrast to conduction, convection, and change of state, does not require any material carrier, as is shown by the way solar radiation spreads through space. Thermal radiation is electromagnetic radiation in the range of wavelengths from 0.2 to 100μ.

The earth's atmosphere reflects, scatters, and absorbs part of the solar radiation. Solar radiation which has not been weakened by these processes is termed extra-terrestrial radiation.

It varies by about 7% with the changing distance of the earth from the sun during the course of the year. For a mean earth-sun distance of 150 x 10^6 km., the intensity of solar radiation, according to the best available observation, is 2.00 (±2%) calories per square centimetre per minute ($cal(cm^2)^{-1}min^{-1}$) when incident to a surface perpendicular to the direction of the rays.

4.2.1 Elements of the Heat Economy

Radiation "S" is the major factor of heat exchange. Heat arrives at the earth's surface from the sun, the sky, and the atmosphere (insolation). Heat is sent back into space (outgoing or terrestrial radiation).

The second factor affecting heat economy, "B", is the flow of heat beneath the surface of the earth. This heat flow may be either upwards or downwards depending upon the conditions.

Thirdly, the air above the ground plays a part in the exchange of heat - "L". This factor also may be positive or negative as it depends not only on conduction of heat but also on mass exchange due to the great mobility of the air.

Finally there is the effect of evaporation 'V'. The quantity of heat in calories required to evaporate 1 gm. of water is called the latent heat of vaporization r_W and varies with temperature.

According to the law of conservation of energy the following equation must be satisfied.

$$S+B+L+V = 0. \qquad \text{..........(1)}$$

This therefore is a fundamental equation containing the basic factors, but however it rèlates only to the simple ideal state.

4.2.2 Radiation Balance at the Earth's Surface

Of all the factors mentioned in 4.2.1 taking part in the heat exchange at the surface of the earth, radiation is the most important.

If insolation is greater than outgoing radiation the balance is positive, if it is less, the balance is negative.

The radiation balance consists of two radiation streams of different spectral ranges. Radiation reaching the surface of the earth consists of that part of direct solar radiation 'I' that is not reflected by clouds, absorbed by the atmosphere, or scattered diffusely, and also that part of non directional sky radiation'H' that represents diffusely scattered radiation that has reached the ground. Part of this radiation is reflected by the earth's surface.

This short wave-length reflected radiation'R' depends on the nature of the ground. The reflection factor or albedo is the ratio of the reflected to the incident radiation, usually expressed as a percentage.

Long wave-length radiation'G' is also of significance in the radiation balance of the earth's surface. The atmosphere of the earth contains water vapour, carbon dioxide, and ozone, all of which absorb radiation and emit it according to Kirchhoff's law. This long wave-length radiation is termed counter-radiation since it counteracts the terrestrial radiation loss.

It has been shown by experiment in relation to long wave-length radiation that the earth radiates like a black body with an equivalent temperature between the shelter temperature and the grass minimum. An albedo of between 0% - 8% has been recorded in the 10μ region, only light sand gave as much as 11%.

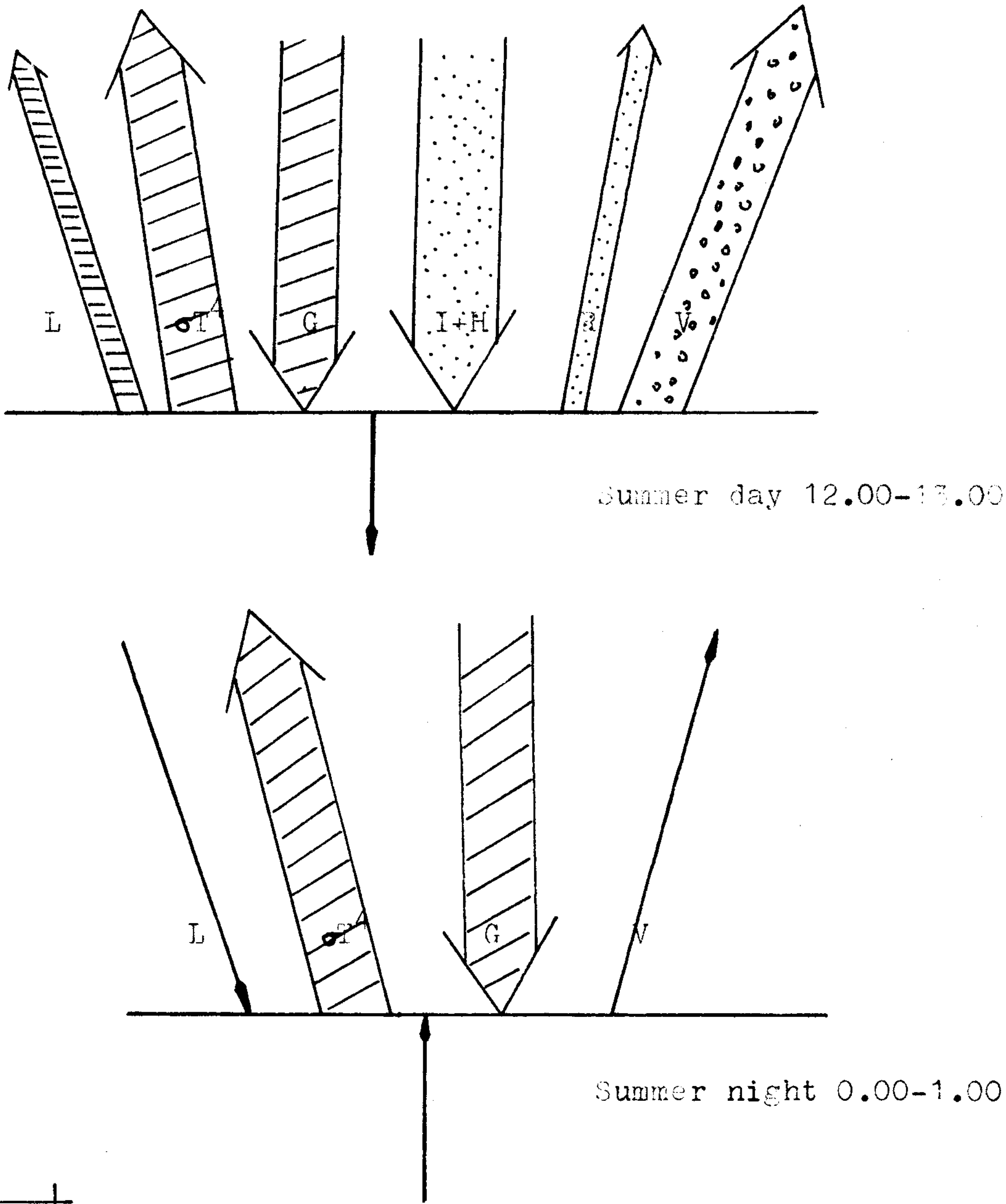
According to the Stefan-Boltzmann law the radiation emitted by the soil surface by day and by night would be exactly σT^4 (T is the surface temperature) if the ground were a black body. The results in the previous paragraph show that this condition is largely fulfilled.

The radiation balance S is therefore given by the equation

$$S = I+H+G-\sigma T^4-R \qquad \text{..........(2)}$$

The last two factors depend on the nature of the ground surface, while the first three are independent of it.

Figure 4.1 shows the magnitude of these factors from 12.00^h to 13.00^h on a summer day in Germany.



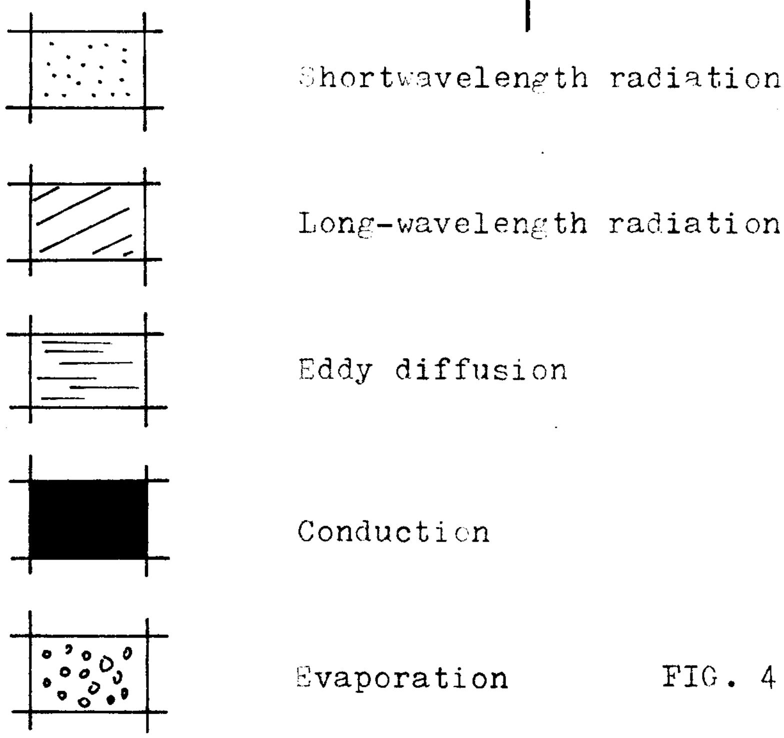


FIG. 4.1 (Geiger p.14)

It is clear from Figure 4.1 how important radiation is in the total heat budget. Short - wavelength radiation is intense, but of short duration.

Stefan-Boltzmann radiation lasts the whole 24 hr. and, since it is largely compensated for by counter-radiation, the balance is small. At night, however, the heat balance is completely dominated by long - wavelength radiation.

Looking once more at the reflection of radiation from natural surfaces, a distinction is made between diffuse and regular reflection. Reflection is described as diffuse when the incident rays are reflected in all directions, without preference for one particular direction. This is the type of reflection that normally occurs at rough surfaces found in nature. Table 4-1 gives the albedos for diffuse reflection for the total range of solar radiation. This table is not complete.

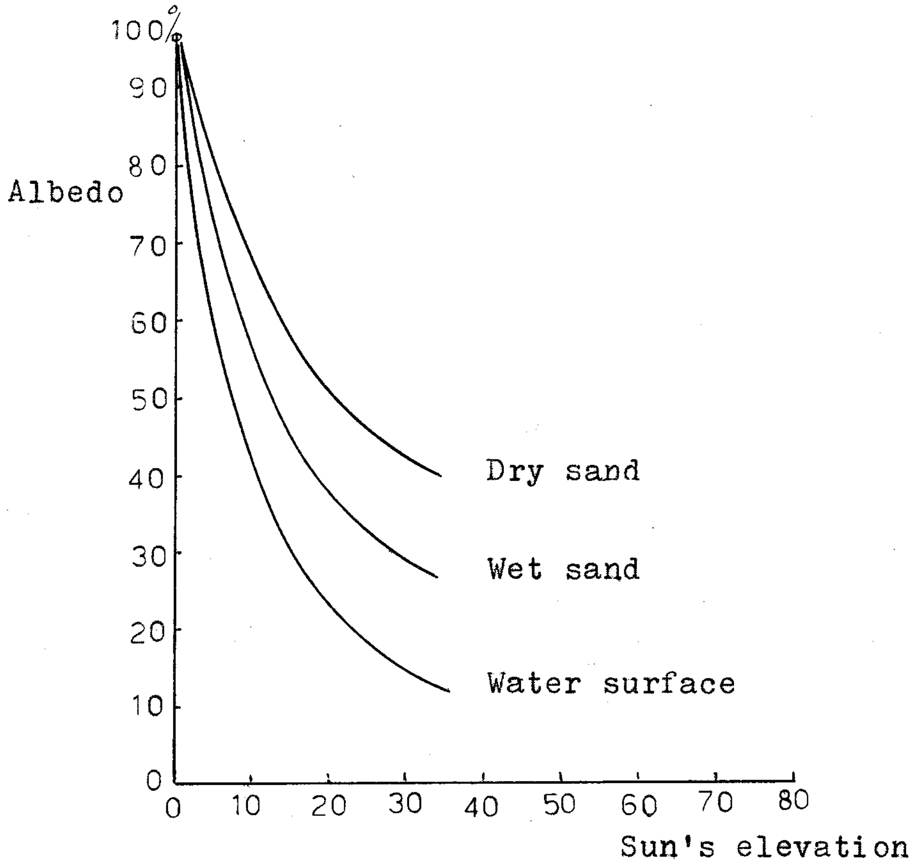
TABLE 4-1

Albedo - for total solar radiation, with diffuse reflection.

Fresh snow cover	75 - 95 %
Dense cloud cover	60 - 90
Old snow cover	40 - 70
Clear firm snow	50 - 65
Light sand dunes	30 - 60
Sandy soil	15 - 40
Meadows of fields	12 - 30
Densely built-up areas	15 - 25
Woods	5 - 20
Dark cultivated soil	7 - 10
Water - Sea	3 - 10

(Geiger Page 15)

Albedo is influenced not only by the nature of a surface, but by its moisture content at any given time. As the water content increases the albedo decreases. Albedo is also a factor of the sun's elevation.



(Geiger p.17)

FIG. 4.2

Figure 4.2 shows the relation between albedo and the elevation of the sun for the range of the solar spectrum. From the zenith to an elevation of 40° there is little change from the values given in Table 4.1. The albedo then increases sharply.

4.2.3 Effects of Topography on outgoing radiation

This discussion is based on measurements taken by *P. Dubois* for the effective outgoing radiation for different angles of elevation. Table 4.2 shows Dubois' measurements.

TABLE 4-2

Angle of Elevation	90	80	70	60	50	40	30	20	10	0
Outgoing Elevation S_L (Relative value)	100	100	98	96	93	89	81	69	51	0

(Geiger Page 23)

Dubois' measurements made it possible for *Lauscher* to determine effective radiation for a number of different types of topography. The results are based on the value of a 5.4 mm Hg. water vapor pressure.

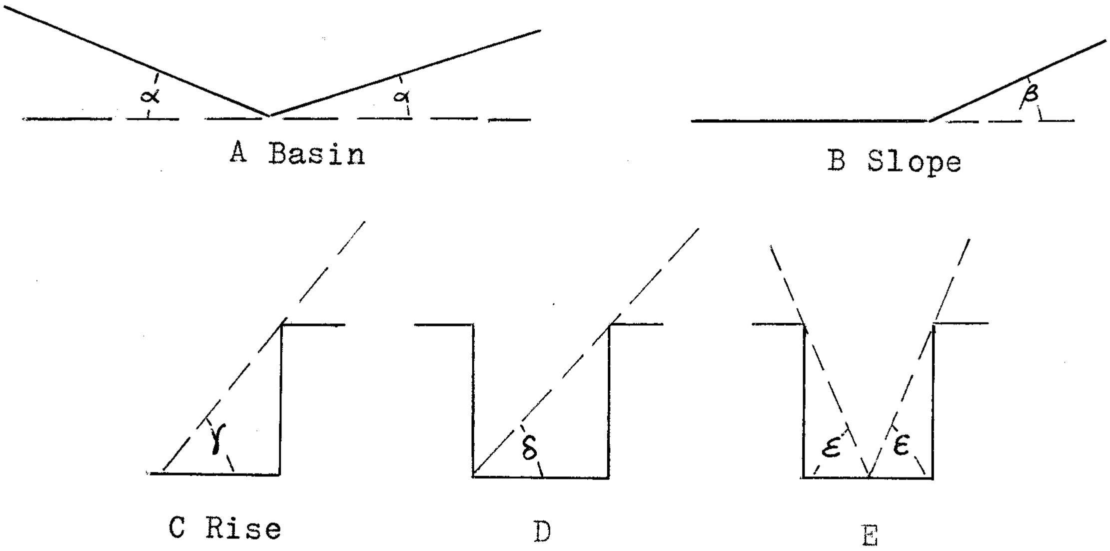


FIG. 4.3 *(Geiger Page 24)*

TABLE 4-3

Angle	(°)		0	5	10	15	20	30	45	60	75	90
Basin	(α)	A	1000	996	982	955	915	793	549	282	79	0
Slope	(β)	B	1000	996	986	970	951	900	796	667	528	396
Rise	(γ)	C	1000	997	992	988	979	951	877	772	639	500
Surface of street.												
	(δ)	D	1000	930	862	797	737	622	452	296	143	0
Middle of street.												
	(ε)	E	1000	993	984	976	958	902	754	544	279	0

(Geiger Page 24)

Figure 4.3 A

When the horizon surrounding a place is uniformly obscured up to an angle α as in a hollow in the ground, in the middle of a circular clearing in a wood, the feature is termed a basin. The figures in row A of Table 4.3 give the effective outgoing radiation in parts per thousand of the unobstructed radiation that would be emitted by a level plane, for various angles of shielding. It may be seen that an angle of shielding of about 20° which is quite noticeable on the ground, does not reduce the radiation by as much as 9%.

Figure 4.3 B

If a plane surface is tilted at an angle β from the horizontal, the effective outgoing radiation is reduced since no measurable quantity of radiation is directed below the horizon. The decrease is negligible for small angles of tilt, and does not reach 10% even with the steepest hill pastures.

Figure 4.3 C

In the vicinity of a sharp rise in the ground, such as a rock face, a man-made wall, or hedge, the effective radiation will be reduced on approaching the wall by an amount depending on the angle γ. At the foot of the wall, or at the edge of a stand of timber, radiation is 50% of that in open country, since half the sky is shielded.

Figure 4.3 D

It is useful to consider a theoretical street, infinite in length, with rows of houses of equal height on either side. This model is useful for town planning, for woodland clearing. Line D in table 4.3 gives the relative values for radiation from horizontal ground as a function of the angle δ. Outgoing radiation is 45% of that in the open country.

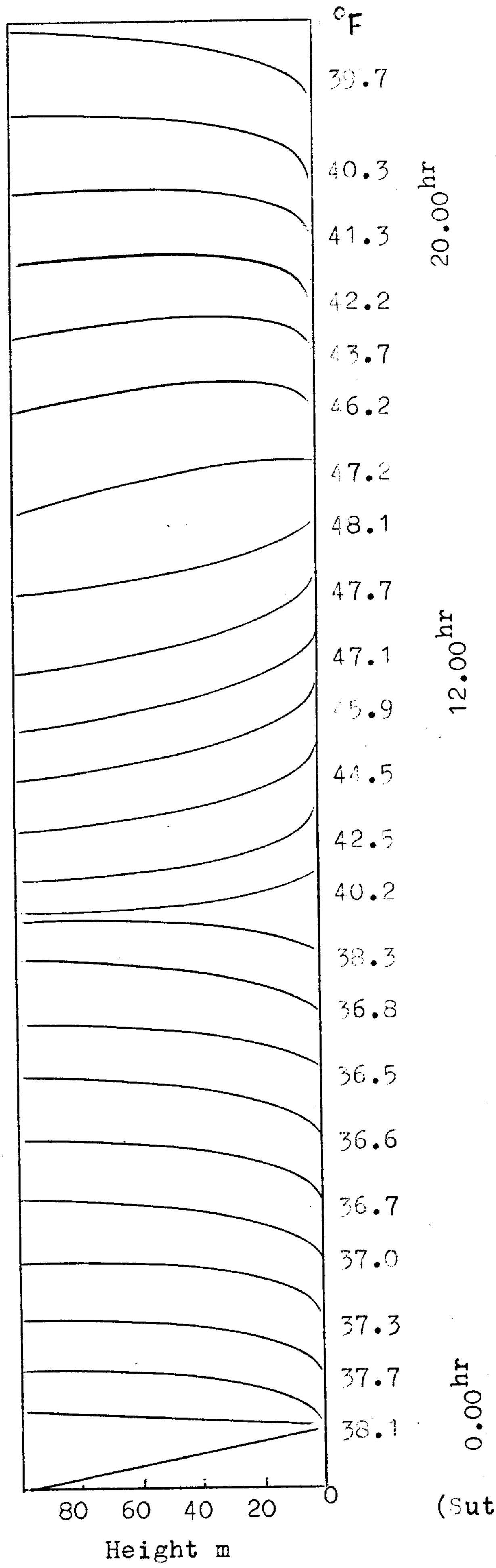
Figure 4.3 E

Outgoing radiation varies with position in the street. Areas near the houses have more protection, and emission is at a maximum in the middle of the street.

4.3 THE TEMPERATURE FIELD IN THE LOWEST LAYERS OF THE ATMOSPHERE

4.3.1 General Features *(Sutton 1953)*

The diurnal variation of temperature in the lowest layers of the atmosphere is a common place feature of daily life. In clear weather the temperature profile in the first hundred metres also exhibits a marked diurnal variation whose character is best revealed by an examination of the gradient of temperature in the vertical, dT/dz. During the hours of daylight, from shortly after dawn to about an hour before sunset, temperature decreases with height, rapidly in the lowest layers and more slowly at the greater heights. At night, temperature increases with height, the gradient again being greatest in the lowest layers. The clear weather oscillation of the temperature profile is clearly shown in a chart in *Sutton Page 121*, repeated in Figure 4.3 , which refers to conditions over undulating pasture land in England in spring between heights 1.2 m and 87.7m. There is one brief period (0800 to 0900) when the layer is approximately isothermal, and a similar period (1500^h to 1600^h) of small temperature gradient. Curvature of the profile is most pronounced in the lowest layers and it is clear that between these heights, at least, the average gradient is numerically greater than the adiabatic lapse rate.



(Sutton p.191)

FIG. 4.5

In overcast conditions, the diurnal variation of the temperature profile almost entirely disappears, the gradient being small at all heights.

It is important to note however the topography and ground surface have a marked affect on the temperature gradient. It was found in England that over chalky soil the gradient was significantly greater than shown in Figure 4.3. In general, daytime values of the temperature gradient in tropical countries are considerably in excess of the summer gradients in temperate climates. In hilly country or in thickly wooded area, the temperature profile are often very irregular because of shielding from insolation.

In clear weather, the mean gradient of temperature in the lower layers increases rapidly during the early part of the morning but remains fairly stable for the hours around midday. In the afternoon the gradient declines in magnitude, becoming zero some time before sunset. On completely overcast , windy days both the temperature and temperature-gradient records are very steady.

4.3.2 Surface Conditions

Any study of the temperature field of the atmosphere immediately adjacent to the ground must necessarily consider conditions of the ground surface itself.

The density of the material forming the surface of the earth varies considerably with locality and with the state of the soil (e.g. whether wet or dry, undisturbed or freshly dug).

The specific heat of soil is likewise very variable. *Wedmore (1941)* gives values ranging from 0.8 for clay to 0.27 for sandy loam.

On general physical grounds, the Conductivity of soil must be variable and, in particular, very dependent on water content. The average thermometric conductivities of most soils lie between 10^{-2} and 10^{-3} cm^2sec^{-1}. This being so it can be seen that the thermometric conductivity of soil is small, being much less than that of air (0.2 cm^2sec^{-1}). It therefore follows that the effect of air temperature will be well in evidence on the surface but will rapidly extinguish with depth.

A well-known example of extremely large gradients is given by *Sinclair (1922)* for the desert soil at Tucson, Arizona (ϕ=+32^{o} approximately).

On June 21 of an unnamed year the maximum and minimum temperatures were as shown in Table 4.4.

The temperature of the true surface can only be conjectured, its maximum must have been in excess of +71.5 C.

TABLE 4.4

Depth below surface (cm)	Maximum Temperature	Time of Maximum	Minimum Temperature	Time of Minimum
(cm)	C		C	
0.4	+71.5	1300	15.0	0400
2	+62.1	1400	22.0	0500
4	+48.1	1530	23.5	0530
7	+44.1	1630	25.2	0600

(Sutton Page 195)

The Tuscon data furnishes an extreme example of large changes of temperature which are a normal feature of conditions very near the surface of the earth.

4.3.3 Surface Temperatures

It is difficult to define the "surface" of the earth for the purpose of temperature investigations, except when vegetation is absent.

Various methods are employed to measure the surface temperature. Some **investigators** place the thermometer with half the element in the soil and half in the air, others use a thermocouple attached to a piece of metal which they move from point to point.

The nature of the material forming the surface layers exercises a marked influence in the temperature of the surface. *Johnson and Davies (1927)* investigated temperatures in layers 15 cm. deep of (1) tar-Macadam; (2) bare earth; (3) grass-covered soil; (4) sand; (5) rubble and (6) bare clay.

They found, for conditions in Southern England, the highest temperatures were reached in Tar-macadam, whose surface was estimated to attain 60°C (140°F) on the hottest days. The corresponding maximum for sand was 55°C (130°F) and for grass-covered surfaces 44°C (111°F). *(Sutton Page 196)*

The time of the maximum surface temperatures from several sources of investigation appears to be approximately 1 hour after the local mid-day.

Some readings taken by *Jackson (1935)* to determine the variety of temperatures which could be simultaneously read in different positions gave the results shown in Table 4.5.

TABLE 4.5

	°F
On damp grass in shade	74
On damp gravel in shade	75
Air temperature in shade	81
8" above damp gravel in sun	97
8" above dry grass in sun	98
On damp gravel in sun	102
On damp grass in sun	105
On warm cement in sun	109
On dry grass in sun	115

(Jackson 1935)

CHAPTER 5

CALIBRATION OF INSTRUMENTS PART I

5.1 General

The calibration of the various temperature measuring devices was conducted using simple techniques. However it was felt that these techniques were sufficient for the purposes. The basic piece of equipment for the calibration tests was a mercury-in-glass thermometer divided to 0.1^{o}C, accurately calibrated by the manufacturer. (See Table 5.1)

5.2 Calibration of Thermometers

The results of all calibration tests will not be given. However the results of the calibration of the thermometers shown in Figure 6.1 are given.

5.2.1 Method

The method employed in the calibration was to place all the thermometers into a fluid bath at approximately 20^{o}C and to raise the temperature in steps to approximately 50^{o}C each time reading the thermometers, including the standard, simultaneously.

5.2.2 Results

The results of the calibration tests are shown in Figure 5.2 where the ordinate gives the correction to be applied to the thermometer reading in order to obtain the true reading.

5.3 CALIBRATION OF THERMOCOUPLES

5.3.1 Method

The calibration of the thermocouples was performed in a similar manner to that adopted for the thermometers. The thermocouples were dipped in a water bath, the temperature of which was raised in steps.

5.3.2 Results

Results of an early calibration test are shown in Figure 5.3(a) and 5.3(b) giving the results for eight thermocouples. Again the ordinate gives the correction to be applied in order to obtain the true reading.

Results of a later calibration are shown in Figures 5.4(a) and 5.4(b).

5.4 CALIBRATION OF THERMISTORS

5.4.1 General

It is difficult to discuss the calibration of thermistors in the same way as the other devices. There are far more components of the thermistor meter which may affect the temperature reading. Several of these components have to be set each time a thermistor is used and hence the setting itself may contribute to an error in temperature.

Figure 5.5 gives the results of a calibration test of the thermistor unit shown in Figure 3.6. However the settings on this instrument are prone to variation and hence the calibration test serves only to give an idea of the accuracy that can be obtained with the instrument.

Calibration of the thermistor unit shown in Figure 3.4 is a much more difficult task as individual settings have to be made each time a particular thermistor is used. It was found to be simpler to prepare a chart similar to that shown in Figure 5.6 where the instrument reading is plotted against the true reading determined using a water bath and thermometer. In this case the same setting can be maintained for all thermistors and a separate chart drawn up for each one. For accurate work it would be necessary to draw up such a chart at frequent intervals.

TABLE 5.1

REPORT ON THERMOMETER

Name on Thermometer: Dobros

Range: -5 to 50°C

Limit of Accuracy: ± 0.05 deg C

Type: Mercury in glass.

Thermometer No.: 06642

Division: 0.1°C

Immersion: TOTAL

Result of Test

Thermometer Reading	Correction to Reading	True Temperature	Average Stem Temperature
0°C	+0.02°C	+0.02°C	-
10°	-0.01	9.99	
20°	+0.04	20.04	
30°	+0.01	30.01	
40°	+0.04	40.04	
50°	+0.01	50.01	

Date: 9.12.68

Report No.: 13647/B.2592.

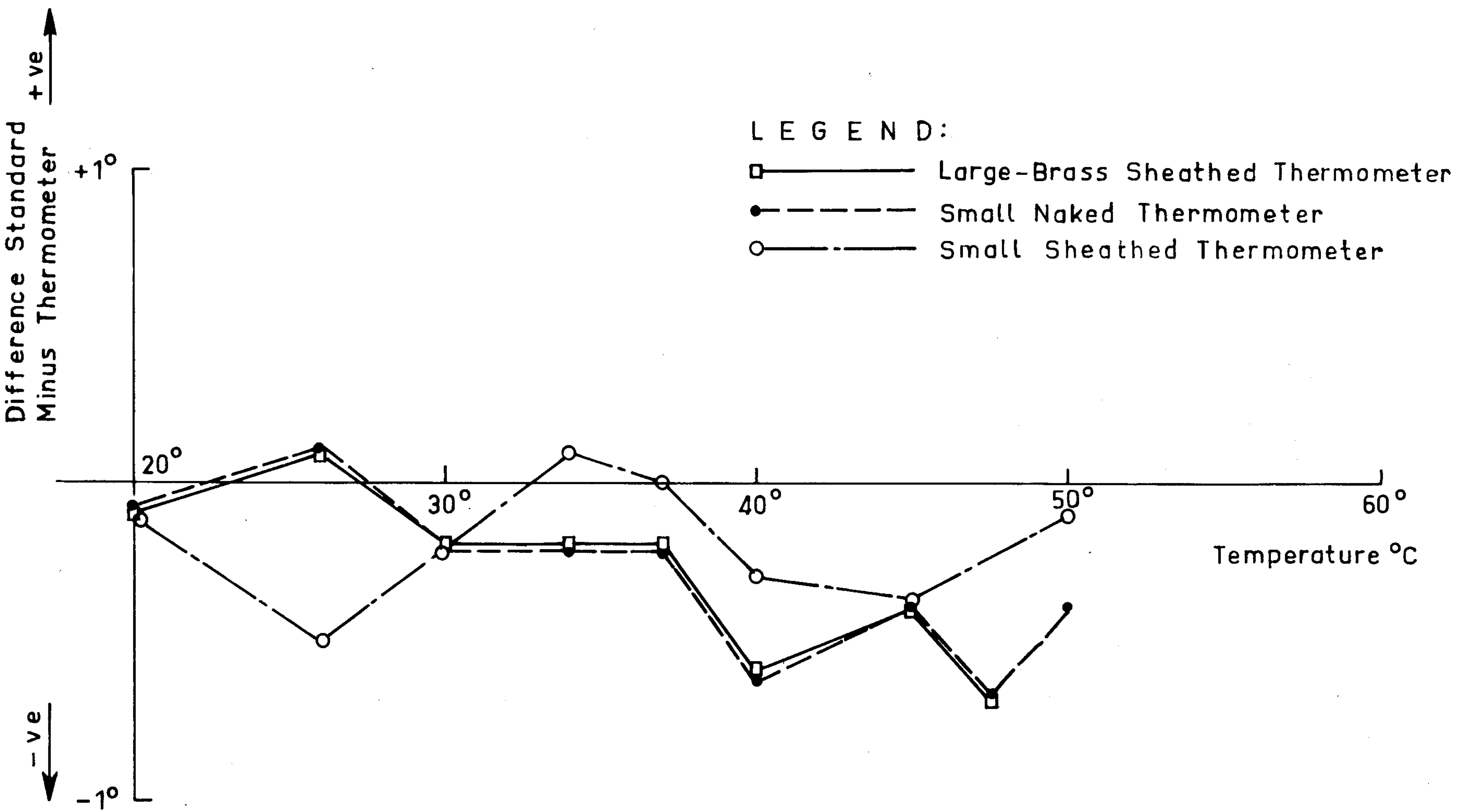


FIG. 5·2: GRAPH GIVES CORRECTION TO RESPECTIVE THERMOMETER READING TO GIVE TRUE TEMPERATURE.

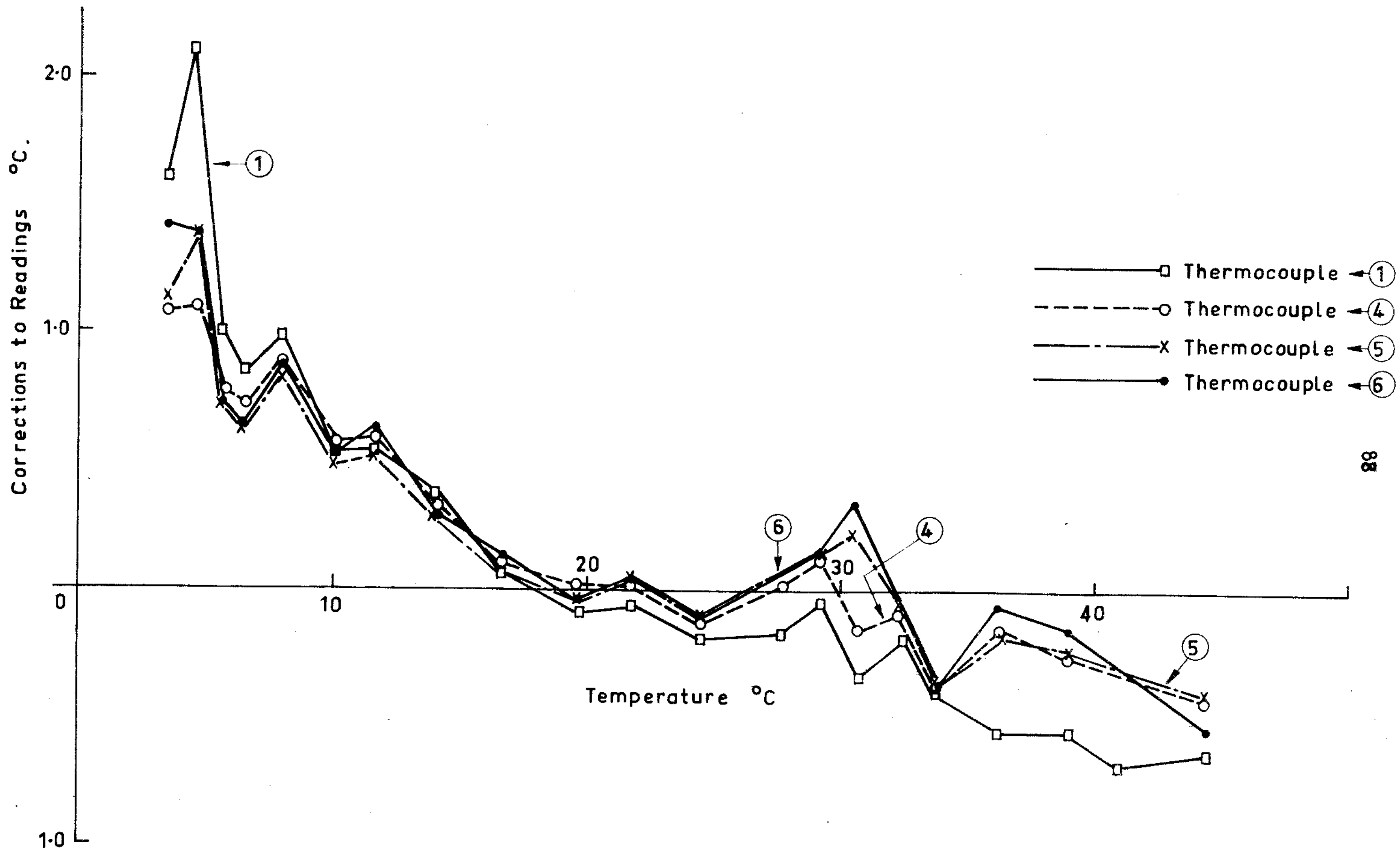


FIG. 5·3 (a): CALIBRATION OF THERMOCOUPLES.

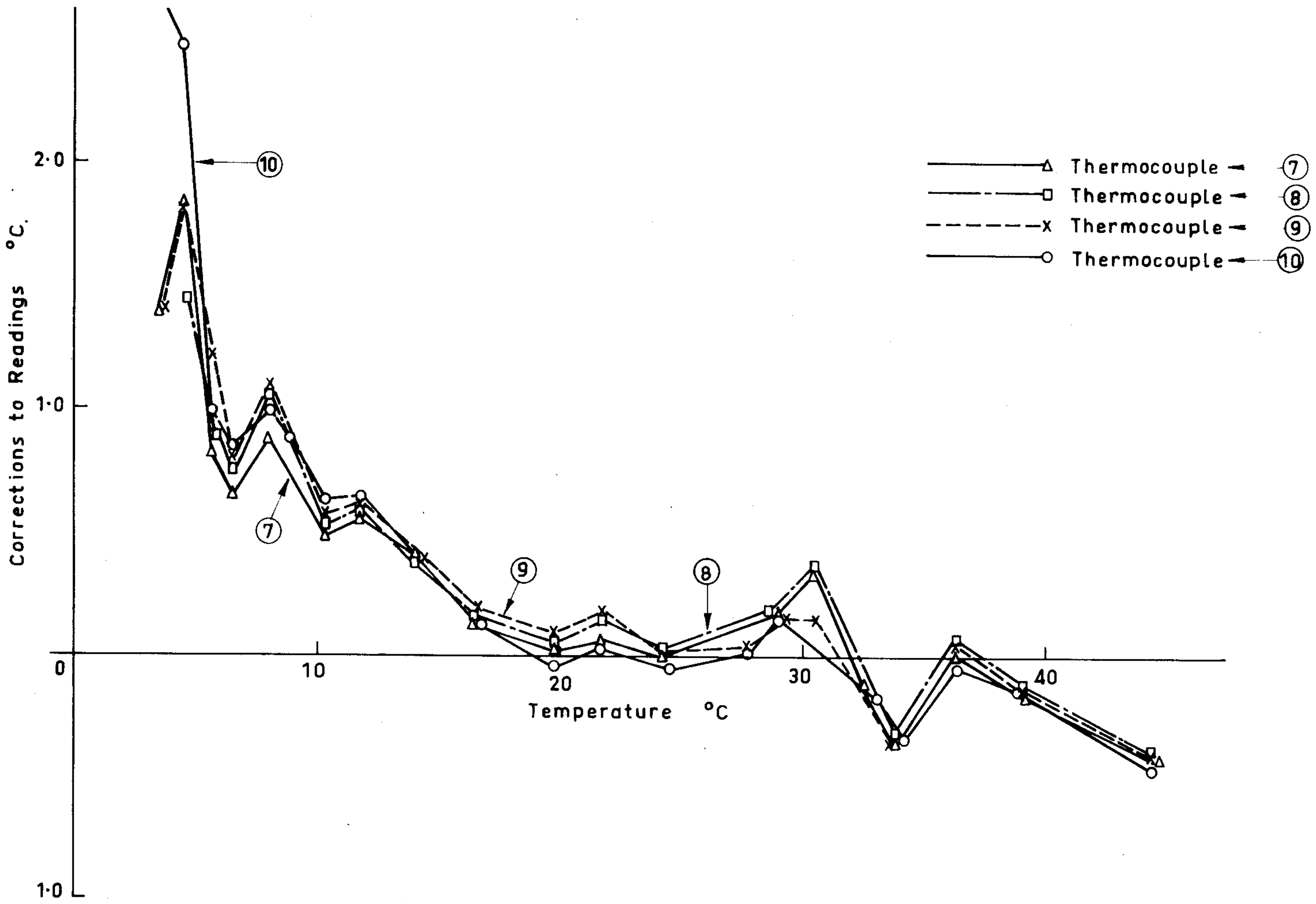
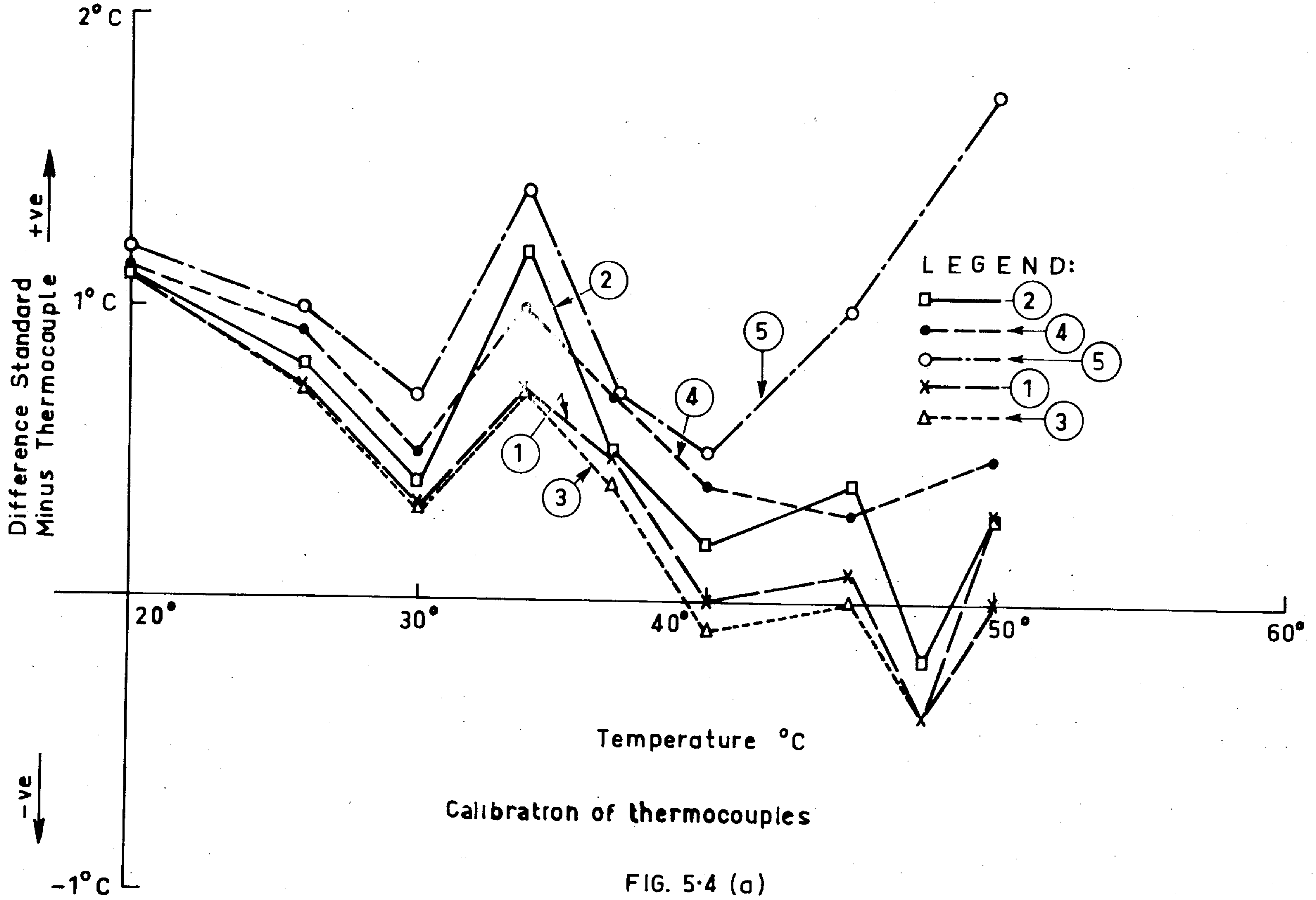
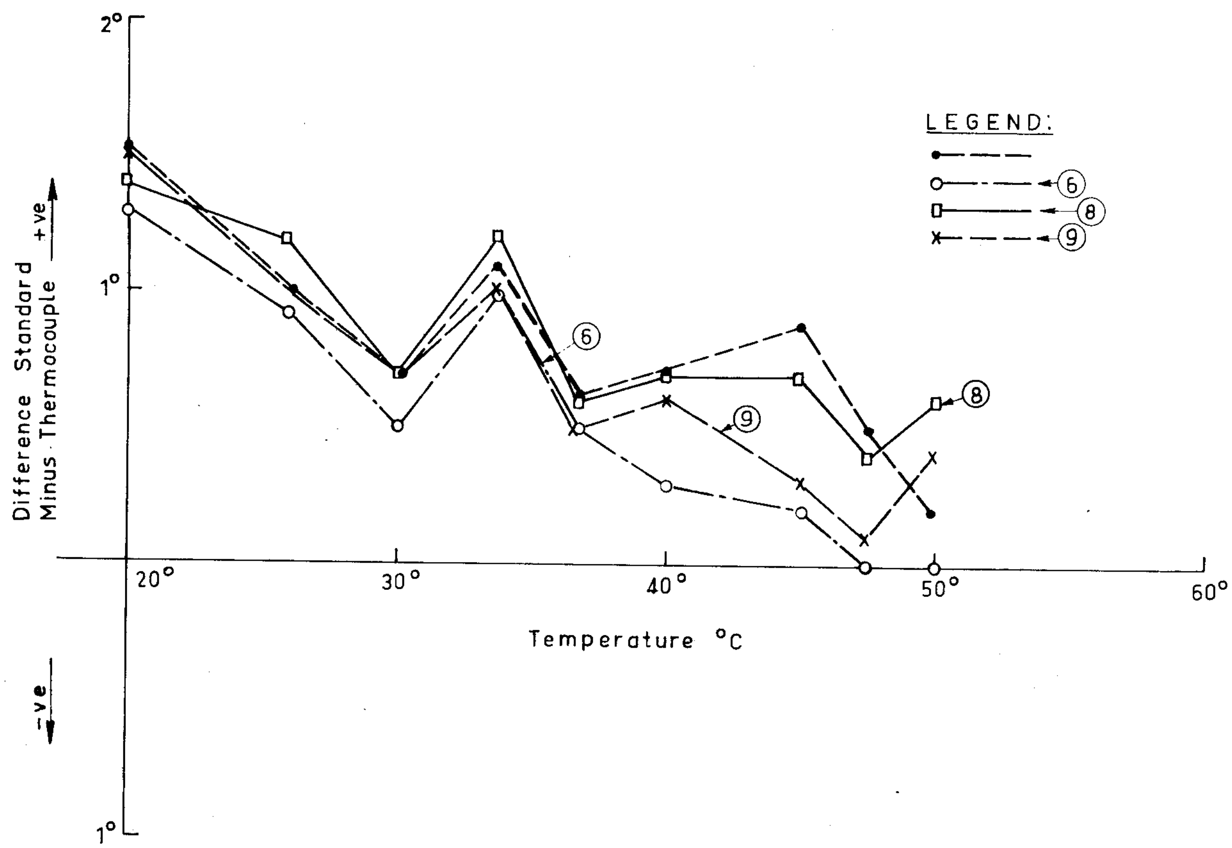


FIG. 5·3 (b): CALIBRATION OF THERMOCOUPLES.



Calibratron of thermocouples

FIG. 5·4 (a)



2°
1°
1°
Difference Standard Minus Thermocouple
+ve
-ve
20°
30°
40°
50°
60°
Temperature °C
LEGEND:
6
8
9

FIG. 5·4 (b)

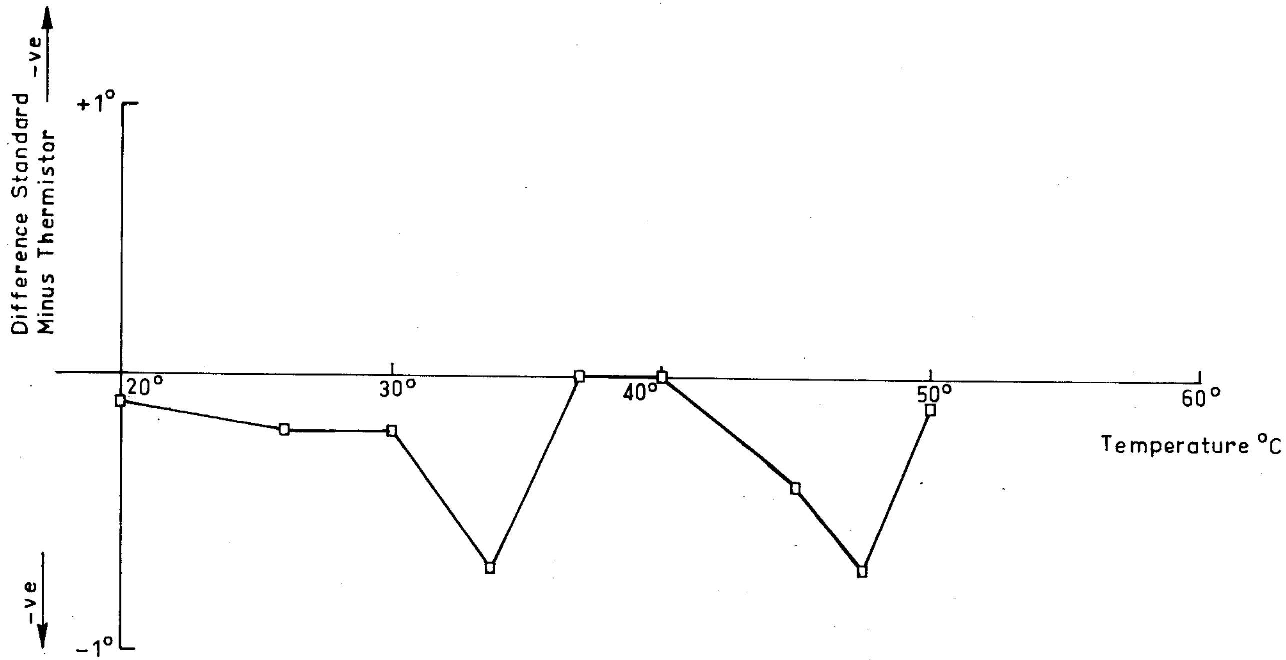


FIG. 5·5: CALIBRATION THERMISTOR UNIT A GRAPH GIVES CORRECTION TO READING TO OBTAIN TRUE TEMPERATURE.

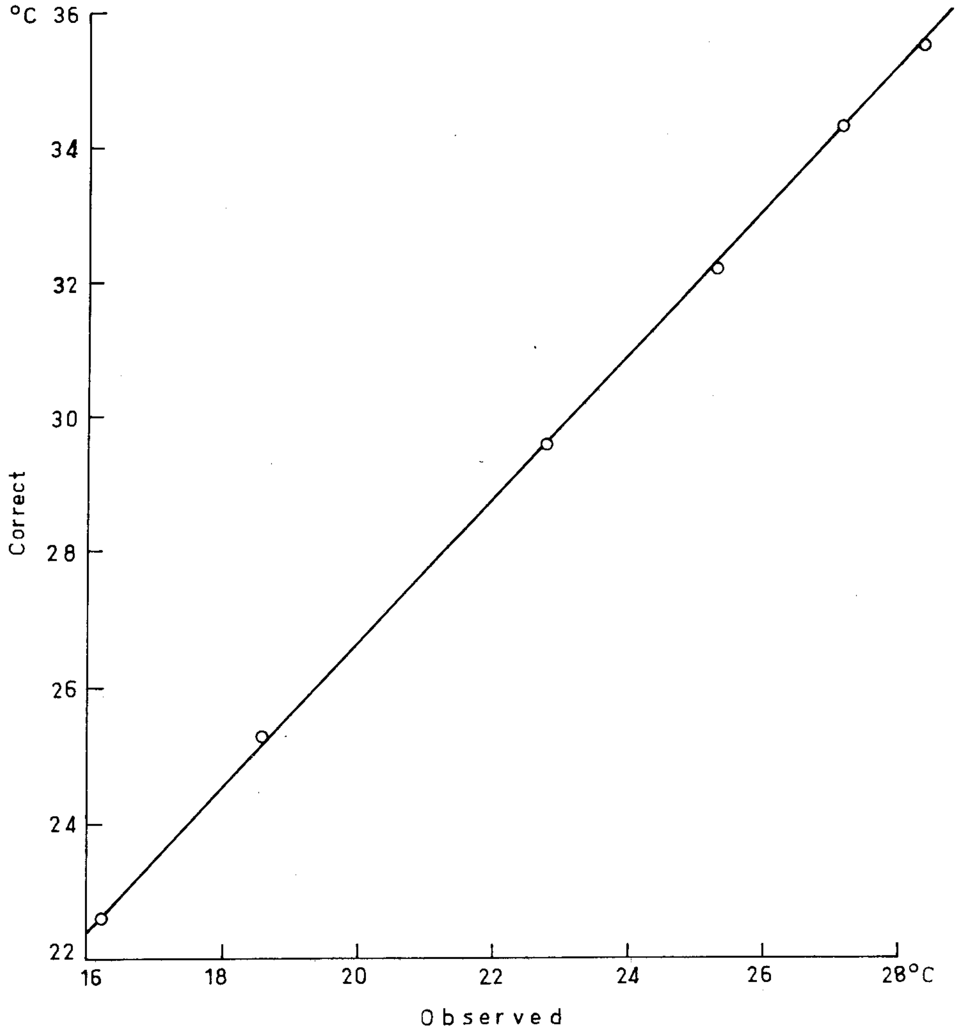


FIG. 5·6: CORRECTIONS TO READINGS TO THERMISTOR 1 FOR READINGS TAKEN ON 26/1/71.

PART II

5.5 GENERAL

As well as the more straight forward calibrations dealt with in Part I more involved calibrations were conducted in the basement corridor of the Civil Engineering building. In this series of tests each of three tapes (1/12" steel, 10 mm. steel, 1/8" invar) were suspended on a short base attached to one wall of the corridor. The temperature conditions in the corridor were stable. The tape was heated electrically and the extension of the tape was accurately measured. This provided a basis for the determination of the temperature of the tape. As well the temperature of the tape was measured with a number of thermocouples and thermistors together with measurement for resistance using a wheatstone bridge.

The aim of these experiments was to test the ability of the thermocouples and thermistors to register the true tape temperature and to draw up a chart of temperature versus resistance for each tape.

5.6 THE EXPERIMENTAL ARRANGEMENT

Figures 5.7 to 5.12 show photographically the equipment used and the arrangement adopted. Figure 5.7 gives an overall view showing at the far end the weights suspended over the pulley onto the dial gauge used for the measurement of the extension. The first set of thermocouples can be seen together with the batteries used for heating the tape.

Figure 5.8 shows the remainder of the equipment including the wheatstone bridge. Figure 5.9 shows the fastening arrangement at the fixed end of the tape whilst Figure 5.10 shows how the extension of the tape is measured by means of a sensitive dial gauge. Figure 5.11 shows the dial gauge which has a least count of .0001 inches and a travel of approximately 1/2"; Figure 5.12 shows the multimeter used to measure the voltage applied in order to heat the tape.

Note: The basement corridor is approximately 25 m long.

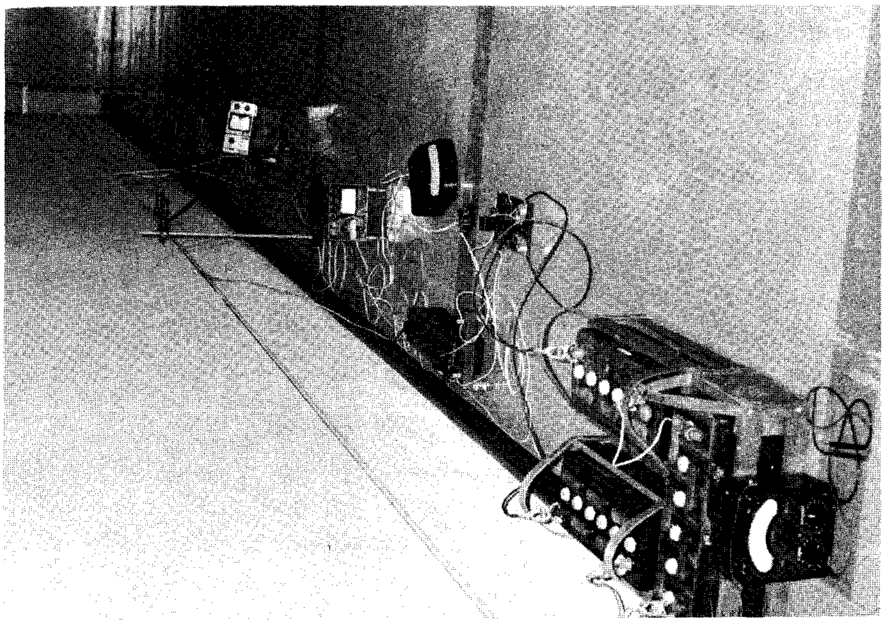


FIG. 5·8

FIG. 5·7

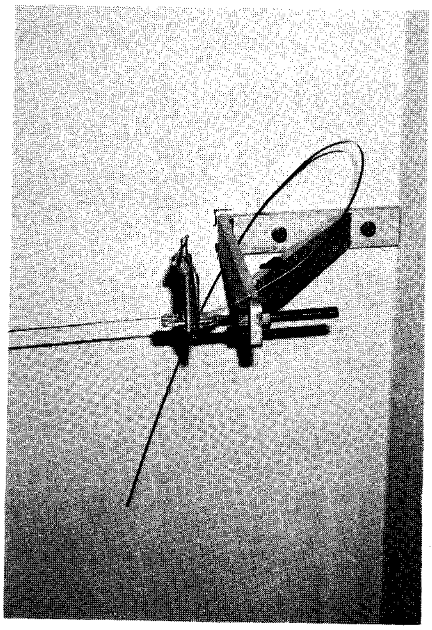


FIG. 5·9

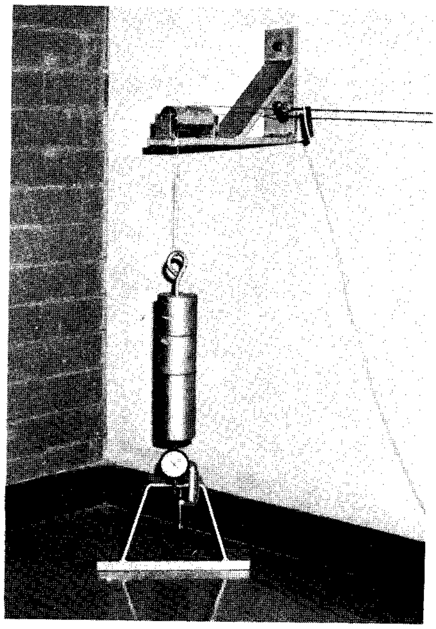


FIG. 5·10

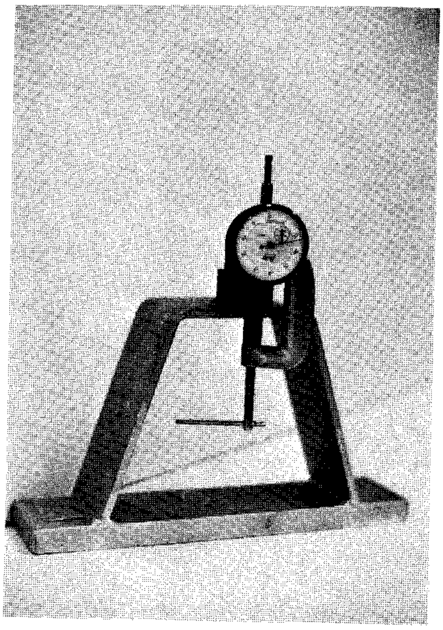


FIG. 5·11

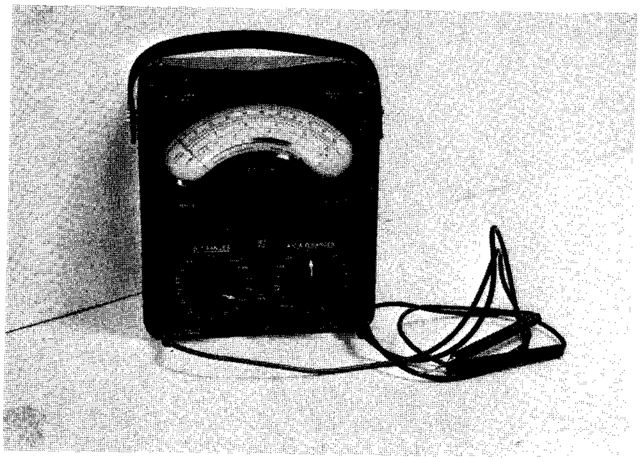


FIG. 5·12

5.7 RESULTS

5.7.1 1/12" Steel Band *(dull surface)*

Figure 5.13 shows diagrammatically an overall view of the arrangement as applied to the 1/12" steel tape. Table 5.3 lists the readings of each of the elements as the voltage is successively increased and decreased in order to heat and subsequently cool the tape. The first part of Table 5.3 lists the results for a 24 m. length of the tape whilst the second part lists those for a 17 m. length.

Figures 5.14 and 5.15 graph the temperature determined from the mean of the readings of each of the elements against resistance as well as the temperature determined from the measurement of the extension of the tape against resistance for each of the lengths mentioned above.

There is good parity between the line of best fit for each set of observations for both lengths. In order that the temperature could be determined from the dialgauge readings a value for the coefficient of thermal expansion had to be adopted. The generally adopted value of $10.8 \times 10^{-6}/^{o}C$ was taken.

Comparing temperatures derived from the mean of all elements with that derived from the measurement of the extension of the tape, the differences are shown in Table 5.2.

TABLE 5.2

1 Mean of thermocouples & thermistors °C	2 Temperature determined from dial gauge °C	3 2-1 °C
24 m band		
22.0	22.0	0.00
25.9	25.8	-0.10
26.0	25.9	-0.10
34.3	35.4	+1.10
44.9	44.4	-0.50
37.3	37.2	-0.10
25.6	26.0	+0.40

Table 5-3

Time hrs. mins	Thermocouples °C				Thermistors °C 1	Thermistors °C 3	Thermocouples °C 1	Thermocouples °C 2	Mean °C	Bridge	Bridge Ohms	Dial Gauge	Dial Gauge °C
		2		4									
(24 metre - 16.12.70													
14.22		22.0		22.0	21.8	21.8	21.9	21.9	21.9		-	2.065	
14.38		22.6		22.5	22.1	22.2	21	21.4	22.0	42987	5.373	2.167	22
14.45		28.8		27.0	26.5	26.0	22.6	23.8	25.9	43600	5.450	3.256	25.8
14.53		28.5		28.0	26.7	26.0	22.5	24.0	26.0	43630	5.454	3.290	25.9
15.01		39.5		38.4	36.0	32.5	29.2	30.5	34.3	45000	5.625	6.077	35.4
15.17		53.7		51.0	45	43.0	36.9	38.0	44.9	46640	5.830	9.140	44.4
15.23		43.0		41.2	39	36.3	31	33	37.3	45620	5.702	7.095	37.2
15.30		27.0		28.0	27	26.3	22	23.5	25.6	43600	5.450	3.305	26.0
(17 metre - 23.12.70													
	2	4	5	1	2	1	2	3					
13.47	22	22.5	22.5	21.3	20.8	22	22	22	22				
13.51	22.5	22.5	22.5	21.4	20.9	22	22	22	22	30970	3.871	5.75	22.0
13.57	29.0	31	29.5	32	32.4	30	28	30	30.2	31818	3.977	13.56	31.4
14.04	46	49	49	50	50	48.5	41	45	47.3	33940	4.242	26.20	49.0
14.10	72	78.5	74			73	63	76	72.7	37035	4.629	44.19	73.7
14.15	47	50.5	48.5	50	50	49	42.5	51	48.6	33910	4.239	27.31	50.4
14.20	31	31.5	31	32	33	31	30	30	31.2	31820	3.977	15.22	33.7
14.28	22.5	22.5	23	21.7	21.1	22.5	22.2	22	22.2	30959	3.870	6.77	22.2

1/12" BAND (DULL SURFACE) 16.12.70 - LOWER GROUND CORRIDOR.

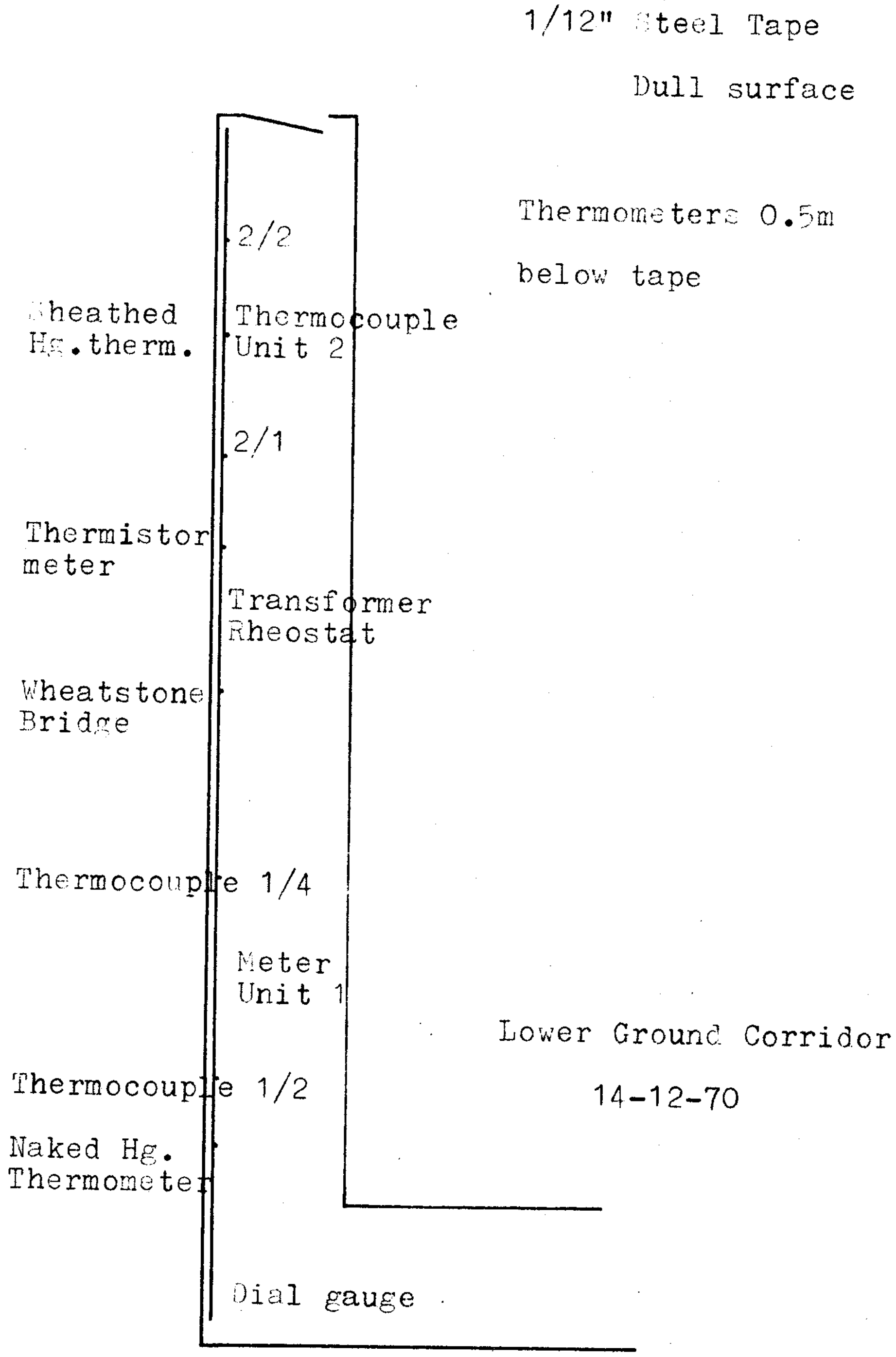

1/12" Steel Tape
Dull surface
Thermometers 0.5m
below tape
2/2
Sheathed
Hg.therm.
Thermocouple
Unit 2
2/1
Thermistor
meter
Transformer
Rheostat
Wheatstone
Bridge
Thermocouple 1/4
Meter
Unit 1
Lower Ground Corridor
14-12-70
Thermocouple 1/2
Naked Hg.
Thermometer
Dial gauge

FIG. 5·13

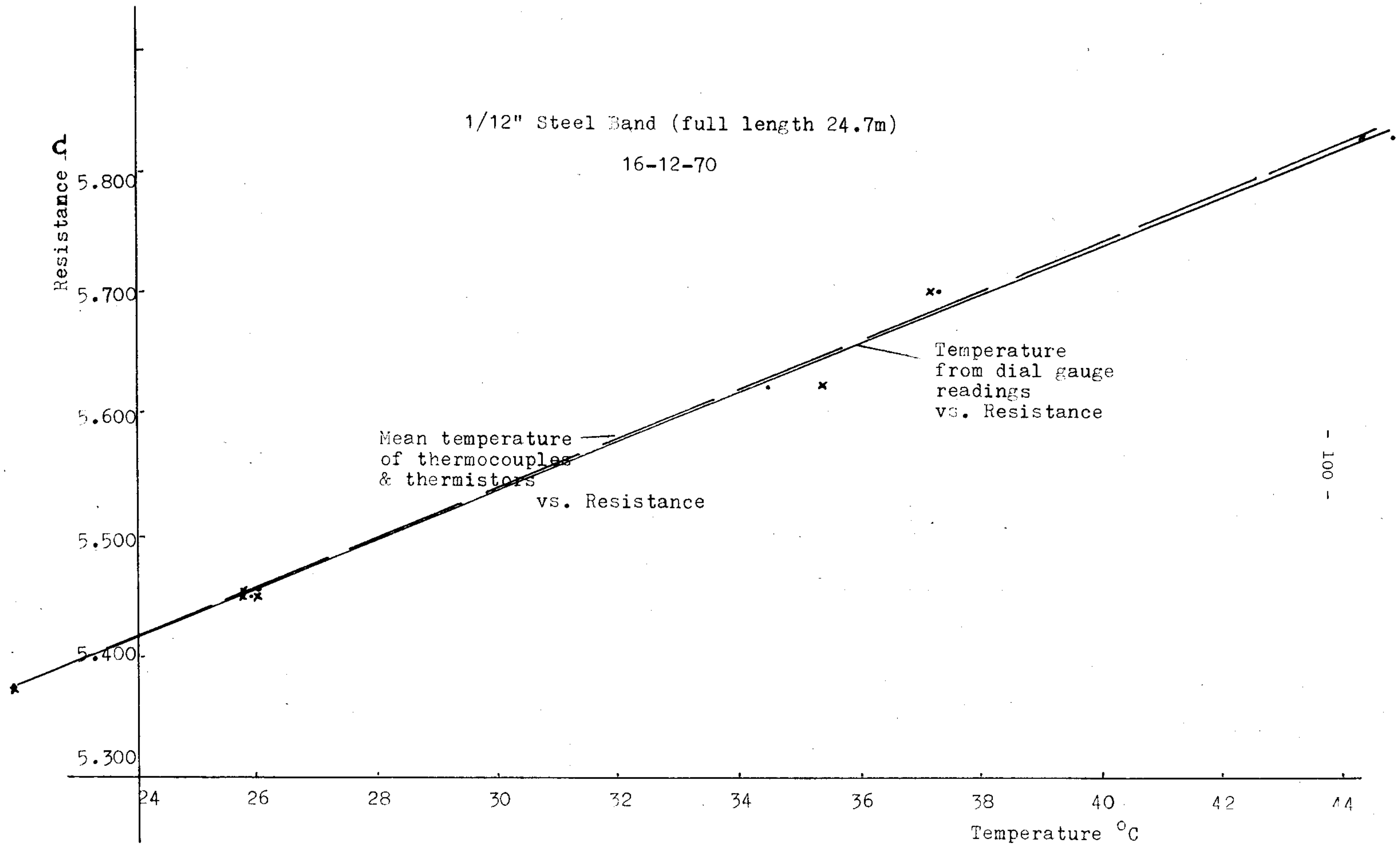

1/12" Steel Band (full length 24.7m)
16-12-70
Resistance Ω
5.800
5.700
5.600
5.500
5.400
5.300
Mean temperature of thermocouples & thermistors vs. Resistance
Temperature from dial gauge readings vs. Resistance
24
26
28
30
32
34
36
38
40
42
44
Temperature °C

FIG. 5.14

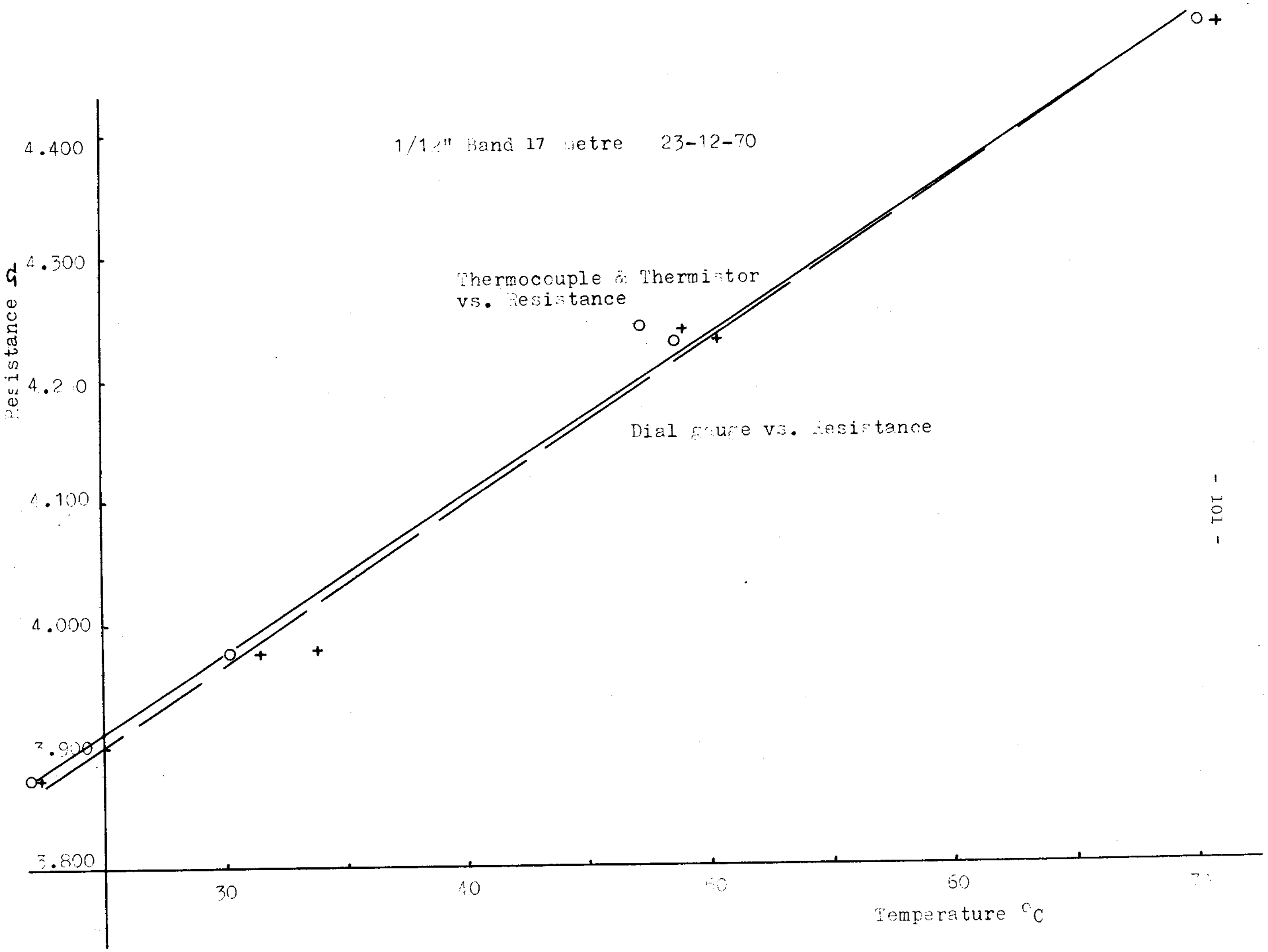

1/12" Band 17 metre 23-12-70
Thermocouple & Thermistor
vs. Resistance
Dial gauge vs. Resistance
Resistance Ω
4.400
4.300
4.200
4.100
4.000
3.900
3.800
30
40
50
60
70
Temperature °C

Fig. [illegible].15

(17 m)		
22.0	22.0	+0.00
30.2	31.4	+1.20
47.3	49.0	+2.70
72.7	73.7	+1.00
48.6	50.4	+1.80
31.2	33.7	+2.50
22.2	22.2	0.00

The discrepancies in the case of the 24 m. length are smaller than those of the 17 **m** length, however the maximum temperature reached in the former case is considerably lower than that of the latter. It is not easy to give reasons for the discrepancies particularly in the case of the 17 m length. It is thought however that the factors are:-

(i) Uncertainty as to the true value of the coefficient of thermal expansion.

(ii) There was a distinct gradient of temperature along the length of the tape. This appeared to have something to do with the method of heating.

(iii) The thermal contact between the thermocouple or thermistor and the tape may have been poor on occasions.

Of these discrepancies it is felt the gradient of temperature along the length of the tape would have had the most significant effect. There is no apparent pattern throughout the discrepancies; where there appears to be an increase in the discrepancy with temperature in the case of the 24 m. length the reverse is the case with the 17 m. length.

5.7.2 10 mm White painted metric tape

Figure 5.16 shows diagrammatically the layout of the equipment used for the experiment on the 10 mm tape whilst Table 5.4 lists the results.

10 mm White painted steel tape

Thermometers 0.5 m below tape

Lower Ground Corridor 17-12-70

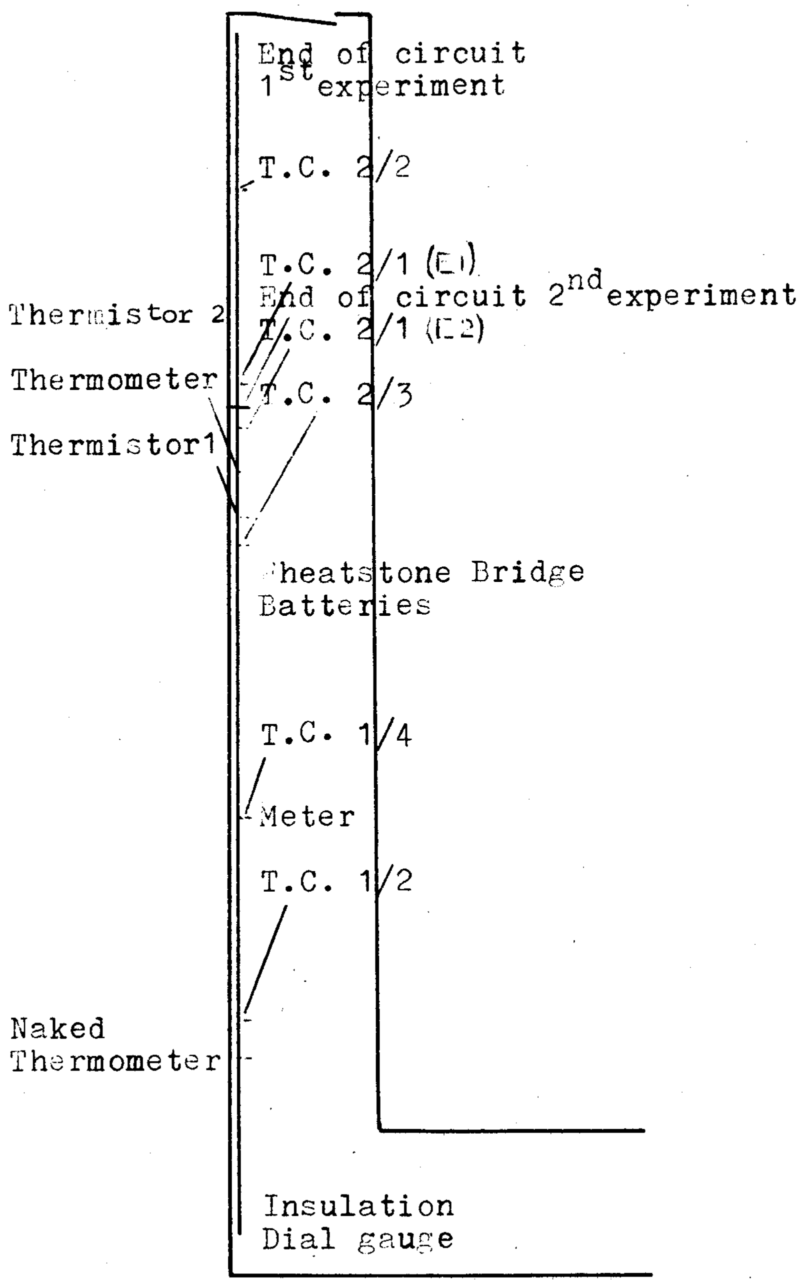


FIG. 5.16

Table 5-4

Time	Thermocouple		Thermistor		Thermocouple		Mean	Bridge	Dial Gauge
	2	4	1	2	3	1			Coeff. of Expansion
Hrs. mins.	°C	°C	°C	°C	°C	°C	°C	Ohms	$10.8 \times 10^{-6}/^{o}C$
15.22	22.1	22.2	22	21.2		22	22		22.0
15.29	27.4	27.0	27.3	27.0		27	27.1	2.398	27.2
15.36	35.6	34.6	35.3	34.7		34	34.8	2.450	36.7
15.42	52.7	48.5	50.0	49.2		49	49.9	2.554	54.1
15.42½	50.7	48.8					49.5		52.0
15.48	33.8	33.2	33.5	34		32	33.5	2.433	34.7
15.53	25.2	25.0	24.8	24.0		24.4	24.7	2.375	25.2
15.57	22.8	22.9	22.4	22		22.3	22.5		22.7
15.43	22.0	21.9	22.2	21.6	22.2	22.2	22.0	2.374	22.0
15.48	25.7	25.6	26	25.4	26.5	25	25.7	2.394	25.4
15.57	32.7	31.7	33	33	33.5	32	32.6	2.451	31.8
16.08	39.9	38.8	39	38	40.2	38	38.9	2.504	41.6
16.14	27.9	27.7	27.3	27.1	28.5	27	27.6	2.413	26.4
16.28	26.4	26.8	26.2	26.2	27.2	26	27.5	2.412	26.7
16.35	22.0	22.2	22.5	21.8	22.8	22.2	22.2	2.376	22.8

17.12.70 (P.M.) 10 mm White Painted Metric Tape - Lower Ground Corridor

As with the 1/12" tape graphs were drawn of the temperature derived by meaning all the elements, against resistance, together with the temperature derived by measuring the extension of the tape, against resistance. These graphs are shown in Figure 5.17 where the pair of lines marked (1) represent the results of a 17 m. section of the tape. However the null-meter used with the Wheatstone bridge was later found to be out of adjustment. The pair of lines marked (2) represent then the results using the same section of tape with a properly adjusted null-meter.

The discrepancies between the temperature derived from the thermocouples and the thermistors and that derived from measurement of the extension of the tape, are listed in Table 5.5. The discrepancies are largest at higher temperatures however I feel the largest discrepancy of 4.2°C is inordinately large. Reference should be made to 5.7.1 for a discussion on the reasons for the discrepancies.

TABLE 5.5

	1	2	3
	Mean temperature from thermocouples & thermistors °C	Temperature derived from dial gauge readings °C	2-1
(1)	22.0	22.0	0.00
	27.1	27.2	+0.10
	34.8	36.7	+1.90
	49.9	54.1	+4.20
	49.5	52.0	+2.50
	33.5	34.7	+0.90
	24.7	25.2	+0.50
	22.5	22.7	+0.20
(2)	22.0	22.0	0.00
	25.7	25.4	-0.30
	32.6	31.8	-0.80
	38.9	41.6	2.70
	27.6	26.4	0.20
	22.2	22.8	0.60

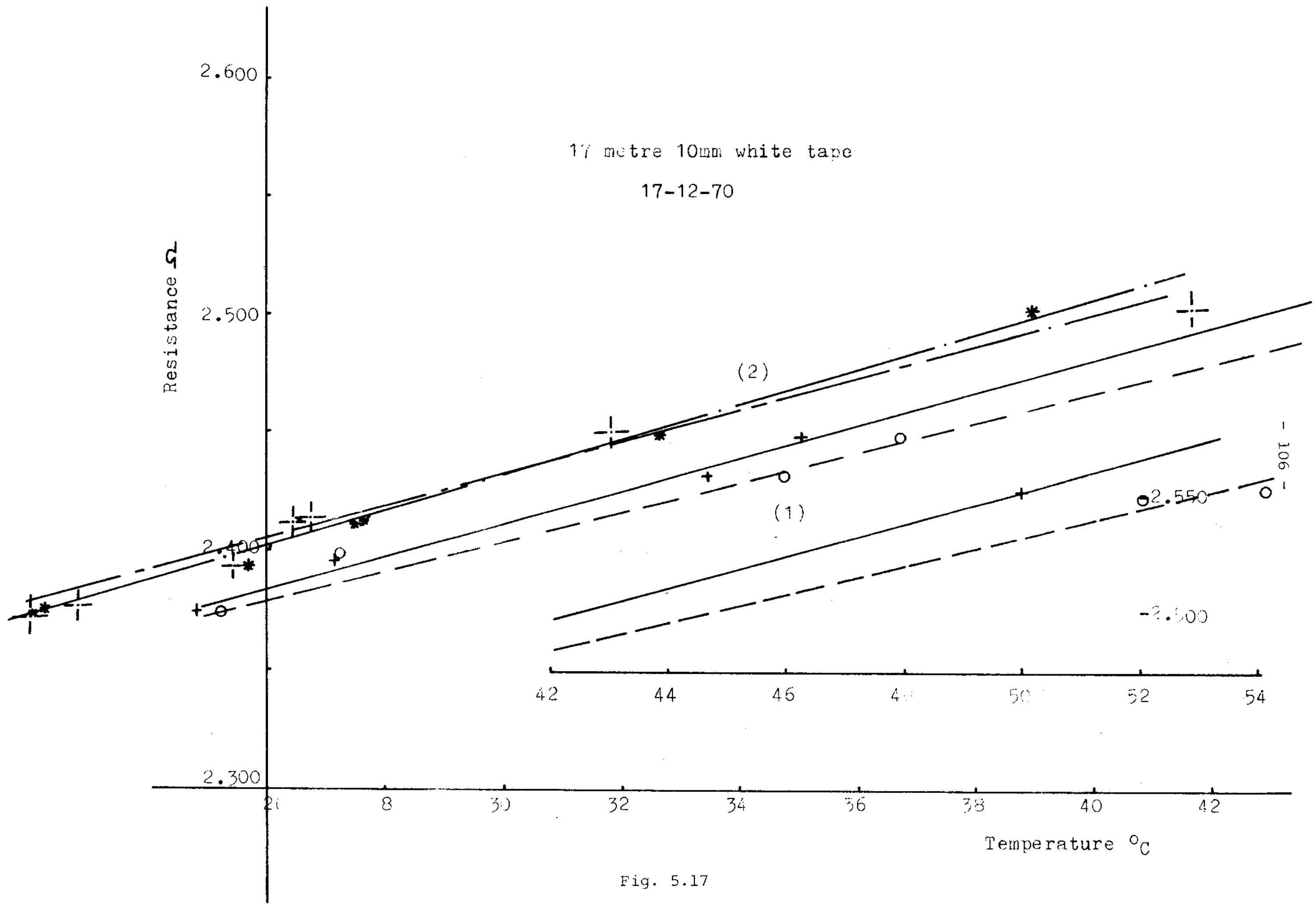

17 metre 10mm white tape
17-12-70
Resistance Ω
2.600
2.500
2.400
2.300
(2)
(1)
2.550
42
44
46
52
54
8
30
32
34
36
38
40
42
Temperature °C

Fig. 5.17

5.7.3 1/8" Invar Tape

The invar tape made up the complement of tapes tested during the test in the lower ground floor corridor. The particular sections of the tape contained many kinks although otherwise in reasonable condition. Figure 5.18 shows the layout of the equipment for the tests whilst Tables 5.6 and 5.7 show the results for the two different sections of invar used.

The two different sections of tape were used, because, although the temperature versus resistance showed a linear relationship with the first section, the expansion of the tape was somewhat erratic and did not appear to follow any pattern at all.

Graphs showing resistance against temperature for each of the sections are given in Figure 5.19. In the case of the section tested on the 21.12.70 the results show little spread and demonstrate linearity except for the first readings of the set. The results of the test of 11.1.71 show considerably larger spread and in fact reveal significant variations to the line of mean fit.

In deriving the temperature of the tape from the dial gauge readings the problem arose of deciding on a value for the coefficient of linear expansion. A physics text *(Resnick & Halliday)* furnished the value $0.7 \times 10^{-6}/^{\circ}C$ where as various surveying publications indicated values ranging from $0.5 \times 10^{-6}/^{\circ}C$ down to negative values. Using $0.7 \times 10^{-6}/^{\circ}C$ the temperatures were derived from the dial gauge readings in each case. These are listed in Tables 5.6 and 5.7. In the case of the 21.12.70 test the results are quite erratic. The results of the 11.1.71 test using the different section of tape, however show a pattern more in keeping with what would be expected.

1/8" Invar tape

Thermometers 0.5 m below tape

Lower Ground Corridor

21-12-70, 11-1-71

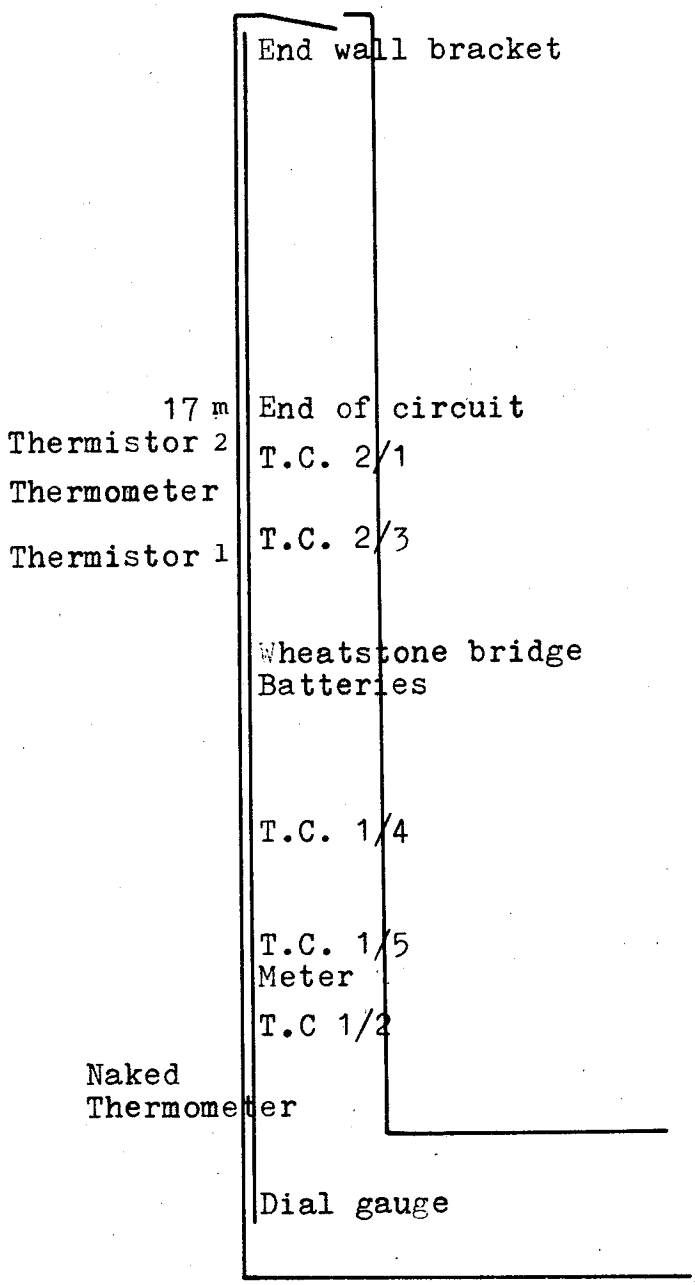


FIG. 5.18

Table 5-6

Time	Thermocouples 2	Thermocouples 5	Thermocouples 4	Hg. Therm.	Therm-istors 1	Therm-istors 2	Thermocouples 1	Thermocouples 2	Thermocouples 3	Thermocouples 4	Hg. Therm.	Dial Gauge	Remarks & Bridge Ω	Mean	Dial Gauge
10.52	21.4	21.5	21.5	21.7	21.6	21.0	22.3	22.1	22.4	-	22.2	20.562	69840 ← 8.730	21.7	21.7
10.57	21.4	21.6	21.6	21.7	21.6	21.0	22.3	22.1	22.4	-	22.2	20.562	69900 → 8.737		
11.03	25.0	25.0	25.0	21.7	26.1	25.4	25.0	24.7	26.2	-	22.2	20.562	70900 ← 8.862	25.3	21.7
11.05	25.6	25.7	25.2	21.7	26.5	26.3	26.6	27.0	25.5	-	22.2	20.562	71030 → 8.879	26.0	21.7
11.15	34.9	35.8	36.2	21.7	39.0	40.0	35.2	35.0	38.7	-	22.2	20.570	72390 ← 9.049	36.8	21.9
11.18	35.4	36.6	37.9	22.2	39.8	39.2	37.0	37.5	35.5	-	22.2	20.570	72480 → 9.060	37.4	21.9
11.24	48.0	53.0	52.2	22.2			48	49	55.5	-	22.2	21.200	74411 ← 9.301	50.9	45.3
11.30	47.6	52.8	52.2	22.2			50	56	48	-	22.2	21.200	74330 → 9.291	51.1	45.3
11.36	26.7	27.0	27.2	22.2	26.8	26.2	28.0	25	28	-	22.2	21.105	70700 ← 8.837	26.7	43.3
11.38	25.8	27.3	27.6	22.2	26.8	26.5	28.0	28.0	26.5	-	22.2	21.105	70810 → 8.851	27.1	43.3
11.44	22.0	22.7	22.6	21.7	21.8	21.2	23.5	23.5	23.0	-	22.2	20.960	70600 ← 8.825	22.5	30.2
					(temperature °C)								70300 → 8.787		

1/8" INVAR - LOWER GROUND CORRIDOR - 21.12.71

Table 5-7

Time	Thermocouple °C			Hg. Therm.	Therm-istors °C		Thermocouples °C				Hg. Therm.	Dial Gauge	Bridge & Remarks	Mean	Dial Gauge
hr m	2	5	4	°C	1	2	1	2	3	4	°C			°C	°C
14.12	21.7	21.7	21.8	21.9	21.5	21	22	22	22	22	21.9	10.73			
14.20	21.8	21.9	21.6	21.9	21.8	21	22	22	23	22	21.9	10.45	69710/69210 (2V)	21.9	21.9
14.23	25.0	24.0	27.8	21.9	25	25.3	26	26	29.5	22	22.2	10.50	71520/71720 (12V)	25.6	23.0
14.31	35.0	32.7	40.5	21.9	33.5	36.5	35	35	43.5	22	22.2	11.00	72770 ← (24V)	36.4	33.6
14.35	36.0	38.3	34.0	21.9	35	36.0	34.5	37	28	22	22.2	11.00	73270 → (24V)	34.8	33.6
14.40	37.0	32.9	41.9	21.9	35	37.0	35	36.5	44	22	22.2	11.00	(24V) ←	37.4	33.6
14.45	53.0	46.8	60.8	22.2	48	50.5	50	53	65.5	22	22.2	11.32	75310 ← (36V)	53.4	40.5
14.48	54.3	56.0	50.0	22.2	47.5	50.5	49	53	38	22	22.2	11.65	75520 → (36V)	49.7	47.5
14.56	37.4	32.0	40.2	22.2	35	36.3	37	36.5	44.5	22	22.2	11.02	73140 ← (23V)	37.3	34.1
15.00	38.9	40.6	34.0	22.2	35	37	34.5	36.5	38	22	22.2	11.03	73200 → (23V)	36.8	34.3
15.05	26.5	24.4	28.6	21.9	25	25.2	26	26.5	30.5	22	22.2	10.60	70801 ← (12V)	26.5	25.1
15.07	27.0	28.0	24.8	21.9	25	25	26	21.5	22	22	22.2	10.60	71081 → (12V)	24.9	25.1
15.10	22.4	21.8	22.2	21.9	21.7	21	22	22.5	23	22	22.2	10.56	70460 ← (2V)	22.1	24.2
15.18	21.2	21.6	21.7	21.9	21.5	21	22	22	22	22	22.2	10.56		21.7	24.2

1/8" INVAR - LOWER GROUND CORRIDOR - 11.1.71

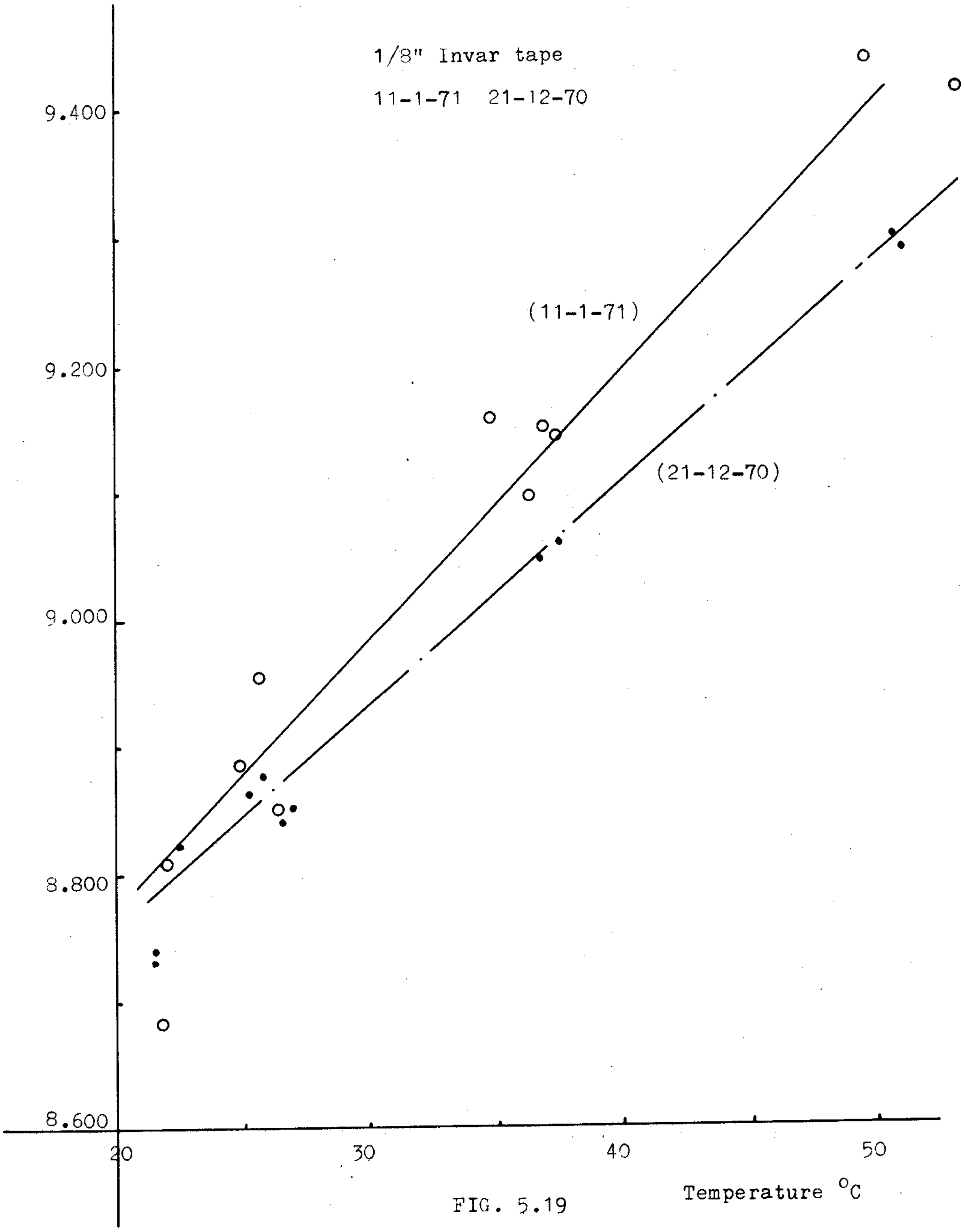

1/8" Invar tape
11-1-71 21-12-70
(11-1-71)
(21-12-70)
9.400
9.200
9.000
8.800
8.600
20
30
40
50
Temperature °C

FIG. 5.19

5.8 COMMENTS ON RESULTS

In general the results indicate that the thermocouples and thermistors register the temperature of the tape correctly. Further it can be seen that the resistance of a particular tape, bears significantly a linear relationship to the temperature.

The 1/8" invar tape does not give results which follow expected trends as closely as the other tapes and in fact the results are difficult to assess. The earlier test with the invar indicates linearity between the temperature measured by the thermocouples and resistance together with erratic results in relation to the measurement of the expansion of the tape by the dial gauge. However results of the later test indicate a patter almost in reverse to those of the earlier test.

It is felt that in the earlier test static friction in the pulley bearings may have been the cause of the erratic results. The bearings were of high quality. It is felt that another fact may have been the many kinks in the tape. This is an interesting problem in itself, however a larger sample of results would be required in order to make a proper assessment of this.

CHAPTER 6

EXPERIMENTS WITH MERCURY-IN-GLASS THERMOMETERS

6.1 GENERAL

The use of mercury-in-glass thermometers for the determination of temperatures of surveyors tapes is a very important subject and one which does not appear to have received sufficient consideration, in this country at least. Most surveyors will merely read the thermometer and apply a correction based on assuming tape characteristics, and that, except in very long lines, the correction to any particular line under say 200 ft. is usually regarded as being negligible.

It is neither generally realized that the temperature measured by the thermometer is based on the air temperature and not the tape temperature, nor that a thermometer is a poor means of measuring the air temperature. A thermometer is basically designed to measure temperature by either total or partial immersion into a liquid or gas. When however a thermometer is subjected to conditions where the heat balance is affected by radiation, convection and conduction then false readings of the temperature of the medium will be obtained. In addition it is important to note that different thermometers will give different readings under such conditions.

It was with this background that experiments were condcuted with various forms of mercury-in-glass thermometers. The experiments were conducted in order to obtain an insight into the general behaviour of thermometers under various conditions as well as examining the problems associated with their field use.

6.2 THE THERMOMETERS USED

The range of thermometers used in the experiments is shown in Figure 6.1. Full details of these thermometers are given in Appendix D. Thermometers A and D which have nickel-plated brass sheaths are representative of the thermometers used by practicing Surveyors in this country. Thermometer C is a naked or unsheathed thermometer and would also be used by practicing Surveyors, whilst B is a large thermometer with a brass sheath. Thermometer E is a large naked thermometer. See Appendix C for full details of these thermometers.

6.3 THE RESPONSE TIME OF THERMOMETERS

6.3.1. The Experimental Arrangement

Simple experiments, designed to gather information on how much the size and form of the thermometer affects the response characteristics of the thermometer, were set up.

The experimental arrangment is shown in Figure 6.2. The thermometer is approximately 9 inches in front of the radiator which was a domestic type of radiator. Each thermometer was placed in front of the radiator in turn, care being taken not to disturb the equipment as each thermometer was placed. In the first instance each thermometer was placed in front of the radiator under ambient conditions and the radiator switched on. Temperatures at approximately one minute intervals were then recorded until the thermometer reached a steady reading. The radiator was then switched off, and the temperature recorded at the same time interval until the thermometer had cooled to near ambient temperature.

A second experiment using the same experimental arrangement as the first was subsequently conducted. In this case the radiator had been going for some time before the thermometers were placed in front of it. Ther thermometer temperature was recorded against time until the thermometer had reached a maximum reading.

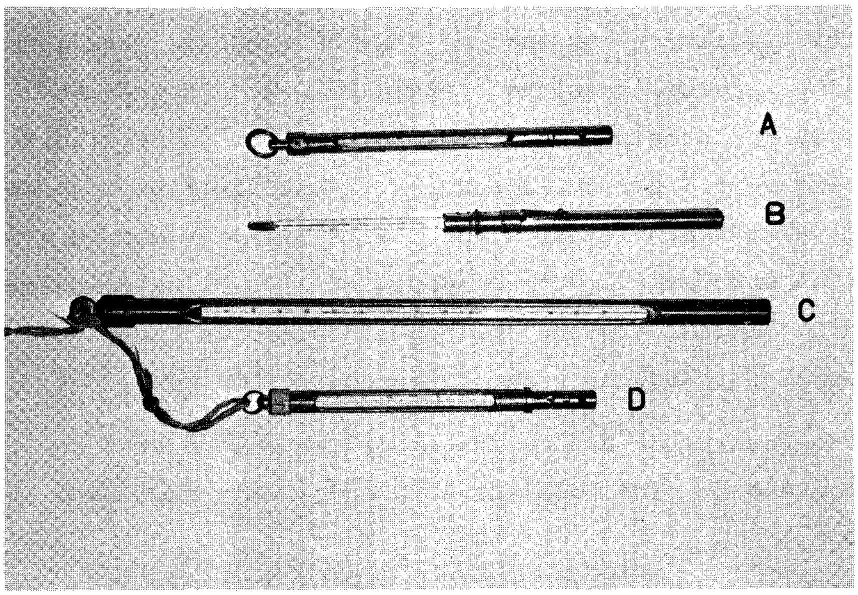


FIG. 6.1

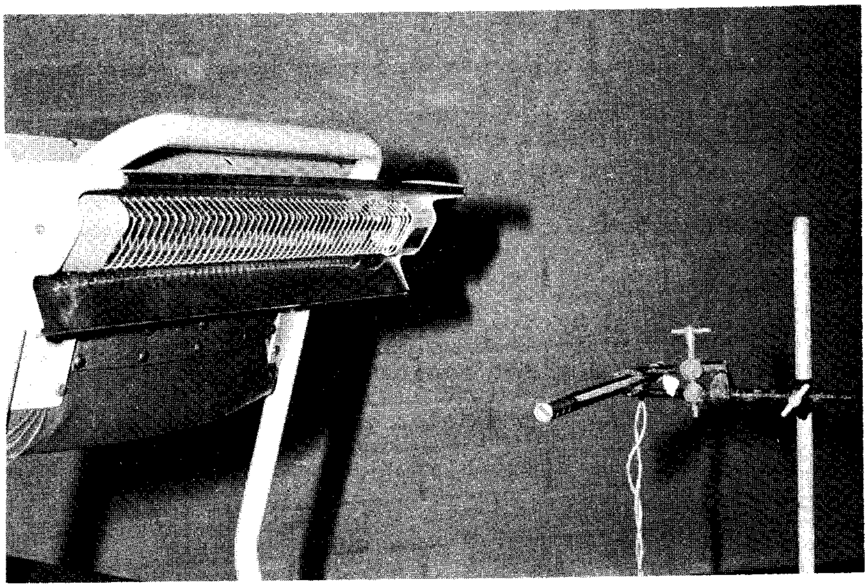


FIG. 6.2

6.3.2 Experimental results

The experiments on each of the thermometers were appropriately spaced in time to allow conditions to stabilize. Further the experiments were conducted on three separate days. There was no particular reason for this. Figure 6.3 shows the results of the first experiment on 10.12.70 in which thermometers A and C were used. Figure 6.4 shows the results of the same experiment conducted on 11.6.71 using thermometers A, B, C and D. Included among the results shown in Figure 6.4 is a repeat experiment on 6.7.71 with thermometer D.

The results of the second experiment, conducted on 6.7.71, are shown in Figure 6.5. Thermometers A, C and D only were used in this experiment.

Additional results which it is felt are of interest are shown in Figure 6.6 and Tables 5.1 and 5.2. The graph shown in Figure 6.6 represents the temperature recorded by a thermocouple placed in the vicinity of a thermometer during experiment 1. The results show the temperature for only a short period of time but none the less indicate the magnitude and frequency of the variation in the temperature. These variations are most likely due to variations in the power supply to the radiator together with the affects of air movement in the room. The important factor demonstrated here however is that the thermometers do not indicate these variations.

The results shown in Table 5.1 and 5.2 show spot temperature readings with a thermocouple on two of the thermometers used in the first experiment. It can be seen from Table 5.1 that the temperature of the sheath as indicated by the thermocouple was effectively that shown by the thermometer. However the temperature of the air in the vicinity of the bulb of the thermometer could in fact be considerably less. A similar pattern is evident in the results shown in Table 5.2.

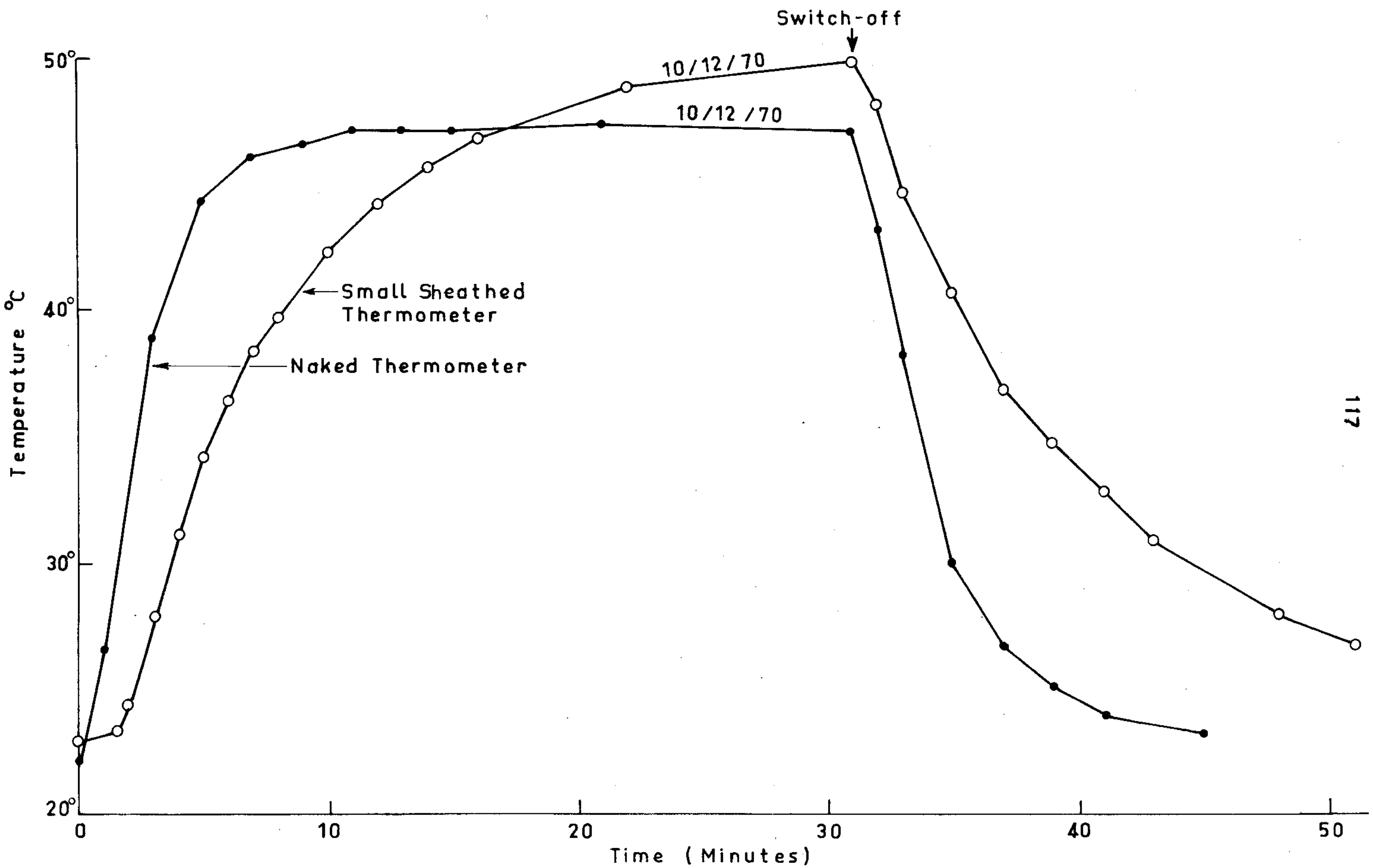

Switch-off
10/12/70
10/12/70
Small Sheathed Thermometer
Naked Thermometer
Temperature °C
50°
40°
30°
20°
0
10
20
30
40
50
Time (Minutes)

FIG. 6·3

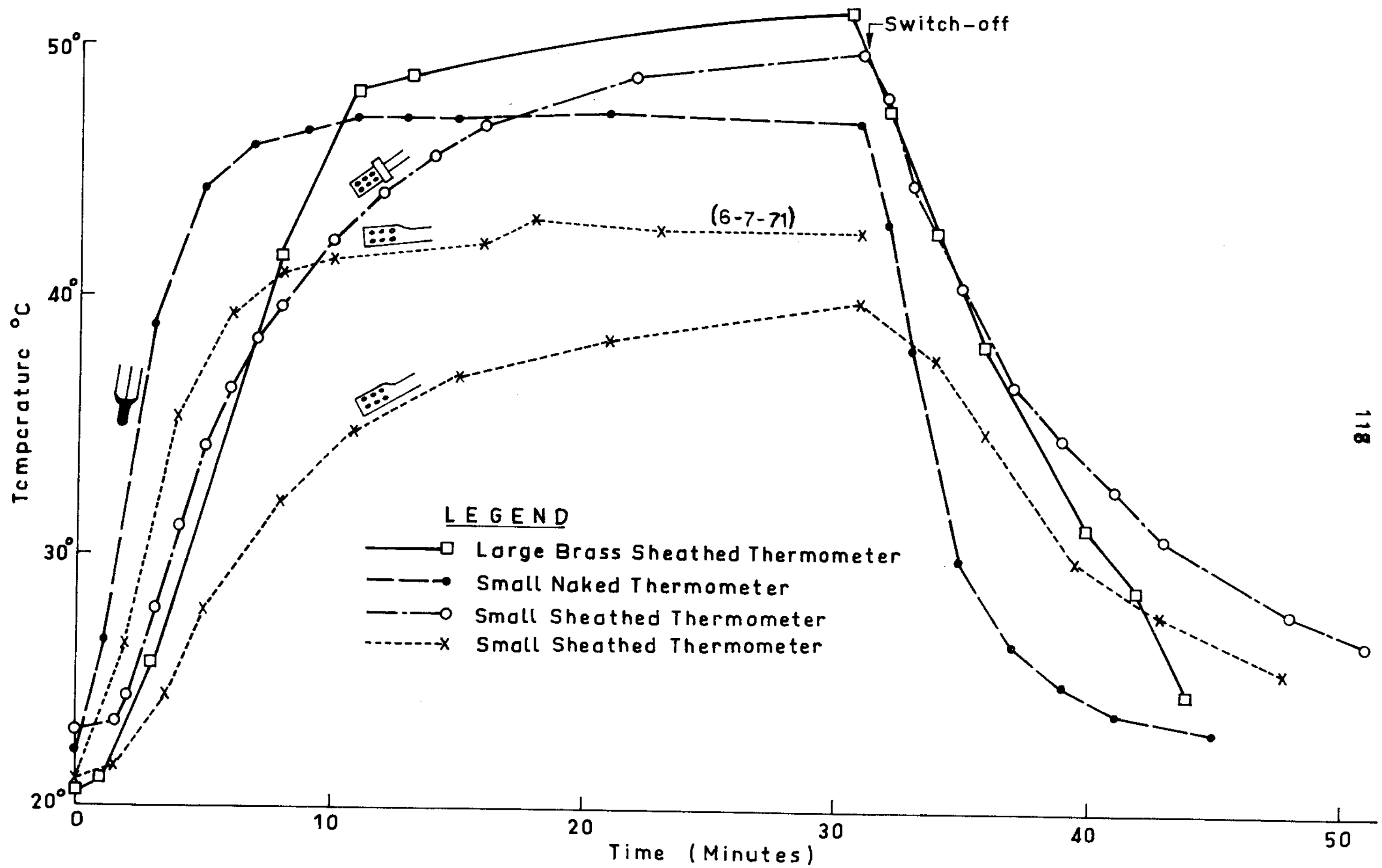

Switch-off
50°
40°
30°
20°
Temperature °C
(6-7-71)
LEGEND
Large Brass Sheathed Thermometer
Small Naked Thermometer
Small Sheathed Thermometer
Small Sheathed Thermometer
0
10
20
30
40
50
Time (Minutes)

FIG. 6.4

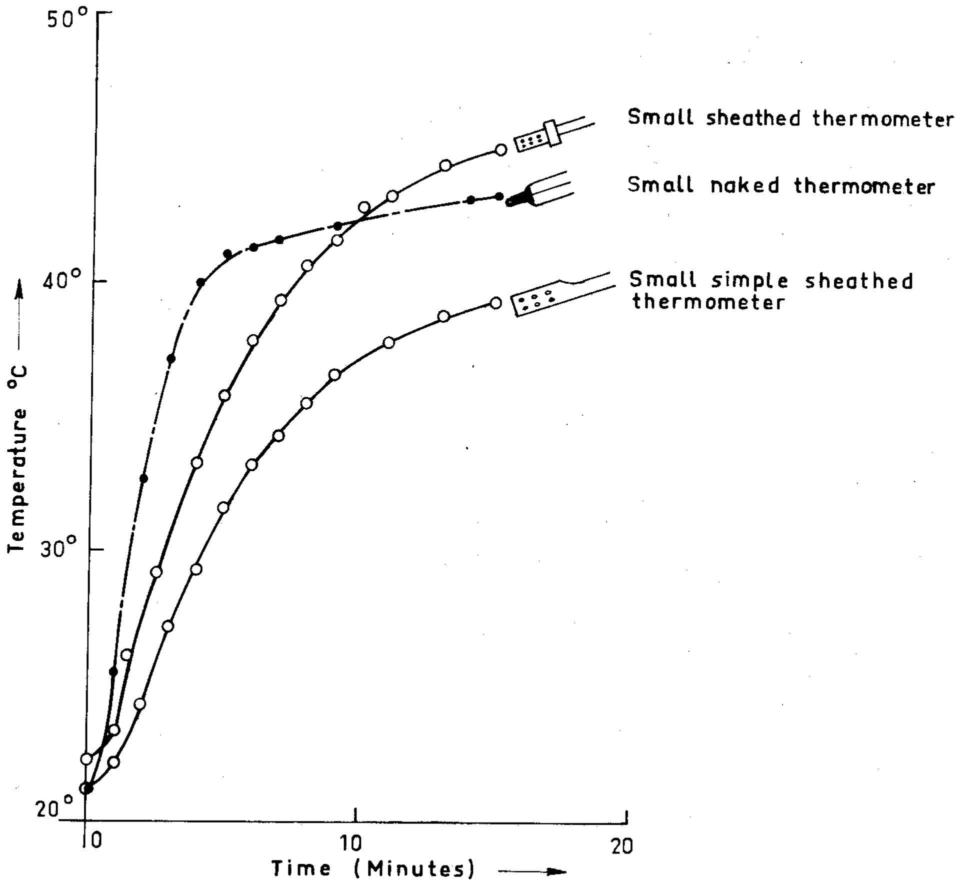


FIG. 6·5 RESPONSE TIME OF THERMOMETERS WHEN PLACED IN AN IDENTICAL POSITION IN FRONT OF A HEAT SOURCE.

6.3.3. Comments on the results

It is evident from the repeated results and the few additional pieces of information that shortcomings existed in the experimental arrangement. However in an endeavour to comment on the results it seems that each of the thermometers behave uniquely under similar conditions.

In relation to the response time of the thermometers it appears that the naked thermometer is more responsive than the sheated thermometers. However the maximum temperature reached by the sheathed themometer was generally higher than that of the naked thermometer, the exception being thermometer D which had a highly reflective sheath.

The spot temperatures taken with the thermocouple indicate the problem involved with the use of mercury-in-glass thermometers for temperature measurement under radiation conditions. In this event the sheath of the thermometer to some degree behaves as a black body and hence falsifies the reading. The results in Figure 6.6 indicate how the thermometers even out the "bumps" in the temperature. Subsequent experiements indicate that the tape does not necessarily follow the same pattern.

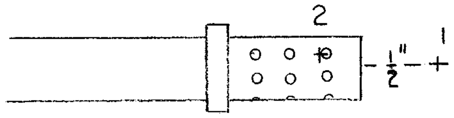


TABLE 6.1

Time h. m.	Point	Thermocouple No.	Thermocouple Rdg. °C	Thermometer Rdg. °C
11.59	1	8	36.5	49.4
11.59	2	8	49.5	49.4
12.02	1	3	31	50
12.02	2	3	48.5	50
12.03	1	8	36	50
12.03	2	8	52.5	50

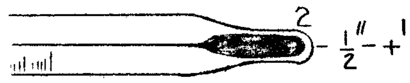


TABLE 6.2

Time h. m.	Point	Thermocouple No.	Thermocouple Rdg. °C	Thermometer Rdg. °C
3.30	1	8	34.5	46.7
3.30	2	8	43.5	46.7
3.33½	1	3	31.5	47.2
3.33½	2	3	43.5	47.2
3.36	1	9	33.5	46.7
3.36	2	9	44.0	46.7

10.12.70

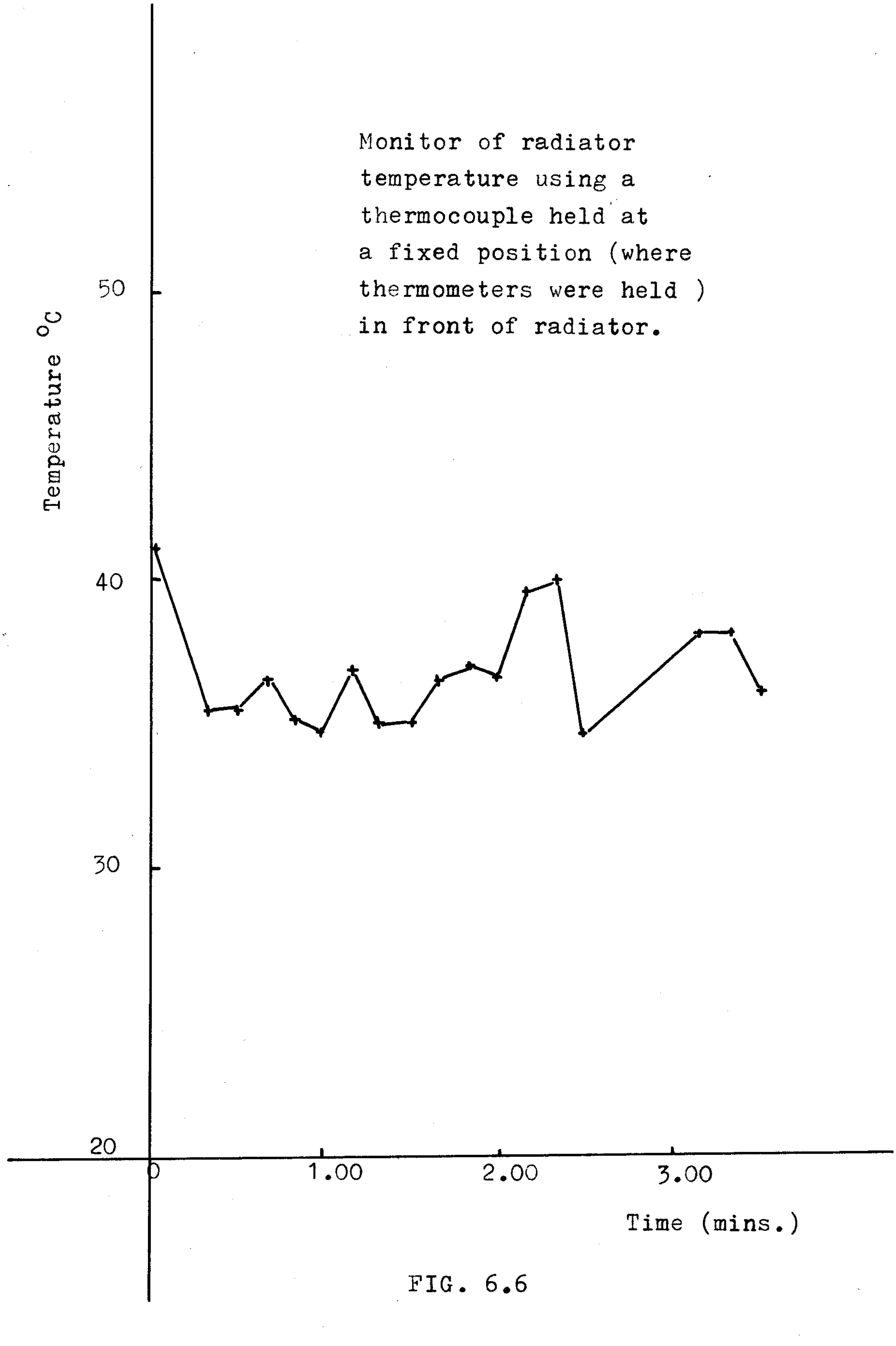

Monitor of radiator
temperature using a
thermocouple held at
a fixed position (where
thermometers were held)
in front of radiator.
Temperature °C
50
40
30
20
0
1.00
2.00
3.00
Time (mins.)

FIG. 6.6

6.4 THE DIFFERENCE IN READING BETWEEN HORIZONTALLY AND VERTICALLY HELD THERMOMETERS

Table 6.3 lists a set of observations taken on vertical and horizontal thermometers placed at the four corners of a frame. The frame was used in an experiment involving a number of different tapes and is described in a later section of this report (See Figure 8.2). The four corners were labelled A, B, C and D for identification purposes only. The thermometers were identical to those labelled A and D in Figure 6.2. The table shows the main difference between the four sets of horizontal and vertical thermometers as well as a dry bulb psychrometer reading. It should be noted that at each of the positions of the frame the thermometers were shaded by a large umbrella and a set of readings under these conditions recorded. The range of the mean differences of horizontal thermometer reading minus vertical thermometer was .5°C to 3.0°C with an average of +1.5°C under unshaded conditions. The respective results for shaded conditions are + .1°C to .7°C and .4°C.

These results corroborate results obtained by pooling values on this aspect for all other field work in which vertical and horizontal thermometers were used. The range for these values was .5°C to 2.6°C with an average of 1.7°C for unshaded conditions and .5°C to 1.2°C and .7°C respectively for shaded conditions.

It should also be noted that air temperature was in the same range for the "pooled" results as for the "frame" results.

The results clearly indicate that there is a definite tendency for the horizontal thermometer to register a higher temperature than the vertical thermometer. It should however be noted that the period during which the results listed in Table 6.2 were taken, occurred close to midday. It is expected that the difference H-V would be a factor of the altitude of the sun. It would follow from this that the difference should be largest during the midday period and the time of highest radiation.

Referring to *Clendinning 1935 (Gold Coast Colony)* in which results are listed for similar experiments, Clendinning's tests covered the period 7.30 hrs - 17.00 hrs and showed similar findings to those above. He found that for this period H-V was invariably positive, reaching a maximum during the midday period. His stated ranges for H-V is $-1.0^{\circ}C$ to $+4.8^{\circ}C$ with a mean of $+ .7^{\circ}C$.

Table 6-3

Time	Thermometers °C								Mean Diff-erence °C	Psychr. °C	Remarks
	A		B		C		D				
11.40	28.3	26.7	28.3	26.7	28.3	27.2	29.4	26.9	+1.7	27.2	.6m above conc. semi sunshine
11.45	30.6	27.8	30.0	27.2	29.4	26.7	30.6	26.9	+3.0	27.2	1m light wind
12.15	30.6	28.6	31.1	30.3	30.0	28.3	29.4	27.8	+1.5	27.2	.6m above asphalt " "
12.20	28.9	27.8	29.4	29.4	28.1	27.5	28.1	27.5	+ .6(s)	27.5	as above shaded by umbrella
12.30	29.2	28.1	28.9	28.6	28.9	28.1	29.7	28.1	1.0	27.5	.8m above asphalt
12.35	27.2	27.2	26.7	26.7	26.7	26.7	27.2	26.7	+0.1(s)	27.2	" shaded by umbrella
13.00	20.3	27.8	30.6	28.3	30.0	27.8	29.2	27.8	+2.1	27.2	.5m above grass sunny, gusty
13.05	28.3	27.3	28.3	27.5	27.5	26.9	27.5	27.2	+0.7(s)	27.2	as above shaded by umbrella
13.10	29.2	27.8	29.2	28.1	28.9	27.8	28.3	27.2	+1.2	27.2	1m above grass, sunny, gusty
13.15	27.8	27.2	27.8	27.2	26.9	26.9	26.9	26.9	+ .3(s)	26.9	" " " shaded by umbrella
15.35	33.0	30.0	32.0	33.0	32.5	31.5	32.0	31.5	+ .9	27.5	.5m above soil, light wind
15.40	31.0	29.5	31.0	31.0	31.0	30.0	30.5	30.0	+ .7(s)	27.5	" " " shaded by umbrella
15.45	30.6	29.5	30.5	31.0	31.0	30.5	31.0	30.0	+ .5	27.5	.9m above soil, sunny light wind
15.50	29.0	29.5	29.0	29.5	29.0	29.0	29.0	28.5	+ .1(s)	27.5	" " " shaded by umbrella

CHAPTER 7

PRELIMINARY LABORATORY EXPERIMENTS WITH TAPES

7.1 GENERAL

A series of experiments, in which outside conditions were simulated by means of a radiator, was conducted with a number of tapes. Figure 7.1 shows the range of tapes used. The aim of the experiment was to establish the factors which affect the temperature behaviour of tapes. All tapes were subjected to the same conditions of radiation and the temperature of the tape and the air surrounding the tape monitored.

The experimental set-up was simple. Control of the conditions was limited to some degree. However the purpose of the experiments was not to make exact measurements but rather to distinguish factors and trends with some degree of accuracy. These factors, as well as providing some insight into the dynamics of temperature in the tape, provided a basis for future field experiments.

7.2 THE EXPERIMENTAL ARRANGEMENT

The source of radiation for the experiments was one of two radiators. These radiators were ordinary office radiators, 1 ft. long and 2 ft. respectively. A sheet of asbestos was placed on the floor to simulate the ground surface. Figure 7.3 gives diagrammatically a view of the entire set-up whilst Figure 7.2 gives a close-up view of the tape and temperature elements.

The earlier experiments were conducted using the smaller of the radiators however experience showed that the heat from this particular radiator was very localized and varied considerably with direction. The larger radiator on the other hand provided more even heating.

Thermocouples were attached to the upper and lower surfaces of the tape as well as being positioned in the air surrounding the tape. The thermocouples were attached to the tape by means of solder. Two thermometers were placed adjacent to the tape and at times thermistors were also used to monitor both the tape and air temperature.

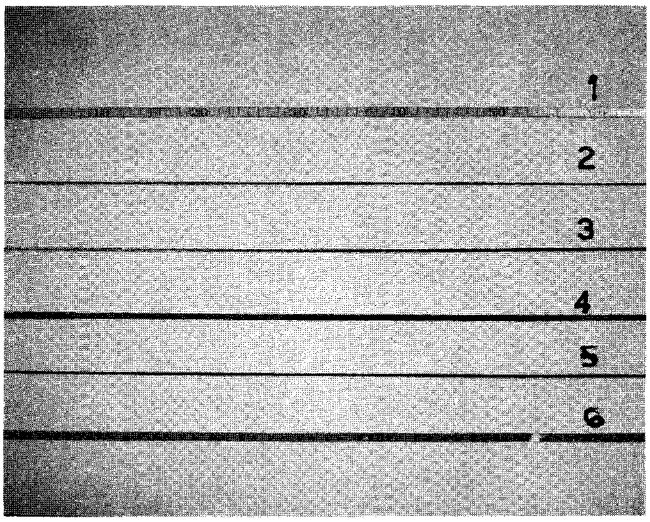


FIG. 7·1

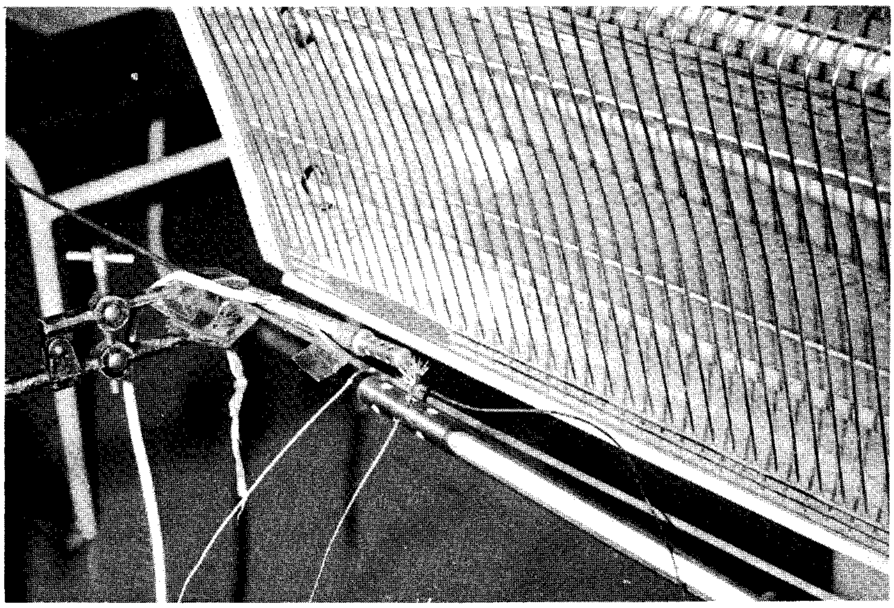


FIG. 7·2

Once the radiator was switched on, the temperature reading of all the elements was monitored. Each of the experiments lasted approximately 40 minutes during which time the system had heated to the extent that it reached a steady state. Subsequent to this the radiator was switched off.

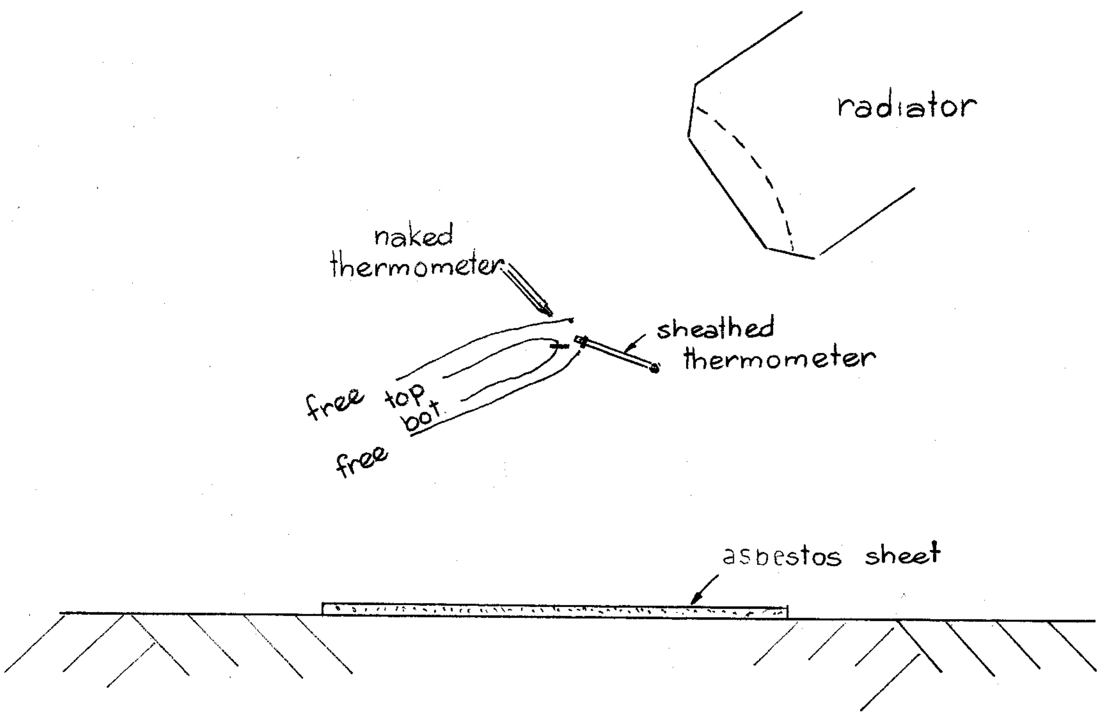


FIG. 7·3

7.3 EXPERIMENTAL RESULTS

Experiments were conducted on the tapes as follows:-

Width (in.)	(mm.)	Surface Quality	Small radiator	Large radiator	Total
1/12"	2	dull	1	2	3
1/10"	2.5	dull	1		1
1/8"	3	bright	2	1	3
1/4"	6	dull	3	1	4
3/8"	10	matt	2	1	3

TABLE 7.1

Taking each of the tapes individually.

7.3.1 1/12" Tape (dull)

Let the experiments, the results of which are shown in Figures 7.4, 7.5 and 7.6, be referred to as experiments 1, 2 and 3. In each of the three experiments on this particular tape it can be seen that the thermometers read considerably higher than the tape. In the first experiment the naked thermometer and the sheathed thermometer read approximately 2-4°C higher than the tape while in the second and third experiments the respective readings were 10-15°C (naked) above, 5-6°C (sheathed) above and 10-12°C (naked) above, 2-5°C (sheathed) above. It should however be noted that the maximum reading of the tape temperature varied in each case. Further in experiments 1 and 3 it can be seen that the tape and free thermocouples followed very closely the same temperature reading whilst in experiment 2 the free thermocouple read significantly lower. The difference in the latter case is probably due to a poor connection between thermocouple and meter or poor positioning of the thermocouple.

7.3.2 1/10" Steel Tape (dull surface) - Experiment 4

In this experiment the small radiator was used and the maximum temperature reached by the tape was 45°C. The tape read marginally higher than the thermometers (1½-2°C) at maximum temperature, whilst the free thermocouples read approximately 6°C lower than the tape. It may also be noted that the tape and free thermocouples follow fluctuations in temperature closely. Further these fluctuations, which could be as large as 3°C, are not indicated in the thermometer readings.

7.3.3 1/8" Invar Tape (shiny surface) - Experiments 5, 6 & 7

In this series of experiments there are significant differences between the results. However in general there is no clear difference between the tape readings and the free thermocouple readings.

Another general pattern evolving is that the tape does not seem to reach high temperatures under heating from the large radiator, whilst the thermometers seem to follow a similar pattern to that resulting from heating from the small radiator.

Experiment 6 gives some indication of the speed at which the tape can gain and lose heat. Undoubtedly the amount of radiant heat striking the tape will be an important factor in this characteristic, however this particular tape was gaining and losing heat at approximately 24^{o}C per minute during the experiment.

7.3.4 1/4" Steel Tape (dull surface) - Experiments 8,9,10 & 11

In this series of experiments, 8, 9, 10 were conducted using the small radiator, whilst 11 was conducted using the large radiator. Experiments 8 and 9 were conducted under the same conditions in that the radiator was positioned beneath the tape. In experiments 10 and 11 the radiator was positioned above and behind the tape as shown in Figure 7.3.

In this series of experiments the tape attains a distinctly higher temperature than any of the other elements. In experiment 8 the tape reads 15-16^{o}C higher than the thermocouples immediately surrounding the tape. The corresponding differences in experiments 9, 10 and 11 are:- 12-15^{o}C, 9-10^{o}C; 3-4^{o}C, 6-8^{o}C; and 9-10^{o}C respectively where there were two free thermocouples in experiments 9 and 10.

It is fairly clear that the tape is behaving to a large degree like a black body. The higher the temperature the greater would be the difference between the surrounding air temperature and the tape temperature.

Additional information can be obtained from Figure 7.14 which shows that the readings given by a thermometer follows closely the temperature of the sheath. Figure 7.16 shows the distinct variation of temperature in the air immediately surrounding the tape. The tape would also be acting as radiator under these conditions. This would have a bearing on the temperature readings mentioned above.

7.3.5 3/8" Steel Tape (matt surface) - experiments 12, 13 & 14

The results of this series of experiments are shown in Figures 7.18 to 7.20. Experiments 12 and 13 were conducted using the small radiator, whislt experiment 14 was conducted using the large radiator.

Although the results of experiment 13 vary significantly from those of 12 and 14, there is however a similar trend throughout the three sets of results. In experiment 12 the tape read 6-7^{o}C higher than the free thermocouples at the "steady state". The corresponding differences in experiments 13 and 14 are 2-3^{o}C and 6-7^{o}C, 6-12^{o}C respectively, where there were two free thermocouples in experiment 14. The thermometers show a different relationship to the other elements in each case. This is probably due to variation in positioning of the thermometers from one experiment to the next. It does however indicate the unsuitability of using a thermometer in this situation.

7.4 OVERALL COMMENTS

(a) A given tape will absorb heat at a particular rate dependent on its surface area and on certain factors of its surface such as colour, material and roughness. The same tape will also dissipate heat at a rate dependent on similar factors, as well as the amount of heat absorbed. The temperature of the tape will stabilize when the rate of absorption of heat equals the rate of dissipation. The temperature of the tape at this point of equilibrium may in fact be hotter than the surrounding air.

(b) The same principle applies to a thermometer when heated by means of radiant heat. Hence the sheath of the thermometer will have a distinct bearing on the temperature reading of the thermometer. It should be stressed that like the tape the thermometer may also reach a temperature greater than the true air temperature.

(c) The position and direction of heat from the radiator may have a bearing on the results. That is whether the radiator is directly facing the broad surface of the tape or only partly facing this surface.

(d) The attachment of the thermocouples to the tape is critical. The thermocouple test junction should be carefully formed preferably by spot welding and be as small as possible. The thermocouple should then be either spot-welded or soldered onto the tape.

(e) The attachment of a thermistor to the tape as shown in Figure 3.5 presents a problem in that the actual sensing element of the thermistor is encased by a thin covering of glass similar to the bulb of a thermometer. The problem is overcome to some degree by the use of a silicon grease. The grease acts as conductor of the heat from the tape to the thermistor. The thermistor is attached by means of adhesive tape. The thermistor is however affected to some degree by the surrounding air conditions.

(f) Initially there was some concern as to whether the entire mass of the tape reached the temperature recorded by the various sensing elements or whether there was a temperature gradient through the tape. Consultation with C.S.I.R.O. Scientists indicated that although there may be small gradient it would not significantly affect results. The results shown in Chapter 5 bear this out.

(g) It may be of interest to note that the present general shape of the tape is perhaps the best from the point of view of heating evenly throughout its mass. This is so, because for a given mass of tape, the shape offers a good surface area.

To illustrate - if the tape were of circular cross-section of radius 1/16" then the surface area for an element 1" long is .3925 sq. ins. To realize the same mass in a rectangular cross-section of 1/50" thickness, the width would be .605". The surface area for an element 1" long would be 1.220 sq. ins.

(h) The thermometers used in the experiments were a poor means of measuring the air temperature surrounding the tape. Apart from the fact that the thermometer will behave as described in (b) above, it is difficult to position the thermometer in order to obtain consistant results if the position of the source is to be altered. Their physical size also made it difficult to position them.

(i) As mentioned previously in this chapter it was felt that the larger radiator was superior to the smaller radiator. It provided a more evenly heated environment which, it is felt, is more representative of real conditions. However the experience with the smaller radiator was valuable in that it gave experience in measurement under more variable conditions.

(j) Dealing with the results more specifically, it is apparent that the two main factors affecting the temperature behaviour of the tape are its width and the surface qualities of the material of the tape. It is difficult to separate them in importance, however it appears that the surface qualities have a more marked effect on the wider tapes.

Most of the investigations conducted in the former British Colonies as described in (1), (2) and (3)* would have related to tapes similar to that used in experiments 8, 9 10 and 11 although this is not entirely clear. In these publications it is generally conceded that the tape was often at a temperature higher than the air, or more particularly than the thermometers used. There was considerable variation in the stated difference of the two temperatures.

(k) The main conclusion drawn from these experiments is that the characteristics of the tape do have bearing on the temperature behaviour of the tape and that unless the temperature measuring instrument measures the temperature of the tape directly these characteristics must be accounted for.

*(1) *Clendinning* *1935*

(2) *Thornhill* *1935*

(3) *Jackson* *1935*

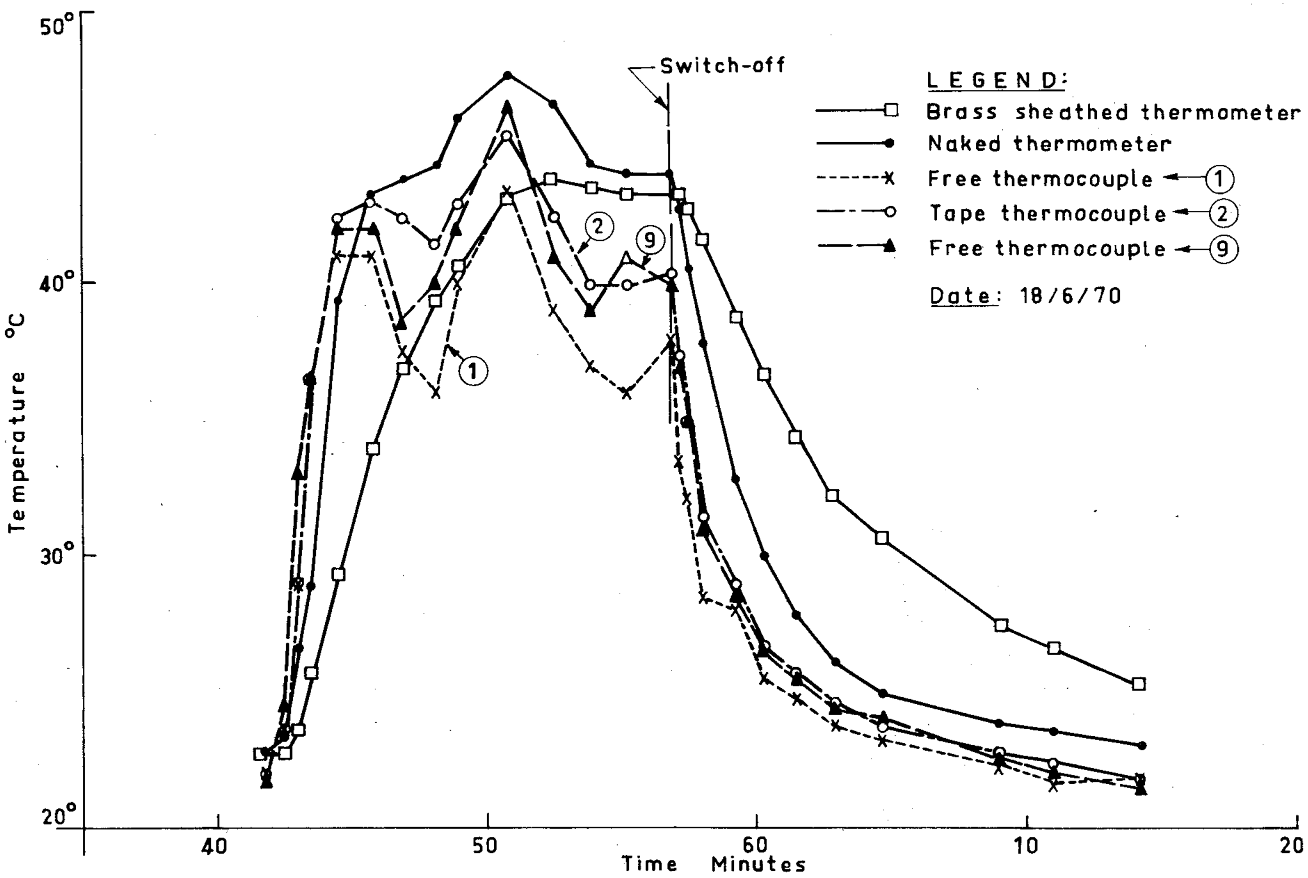


FIG.7·4: TEST ON DULL 1/12" TAPE

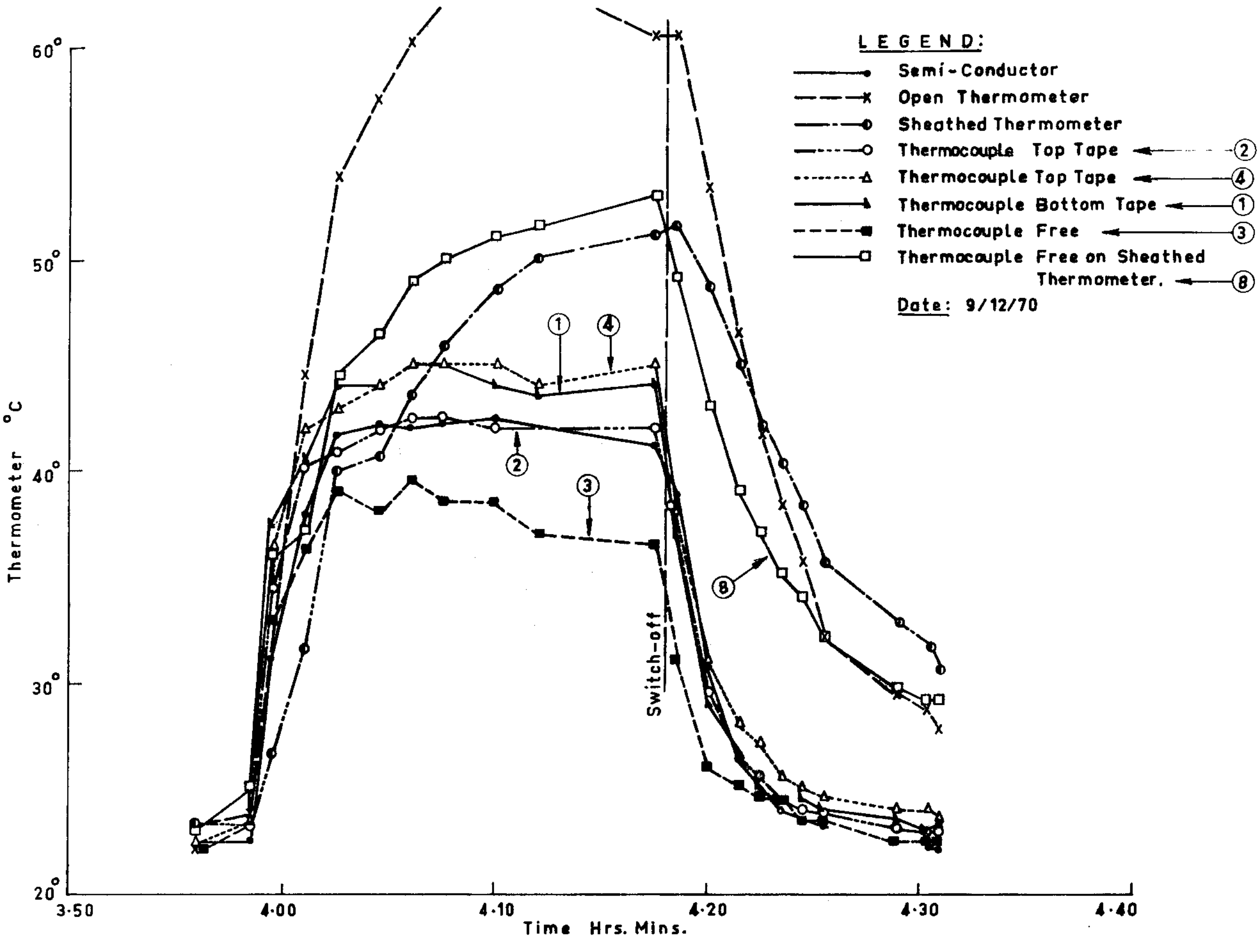


FIG. 7·5: TEST ON 1/12" DULL SURFACE TAPE

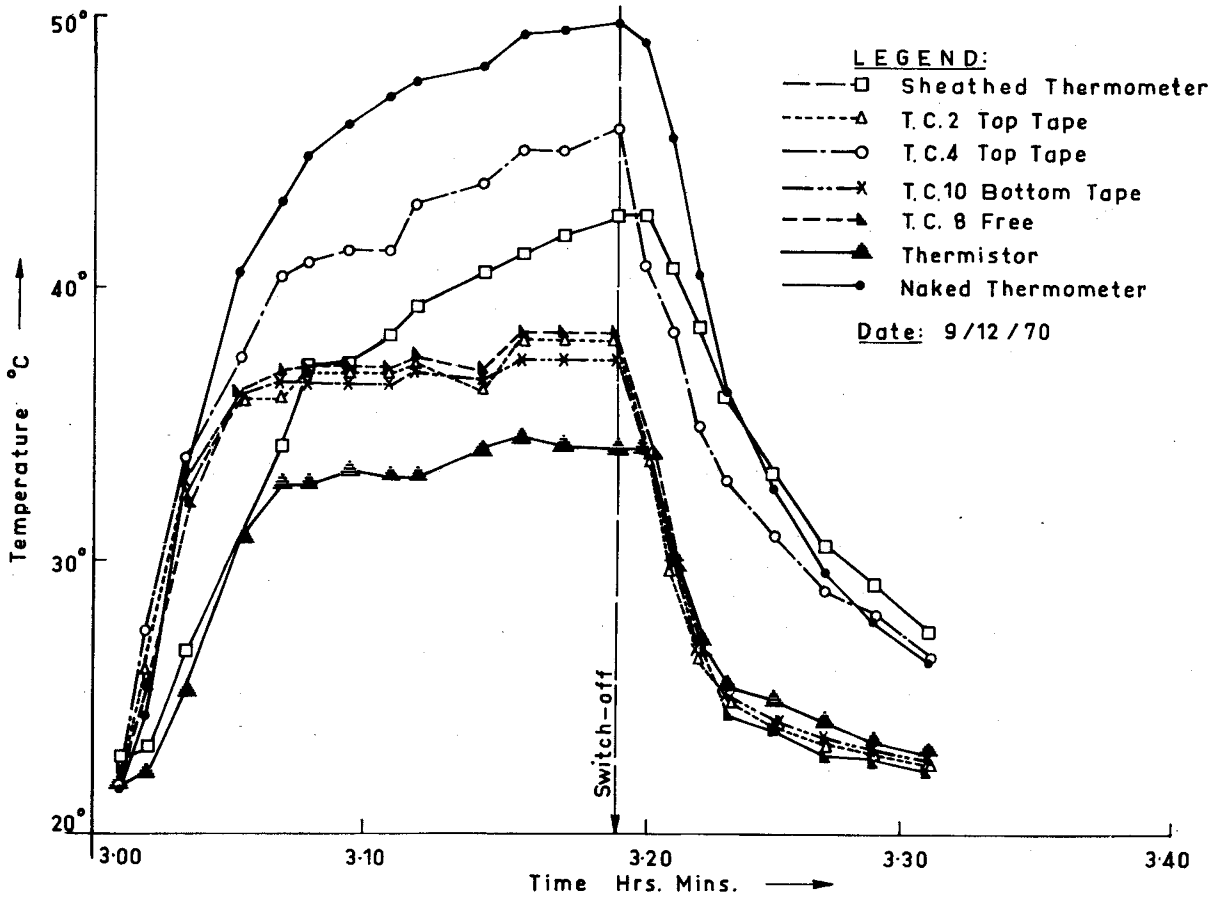


FIG.7·6: TEST ON 1/12" DULL SURFACE TAPE

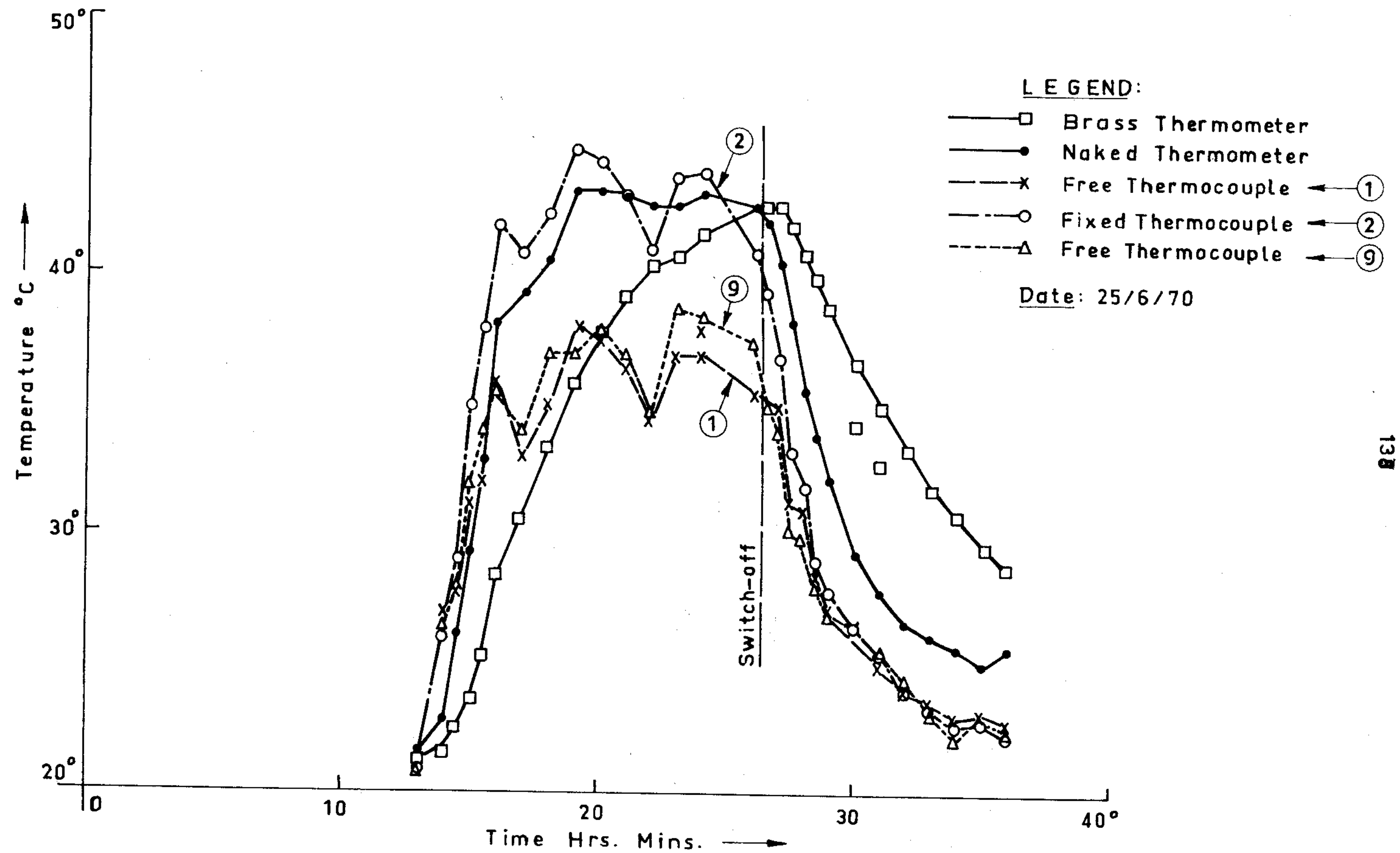


FIG. 7·7: TEST ON DULL 1/10" STEEL BAND

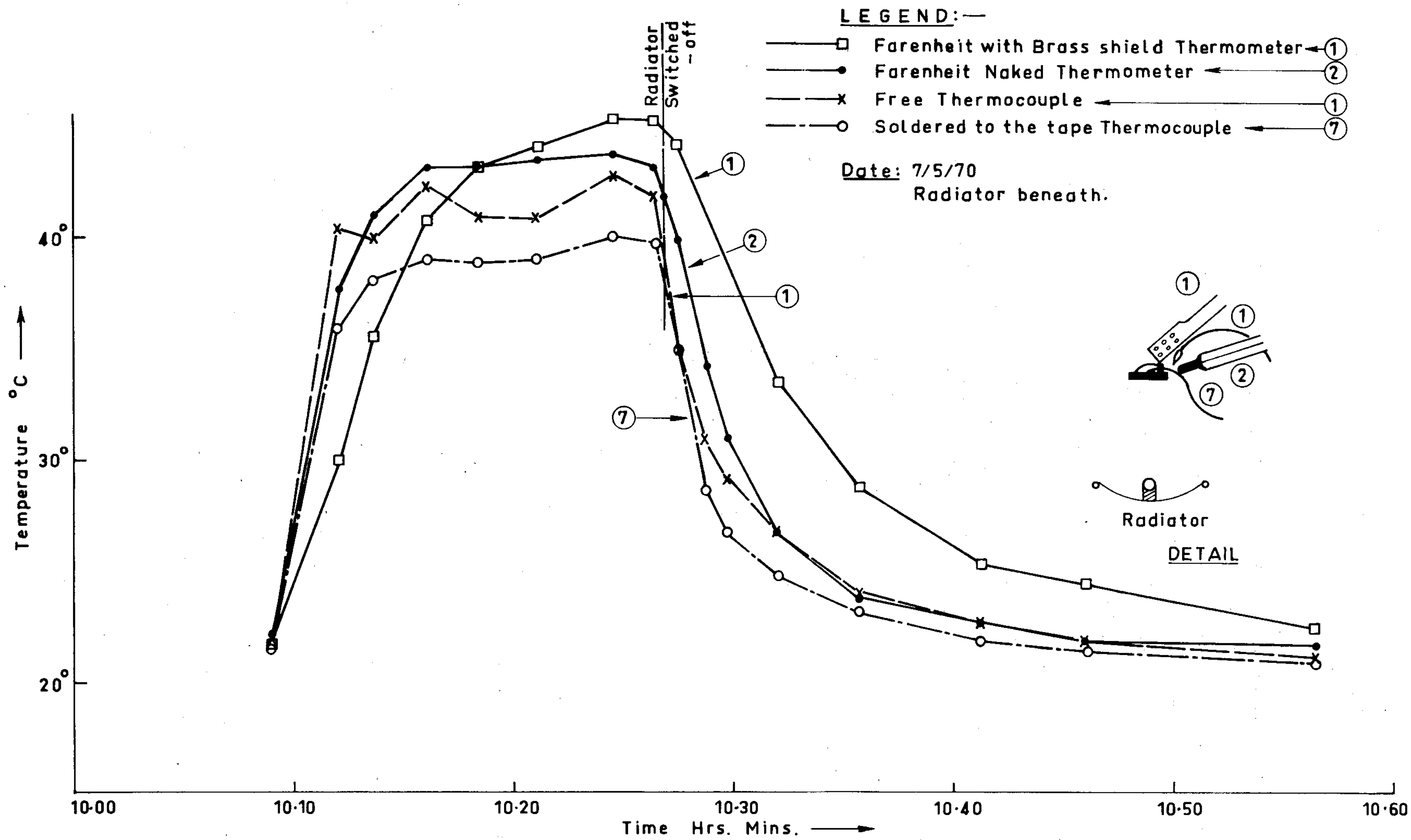


FIG. 7·8: TEST ON $\frac{1}{8}$" BRIGHT BAND TAPE.

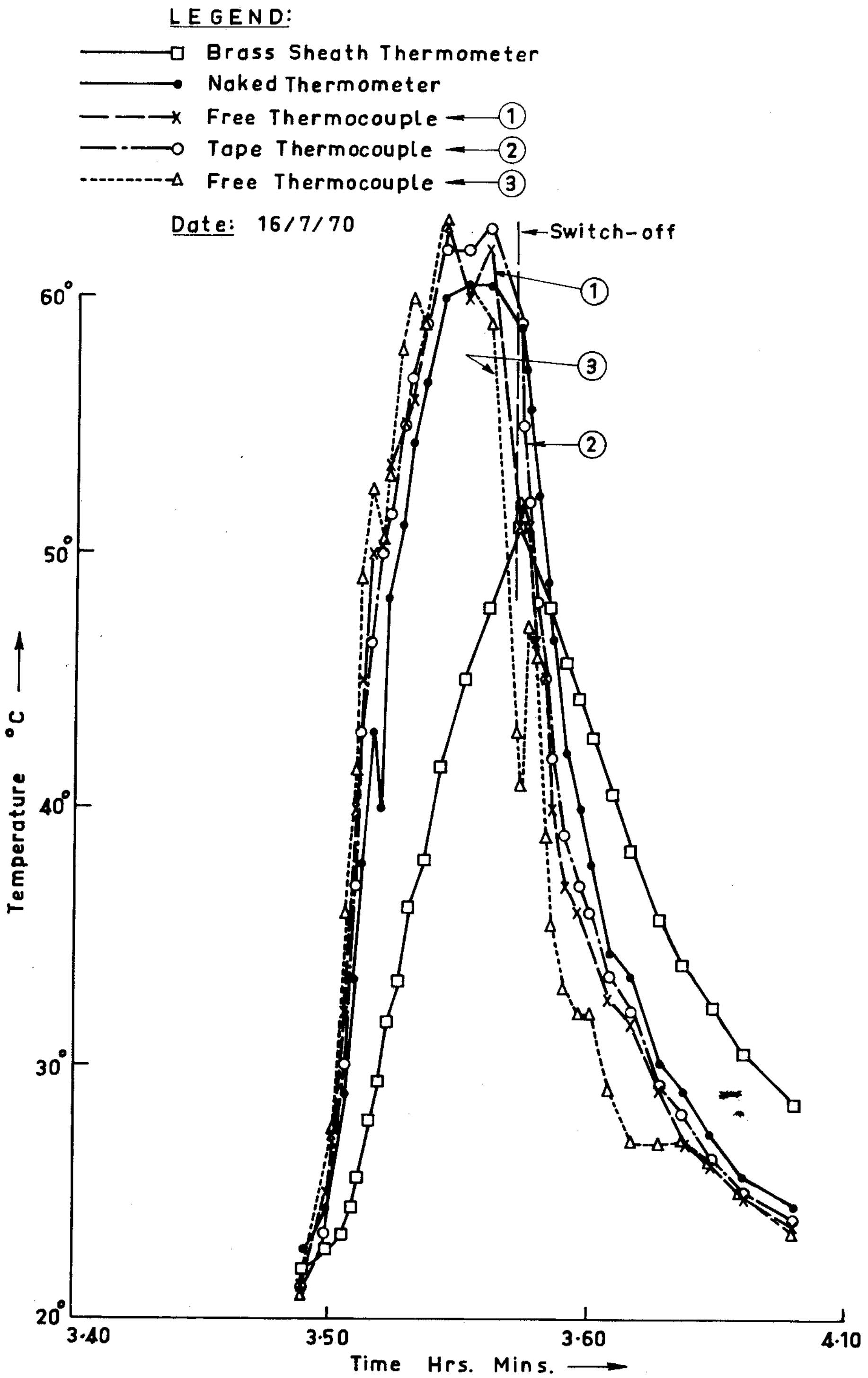


FIG. 7·9: TEST ON 1/8" SHINY SURFACE TAPE

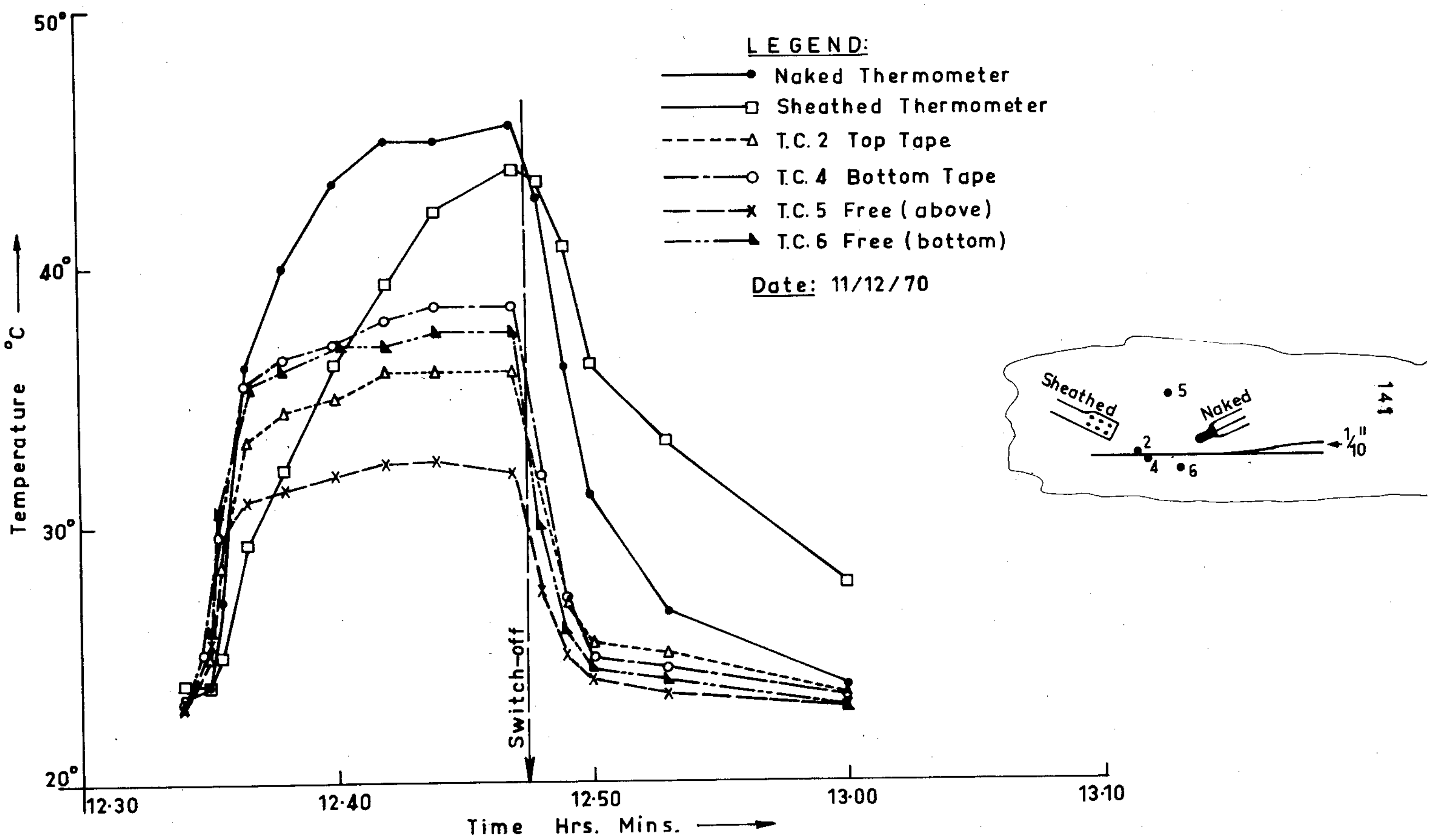


FIG. 7·10: TEST ON 1/8" SHINY TAPE

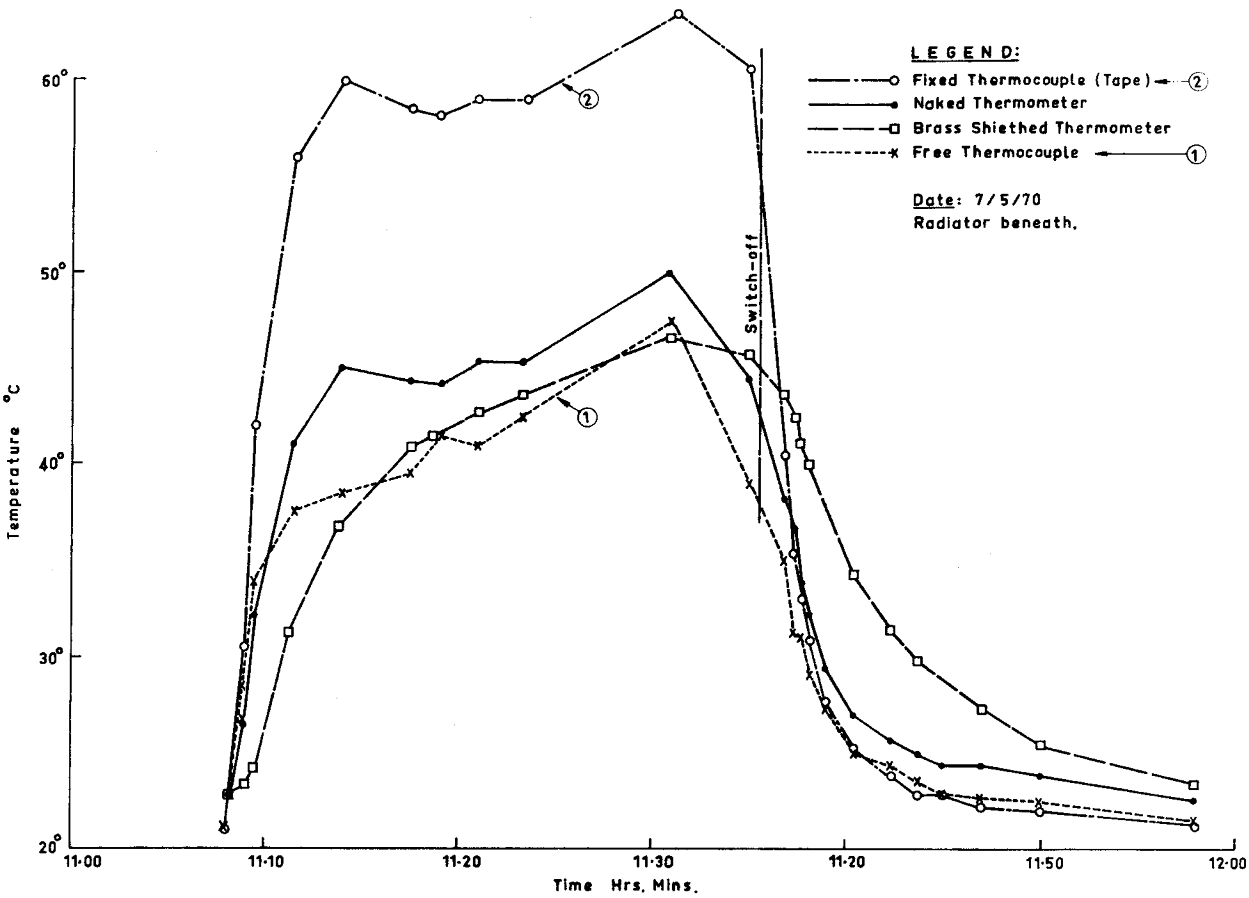


FIG. 7·11: TEST ON 1/4" WIDE BLACKENED LUFKIN STEEL TAPE

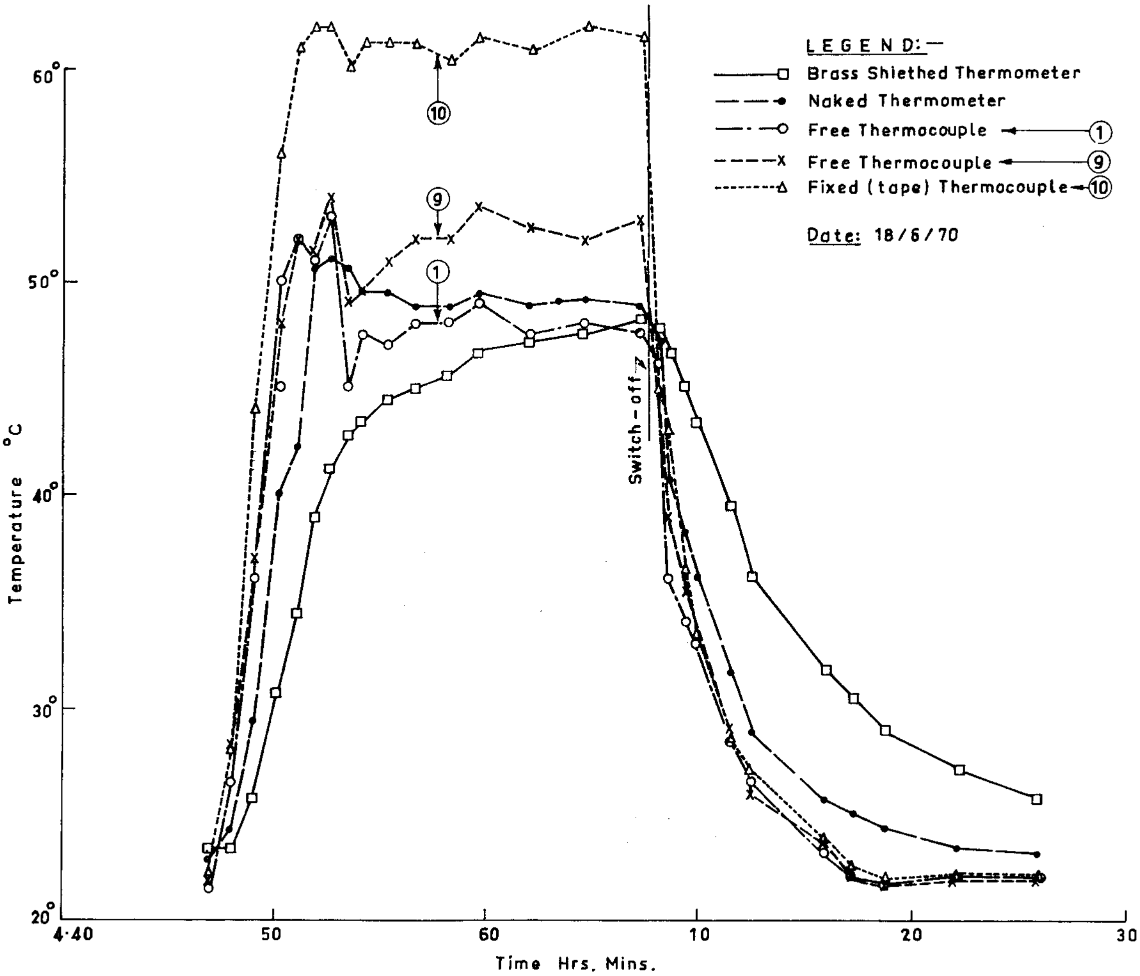


FIG. 7·12: TEST ON 1/4" WIDE DULL SURFACE TAPE.

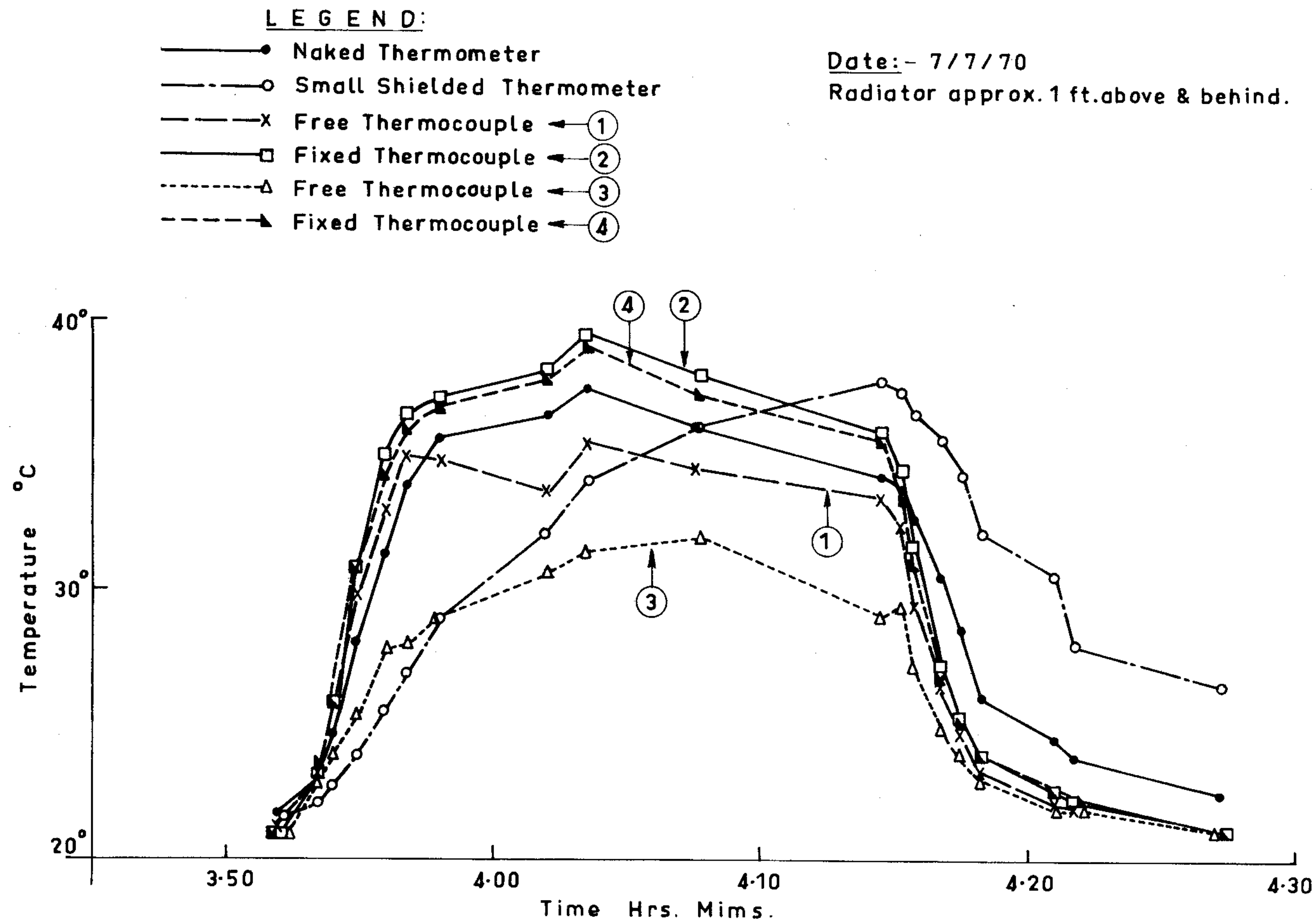


FIG. 7·13: TEST ON 1/4" LUFKIN DULL SURFACE TAPE

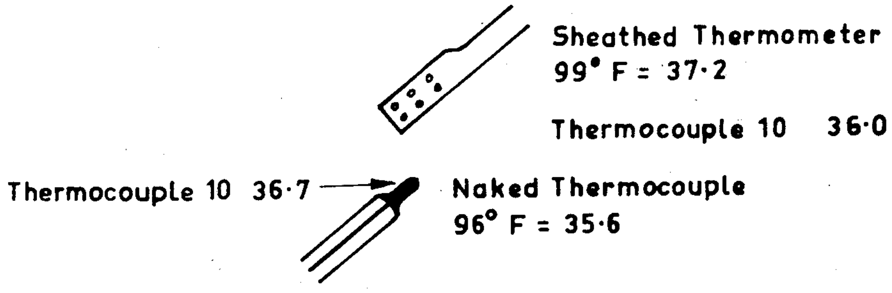


FIG. 7·14

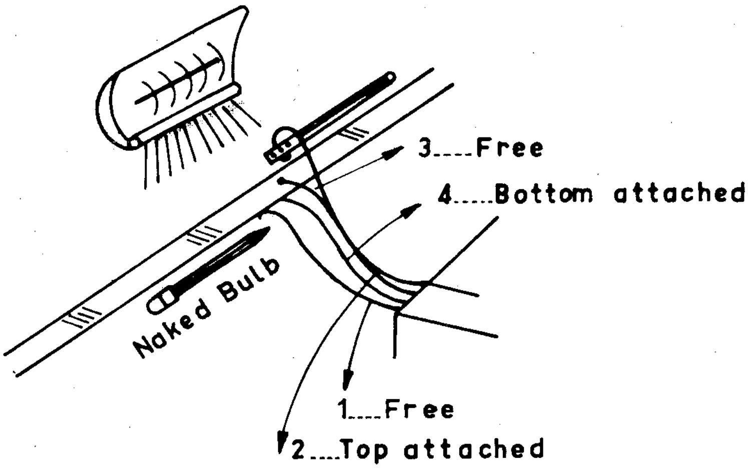


FIG. 7·15

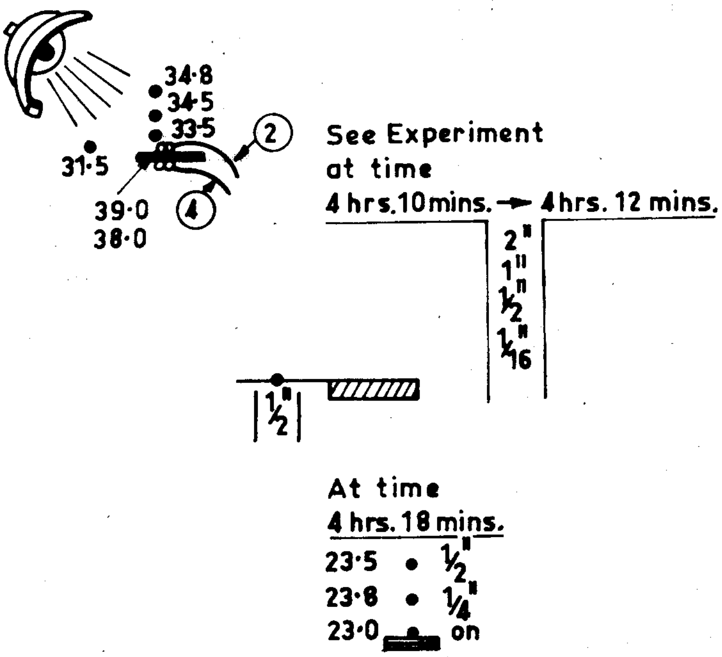


FIG 7·16

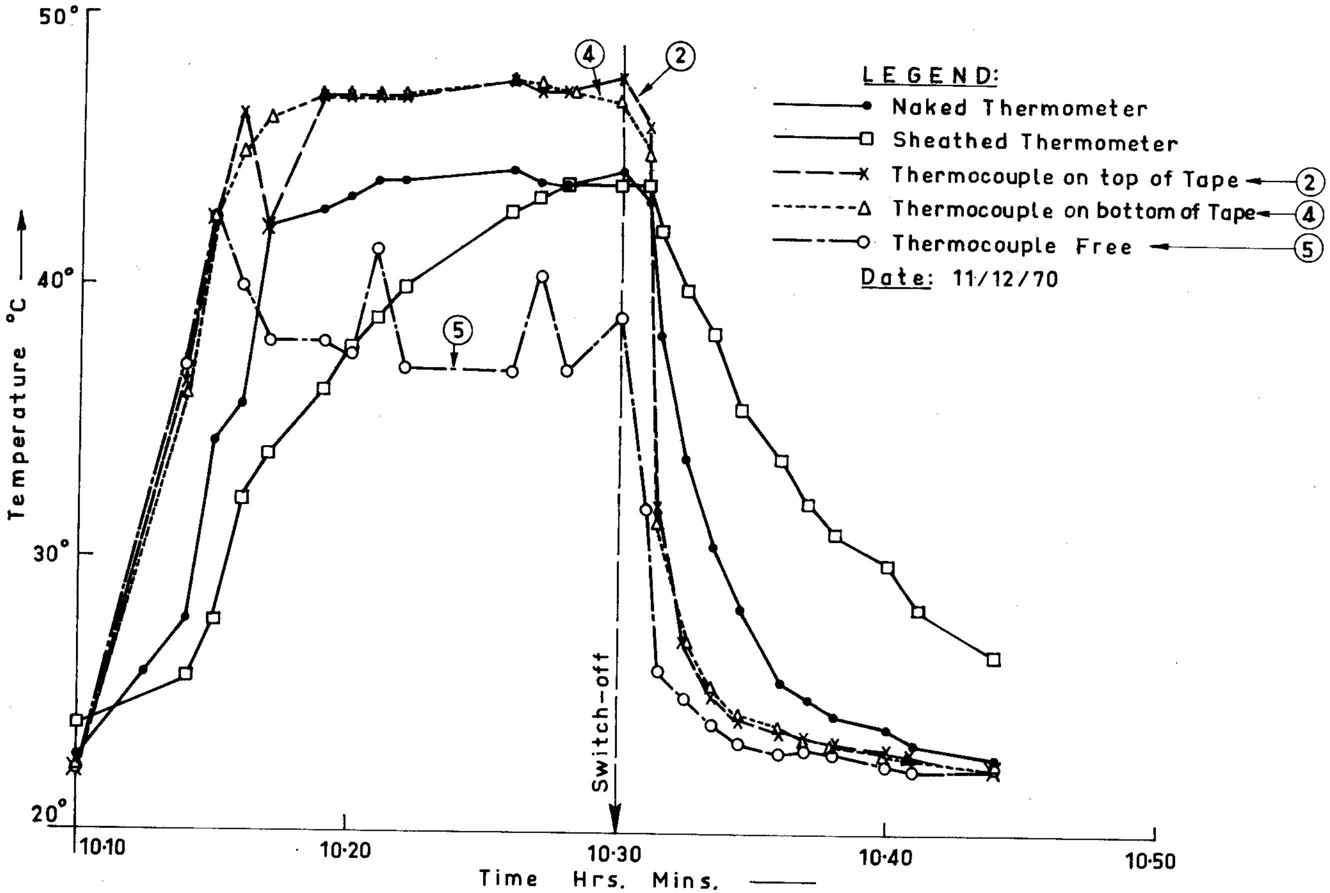


FIG. 7·17: TEST ON 1/4" WIDE DULL SURFACE

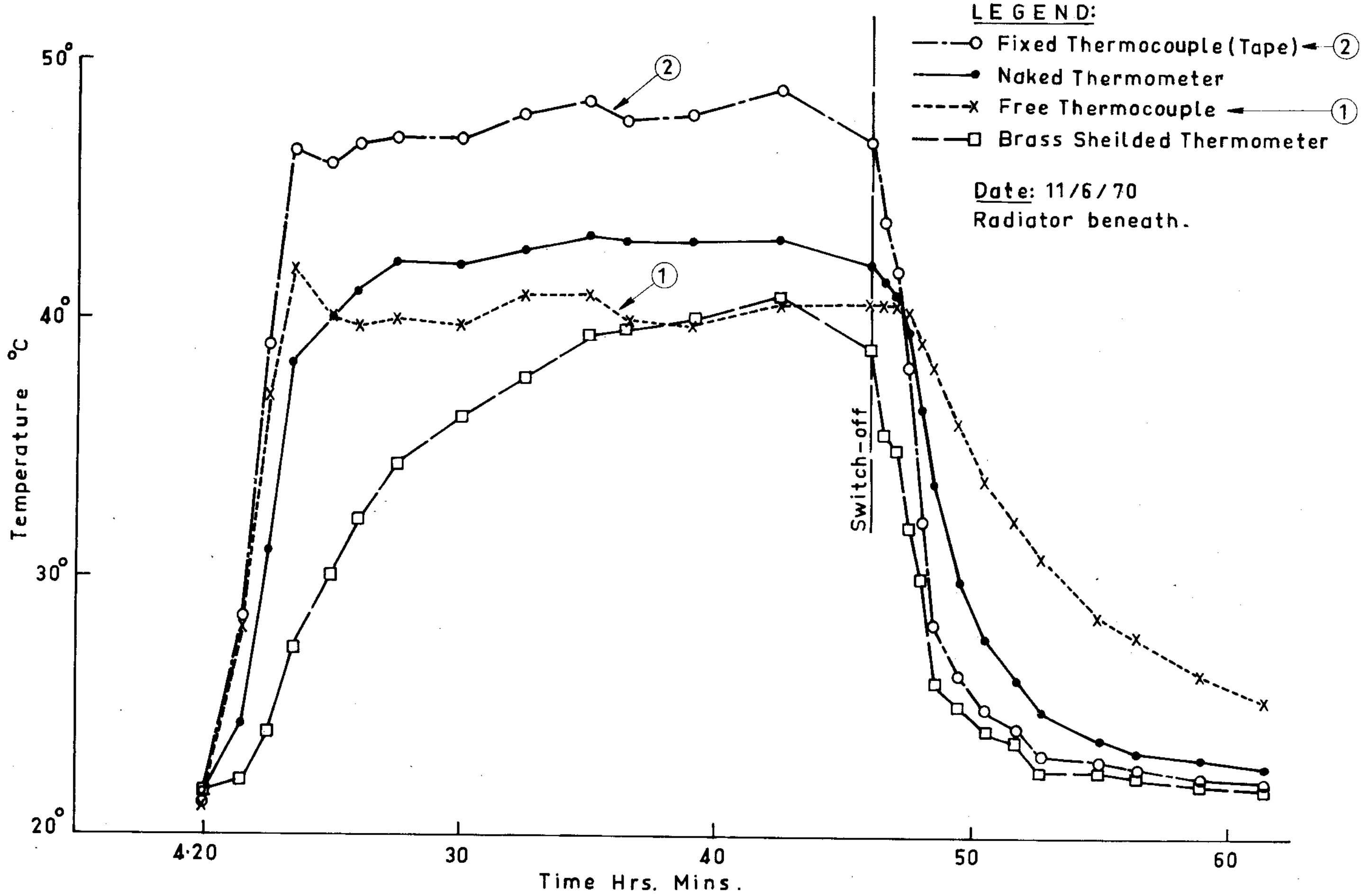


FIG.7·18: TEST ON 3/8" STEEL LUFKIN TAPE CHROME SURFACE

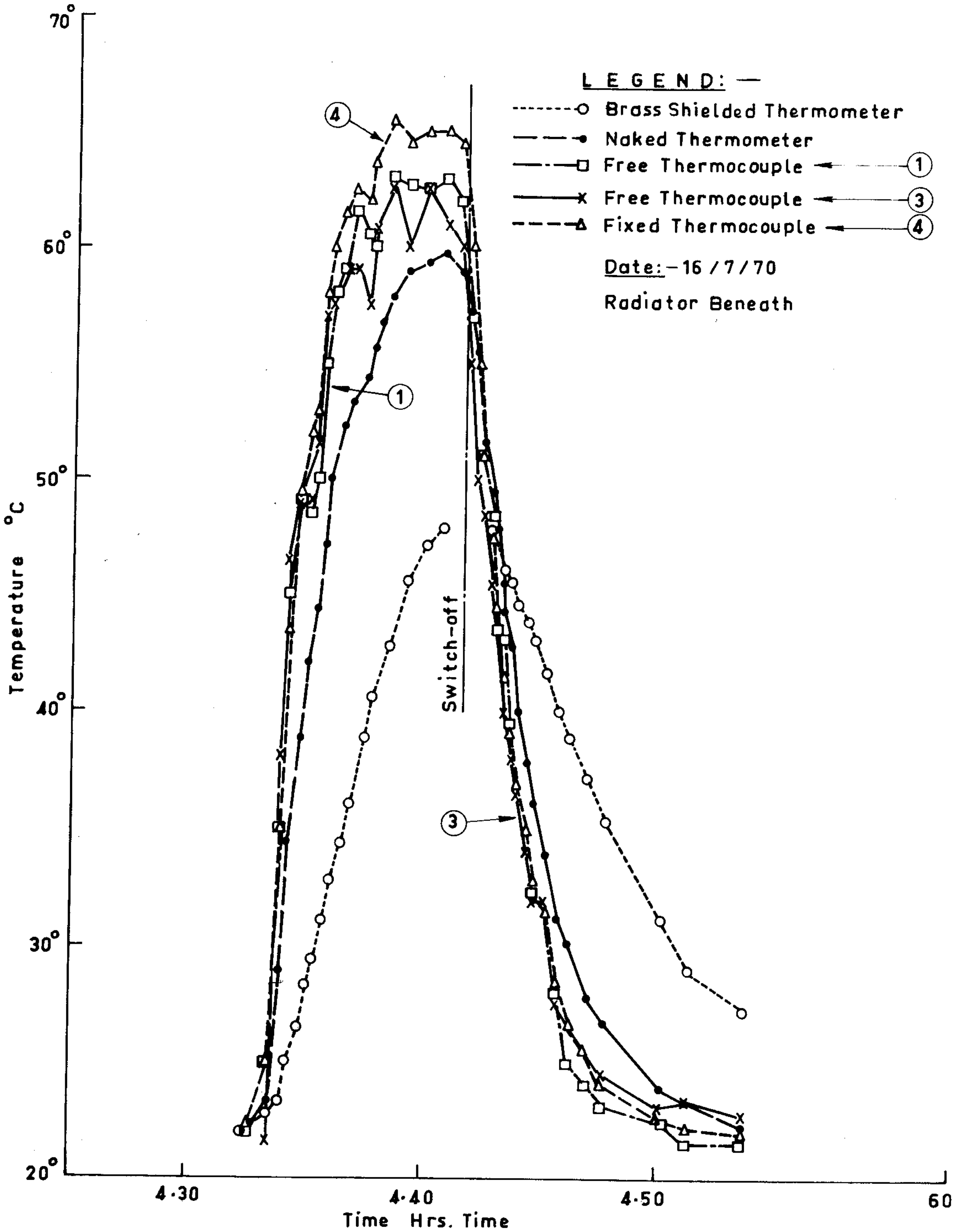


FIG. 7·19 TEST ON LUFKIN TAPE CHROME SURFACE SEMI-BRIGHT

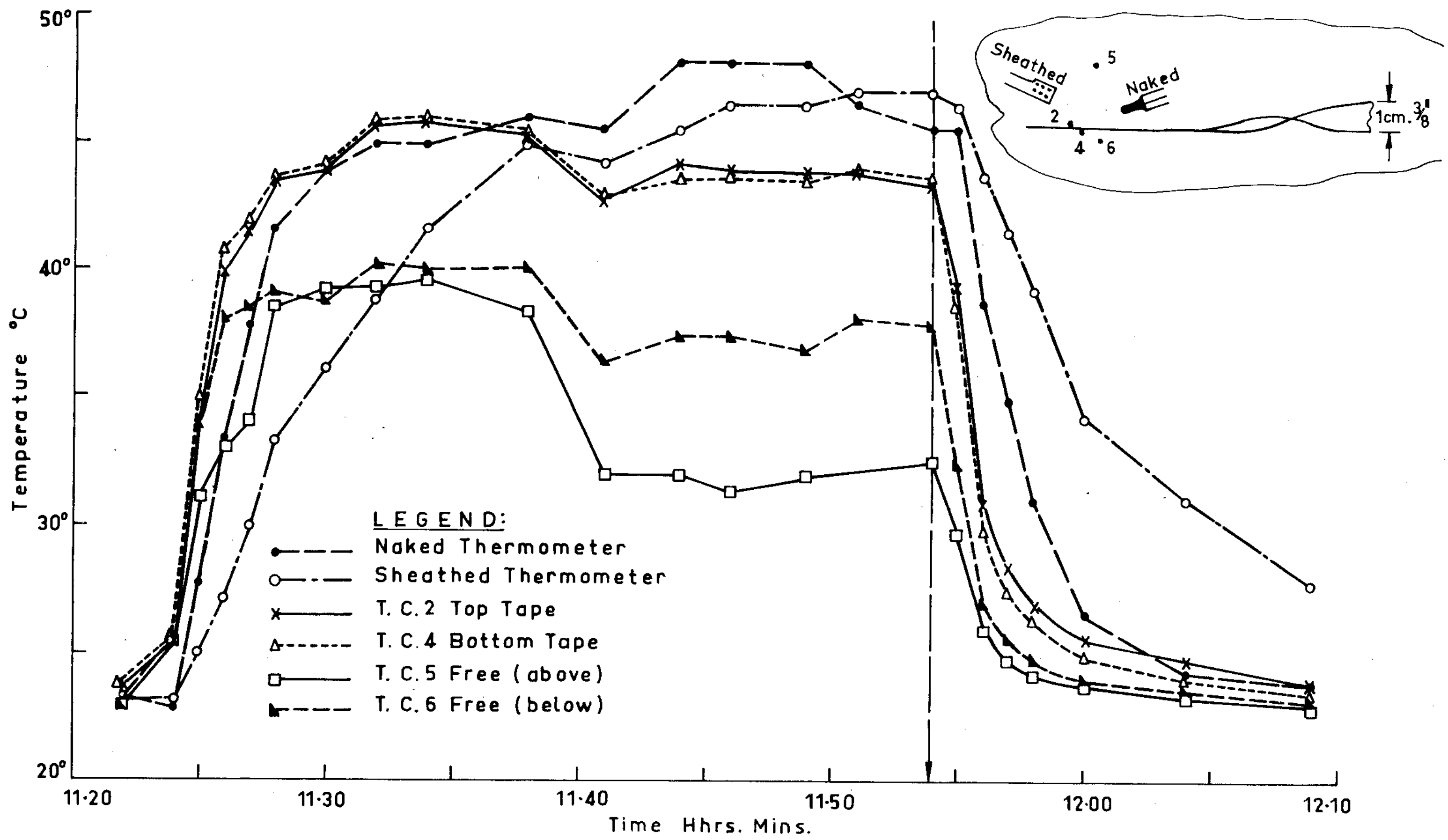


FIG. 7·20 3/8" LUFKIN CHROME SURFACE, 12/12/70.

CHAPTER 8

FIELD TESTS

8.1 GENERAL

During January, 1971, two field experiments were conducted in the first case tapes (1), (2) and (3) Figure 7.1 and in the second case all the tapes shown in figure 7.1. The first test is illustrated in Figure 8.1 which shows the experimental arrangement on the roof of the Civil Engineering/Surveying building. The equipment used in the second test is shown in Figure 8.2.

A long period of inclement weather curtailed the field work severely. As items of equipment had been borrowed and had to be returned by a set date it meant the experiments had to be either abandoned or modified. The second experiment mentioned above was a result of this as it was originally intended to conduct an extended series of experiments of the first type.

The purpose of the field tests was to determine the behaviour of the different tapes under a variety of field condition as well as evaluating the various temperature measuring devices. It was not possible for reasons mentioned above to obtain results under the variety of conditions hoped for however the results which follow do allow broad conclusions to be reached.

8.2 THE ROOF EXPERIMENTS

The Experimental Arrangement

The equipment used for the roof experiments was identical to that used in the calibration tests conducted in the lower ground corridor. As mentioned earlier Figure 8.1 shows the experimental arrangement.

It was not possible to use the dial gauge to measure the extension of the tape as it was done in the lower ground corridor. A breeze was invariably blowing across the site causing the tape to "flutter". This resulted a wavering longitudually of the tape of ½ mm. at least, making measurements for extension meaningless. The tripods shown in Figure 8.1 were used to suppress the fluttering which had a tendency to break the connections between the tape and the thermocouples and thermistors, which were attached to the tape.

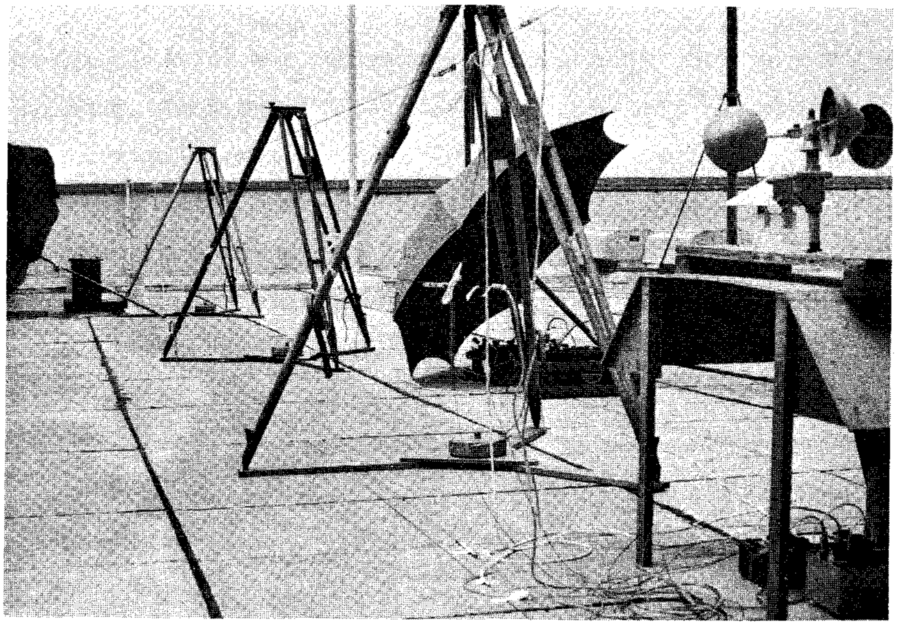


FIG. 8·1

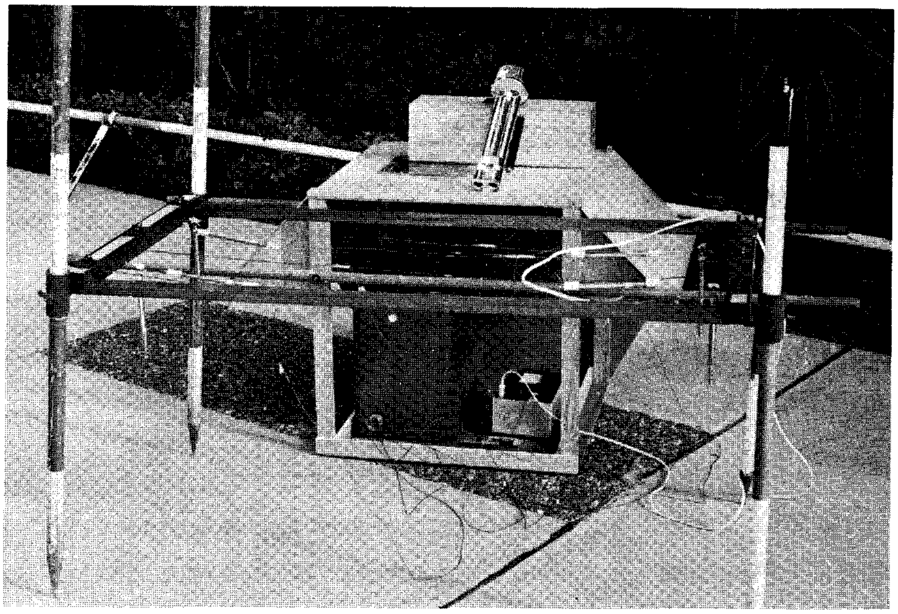


FIG. 8·2

The tape was suspended at three levels - on the ground, 0.7 m. and 1.2 m. at the beginning separately and later simultaneously. Thermometers of the types A, C and D Figure 6.1 were attached both horizontally and vertically to the tape at each of the upper levels whilst horizontal thermometers only were attached to the ground level. Thermocouples and in some cases thermistors were attached adjacent to the thermometers at each of the levels. An anemometer was used to record the wind speed. The Wheatstone bridge was used to measure the resistance of the tape at the upper level.

8.3 EXPERIMENTAL RESULTS

8.3.1 Symbols and Notations

(a) Abbreviations

TC = Thermocouples

TST = Thermistor

SThs = Thermometer, short sheathed

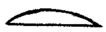
SThl = Thermometer, long sheathed

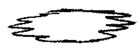
nThs = Thermometer, naked, short.

e.g.

VsThs (5) = Vertical, short, sheathed thermometer No. 5

(b) Symbols

 Umbrella

 Cloud  Sun

8.3.2 Results for 10 mm. White Painted Metric Tape

The field work on this particular tape was conducted on the 12th January, 1971, and it can be seen from the result sheet, shown in Table 8.1, that the air temperature reached a maximum of approximately 30°C and a 12 k.p.h. seabreeze was blowing.

The tape was placed at the three levels indicated in 8.2 and a set of readings taken. Figure 8.3 shows the positions of each of the temperature measuring elements along the length of the tape.

10 mm white painted, steel metric tape

Date 12-1-71

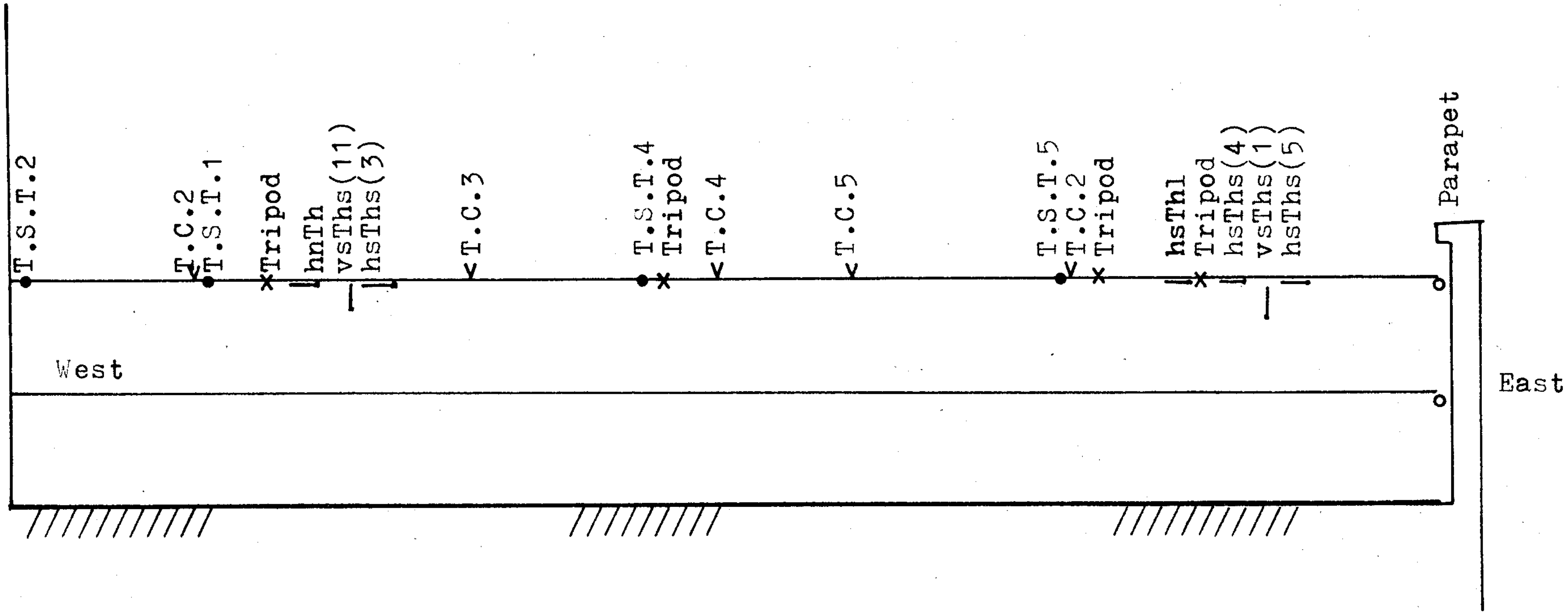


FIG. 8.3

TABLE 8.1

12.1.71

10mm. WHITE PAINTED METRIC TAPE

ROOF

Time	Thermometers				Thermocouples			T.S.T.	Thermometers			Thermocouples		Thermistors			Bridge	Remarks
	5	4	1	1	2	4	5	5	N-	11	3	2	3	2	1	4		
11.16 → 11.19	31.1	31.9	-	28.3	29	28½ 25 → 30	28½ 25 → 31	28.7	27.2	27.2	27.2	26	29	29.8	25.5	30.5	19,400 ← 28.8 19,450 → 29.6	Height: abt. 1.2m. Wind: 14-21 R.P.M.
11.35	29.4	30.6	-	27.2	26½-28	27	28	27.5	28.3	26.1	27.2	26	28	28.8	26	28.5	19,360 ← 28.2	Wind: 2.3°C
12.22	30	30.6	30.6	27.8	29	29	29	27.5	27.5	25.6	26.1	30+	29.5	28	27	28.5	19,430 → 29.5 19,540 ← 31.0 19,560 → 31.6	
NOTES					2-3°C affect 3°C Variation in temp.													
12.50	28.3	-	28.3	27.2	28.5	30.0	29.5	29.5	26.7	26.1	26.7	29.5	28.5	25.5	29	30+	19,520 ⇄ 31.[illegible]	Height: Abt. .7m.
14.05	28.6	-	28.3	28.1	29 2-3°C Variation	27.5	27.5		26.1	26.1	26.7						19,530 31.0	Wind: 26 R.P.M. Shadow: 1460 Wind: 16 R.P.M.
14.20	33.3	-	35	33.6	35.8 4-5° Variation	37	37	30+	34.2	35	33.3	25	33	26	26	30+	19,760 → 35 19,830 ← 36.2	Height: On Ground 3m. in shadow.

Table 8.2 shows the results meaned for particular instruments and positions.

TABLE 8.2

The 10 mm White Painted Tape

Time	Thermometers Horizontal Naked	Δ	Sheathed	Δ	Vertical Sheathed	Thermocouples	Δ (WB)	Thermistors	Δ (WB)	Wheat-stone Bridge	Remarks
11.16	27.2	+2.9	30.1	+2.3	27.8	28.5	+ .3	28.6	+ .2	28.8	1.2m
11.35	28.3	+0.8	29.1	+2.5	26.6	27.5	+1.3	27.7	+1.1	28.8	1.2m
12.22	27.5	+1.8	29.3	+2.6	26.7	29.5	+1.7	27.7	+2.5	31.2	1.2m
12.50	26.7	+1.0	27.7	+1.0	26.7	29.5	+1.8	29.5	+1.5	31.0	0.7m
14.20	34.2	-0.3	33.9	-	34.3	35.7	- .1		-	35.6	0.0m Wind

A number of points are evident from Table 8.2. The temperature of the tape, as determined by the thermocouples and thermistors as well as being close to one another are close to the temperature determined from the wheatstone bridge readings. It is also evident that the characteristics and the position of the thermometer have a distinct bearing on its reading. The naked thermometer consistently read lower than the sheathed thermometer and the vertical thermometers read approximately 2.5°C lower than the horizontal thermometers. *Clendinning (1935)* conducted extensive tests with sheathed thermometers held both horizontally and vertically and I refer readers to his report. *Johnson (1954)* and *Thornhill (1935)* also conducted valuable research into the use of thermometers for the temperature determination of a survey tape. The findings here corroborate those of the earlier researchers.

It should be noted that the difference in reading between a vertically held thermometer and a horizontally held thermometer would be a factor of the altitude of the sun and hence the time of day. The difference between the readings should in fact be reversed at sunrise passing through a point of inflexion at mid morning reaching a maximum at midday and repeating the morning pattern to sunset.

The result sheet gives values for the effect on the temperature of the tape, of shading by means of a beach umbrella as well as the effect of the sun being blocked by cloud. Both these factors caused a drop of 2-3°C in the temperature of the tape.

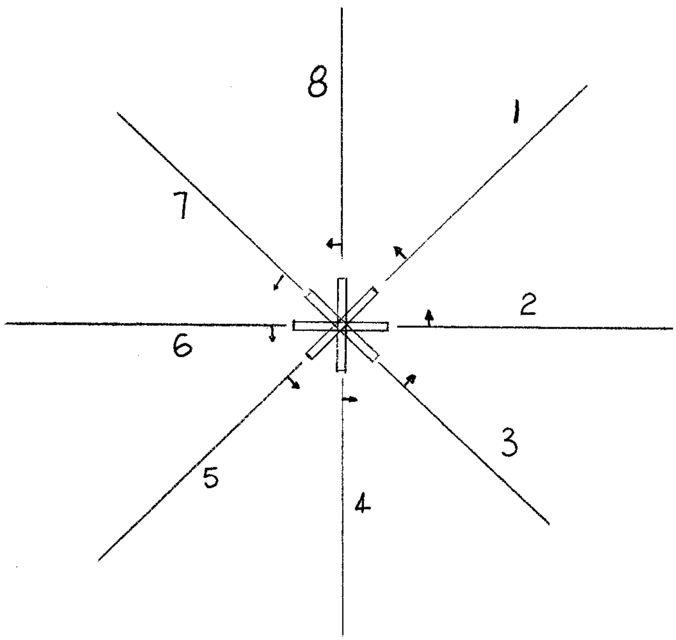


FIG. 8·4

TABLE 8.3

TIME 12.10, 12.1.70

Position	T.C.2 ^{O}C	T.S.T. ^{O}C	Position	T.C.2 ^{O}C	T.S.T. ^{O}C
1	30.5	30	5	28	27
2	30.0	29	6	27	26
3	28.0	27	7	28	27
4	27.0	26	8	29	28

The results shown in Table 8.3 indicate the temperature readings resulting, when the tape is twisted at different angles to the sun. The eight different positions are shown in Figure 8.4.

The results represent one set of observations only. However a variation is evident between the temperature readings in each position. It is expected that the temperature in each of the 180^{O} opposed positions would be identical. This is not indicated in the results. Previous experience in the laboratory indicated that thermocouples attached to the top and bottom of a tape register effectively the same reading. However in the field it is difficult to maintain the same conditions of wind and sun with time which would have a bearing on results. Further the conditions of the air surrounding the tape is different in the field than in the laboratory. There is more likelihood of currents which would affect the temperature occurring in the field.

8.3.3 1/8" Invar Tape

The tests on the invar tape were conducted on the 13th, 14th and 15th January, 1971. Figure 8.5 indicates the position of each of the temperature measuring elements along the length of the tape. Tables 8.4 and 8.5 list the results for the tests.

In this series of tests the tapes were suspended at each of the levels simultaneously.

Invar 14-1-71
Fine, light wind, some cloud

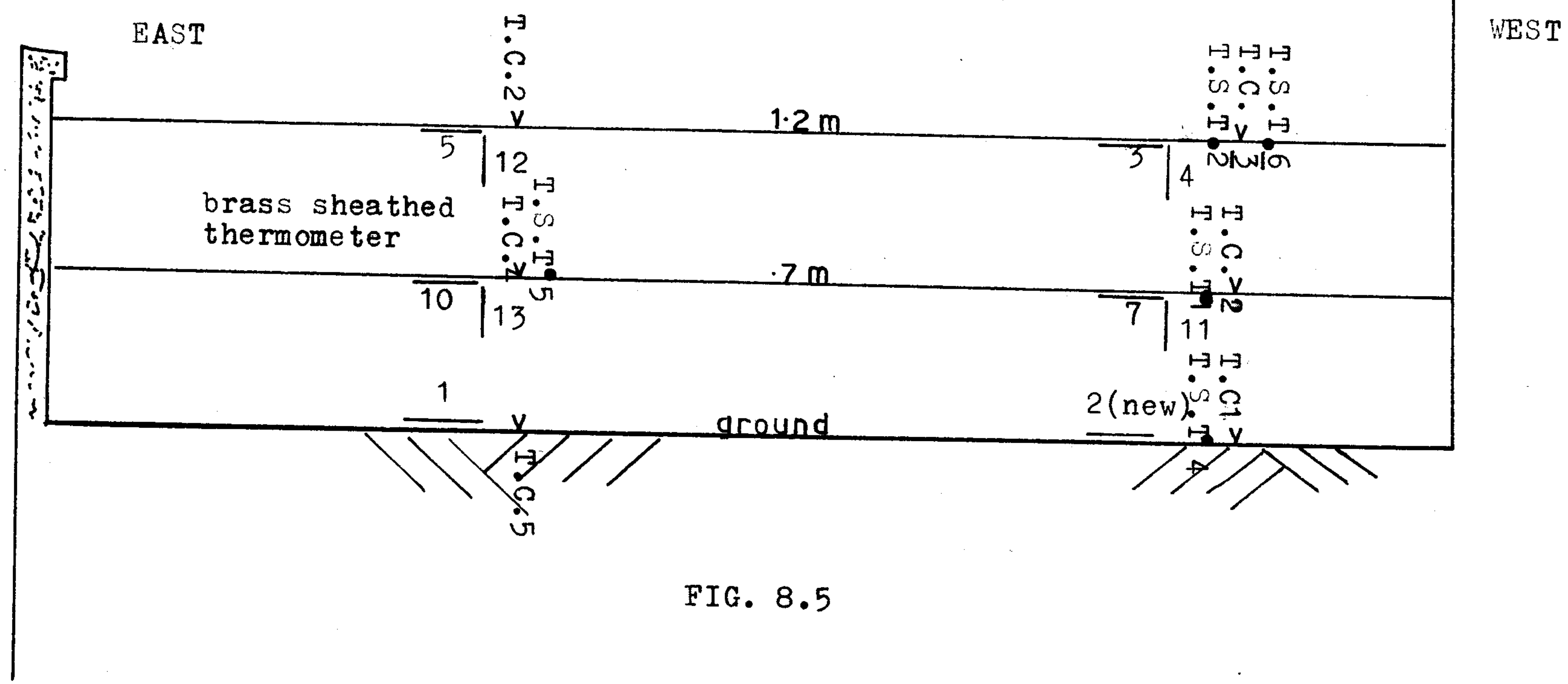


FIG. 8.5

TABLE 8.4

INVAR. 13.1.71

TIME	THERMOCOUPLES °C			THERMISTOR	REMARKS
	1	2	3	°C	
14-26	26.5	24.5	24.5	26.5	All cloud Alto 1.2 m stratus. 0.7 m Fracto Nimbus 0 m Seabreeze
14-27	26	24	24	26	More cloud than above.
14-40	24	22	22	25	Heavy Cloud.
14-54	25	23	23	25	Medium-Heavy Cloud.

TABLE 8.5

INVAR. 14.1.71 — FINE, WIND, SOME CLOUD — WIND: 24 R.P.M.

TIME	Thermocouples Top	Thermocouples Middle	Thermocouples Bottom	T.S.T.	Thermometers Top		Thermometers Middle		Thermometers bottom		Thermocouples Top	Thermocouples Middle	Thermocouples Bottom	Thermistors Top		Thermistors Middle	Thermistors Bottom	Thermometers Top					REMARKS
	2	4	5	5	5(H)	12(V)	L(H)	13(V)	1(H)	N/A(V)	3	2	1	2	6	1	4	3(H)	4(V)	7(H)	11(V)	2(H)	
12.24											26.0	25.5	29.5	25	30	26.5	27.5	25	23.6		23.3		
											22.5	22	25	23.5	25	23	24	24.4	23.3		23.3		
	27.0	26.0	35	27.0	25.8		28.3		34.2														
	26.0	26.5	33.5	25.0	25.6		28.1		29.4														
12.50																		25.8	24.4	26.7	24.7	35.0	
																		24.7	23.9	24.7	23.6	31.1	
12.45					26.1	25.0	28.6	25.6	35.2														
					26.1	24.7	27.8	24.4	32.5														
13.1.71																							
15.20	26.5	27	27		28.6		28.6											27.2			27.2		
			tape	partly in shade - shade at 13.3m. @ 15.20																			
			Wind	13 R/Min Seabreeze, Factus - Fractonimbus, Temp. ½ to 1°C due to wind.																			
15.25				26							25½	24	24			25	25.5						Bridge ← 68 700 → 68 600
												½° to 1°C affect. 1°-1½°C											
15.1.71																							
8.45	22.0	22.0	23.0	22.0	22	21	22.2	21.7	24.4	-	20	20	22.0	22.0	-	21.5	-	22.0	22.0	22.0	21.7	24.7	

TABLE 8.6

TIME	LEVEL	THERMOCOUPLE	THERMISTOR	V	H	REMARKS
13.1.71						
14.26	0 m	26.5	26.5	-	-	Alto stratus.
	0.7 m	24.5	-	-	-	
	1.2 m	24.5	-	-	-	Fracto Nimbus & Seabreeze
14.27	0 m	26	26	-	-	Cloud
	0.7 m	24	-	-	-	becoming
	1.2 m	24	-	-	-	heavier.
14.40	0 m	24	25	-	-	heavy cloud.
	0.7 m	22	-	-	-	
	1.2 m	22	-	-	-	
14.54	0 m	25	25	-	-	Medium to
	0.7 m	23	-	-	-	heavy
	1.2 m	23	-	-	-	cloud.
14.1.71						
12.24	0 m	29.5	27.5			
Western	0 m	25.0	24.0			
	0.7 m	25.5	26.5	23.3		
	0.7 m	22.0	23.0	23.3		
	1.2 m	26.0	27.5	23.6	25.0	
	"	22.5	24.2	23.3	24.4	
12.24	0 m	35			34.2	
Eastern	0 m	33.5			29.4	
	0.7 m	26.0	27.0		28.3	
	0.7 m	26.5	25.6		28.1	
	1.2 m	27.0			25.8	
	1.2 m	26.0			25.6	
15.4.71						
	0 m	23			24.4	
Eastern	0.7 m	22		21.7	22.2	
	1.2 m	22.0		21.0	22.2	
	0 m	22.0			24.7	
Western.	0.7 m	20.0	21.5	21.7	22.0	
	1.2 m	20.0	22	22.0	22.0	

Table 8.6 shows the results meaned and categorized. The results of the 13th indicate the temperature readings at each of the three levels. The weather on this day included cloud as shown in the remarks section of the table. There was no apparent difference in temperature between the 0.7m. and 1.2m. levels, however the tape on the ground registered a temperature 2°C higher.

The results of the 14th show similar trends to the previous results. The temperature was slightly higher then that of the previous day but more importantly there was less cloud. The upper two levels indicated similar temperatures whilst the ground level tape was 2° - 4°C hotter than the upper levels on the western end and 8° - 9°C hotter at the eastern end. As with the previous test the vertical thermometer indicated readings lower than their horizontal counterparts. In general the horizontal thermometer readings were closer to those of the thermocouples.

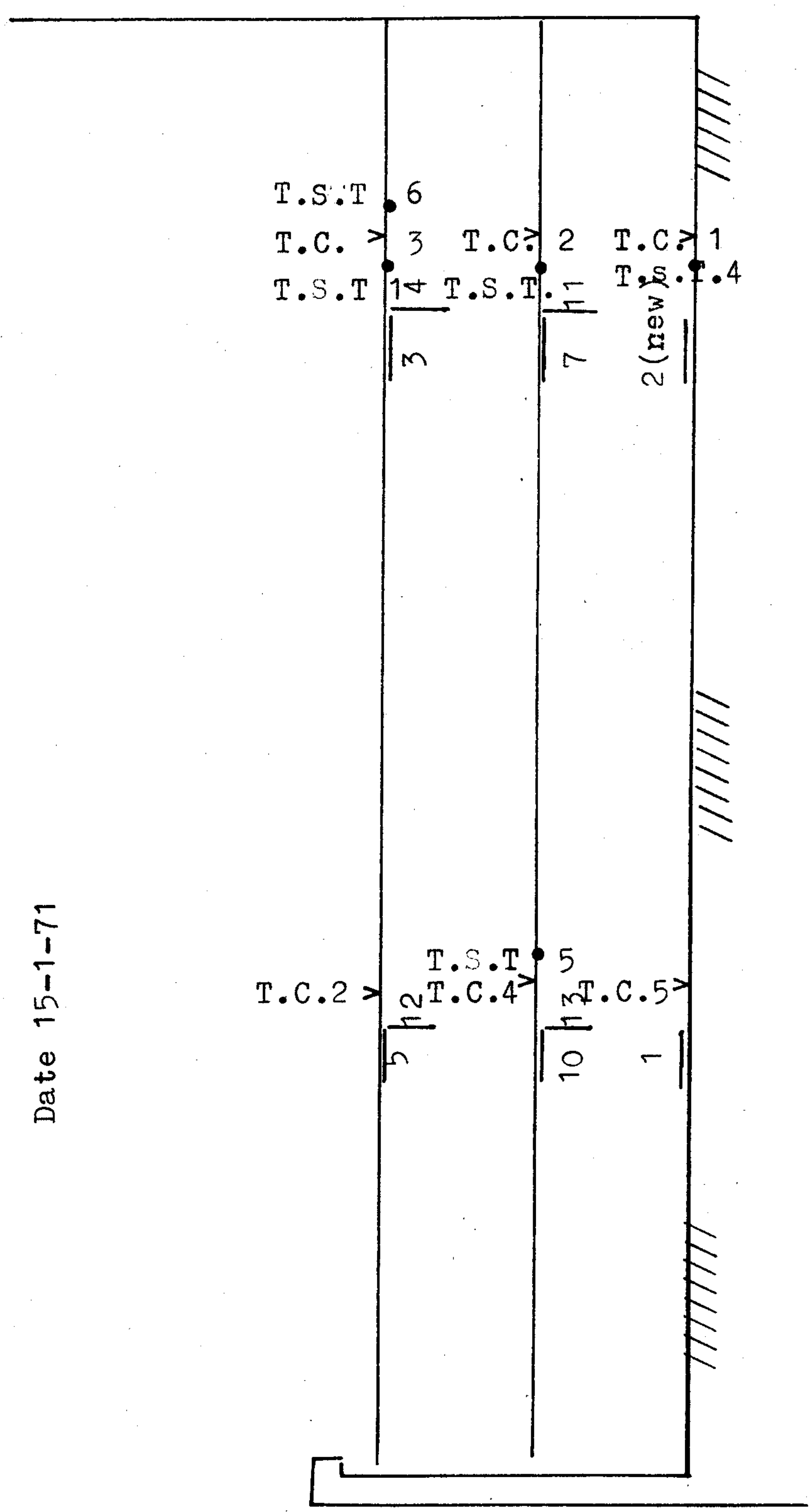
8.3.4 1/12" Steel Tape

Tests on this tape were conducted on the 15th and 16th January, 1971. Figure 8.6 indicates the positions of each of the temperature measuring elements whilst table 8.7 lists the results. Again the tape was suspended at each of the three levels simultaneously.

Referring to Table 8.8 which shows the results meaned and categorized, it can be seen the pattern of differences between the various elements is not clear-cut. Adopting the thermocouple value as the tape temperature it can be seen that in general the horizontal thermometers read a higher temperature. The difference between the thermocouple temperatures and those of the horizontal thermometer, range from +1.1°C to-4.9°C with a mean of -1.3°C. The differences between the thermocouple temperatures and the vertical thermometers range from +2.8°C to -2.5°C with a mean of + .4°C. For this particular tape and for these particular thermometers it appears that the vertical thermometers more closely approximate the tape temperature.

Again as in the previous tests the vertical thermometers registered a lower temperature than their horizontal counterparts.

West



East

1/12" Steel tape

Date 15-1-71

FIG.8.6

TABLE 8.7

1/12" (2.2 mm Steel)   15.1.71

	Thermocouples Top	Mid	Bot	Free	Middle T.S.T.	Thermometers Top		Middle		Bot	Thermocouples Bot	Mid	Top		Top	Mid	Thermistors Top	Mid	Bot	Top	Thermometers Top		Middle	Bot
	2	4	5	6	5						1	2	3	4	5	6	1	2	4	6				
12.00	27	27.5	34	28	26	26.1	24.2	28.3	25.8	38.9	33	18	75	19	-	-	26	25	30	22	25	24.2	25.8	25.3	35.6
	Remarks: Wind 21 R/M 16 R/M																								
13.10	28	29	35		28	27.5	25.8	28.6	27.5	36.1	35.5	22.5	22.5	24.0			26.5	26.0	30+	24	25.6	25.0	26.1	25.0	36.1S
	27.5	28	31			26.7	25.6	26.9	26.4	32.8	31.5	20.5	20.5	22.5			24	24.5	30+	23.5	25.0	24.4	25.0	24.4	33.9C
	Remarks: Wind 11 R/M																								
	Remarks: Cumuli Altostratus, cirrostratus. Alto cumuli & sea breeze. Stratus - Intermitten sun weakened by cirro stratus.																								
Saturday 16.1.71																								
12.06	32.5	35	44	33.5	31	34.2	31.7	35.0	32.8	35.0	44	30.5	30.5	30.5	31	31	32.5	31.5	28	30+	32.2	31.1	33.3	30.8	44
	29	3-	33	32	29	31.7	29.4	31.9	31.4	38.9	40	27.5	27.5	29	33	28	28	28.5	34.5	29	30.8	30.0	30.6	29.4	40.6
	Remarks: Wind 10 R/M																								
	Remarks: Scattered Cumulus Sirius.																								

TABLE 8.8

15.1.71

Time	Level m	Thermocouples °C	Thermistors °C	Thermometers °C V °C	T.C.-V °C	H	T.C.-H	H-V °C	Remarks
12.00	0	34	-			38.9	-4.9		Wind 14
(E)	0.7	27.5	26	25.8	+1.7	28.3	- .8	+2.5	kph
	1.2	27.0	-	24.2	+2.8	26.1	+ .9	+1.9	cumulus
	0	33	30	-		35.6	-2.6		in south
(W)	0.7	-	25	25.3		25.8		+ .5	"
	1.2	-	26	24.2		25.0		+ .8	"
13.10	0	35	-	-		36.1	-1.1		Sun
(E)	0	31	-	-		32.8	-1.8		Shade
	0	35.5	-	-		36.1	- .6		S
(W)	0	31.5	-	-		33.9	-2.4		Sh
	0.7	29	28	27.5	-1.5	28.6	+ .4	+1.1	S
(E)	0.7	28	-	26.4	+1.6	26.9	+1.1	+ .5	Sh
	0.7	22.5 *	26.0	25.0		26.1		+ .9	S
(W)	0.7	20.5 *	24.5	24.4		25.0		+ .6	Sh
	1.2	28.0		25.8	+2.2	27.5	+ .5	+1.7	S
(E)	1.2	27.5		25.6	+1.9	26.7	+ .9	+1.1	Sh
	1.2	24.0	26.5	25.0	-1.0	25.6	-1.6	+0.6	S
(W)	1.2	22.5	24.0	24.4	-1.9	25.0	-2.5	+ .6	Sh

Wind 7 k.p.h. Cumuli, Altostratus, cirrostratus.
Altocumuli & Seabreeze; Fracto Stratus.
Intermittent sun weakened by cirrustratus.

* appeared to be some fault with the meter for these readings.

16.1.71 Wind 6 k.p.h. Scattered Cumulus - Cirrus.

Time	Level m	Thermocouples °C	Thermistors °C	V °C	T.C.-V °C	H	T.C.-H	H-V °C	Remarks
12.06	0	44				35.0	+9.0		Sun
(E)	0	33				33.3	- .3		Shade
	0	44				44	0.0		S
(W)	0	40				40.6	-0.6		Sh
	0.7	35	31	32.8	+2.2	35.0	0.0	+2.2	S
(E)	0.7	31	29	31.4	- .4	31.9	-0.9	+ .5	Sh
	0.7	30.5	31.5	30.8	- .3	33.3	-2.8	+2.5	S
(W)	0.7	27.5	28.5	29.4	-1.9	30.6	-3.1	+1.2	Sh
	1.2	32.5		31.7	+ .8	34.2	-1.7	+2.5	S
(E)	1.2	29.0		29.4	- .4	31.7	-2.7	+2.3	Sh
	1.2	30.5	31.5	31.1	- .6	32.2	-1.7	+1.1	S
(W)	1.2	27.5	28.5	30.0	-2.5	30.8	-3.3	+ .8	Sh

8.3.5 Overall Comments

From the short number of tests conducted certain patterns became clear as well some shortcomings with the experimental arrangement.

It is felt that in order to use the Wheatstone bridge, or a similar resistance measuring device, as an appropriate standard in this kind of field test that the calibration should be conducted in the field. The tape should be set up with all the temperature measuring elements attached and under very still conditions such as the early morning. The calibration could then be performed using the dial gauge.

It appears from the results on the 10 mm. tape that the thermocouples register a temperature significantly close to that derived by resistance measurement. However it must be borne in mind that the thermocouple registers a spot temperature whilst the resistance measurement represents an integrated measurement. It is felt however that the thermocouple does offer a better means of temperature measurement than the mercury thermometer.

The thermistor also gave results significantly similar to those of the thermocouple. However the thermistor was not as simple to use as the thermocouple for the purposes of this research. This was mainly due to:-

(i) The difficulty in attaching the thermistor to the tape.

(ii) There was doubt as to whether the heat was perfectly conducted from the tape to the thermistor

(iii) The calibration of each thermistor before use became a nuisance.

It is felt that most of these problems could be overcome with proper developments. The difficulties listed in (i) and (iii) could be covercome by using different types of sensing elements. A different type of element may be glued to the tape. The calibration problem would be lessened by using a chart as shown in Figure (5.6).

The thermistor unit is a simpler unit to manufacture than the thermocouple unit and could be built in departmental workshops by departments which employed the appropriate technical staff. The commercial cost of the respective units is much the same.

It is evident from the results that thermometers can provide an adequate means of temperature measurement up to temperatures of 30°C if properly used. The characteristics of the tape will have a bearing on how the thermometer is to be used. In general the thermometer should be sheathed. The sheath should be made from the same material as the tape and the surface finish on the sheath should be identical to that of the tape. Also in general the thermometer should be held horizontally at the same height as the tape and should be given 3 - 5 minutes for the reading to settle.

It was also observed from the tests discussed above that the thermometers tend to drag in relation to temperature changes. The tape is quite responsive to temperature changes and it can be seen from the result sheet that clouds produce a drop in temperature of 2 - 3°C also a gust of wind may cause the temperature to drop 1°C.

8.4 FIELD TESTS WITH FRAME-HELD TAPES

8.4.1 The Experimental Arrangement

As stated in Section 8.1 field work was conducted using the apparatus shown in Figure 8.2. The position of the tapes in the frame and their description are shown in Figure 8.7.

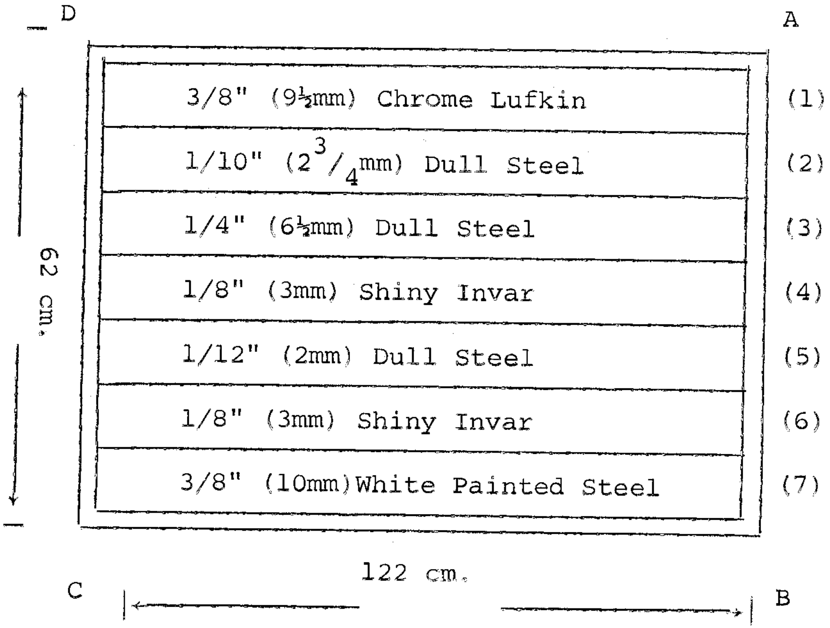


Figure 8.7

A thermocouple was attached to each of the tapes and both horizontal and vertical thermometers were placed in each of the four corners A, B, C, D.

8.4.2 Experimental Results

Table 8.9 list the observations for the field work. The frame was placed on conrete, asphalt, grass and bare soil surfaces respectively and subsequently raised to approximately 0.5m and 1.0m above each surface and readings taken. At each of the three levels the tapes and thermometers were shaded by a large umbrella for a second set of readings.

The performance of the thermometers is dealt with separately in Section 6.4, hence for the purposes of this discussion the mean horizontal and vertical values will be taken to represent the thermometer readings.

TABLE 3.9

Time	3/8" Steel Chrome	1/10" Steel Dull	1/4" Steel Dull	1/8" Invar Sunny	1/12" Steel Dull	1/8" Invar Shiny	3/8" Steel White Painted	A H	A V	B H	B V	C H	C V	D H	D V	Mean H	Mean V	Psychrometer	Remarks	Wind k.p.h	Height m
																			Conc.Surf.		
11.40	32.0	30.0	32.0	31.0	31.0	31.5	32.5	28.3	26.7	28.3	26.7	28.3	27.2	29.4	26.9	28.6	26.8	27.2	(semi sunshine	5	.6
11.45	40.0	32.5	33.0	33.0	38.0	37.0	35.0	30.6	27.8	30.0	27.2	29.4	26.7	30.6	26.9	30.1	27.1	"	(Alto stratus " "		.1
11.50	36.5		36.0	32.0	33.0	34.0	36.0	32.8		33.3		32.8		35.6		33.6		"	sunny		0·
12.05	40.0		39.0	33.0	34.5	35.0	38.0	37.7		37.7		34.4		32.8		35.6	-	"	Asphalt Surface Artificially		0
12.10	31.5		32.5	30.0	31.0	31.5	34.0	32.8		35.0		31.1		31.1		32.5		"	" shaded		0
12.15	35.0		36.0	32.0	32.5	33.0	34.5	30.6	28.6	31.1	30.3	30.0	28.3	29.4	27.8	30.3	28.7	27.2	sunny	4	.6
12.20	28.0		29.0	30.0	30.0	30.0	30.0	28.9	27.8	29.4	29.4	28.1	27.5	28.1	27.5	28.5	28.0	27.5	Artificially shaded	9	.6
12.30	34.0		33.0	30.0	29.5	30.0	32.0	29.2	28.1	28.9	28.6	28.9	28.1	29.7	28.1	29.0	28.2	"	sunny		.8
12.35	29.0		29.0	28.5	28.0	28.5	28.5	27.2	26.7	27.2	27.2	26.7	26.7	27.2	26.7	27.2	26.7	27.2	Artificially shaded	14	.8
12.50	39.0	26.0	38.0	34.0	36.0	37.0	36.0	34.4		34.4		34.4		33.9		34.3	-	27.5	Grass Surface	14	0
13.00	36.0		36.0	32.0	32.0	33.0	34.0	30.3	27.8	30.6	28.3	30.0	27.8	29.2	27.8	30.0	27.9	"	Gusty,cloud, sunny		.5
13.05	29.5		29.0	28.0	28.0	29.0	29.0	28.3	27.3	28.3	27.5	27.5	27.2	27.5	27.2	27.9	27.2	27.5	artificially shaded, gusty		.5
13.10	34.0		34.0	31.0	31.0	32.0	32.0	29.2	27.8	29.2	28.1	28.9	27.8	28.3	27.2	28.9	27.7	"	Sunny, Gusty		1.0
13.15	27.0		27.0	26.0	26.0	26.5	26.5	27.8	27.	27.8	27.2	26.9	26.9	27.2	26.9	27.4	27.0	26.9	Artificially shaded		1.0
15.25	38.0		38.5	35.0	35.0	37.0	36.5	35.0		35.0		36.7		35.6		35.5		27.5	Soil Surface	4	0
15.30	30.0	30.0	30.0	29.0	29.0	31.0	29.5	32.5		33.1		33.3		33.1		33.0		"	Artif. shaded		0
15.35	33.5	32.0	34.0	31.0	31.0	31.0	32.0	33.0	30.0	32.0	33.0	32.5	31.5	32.0	31.5	32.4	31.5	"	Sunny,cloud		.5
15.40	31.0	29.5	30.5	29.0	29.0	29.0	30.0	31.0	29.5	31.0	31.0	31.0	30.0	30.5		30.9	30.1	"	Artif.shaded		.5
15.45	32.5	30.5	32.5	29.0	29.5	30.0	31.0	30.5	29.5	30.5	31.0	31.0	30.5	31.0	30.0	30.7	30.2	"	Sunny		.9
15.50	27.0	27.0	27.0	26.5	26.5	27.0	27.0	29.0	28.5	29.0	29.5	29.0	29.0	29.0	28.5	29.0	28.9	27.5	Artif.shaded light wind		/9

Commenting generally, it can be seen from the result sheet that as with previous field work the horizontal thermometers registered higher readings than the vertical thermometers. The difference between the two is least when they are under conditions of shade. It is indicated from the remarks column that the wind strength varied throughout the period in which the work was conducted. The air temperature as registered by the psychrometer remained significantly the same for the entire period.

The range of temperature between the various tapes followed a fairly consistent pattern throughout the test period. Table 8.10 shows the tapes divided into the two categories of wide and narrow. The 3/8" chrome, 1/4" dull steel and 3/8" white painted tapes comprise the wide category whilst the 1/8" shiny invar, 1/12" dull steel and 1/10" dull steel comprise the narrow category. It can be seen from the result sheet that the range of temperature of the tapes in each category in general was $2^{\circ}C$ and in many cases $1^{\circ}C$. The temperature listed in Table 8.10 under each category was an approximate mean of the tapes comprising the category. The range of difference in temperature between the two categories was $1^{\circ} - 5^{\circ}C$ with a mean of $2.6^{\circ}C$ for unshaded conditions and the respective values for shaded conditions are $0 - 1.5^{\circ}C$ and $0.8^{\circ}C$. The mean thermometer readings seem to bear a rather varying relationship to those of the tape. Comparing the mean horizontal thermometer readings with the temperatures listed under the narrow tape category. The difference between the two temperatures varies from $-3^{\circ}C$ to $+3^{\circ}C$ with a mean of approximately $0^{\circ}C$.

8.4.3 Comments on Results

It would be unwise to make any sweeping conclusions from this set of results for two reasons:-

(i) The performance of the apparatus was not verified in any way

(ii) The period of time represented in the results was short.

TABLE 8.10

Time	Wide °C	Narrow °C	Difference W-N °C	H °C	V	Comment	Narrow-H
11.40	32.0	31.0	1.0	28.6	26.8		+2.4
11.45	35.0	33.0	2.0	30.1	27.1		+2.9
11.50	36.0	33.0	3.0	33.6	-		- .6
12.05	39.0	34.0	5.0	35.6	-		-1.6
12.10	32.5	31.0	1.5	32.5	-	S	-1.5
12.15	35.0	32.5	2.5	30.3	28.7		+2.2
12.20	29.0	30.0	1.0	28.5	28.0	S	+1.5
12.30	33.0	29.5	3.5	29.0	28.2		+ .5
12.35	29.0	28.5	.5	27.2	26.7	S	+1.3
12.50	38.0	36.0	2.0	34.3	-		+1.7
12.55	33.0	33.0	0	32.5		S	+ .5
13.00	35.5	32.0	3.5	30.0	27.9		+2.0
13.05	29.0	28.0	1.0	27.9	27.2	S	+ .1
13.10	33.5	31.5	2.0	28.9	27.7		+2.6
13.15	27.0	26.0	1.0	27.4	27.0	S	-1.4
15.25	37.5	35.0	2.5	35.6			- .6
15.30	30.0	30.0	0	33.0		S	-3.0
15.35	33.0	31.0	2.0	32.4	31.5		-1.4
15.40	30.5	29.0	1.5	30.9	30.1	S	-1.9
15.45	32.0	29.5	2.5	30.7	30.2		-1.2
15.50	27.0	26.5	.5	29.0	28.9	S	-2.5

TABLE 8.11

Calibration of Thermocouples for Tests conducted on 27.1.71

Thermometer °C	Thermocouples °C		
	5	6	7
33	34	34	34
37.5	39.0	38.5	39.5
27.5	28.5	28.5	28.5
	2	3	4
32	33	33	33
37	38	38	38
27.2	28.5	28.5	28.5

However it does seem fair to look at the general patterns indicated in the results and to make relative comparisons. It is clear that the width of the tape has an important bearing on the temperature behaviour of the tape. The range of difference in temperature between the general categories of wide and narrow tapes is 2.5°C to 8.0°C with a mean of 4.3°C under unshaded conditions and .5°C to 4.0°C and 1.7°C respectively for shaded conditions - taking all results into account.

The laboratory experiments indicated that the width and surface qualities had roughly equal bearing on the tapes behaviour. The ¼" width steel tape had surface qualities apparently most conducive to heat absorption and registered temperatures approximately equal to 3/8" chrome Lufkin tape or the 3/8" white painted tape. The extra width of the latter tapes however makes the comparison more difficult but the results tend to corroborate the laboratory findings. The results also indicate that there is not a large range in the temperature readings of the tape in the narrow category. The range is 0°C to 2°C with a mean 1°C.

Perhaps the most difficult aspect of the test to explain is the apparent changes in the thermometer temperatures in relation to tape temperature. The earlier tests on the roof did not indicate this same pattern. For the first half of the results the mean temperature of the horizontal thermometers was less than that of the narrow tapes and then for the latter the position switched. There seems to be no obvious reason for this pattern. The discrepancy between the tape temperatures and that given by the thermometers in general terms is larger in this set of results than indicated in tests described in the first section of this chapter.

CHAPTER 9

CONCLUSIONS

Looking at length accuracies in terms of temperature:-

$$\frac{\Delta L}{L} = \alpha \Delta T \quad \alpha \text{ taken as } 6.2 \times 10^{-6}/^{\circ}F$$
$$10.8 \times 10^{-6}/^{\circ}C$$

Considering ΔT as an error rather than as the difference between standard and field temperature.

For a length accuracy of 1 in 30 000

$$\frac{10^{-4}}{3} = 10.8 \times 10^{-6} \times \Delta T$$

$$\Delta T \doteqdot 3^{\circ}C$$

Surveyors demanding millimetre accuracy over a tape length of 100m, i.e. 1 in 100 000 need to ensure the temperature determination is accurate to better than $1^{\circ}C$ ($1^{\circ}C$ represents an error 1 in 100 000 in itself).

The main conclusion coming from the research is that surveyors can obtain adequate accuracy for the majority of survey work using the steel tape and a thermometer for the temperature determination. However it can not be overstressed that the standardization of equipment will play an important role in achieving this. It is recommended that the tape be 1/12" to 1/8" wide steel. The thermometer should be *thermally balanced* in relation to the tape. It is further suggested that the Australian Standards Association be approached with the aim of negotiating a satisfactory design for field thermometers which would then be pronounced by that Association under a Code Number.

Other important conclusions coming from the research are:-

(i) Surveyors must understand the dynamics of temperature measurement in order to achieve satisfactory results.

(ii) Precise surveys are best conducted under cloudy conditions.

(iii) Precise taping under conditions of high temperature and sunlight should be conducted with the tape off the ground. More than one thermometer should be used for the temperature determination. The thermometers should in *general* be held horizontally at tape level.

(iv) Other methods of determining the tape temperature deserve consideration by surveyors.

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APPENDIX A

The Details of the Design of the Thermistor Thermometer

The device provides a means of measuring temperature similar to the thermocouple thermometer both of which have the advantages of quick response, monitoring at a distance and an easy to read display.

The operation of the device is based on the resistance temperature characteristic of the thermistor. The thermistor is a resistor with a high negative temperature coefficient. That is its resistance change, which is negative, is marked with a change in temperature.

The circuit is a simple one. It is basically a "bridge" configuration. An elementary circuit is shown in Figure A-1. It consists of four resistors, R1, R2, R3, and R4. Resistors 1, 2 and 3 are conventional types, preferably chosen to have the lowest possible temperature coefficient. Resistor R4 is the thermistor.

Under certain conditions such a bridge circuit can be said to be "balanced". That is there is no potential difference between points "A" and "B".

Such a balanced condition can only exist if

(i) all four resistors are equal

(ii) R_1 and R_2 are equal and R_3 and R_4 are also equal but different from R_1 and R_2

(iii)

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

If these conditions are not satisfied, the bridge will be unbalanced and the meter will deflect on the conditions causing the unbalance. For example: Let us assume that R1 and R2 are equal. The bridge will now balance if R3 and R4 are equal, but consider what happens if R4 is less than or greater than R3. If R4 is less than

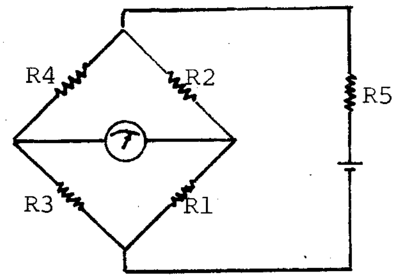


Figure A-1

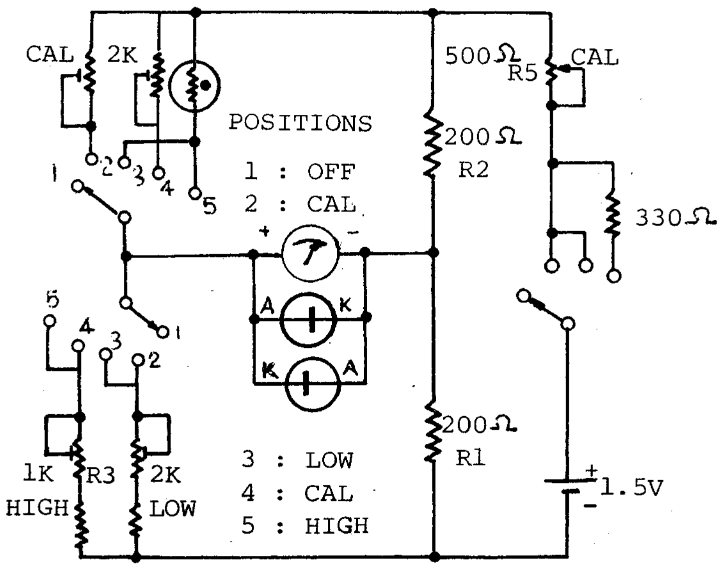


Figure A-2

R3 then point "A" will be closer to the positive end of the system than point "B" and the meter will read up the scale. If R4 is larger than R3, the reverse reasoning will apply and the meter will try to read down the scale.

To make use of these characteristics, Rl is made equal to R2. The resistance of R4 (the thermistor) is determined at the lowest temperature it is wished to measure. R3 is then made equal to this value. The bridge will then balance at the minimum temperature. The zero of the meter is then calibrated to this minimum temperature.

As the temperature of the thermistor increases, its resistance decreases. This moves the point "A" towards the positive end of the network, making it positive with respect to "B", and the meter moves up the scale. How far it moves for a given change depends on the sensitivity of the meter, the voltage of the battery, and the value of R5. Within certain limits, it is possible to select these so that full-scale deflection of the meter corresponds to the maximum temperature we wish to measure. We can thus calibrate this point. It is usual to assume that the temperature coefficient of the thermistor is linear for a small range (20°C) of temperature.

The power supply for this particular unit is a 1.5V alkaline cell ("AA" size) which should provide 1,000 hrs. of operation.

The instrument was designed to read temperatures between 10°C to 50°C where two ranges of 20°C were used to obtain this. The least count of the meter is 1°C which gives a separation of approximately ¼ inch between divisions, making further interpretation possible.

Due to the normal spread of thermistors, it is not possible to nominate on exact value for R3, although it is possible to make an approximation from published data, usually in graphical form. Final adjustment and selection of resistance values must be made by direct comparison with a reliable thermometer. The resistor may then be adjusted either by adding series of parallel resistors, or my making part of the resistance adjustable. The latter was adopted in this case.

Adjustment of R5 is provided by substituting, for the thermistor, a conventional resistor having the same resistance value as the thermistor at the full scale temperature. R5 is then adjusted until the meter reads full scale, left on this setting, and the thermistor restored to the circuit in place of the substitute resistance. This allows a convenient method of checking the calibration of the instrument to take care of minor changes in battery voltage. In the instrument a multi-position switch which provides this calibrate facility as the first step from the "OFF" position is followed by an active range. Thus there is an automatic reminder to calibrate the instrument every time it is switched on.

Reference is made to the circuit shown in Figure A-2. A five position panel switch selects "OFF" "calibrate low", "low" "calibrate high" and "high" in that order.

The "off" position is self explanatory, the main function being to open the battery circuit. In the "Calibrate low" and "Calibrate high" position the battery is switched on and the bridge circuit operates in the normal manner, except that a resistor is substituted for the thermistor.

The values of the resistors are made equal to that of the thermistor at the full scale temperature, lower range and upper range respectively. The calibrate pot (R5) is then adjusted for full-scale reading.

In the "Low" and "High" positions the thermistor is switched into the circuit and the instrument is ready to use. When "High" is selected a new value of R3 is engaged, which represents the thermistor resistance at the low end of the new scale, and to add a resistor in series with the calibrate pot.

Resistors R1 and R2 are 200 ohm, and are wire-wound types in the interest of long term stability. For the low range position R3 is made up of a 1.8K fixed resistor and a 2K adjustable type. For the high range it is a 560 ohm fixed and a 1K adjustable.

An overall calibration should be conducted with the aid of a good quality, conventional thermometer. The thermistor should be strapped to the lower end of the thermometer such that the thermistor element is adjacent to the bulb of the thermometer. The whole combination is then immersed in water and the water heated or cooled as required to give the necessary temperature check points.

This gives a brief description of the construction of the thermistor thermometer. Readers are referred to *Horsfield* and *Watson* (Electronics Australia, September 1968, Vol. 30 No. 6) for a full description.

APPENDIX B

Details of the Components of the Wheatstone Bridge

The Wheatstone Bridge circuit used in the experimental work is shown in Figure 3.7. As stated in 3.4.1 the circuit is identical to that adopted by *Attwell (Clark and Johnson 1951)* of the National Physics Laboratory for his study of standardization of steel tapes with reference to their resistance.

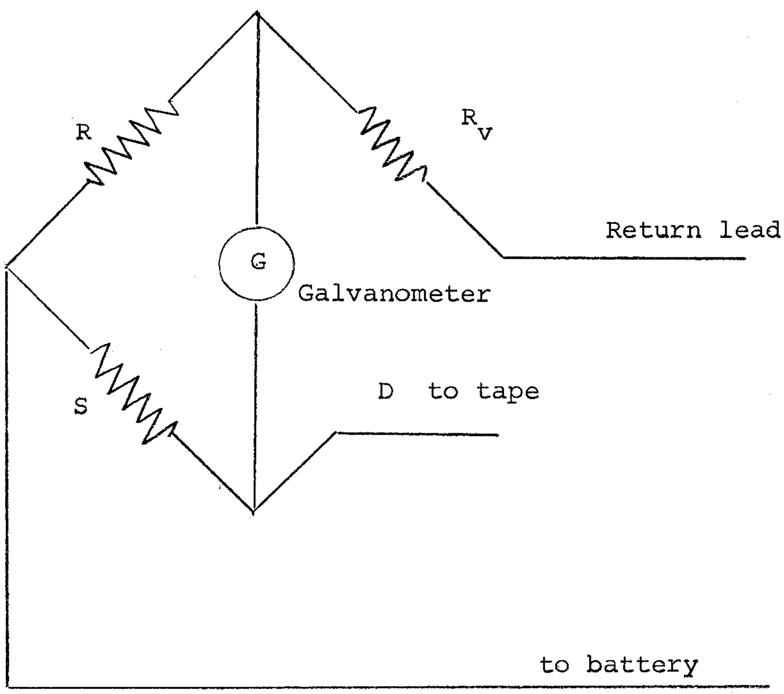


FIG. B-1

The components of the bridge were "standard" items for this type of circuit. "R" was a standard resistor of 1 000 ohms in the form of wire wound on card which was approximately 2 inches by 3 inches. It was not a resistor of a high order but was none the less sufficient for the job.

"R_v"- the variable resistance was a five dial decade box with the ranges -

1	-	10
10	-	100
100	-	1000
1000	-	10000
10000	-	100000

The resistance of the tape is given by the formula

$$\text{Resistance Tape} = \frac{S}{R}\,(R_v + \text{lead}) - D$$

where D is the resistance of the leads connecting the tape into the circuit.

R is a 1 000 ohm resistor.

S is a standard .125 ohm resistor.

Hence if the resistance of the tape is of the order of 5 ohms then R_v is of the order of 40 000. If the result sheets in Chapter 5 are inspected for the R_v readings, it will be seen that values ranging from 30 000 to 80 000 are recorded depending on the tape and tape length.

S

As stated above "S" is a standard resistor. In this case it was a length of manganin wire having a resistance of .125 ohms. The wire was mounted under a short piece of wood as shown in Figure B-2, which gives a view from underneath.

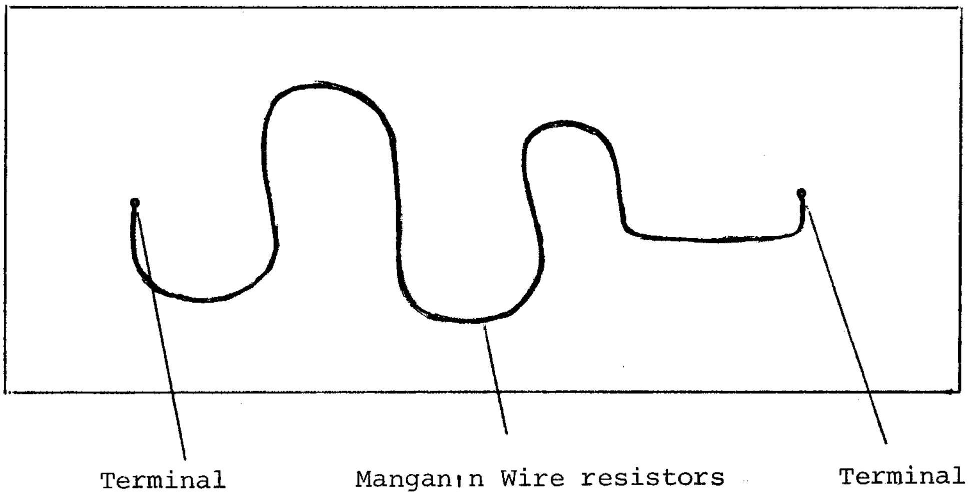


Figure B-2

The Galvanometer

The galvanometer was a sensitive spot galvanometer as shown in Figure B-3.

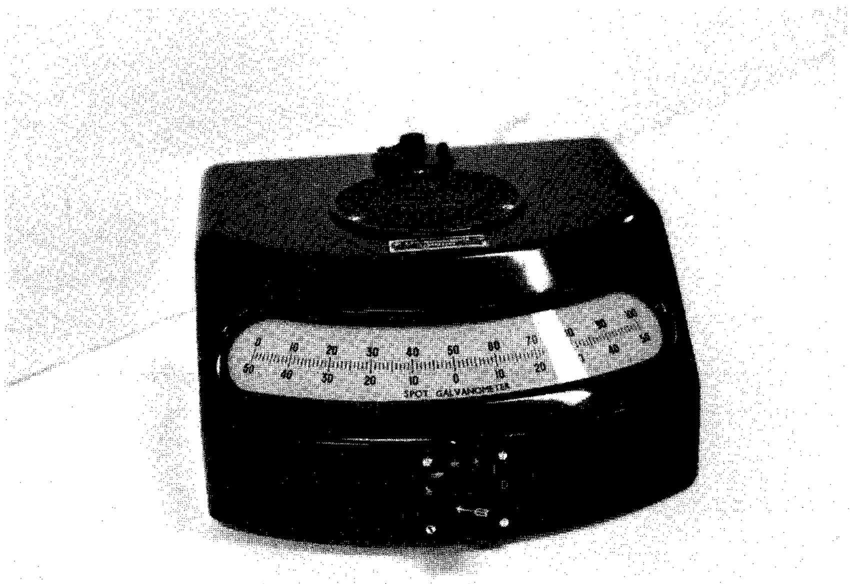


Figure B-3

APPENDIX C.

The dimensions and details of the thermometers shown in Figure 6.1 are as follows.

Thermometer A

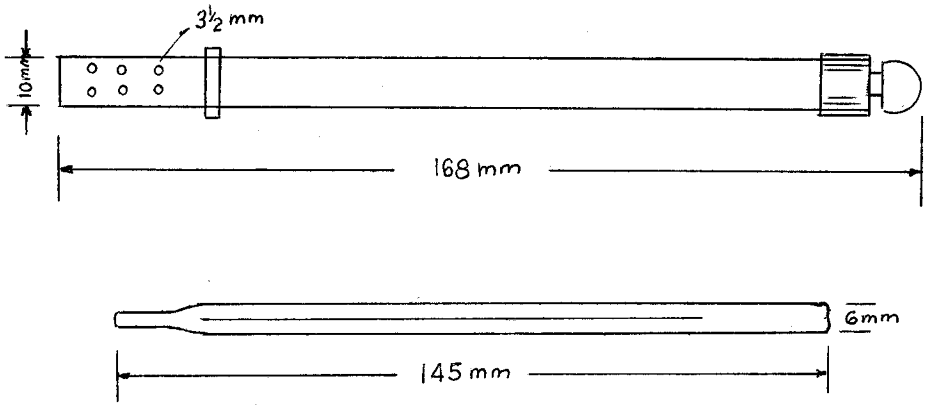


Figure C-1

Manufacturer: G. H. Zeal

Range: 20°F to 180°F

Value of one interval: 2°F

Thermometer B

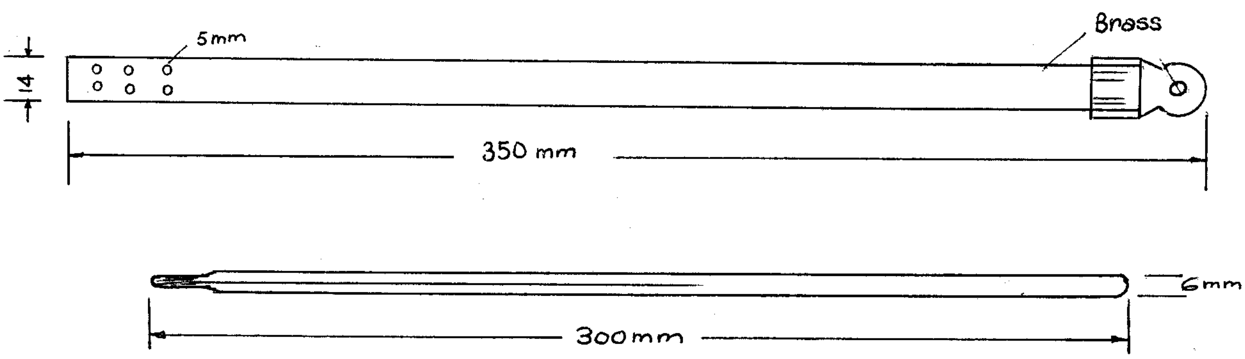


Figure C-2

Manufacturer:	not shown on case
Range:	$-35^{\circ}F$ to $+120^{\circ}F$
Value of one Interval:	$1^{\circ}F$

Thermometer C

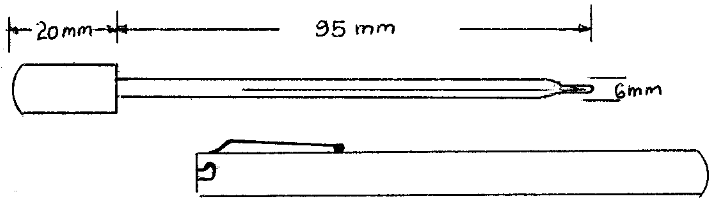


Figure C - 3

Manufacturer:	G. H. Zeal
Range:	$40^{\circ}F$ to $140^{\circ}F$
Value of one Interval:	$2^{\circ}F$

Thermometer D

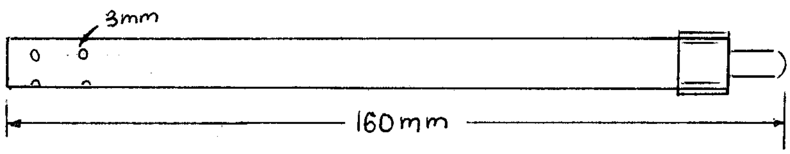


Figure C - 4

Insert identical to Thermometer A.

Manufacturer:	not shown on case Insert - G. H. Zeal
Range:	$20^{\circ}F$ to $180^{\circ}F$
Value of one interval:	$2^{\circ}F$

Thermometer F - Calibrated Thermometer

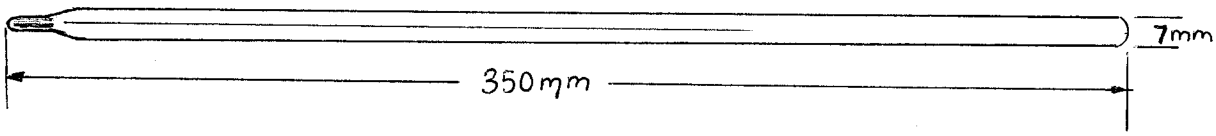


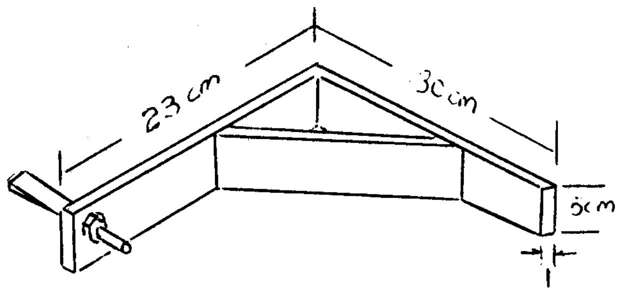
Figure C-5

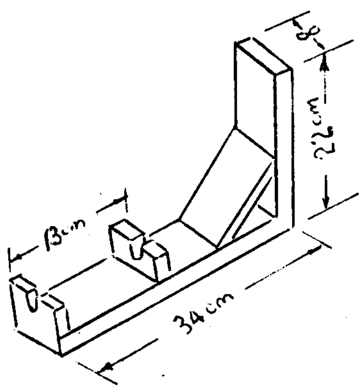
Manufacturer:	Dobbie Bros.
Range:	$-5^{o}C$ to $50^{o}C$
Value of one Interval:	$.1^{o}C$

APPENDIX D

Details of equipment which was constructed for the Experimental work.

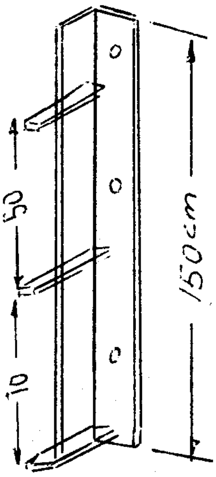
1. Wall Brackets - Refer to Figures 5-9 and 5-10.



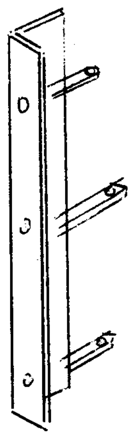


Material: In both cases-mild steel

2. Roof Brackets - Refer to Figure 8-1



(a)

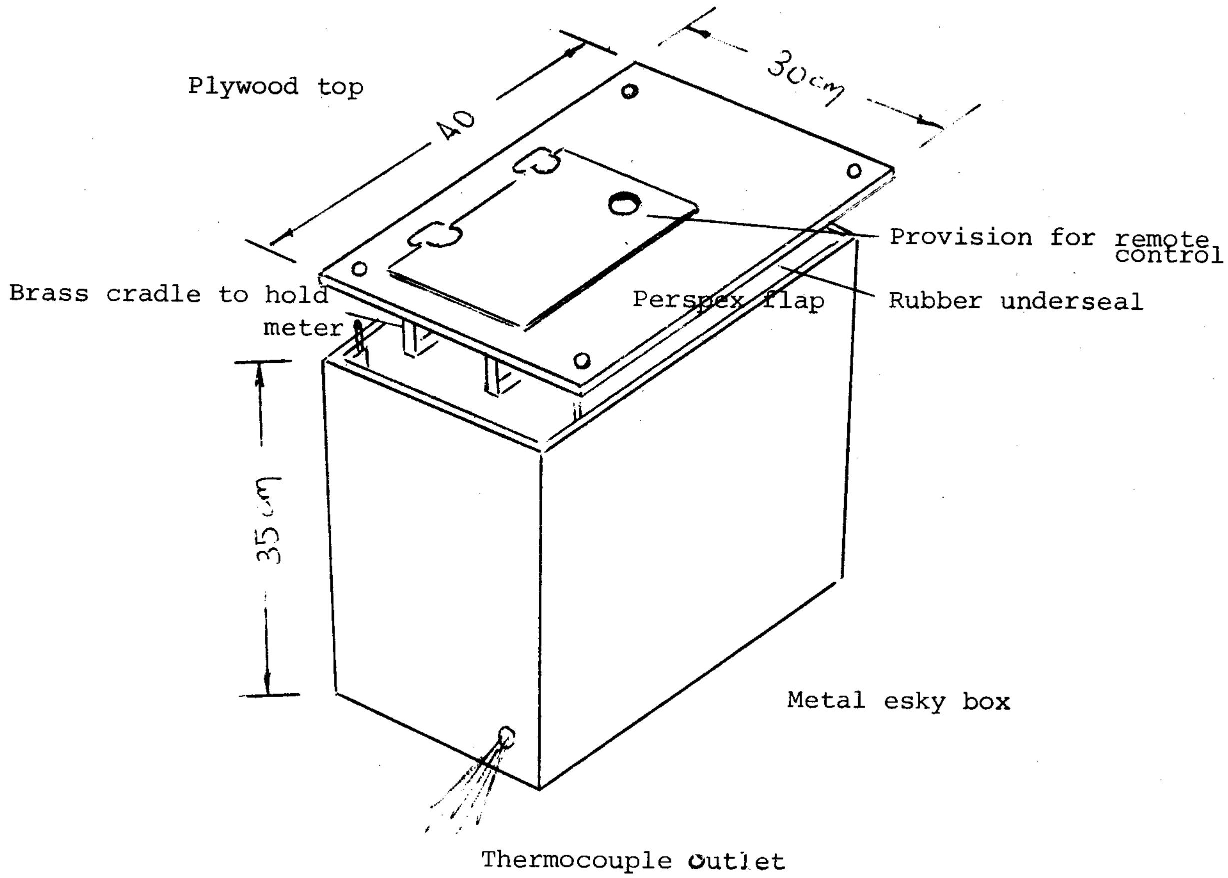


Material: Mild steel

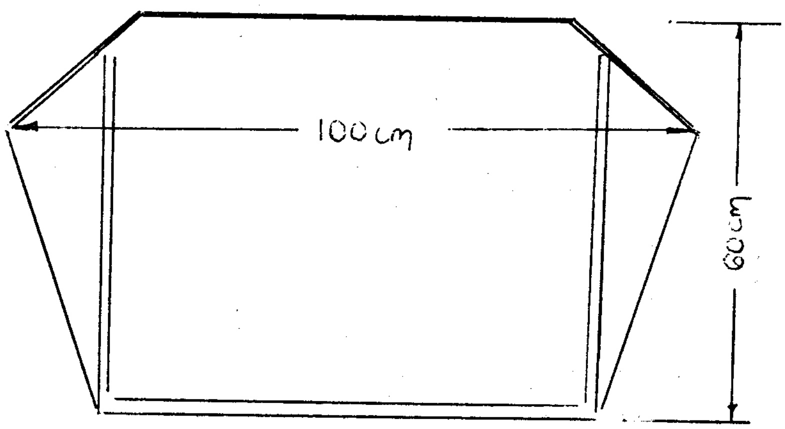
Dimensions : as for (a)

(b)

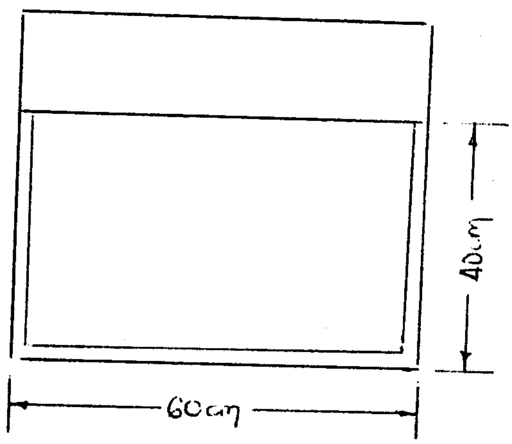
3. Esky Conversion - Refer to Figure 3.3.



4. **Shelter Box** - Refer to Figure 8-1 and 8-2.



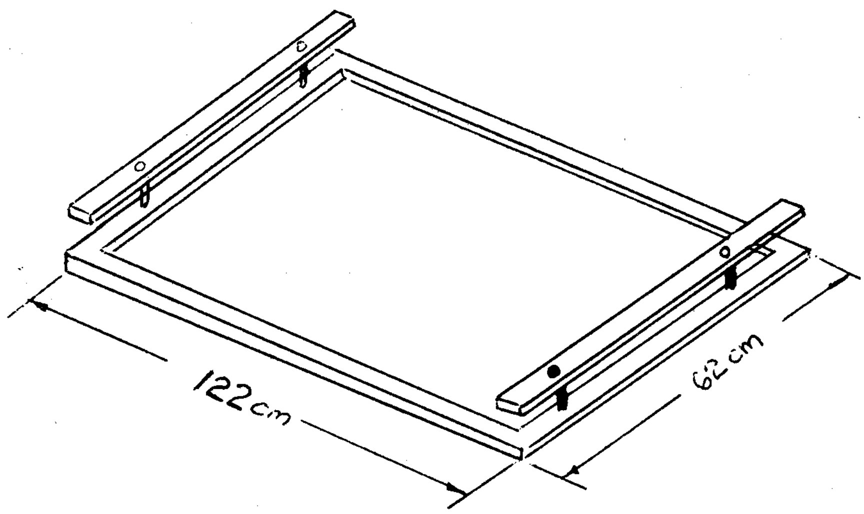
Front elevation



Side elevation

Material : Plywood

5. Tape Rack - Refer to Figure 8.2



Material : Wood

BIOGRAPHICAL NOTES.

A.H. CAMPBELL at present holds the position of Instructor in the School of Surveying, University of N.S.W. to which he was appointed in 1970. He completed the Bachelor of Surveying degree in 1967 at the University of N.S.W. Mr. Campbell has worked for the private firms of Bannister & Hunter at Gosford and P.W. Rygate and West in Sydney. He received his license in 1968. Mr. Campbell has just completed his Master of Surveying Science degree at the University of N.S.W. His current research interest includes in addition to the published topic survey, adjustment with particular reference to large scale adjustments.

SCHOOL OF SURVEYING - UNIVERSITY OF NEW SOUTH WALES

Kensington. N.S.W. 2033.

Reports from the then Department of Surveying, School of Civil Engineering.

* 1. The discrimination of radio time signals in Australia.
G.G. BENNETT *(UNICIV Report No.D-1)*

* 2. A comparator for the accurate measurement of differential barometric pressure.
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* 7. Control for Mapping. (Proceedings of Conference, May 1967)
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21. The registration and cadastral survey of native-jeld rural land in the Territory of Papua and New Guinea.
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22. Communications from Australia to Section V, International Association of Geodest, XV General Assembly, International Union of Geodesy & Geophysics, Moscow 1971.
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