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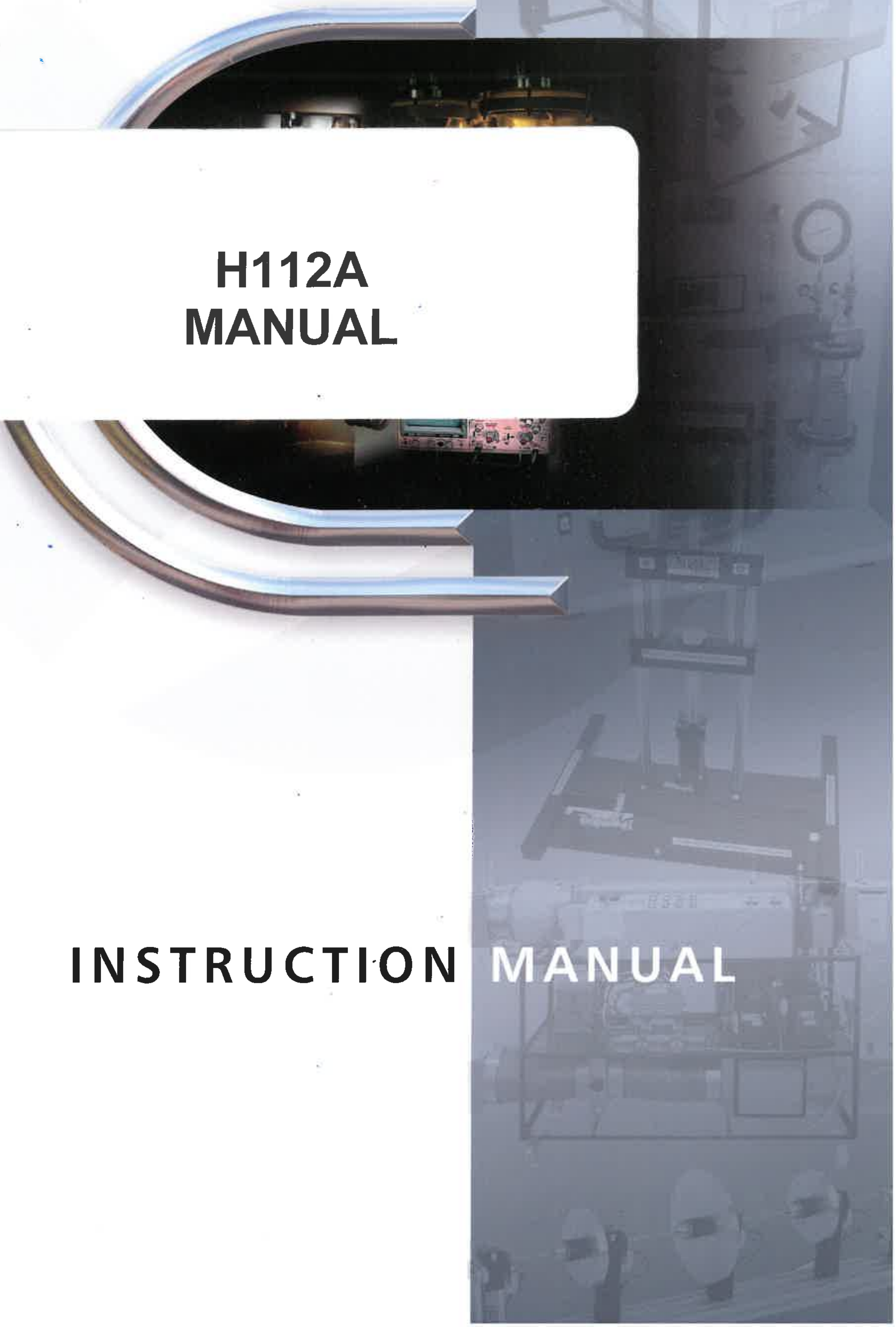


H112A MANUAL

INSTRUCTION MANUAL

EXPERIMENTAL

OPERATING

AND

MAINTENANCE PROCEDURES

OPTIONAL

LINEAR HEAT CONDUCTION UNIT

H112A

H112A_E_1_107
NOV 11

TABLE OF CONTENTS

SYMBOLS AND UNITS

Symbol		Units
D	Diameter of element	m
A	Heat transfer area	m^2
Δx	Distance or thickness	m
V	Voltage to heating element	V
I	Current to heating element	A
Q	Power to heating element and heat transfer rate	W
T	Temperature measured	°C
ΔT	Temperature Difference	K
k	Thermal conductivity	W/mK
U	Overall heat transfer coefficient	W/m^2K
R	Resistance to heat flow	m^2K/W
t	Elapsed time	seconds

Subscripts

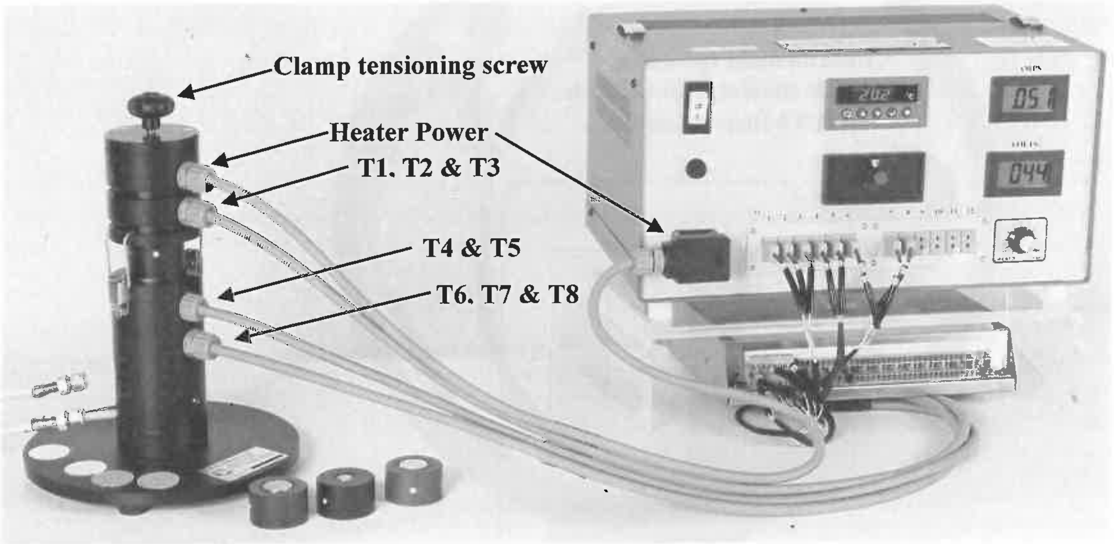
hot	Heating section
cold	Cooling section
int	Intermediate section
hotface	Contact face of heated section
coldface	Contact face of cooling section
1,2,3,4....	Thermocouple positions

Figure A1

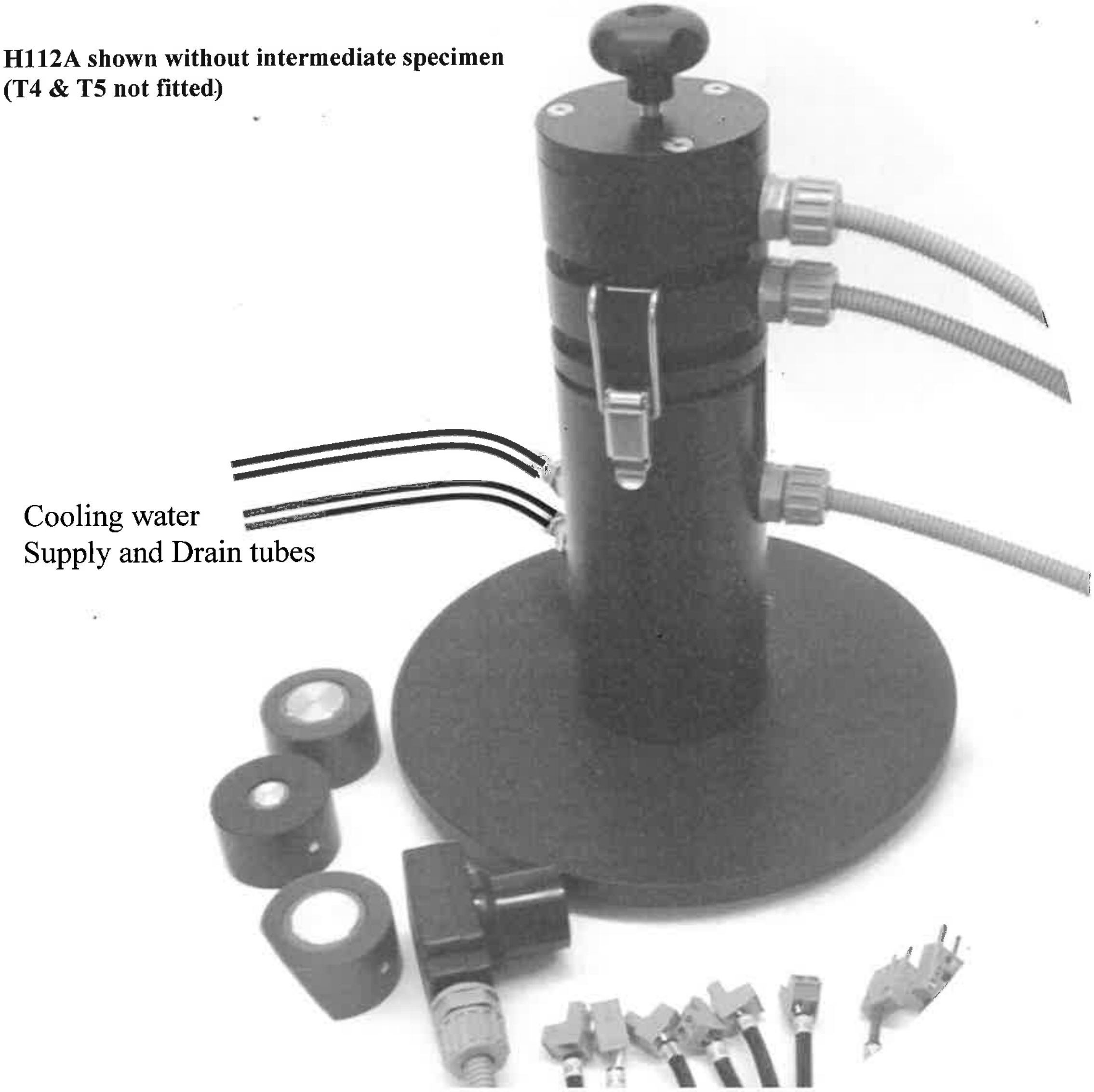
TYPICAL INSTALLATION

H112 shown with H112A Linear Heat Conduction Unit and HC112A Data Acquisition Upgrade.

Note that the digital temperature indicator and selector switch shown, have been replaced by a combined indicator and selector



H112A shown without intermediate specimen (T4 & T5 not fitted)



A2

Figure A2
Specimen supplied

Intermediate specimen
25mm diameter Brass with
T4 & T5 thermocouples

Paper disc insulator

Cork disc insulator

25mm diameter Aluminium

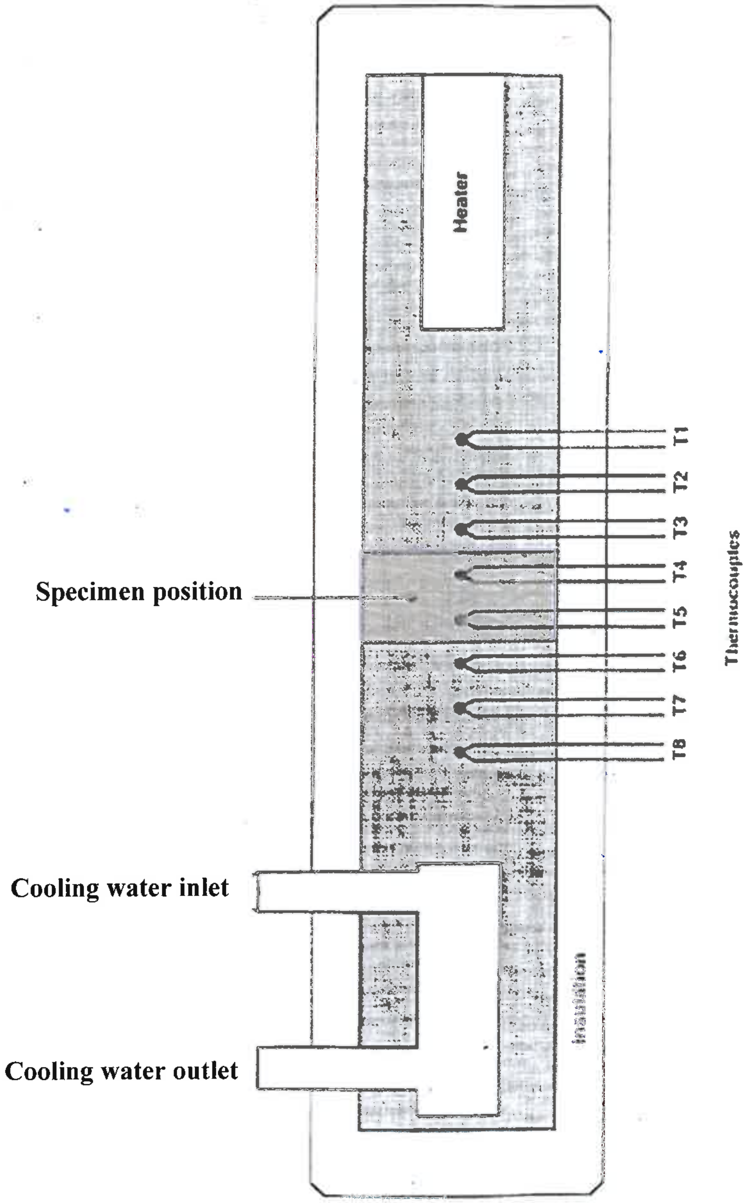
25mm diameter Stainless Steel

13mm (Reduced diameter) Brass

Heat transfer paste

Figure A3

SCHEMATIC H112A Linear Heat Conduction Unit



DESCRIPTION
LINEAR HEAT CONDUCTION H112A

Please refer to Figure A1 page A1, A2 page A2 and A3 page A3.

The Linear Heat Conduction unit H112A allows the investigation of the basic laws of heat transfer by conduction through a solid. The H112A is dependant upon the Heat Transfer Service Unit H112, for heater power and temperature measurement.

The unit is mounted on a plastic base plate that must be placed on a surface, ideally to the left of the Heat Transfer service Unit H112.

The heat transfer module is cylindrical and mounted with its axis vertical to the base plate. The heating section houses a 25mm diameter cylindrical brass section with a nominally 65Watt (at 240V AC) cartridge heater in the top end. An integral high temperature cut out (automatic reset) prevents overheating. Power is supplied to the heater from the Heat Transfer Service Unit H112 via the 8-pole plug and lead.

Three fixed thermocouples T1, T2, T3 are positioned along the heated section at 15mm intervals.

The cooling section is also manufactured from 25mm diameter brass to match the heated top section and is cooled at its bottom end by water flowing through a chamber in the material.

Three fixed thermocouples T6, T7, T8 are positioned along the cooled section at 15mm intervals

Four intermediate sections are supplied to place between the heated and cooled sections.

The heated section, cooling section and all the intermediate sections are located co-axially inside plastic housings. An annular air gap insulates the specimens from the surroundings and minimise heat losses/gains.

The heated and cooled sections incorporate centralising ‘O’ rings to ensure that each are held concentrically. Similar ‘O’ rings are fitted to the intermediate sections so that they are installed in alignment.

Toggle clamps ensure that the heated and cooled sections are held tightly together, with or without the intermediate sections installed. **Slacken the clamp tensioning screw before releasing the toggle clamps** and re-apply tension after fitting a new specimen, thus avoiding over-stressing the clamping device.

Water for the cooled section is supplied from a local tap via the supplied hoses.

The water flow rate is adjusted by manual control of the supply tap. After cooling the cooled section, the water is allowed to run to a drain via the outlet hose.

The four intermediate sections supplied are as follows: -

Brass Specimen

30mm long, 25mm diameter fitted with two thermocouples T4, T5 at 15mm intervals along the axis. With the brass specimen clamped between the heated and cooled sections a uniform 25mm diameter brass bar is formed with 8 uniformly spaced (15mm intervals) thermocouples (T1 to T8). Refer to Figure A3 on page A3. The specimen is marked ‘TOP’ to ensure T4 precedes T5.

Stainless Steel Specimen

30mm long, 25mm diameter. No thermocouples fitted

Aluminium Specimen

30mm long, 25mm diameter. No thermocouples fitted.

Brass Specimen with Reduced Diameter

30mm long, 13mm diameter. No thermocouples fitted.

In addition, the heat conducting properties of insulators such as cork and paper may be found by clamping the insulating discs between the heated and cooled sections.

The effect of good thermal contact between conducting surfaces is demonstrated by experiments with and without toggle clamps.

The value of heat transfer paste may be verified by experiments with and without paste.

INSTALLATION
LINEAR HEAT CONDUCTION UNIT H112A
WITH HEAT TRANSFER SERVICE MODULE H112

Refer to Figure A1 on page A1 and Figure A2 on page A2 and figure 3 on page A3

It is assumed that the basic INSTALLATION AND COMMISSIONING procedures for the Heat Transfer Service Unit H112 have been completed as detailed in the H112 manual.

Ensure that the main switch is in the OFF position.

Place the Linear Heat Conduction unit on a flat surface adjacent to the Heat transfer Service Unit H112

Temperature Sensors

The eight temperature sensors are type K thermocouples and each lead has a number label.

The miniature plugs on each thermocouple have one wide and one narrow flat blade that match the slots on the thermocouple sockets. Connect the plugs to the corresponding numbered sockets on the Heat transfer service Unit H112.

Heating Element

Connect the 8-pole power lead to the OUTPUT socket on the front panel of the Heat Transfer Service Unit H112.

Cooling Water Supply

The Linear Heat Conduction H112A requires connection to a source of clean, cold water with a flow of approximately 1.5 litres/minute. This should be fitted with an isolation valve so that when not in use the supply can be turned off.

Connect to the cold-water inlet point using the PVC tubing supplied.

Cooling Water Drain

Connect the PVC tubing to the outlet nozzle. This should be led to a drain and the tube secured so that it cannot fall out during use.

OPERATING PROCEDURE

Heat Transfer Service Unit H112 with Linear Heat Transfer Unit H112A

Refer to Figure A1 on page A1 and Figure A2 on page A2 and Figure A3 on page A3.

1. Ensure that the main switch is in the off position (the digital displays should not be illuminated). Ensure that the residual current circuit breaker on the rear panel is in the ON position. **Note that this should be tested for normal operation at intervals specified by local regulations using the method described in the MAINTENANCE section.**

2. Turn the voltage controller anti-clockwise to set the AC voltage to minimum. Ensure the Linear Heat Transfer Unit H112A has been connected to the Heat Transfer Service Unit H112 as detailed in the INSTALLATION procedure on page A6.

3. Ensure the cold water supply and electrical supply are turned on at the source. Open the water tap until the flow through the drain hose is approximately 1.5 litres/minute. The actual flow can be checked using a measuring vessel and stopwatch if required but this is not a critical parameter. The flow has to dissipate up to 65W only.

4. Release the toggle clamp tensioning screw and clamps. Ensure that the faces of the exposed ends of the heated and cooled sections are clean. Similarly, check the faces of the intermediate specimen (if in use) to be placed between the faces of the heated and cooled sections. **If instructed in the individual procedures for the experiment, coat the mating faces of the heated and cooled sections and the intermediate section (if used) with thermal conduction paste.** Ensure the intermediate section to be used is in the correct orientation then clamp the assembly together using the toggle clamps and tensioning screw.

6. Turn on the main switch and the digital displays should illuminate. Set the temperature selector switch to T1 to indicate the temperature of the heated end of the bar. **Rotate the voltage controller to increase the voltage to that specified in the procedure for each experiment.**

7. Observe the temperature T1. This should begin to increase.

8. Allow the system to reach stability, and take readings and make adjustments as instructed in the individual procedures for each experiment. *If using the optional Computerised Data Acquisition Upgrade HC112, additional instructions will be given in the HC112 Manual.*

9. When the experimental procedure is completed, it is good practice to turn off the power to the heater by reducing the voltage to zero and allow the system a short time to cool before turning off the cooling water supply.

10. Ensure that the locally supplied water supply isolation valve to the unit is closed. Turn off the main switch and isolate the electrical supply.

11. Note that if the thermal conducting paste is left on the mating faces of the heated and cooled sections for a long period it can be more difficult to remove than if removed immediately after completing an experiment. If left on the intermediate sections it can attract dust and in particular grit which acts as a barrier to good thermal contact.

MAINTENANCE
Linear Heat Transfer Unit H112A

Water Cooling Circuit
The unit should be disconnected from the water supply when not in use. If the ambient storage conditions are likely to be at or below 0°C then the unit should be drained by disconnecting the supply tube and allowing the water to drain through the outlet tube.

Intermediate Sections
After use, the intermediate sections should be cleaned and stored to avoid damage to the contact surfaces.

Any build up of thermal paste on the contact surfaces should be removed with a liquid metal polish applied with a soft cloth. Aggressive solvents should not be used as these may affect the plastic insulation material.

Toggle Clamps
The toggle clamps are in fixed positions on the sides of the cooled section and are not adjustable. The thermal contact between the heated and cooled sections depends upon clean surfaces and the compression applied by the toggle clamps.

If the clamps become distorted with use, it is possible to increase tension to the original condition by VERY CAREFULLY bending the curved wire arms of the clamps. Do not over bend the arms as the unit can be damaged.

Heated and Cooled Sections Adjustment
The heated section is allowed to slide by an amount that enables adjustment of the tension on the toggle clamps. The black knob at the top of the unit (See page 1) may be turned carefully to adjust the load on the toggle clamps. **Do not over tension the toggle clamps.**

(Cooled Section)
The brass end face of the cooling section should protrude approximately 1mm above the end face of the plastic insulation that surrounds it.

After adjustment of the heated section, there should be between 0.5mm and 1.0mm gap between the end faces of the plastic insulators OUTER DIAMETER. This will indicate that the inner diameter and brass surfaces are in good contact.

If the gap is too large, loosen the M5 hexagonal socket screw on the side of the cooled section with a 2.5mm AF (Across Flats) hexagonal key.

At the bottom of the cooled section is a central M8 hexagonal socket screw that is accessible through a hole in the base plate. This may be turned using a 4mm AF (across Flats) hexagonal key and can be used to adjust the axial position of the brass bar relative to the insulation. Keep the brass bar pressed against the M8 screw while adjusting and when in the correct position tighten the M5 screw on the side to retain the bar.

To finally check the contact lightly smear the two faces with thermal paste and clamp the heating and cooling section together. Release the two sections and check the faces to ensure that the paste has been evenly displaced by contact.

USEFUL DATA
Linear Heat Transfer Unit H112A

Heated Section
Material: Brass, 25mm diameter, Thermocouples T1, T2, T3 at 15mm spacing
Thermal Conductivity: Approximately 121 W/m K

Cooled Section
Material: Brass, 25mm diameter, Thermocouples T6, T7, T8 at 15mm spacing
Thermal Conductivity: Approximately 121 W/m K

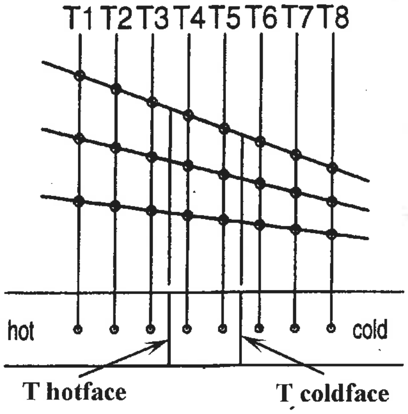
Brass Intermediate Specimen
Material: Brass, 25mm diameter x 30mm long. Thermocouples T4, T5 at 15mm spacing centrally spaced along the length.
Thermal Conductivity: Approximately 121 W/m K

Stainless Steel Intermediate Specimen
Material: Stainless steel, 25mm diameter x 30mm long. No thermocouples fitted.
Thermal Conductivity: Approximately 25 W/m K

Aluminium Intermediate Specimen
Material: Aluminium Alloy, 25mm diameter x 30mm long. No thermocouples fitted.
Thermal Conductivity: Approximately 180 W/m K

Reduced Diameter Brass Intermediate Specimen
Material: Brass, 13mm diameter x 30mm long. No thermocouples fitted.
Thermal Conductivity: Approximately 121 W/m K

Hot and Cold Face Temperature
Due to the need to keep the spacing of the thermocouples constant at 15mm with, or without the intermediate specimens in position the thermocouples are displaced 7.5mm back from the end faces of the heated and cooled specimens and similarly located for the Brass Intermediate Specimen.



Hence,

$$T\ \text{hotface} = T3 - \frac{(T2 - T3)}{2} \qquad T\ \text{coldface} = T6 + \frac{(T6 - T7)}{2}$$

Note that the equations are of the above form as the distance between T3 and the hot face and T6 and the cold face are equal to **half** the distance between the adjacent pairs of thermocouples.

CAPABILITIES OF THE LINEAR HEAT TRANSFER UNIT H112A WITH THE HEAT TRANSFER SERVICE UNIT H112

1. To measure the temperature distribution for steady state conduction of energy through a uniform plane wall and demonstrate the effect of a change in heat flow.

2. To understand the use of the Fourier Rate Equation in determining rate of heat flow through solid materials for one dimensional, steady flow of heat.

3. To measure the temperature distribution for steady state conduction of energy through a composite plane wall and determine the Overall Heat Transfer Coefficient for the flow of heat through a combination of different materials in use.

4. To determine the thermal conductivity **k** of a metal specimen.

5. To demonstrate that the temperature gradient is inversely proportional to the cross-sectional area for one dimensional flow of heat in a solid material of constant thermal conductivity.

6. To demonstrate the effect of contact resistance on thermal conduction between adjacent materials.

7. To understand the application of poor thermal conductors and determine the thermal conductivity k of a poor thermal conductor.

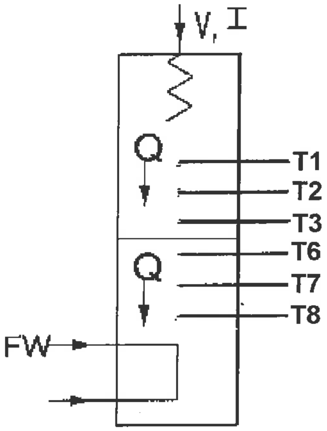
8. To observe unsteady state conduction of heat and to use this in observation of the time to reach stable conditions.

1. To measure the temperature distribution for steady state conduction of energy through a uniform plane wall and demonstrate the effect of a change in heat flow.

It is assumed that the **INSTALLATION AND COMMISSIONING** procedures for the linear heat conduction unit H112A have been completed as detailed on pages A4 to A6.

PROCEDURE
Following the basic **OPERATING PROCEDURE** on page A7 smear the faces of the heated and cooled sections with thermal conducting paste and clamp them together **without** any intermediate section in place.

Schematically this produces a svstem as shown below.



Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to 90 volts.

Monitor temperatures T1, T2, T3, T6, T7, T8 until stable.

When the temperatures are stabilised record:
T1, T2, T3, T6, T7, T8, V and I.

Reset the heater voltage to 120 volts and repeat the above procedure again recording the parameters T1, T2, T3, T6, T7, T8, V and I when temperatures have stabilised.

Reset the heater voltage to 170 volts and repeat the above procedure again recording the parameters T1, T2, T3, T6, T7, T8, V and I when temperatures have stabilised.

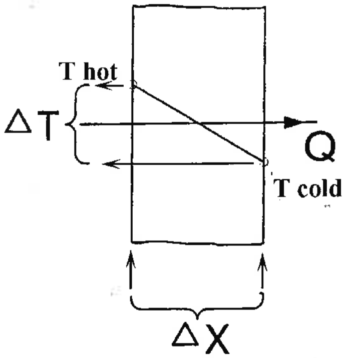
Reset the heater voltage to 200 volts and repeat the above procedure again recording the parameters T1, T2, T3, T6, T7, T8, V and I when temperatures have stabilised.

When completed, if no further experiments are to be conducted reduce the heater voltage to zero and shut down the system as detailed in the operation section on page A7.

The theory being demonstrated, sample observations and calculations are shown in the following pages.

THEORY

If the heated and cooled surfaces are clamped tightly together and are in good thermal contact, then the two sections can be considered as a continuous homogenous sample of uniform cross section and material.



According to Fourier's law of heat conduction:
If a plane section of thickness **Δx** and constant area **A** maintains a temperature difference **ΔT** then the heat transfer rate per unit time $\dot{Q}$ by conduction through the wall is found to be:

$$\dot{Q} \propto A \frac{\Delta T}{\Delta x}$$

$$\dot{Q} = C \frac{\Delta T}{\Delta x}$$

$$\frac{\dot{Q}}{\left(\frac{\Delta T}{\Delta x}\right)} = C$$

Where, **C** is a constant that will be examined at a later stage.

Overleaf are sample test results and illustrative calculations showing the application of the above theory.

OBSERVATIONS

Sample test results

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
	°C	°C	°C	°C	°C	°C	°C	°C	Volts	Amps
1	30.9	28.4	25.9			24.5	21.9	20.1	88	0.098
2	41.1	36.9	32.7			29.7	25.5	22.2	117	0.129
3	64.3	56.3	48.4			41.7	33.8	27.2	164	0.184
4	89.3	77.5	65.6			55	42.9	32.6	203	0.226
Distance from T1	**0.000**	**0.015**	**0.030**	---	---	**0.045**	**0.060**	**0.075**	---	---

CALCULATED DATA

Sample No.	$\dot{Q}$	ΔT_{1-3}	ΔT_{6-8}	Δx_{1-3}	Δx_{6-8}	$\frac{\Delta T_{1-3}}{\Delta x_{1-3}}$	$\frac{\Delta T_{6-8}}{\Delta x_{6-8}}$	$\dot{Q}/\left(\frac{\Delta T_{1-3}}{\Delta x_{1-3}}\right)$	$\dot{Q}/\left(\frac{\Delta T_{6-8}}{\Delta x_{6-8}}\right)$
--	W	K	K	m	m	K/m	K/m	W/mK	W/mK
1	8.6	5.0	4.4	0.03	0.03	166.7	146.7	0.051	0.058
2	15.1	8.4	7.5	0.03	0.03	280.0	250.0	0.054	0.060
3	30.26	15.9	14.5	0.03	0.03	530.0	483.3	0.057	0.063
4	45.99	23.7	22.4	0.03	0.03	790.0	746.7	0.058	0.062

For sample No.1 the example calculations are as follows:

Heat transfer rate from the heater

$$\dot{Q} = V \times I$$
$$= 88 \times 0.098$$
$$= 8.6 \text{ Watts}$$

Temperature difference in the heated section between T1 and T3

$$\Delta T_{hot} = \Delta T_{1-3} = T_1 - T_3$$
$$= 30.9 - 25.9$$
$$= 5.0 \text{ K}$$

Similarly the temperature difference in the cooled section between T6 and T8

$$\Delta T_{cold} = \Delta T_{6-8} = T_6 - T_8$$
$$= 24.5 - 20.1$$
$$= 4.4 \text{ K}$$

The distance between the temperature measuring points, T1 and T3 and T6 and T8, are similar

$$\Delta x_{1-3} = 0.03\text{m}$$

$$\Delta x_{6-8} = 0.03\text{m}$$

Hence, the temperature gradient along the heated and cooled sections may be calculated from

$$\text{Heated Section } \frac{\Delta T_{1-3}}{\Delta x_{1-3}} = 166.7 \text{ K/m}$$

$$\text{Cooled Section } \frac{\Delta T_{6-8}}{\Delta x_{6-8}} = 146.7 \text{ K/m}$$

If the constant rate of heat transfer is divided by the temperature gradients, the value obtained will be similar if the equation

$$\dot{Q}=C\ \frac{\Delta T}{\Delta x}$$

$$\frac{\dot{Q}}{\left(\frac{\Delta T}{\Delta x}\right)}=C$$

is valid.

Hence, substituting the values obtained gives for the heated section and cooled sections respectively the following values.

$$\dot{Q}\Big/\left(\frac{\Delta T_{1-3}}{\Delta x_{1-3}}\right) = \frac{8.6}{166.7} = 0.051\ \text{W/mK}$$

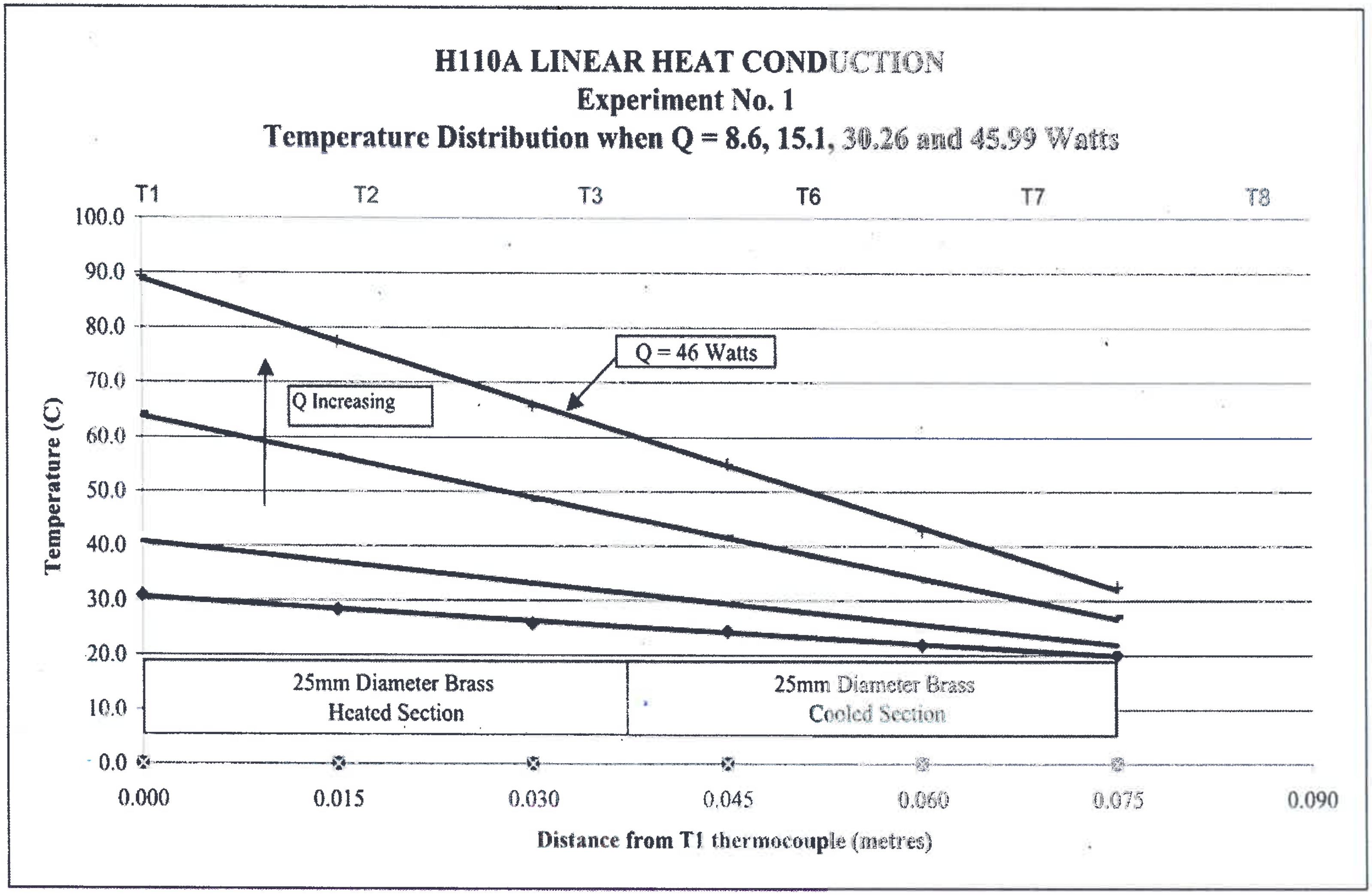
$$\dot{Q}\Big/\left(\frac{\Delta T_{6-8}}{\Delta x_{6-8}}\right) = \frac{8.6}{146.7} = 0.058\ \text{W/m}$$

As may be seen from the above example and the tabulated data the function

$$\frac{\dot{Q}}{\left(\frac{\Delta T}{\Delta x}\right)}=C$$

does result in a constant value within the limits of the experimental data .

The sample data is plotted graphically on the following page to reinforce the linear nature of the temperature along the bar


H110A LINEAR HEAT CONDUCTION
Experiment No. 1
Temperature Distribution when Q = 8.6, 15.1, 30.26 and 45.99 Watts
T1
T2
T3
T6
T7
T8
Temperature (C)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Q = 46 Watts
Q Increasing
25mm Diameter Brass Heated Section
25mm Diameter Brass Cooled Section
0.000
0.015
0.030
0.045
0.060
0.075
0.090
Distance from T1 thermocouple (metres)

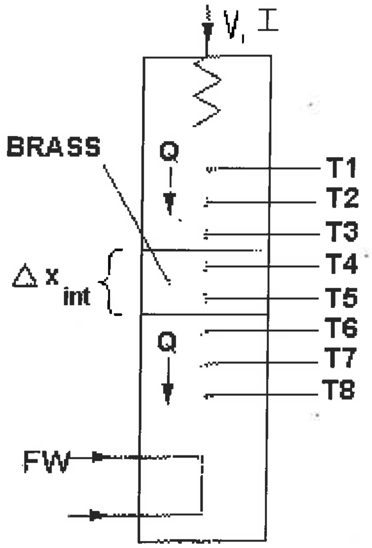
2. To understand the use of the Fourier Rate Equation in determining rate of heat flow through solid materials for one dimensional, steady flow of heat.

It is assumed that the **INSTALLATION AND COMMISSIONING** procedures for the linear heat conduction unit H112A have been completed as detailed on pages A4 to A6.

PROCEDURE

Following the basic **OPERATING PROCEDURE** on page A7 smear the faces of the heated and cooled sections with thermal conducting paste and clamp them together **with the Brass Intermediate Specimen** in place.

Schematically this produces a system as shown below.



Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to approximately 120 volts. This will provide a reasonable temperature gradient along the length of the bar. If however the local cooling water supply is at a high temperature (25-35 °C or more) then it may be necessary to increase the voltage supplied to the heater. This will increase the temperature difference between the hot and cold ends of the bar.

Monitor temperatures T1, T2, T3, T4, T5, T6, T7, T8 until stable.

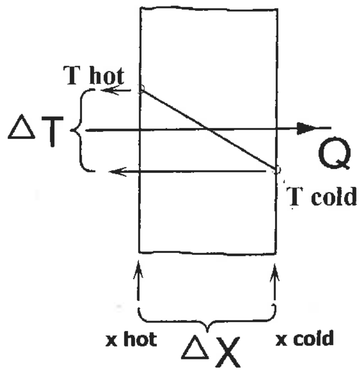
When the temperatures are stabilised record:
T1, T2, T3, T4, T5, T6, T7, T8, V, I

Increase the heater voltage by approximately 50 volts and repeat the above procedure again recording the parameters T1, T2, T3, T4, T5, T6, T7, T8, V, I when temperatures have stabilised.

When completed, if no further experiments are to be conducted reduce the heater voltage to zero and shut down the system as detailed in the operation section on page A7.

THEORY

If the heated and cooled surfaces are clamped tightly together and are in good thermal contact, then the two sections can be considered as a continuous homogenous sample of uniform cross section and material.



According to Fourier's law of heat conduction:

If a plane section of thickness **Δx** and constant area **A** maintains a temperature difference **ΔT** then the heat transfer rate per unit time $\dot{Q}$ by conduction through the wall is found to be:

$$\dot{Q} \propto A\frac{\Delta T}{\Delta x}$$

where $\Delta x = (x_{hot} - x_{cold})$

and $\Delta T = (T_{hot} - T_{cold})$

If the material of the wall is homogeneous and has a thermal conductivity **k** then

$$\dot{Q} = -kA\frac{\Delta T}{\Delta x}$$

The negative sign follows thermodynamic convention in that heat transfer is normally considered **positive** in the direction of temperature **fall**. However, for the purposes of the following illustrations the negative sign will be ignored.

Overleaf are sample test results and illustrative calculations showing the application of the above theory.

OBSERVATIONS

Sample test results

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
	°C	°C	°C	°C	°C	°C	°C	°C	Volts	Amps
1	48.8	44.7	40.5	37.2	32.8	29.4	25	22.1	117	0.128
2	77.8	70.1	62.3	55.1	47.3	40.2	32.4	26.5	164	0.183
3										
4										
Distance from T1	**0.000**	**0.015**	**0.030**	**---**	**---**	**0.045**	**0.060**	**0.075**	**---**	**---**

CALCULATED DATA

Brass Intermediate Specimen cross sectional Area A= 0.00049m^2

Sample No.	$\dot{Q}$	ΔT_{1-3} hot	ΔT_{4-5} int	ΔT_{6-8} cold	Δx_{1-3} hot	Δx_{4-5} int	Δx_{6-8} cold	$k_{1-2\ hot}$	$k_{4-5\ int}$	$k_{6-8\ cold}$
	Watts	K	K	K	m	m	m	W/mK	W/mK	W/mK
1	15.0	8.3	4.4	7.3	0.030	0.015	0.03	110.4	104.2	125.6
2	29.9	15.5	7.8	13.7	0.030	0.015	0.03	118.0	117.2	133.5
3										
4										

The distances between the thermocouple sensors are as follows. Note that the distance between T4 and T5 is less than the other pairs of thermocouples.

$$\Delta x_{1-3} = \mathbf{0.03m}$$

$$\Delta x_{4-5} = \mathbf{0.0015m}$$

$$\Delta x_{6-8} = \mathbf{0.03m}$$

For sample No.1 the example calculations are as follows:

Heat transfer rate from the heater

$$\dot{Q} = V \times I$$

$$= 117.0 \times 0.128$$

$$= 15.0 \text{ Watts}$$

Hence the thermal conductivity **k** of the sections of bar are,

$$k_{1-3} = \frac{\Delta x_{1-2}\,\dot{Q}}{\Delta T_{1-3}\,A}$$

$$= \frac{0.03 \times 15.0}{8.3 \times 0.00049}$$

$$= 110.4 \text{ W/mK}$$

and similarly

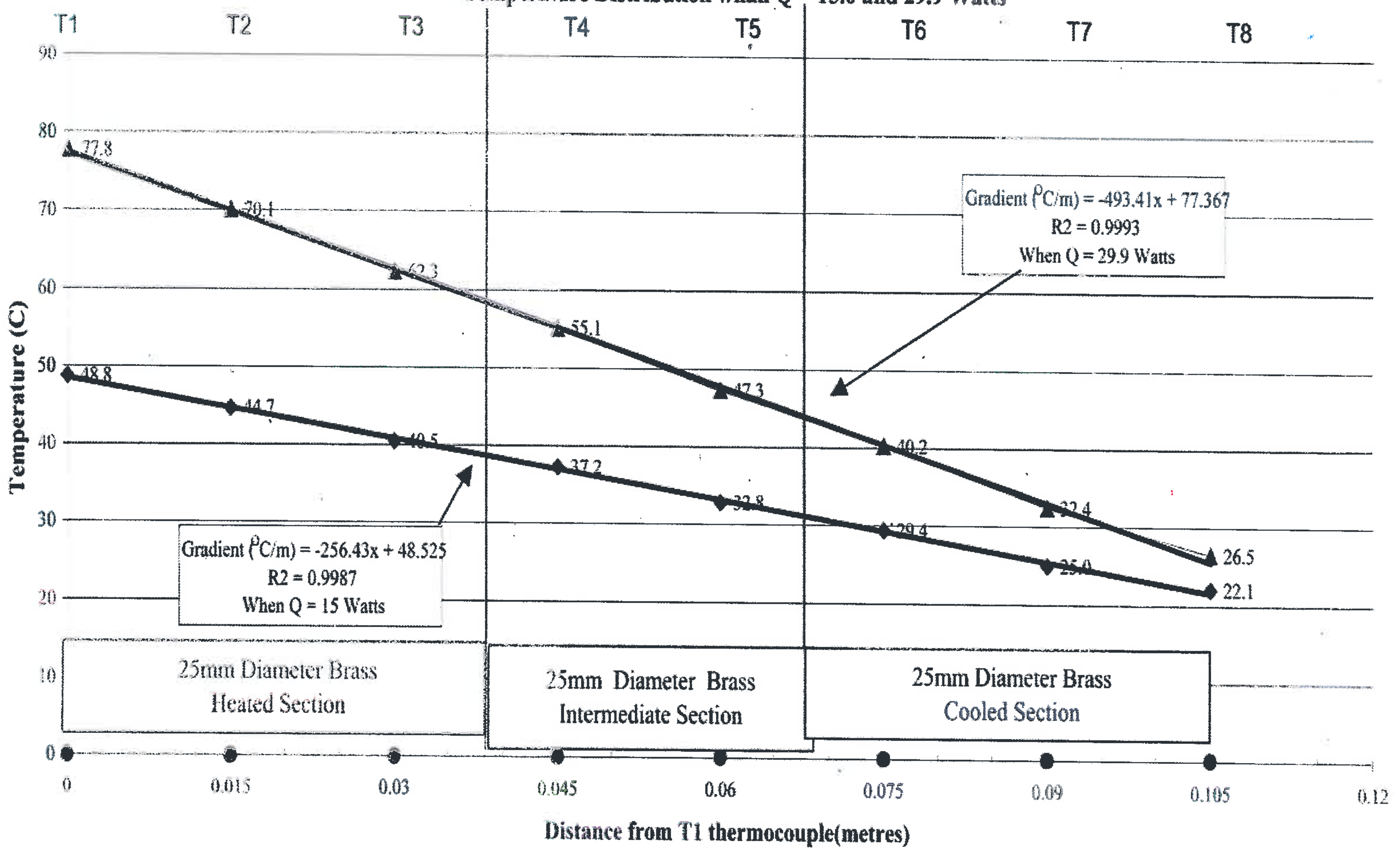
$$k_{3\text{-}4} = \frac{0.0015 \times 15.0}{4.4}$$
$$= 104.2 \text{ W/mK}$$

$$k_{6\text{-}8} = \frac{0.03 \times 15.0}{7.3}$$
$$= 125.6 \text{ W/mK}$$

It may be seen that the thermal conductivity in every case is similar. Differences occur due to the heat losses from the specimen that is not accounted for.

The sample data is plotted on the following page. Note that the temperature profiles are straight lines and that increased heat flow results in an increased slope.

H110A LINEAR HEAT CONDUCTION
Experiment No.2
Temperature Distribution whan Q = 15.0 and 29.9 Watts

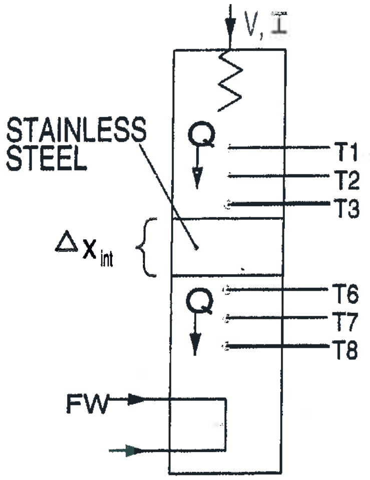


3. To measure the temperature distribution for steady state conduction of energy through a composite plane wall and determine the Overall Heat Transfer Coefficient for the flow of heat through a combination of different materials in use.

It is assumed that the **INSTALLATION AND COMMISSIONING** procedures for the linear heat conduction unit H112A have been completed as detailed on pages A4 to A6.

PROCEDURE
Following the basic **OPERATING PROCEDURE** on page A7 smear the faces of the heated and cooled sections with thermal conducting paste and clamp them together **with the Stainless Steel Intermediate Specimen** in place.

Schematically this produces a system as shown below.



Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to approximately 90 volts. This will provide a reasonable temperature gradient along the length of the bar. If however the local cooling water supply is at a high temperature (25-35 °C or more) then it may be necessary to increase the voltage supplied to the heater. This will increase the temperature difference between the hot and cold ends of the bar.

Monitor temperatures T1, T2, T3, T6, T7, T8 until stable.

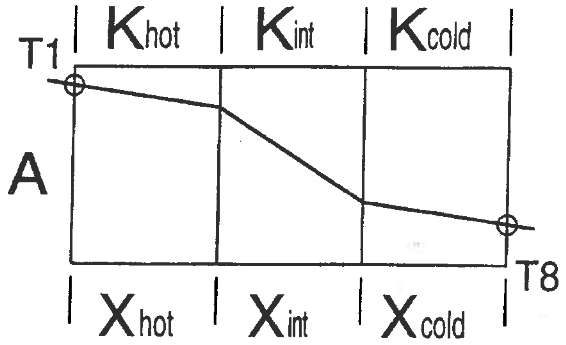
When the temperatures are stabilised record:
T1, T2, T3, T6, T7, T8, V, I

Increase the heater voltage by approximately 30 volts and repeat the above procedure again recording the parameters T1, T2, T3, T6, T7, T8, V, I when temperatures have stabilised.

When completed, if no further experiments are to be conducted reduce the heater voltage to zero and shut down the system as detailed in the operation section on page A7. Overleaf are sample test results and illustrative calculations showing the application of the above theory.

THEORY

If the heated and cooled sections are clamped tightly together so that the end faces are in good thermal contact with the stainless steel intermediate section a composite bar of the form shown below is formed.



Assuming that the energy entering the heated end is conducted **without** loss to the surroundings through to the cooled end, the heat flow through each section must be equal.

Hence, by applying Fourier's law to each section .

$$\frac{\dot{Q}}{A}=\frac{k_{cold}\,\Delta T_{cold}}{\Delta x_{cold}}=\frac{k_{int}\,\Delta T_{int}}{\Delta x_{int}}=\frac{k_{hot}\,\Delta T_{hot}}{\Delta x_{hot}}$$

From this

$$(\Delta T_{hot}+\Delta T_{int}+\Delta T_{cold})=\frac{\dot{Q}}{A}\left(\frac{\Delta x_{hot}}{k_{hot}}\right)+\frac{\dot{Q}}{A}\left(\frac{\Delta x_{int}}{k_{int}}\right)+\frac{\dot{Q}}{A}\left(\frac{\Delta x_{cold}}{k_{cold}}\right)$$

Then

$$\begin{aligned}(T1-T8)&=(\Delta T_{hot}+\Delta T_{int}+\Delta T_{cold})\\ &=\frac{\dot{Q}}{A}\left(\frac{\Delta x_{hot}}{k_{hot}}\right)+\frac{\dot{Q}}{A}\left(\frac{\Delta x_{int}}{k_{int}}\right)+\frac{\dot{Q}}{A}\left(\frac{\Delta x_{cold}}{k_{cold}}\right)\\ &=\frac{\dot{Q}}{A}\left(\frac{\Delta x_{hot}}{k_{hot}}+\frac{\Delta x_{int}}{k_{int}}+\frac{\Delta x_{cold}}{k_{cold}}\right)\end{aligned}$$

Hence

$$\frac{(T1-T8)}{\left(\frac{\Delta x_{hot}}{k_{hot}}+\frac{\Delta x_{int}}{k_{int}}+\frac{\Delta x_{cold}}{k_{cold}}\right)}=\frac{\dot{Q}}{A}=U\,(T1-T8)$$

And

$$\frac{\dot{Q}}{A(T1-T8)}=U$$

where

$$\frac{1}{U}=\left(\frac{\Delta x_{hot}}{k_{hot}}+\frac{\Delta x_{int}}{k_{int}}+\frac{\Delta x_{cold}}{k_{cold}}\right)=R$$

Where **U** is the overall heat transfer coefficient and **R** is the thermal resistance of the composite material.

OBSERVATIONS

Sample test results

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
	°C	°C	°C	°C	°C	°C	°C	°C	Volts	Amps
1	52.7	50.6	48.3			22.7	20.1	19.3	87	0.099
2	76.8	73.3	69.7			26.2	22.7	20.8	116	0.128
3										
4										
Distance from T1	**0.000**	**0.015**	**0.030**	**---**	**---**	**0.045**	**0.060**	**0.075**	**---**	**---**

CALCULATED DATA

Specimen cross sectional Area A= 0.00049m^2

Conductivity of Brass heated and cooled section = 121 W/mK

Conductivity of Stainless Steel intermediate section = 25 W/mK

Sample No.	$\dot{Q}$	$\Delta T_{1\text{-}8}$	Δx_{hot}	Δx_{int}	Δx_{old}	k_{hot}	k_{int}	k_{cold}
--	W	K	m	m	m	W/mK	W/mK	W/mK
1	8.37	33.4	0.0375	0.03	0.0375	121	25	121
2	14.88	56.0	0.0375	0.03	0.0375	121	25	121
3								
4								

Sample No.	$U = \dfrac{1}{\left(\dfrac{X_{hot}}{k_{hot}} + \dfrac{X_{int}}{k_{int}} + \dfrac{X_{cold}}{k_{cold}}\right)}$	$\dfrac{\dot{Q}}{A(T1 - T8)} = U$
--	W/m^{2}K	W/m^{2}K
1	549.5	510.4
2	549.5	541.2
3		
4		

For sample No.1 the example calculations are as follows:

Brass Intermediate Specimen and hot and cold section cross sectional Area

$$A = \frac{\pi D^2}{4}$$

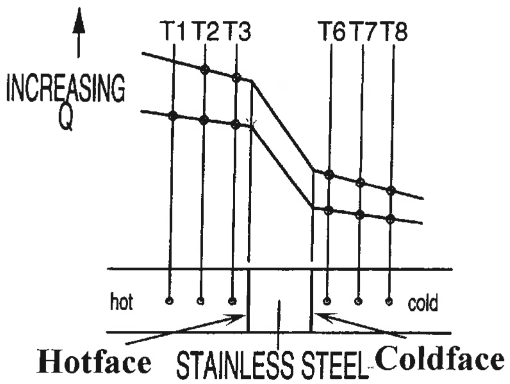
$$= \frac{\pi \times 0.025^2}{4}$$

$$= \mathbf{0.00049\ m^2}$$

The temperature difference across the bar from T1 to T8

$$\mathbf{T1 - T8 = (52.7 - 19.3) = 33.4\ °C}$$

Note that Δx_{hot} and Δx_{cold} are the distances between the thermocouple T1 and the hot face and the cold face and the thermocouple T8 respectively. Similarly Δx_{int} is the distance between the hot face and cold face of the intermediate stainless steel section.



The distances between surfaces are therefore as follows.

$$\Delta x_{hot} = 0.0375\text{m}$$
$$\Delta x_{int} = 0.030\text{m}$$
$$\Delta x_{cold} = 0.0375\text{m}$$

Heat transfer rate from the heater

$$\dot{Q} = V \times I$$
$$= 87 \times 0.099$$
$$= 8.37 \text{ Watts}$$

Hence

$$U = \frac{\dot{Q}}{A(T1 - T8)}$$
$$= \frac{8.37}{0.00049 \times (52.7 - 19.3)}$$
$$= 510.4 \text{ W/m}^2\text{K}$$

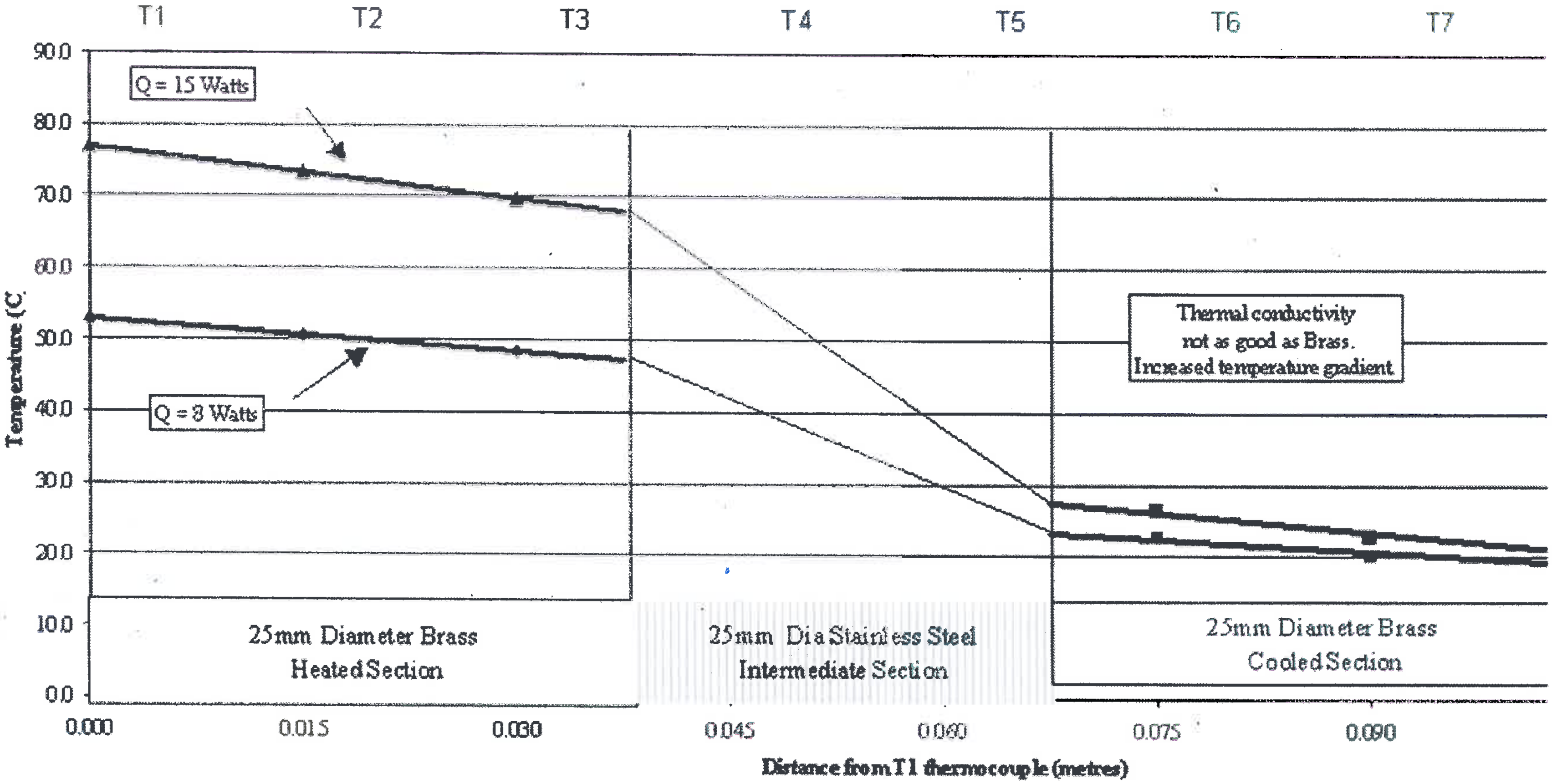
Similarly

$$U = \frac{1}{\left(\frac{Xhot}{khot} + \frac{Xint}{kint} + \frac{Xcold}{kcold}\right)}$$
$$= \frac{1}{\left(\frac{0.0375}{121} + \frac{0.03}{25} + \frac{0.0375}{121}\right)}$$
$$= 549.5 \text{ W/m}^2\text{K}$$

Note that the U value resulting from test data differs from that resulting from assumed thermal conductivity and material thickness. This is most likely due to un-accounted for heat losses and thermal resistances between the hot face interface and cold face interface with the stainless steel intermediate section.

The temperature data may be plotted against position along the bar and straight lines drawn through the temperature points for the heated and cooled sections. Then a straight line may be drawn through the hot face and cold face temperatures to extrapolate the temperature distribution in the stainless steel intermediate section.

The sample data is plotted on the following page.



H110A LINEAR HEAT CONDUCTION
Experiment: C
Temperature Distribution when Q = 8.37 and 14.88 Watts

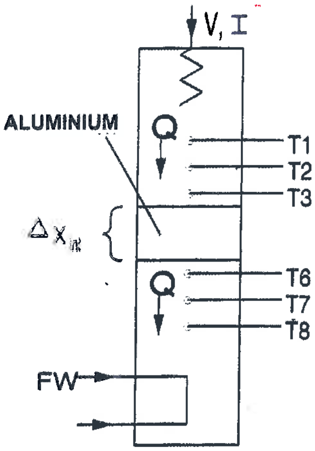
4. To determine the thermal conductivity k of a metal specimen.

It is assumed that the **INSTALLATION AND COMMISSIONING** procedures for the linear heat conduction unit H112A have been completed as detailed on pages A4 to A6.

PROCEDURE

Following the basic **OPERATING PROCEDURE** on page A7 smear the faces of the heated and cooled sections with thermal conducting paste and clamp them together **with the aluminium intermediate** section in place.

Schematically this produces a system as shown below



Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to approximately 150 volts. This will provide a reasonable temperature gradient along the length of the bar. If however the local cooling water supply is at a high temperature (25-35 °C or more) then it may be necessary to increase the voltage supplied to the heater. This will increase the temperature difference between the hot and cold ends of the bar.

Monitor temperatures T1, T2, T3, T6, T7, T8 until stable.

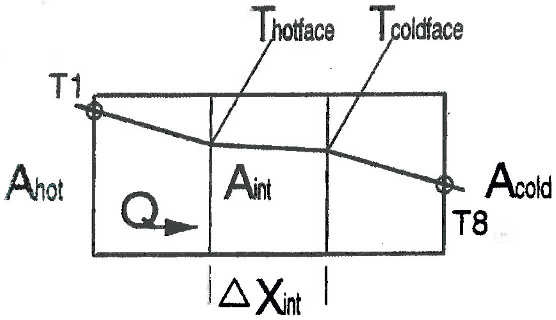
When the temperatures are stabilised record:
T1, T2, T3, T6, T7, T8, V, I

Increase the heater voltage by approximately 50 volts and repeat the above procedure again recording the parameters T1, T2, T3, T6, T7, T8, V, I when temperatures have stabilised.

When completed, if no further experiments are to be conducted reduce the heater voltage to zero and shut down the system as detailed in the operation section on page A7.

THEORY

If the heated and cooled sections are clamped tightly together so that the end faces are in good thermal contact with the stainless steel intermediate section a composite bar of the form shown below is formed.



Assuming that the energy entering the heated end is conducted **without loss** to the surroundings through to the cooled end the heat flow through each section must be equal.

Hence by applying Fourier's law to the Aluminium centre section

$$\dot{Q} = k_{int} A_{int} \frac{\Delta T_{int}}{\Delta x_{int}}$$

Where

$$\Delta T_{int} = (T_{hotface} - T_{coldface})$$

By re-arranging the formula the thermal conductivity k_{int} of the intermediate section can be calculated from:

$$k_{int} = \frac{\dot{Q}\Delta x_{int}}{A_{int}(T_{hotface} - T_{coldface})}$$

Overleaf are sample test results and illustrative calculations showing the application of the above theory.

OBSERVATIONS

Sample test results

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
	°C	°C	°C	°C	°C	°C	°C	°C	Volts	Amps
1	61.6	55.6	49.3			36.6	30.2	25.5	143	0.16
2	92.5	82.5	72.4			49.5	39.4	31.1	190	0.213
3										
4										
Distance from T1	**0.000**	**0.015**	**0.030**	**---**	**---**	**0.045**	**0.060**	**0.075**	**---**	**---**

CALCULATED DATA

Specimen cross sectional Area A= 0.00049m^2

Conductivity of Brass heated and cooled section = 121 W/mK

Conductivity of Aluminium intermediate section = 180 W/mK

Sample No.	$\dot{Q}$	$T_{hotface}$	$T_{coldface}$	ΔT_{int}	k_{int}
	Watts	°C	°C	K	W/mK
1	22.95	46.15	39.8	6.35	220.85
2	40.4	67.35	54.55	12.80	192.87
3					
4					

For sample No.1 the example calculations are as follows:

Aluminium Intermediate Specimen and hot and cold section cross sectional Area

$$A = \frac{\pi D^2}{4}$$

$$= \frac{\pi \times 0.025^2}{4}$$

$$= 0.00049 \text{ m}^2$$

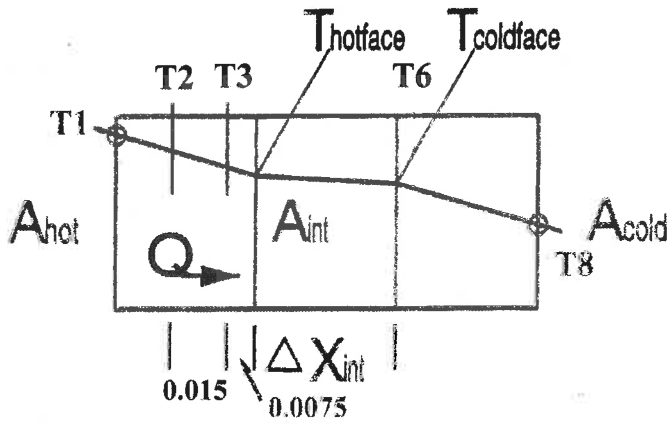
Heat transfer rate from the heater

$$\dot{Q} = V \times I$$

$$= 143.0 \times 0.16$$

$$= 22.95 \text{ Watts}$$

Note that the thermocouples T3 and T6 do not record the **hot face** and **cold face** temperatures, as they are both displaced by 0.075m from T3 and T6 as shown.



If it is assumed that the temperature distribution is linear, as is shown in experiment 1 then the actual temperature at the hot face and cold face may be determined from the following equations.

$$T_{hotface} = T3 - \frac{(T2-T3)}{2}$$

and

$$T_{coldface} = T6 + \frac{(T6-T7)}{2}$$

Hence in sample No.1

$$T_{hotface} = 49.33 - \frac{(55.6-49.3)}{2}$$

$$= 46.15\ °C$$

and

$$T_{coldface} = 36.6 + \frac{(36.6-30.2)}{2}$$

$$= 39.8\ °\ C$$

Hence

$$\Delta T_{int} = T_{hotface} - T_{coldface}$$

$$= 46.15 - 39.80$$

$$= 6.35\ °C$$

From the above parameters, the thermal conductivity of the aluminium intermediate section may be calculated.

$$k_{int} = \frac{\dot{Q}\Delta x_{int}}{A_{int}(T_{hotface} - T_{coldface})}$$

$$= \frac{\dot{Q}\Delta x_{int}}{A_{int}\Delta T_{int}}$$

$$= \frac{22.95 \times 0.030}{0.00049 \times 6.35}$$

$$= 220.85\ W/mK$$

The thermal conductivity of the aluminium intermediate sample may also be calculated from the data if it is plotted on a graph. This allows the $T_{hotface}$ and $T_{coldface}$ to be determined by extrapolating the line back from T3 and T6 to the hot face and cold face positions on the graph.

The data is plotted on page A30.

From the graph the slope of the line for the 22.95 Watt test (Sample 1) is

$$\frac{\Delta T_{int}}{\Delta x_{int}} = (-)\ 211\ \mathrm{K/m}$$

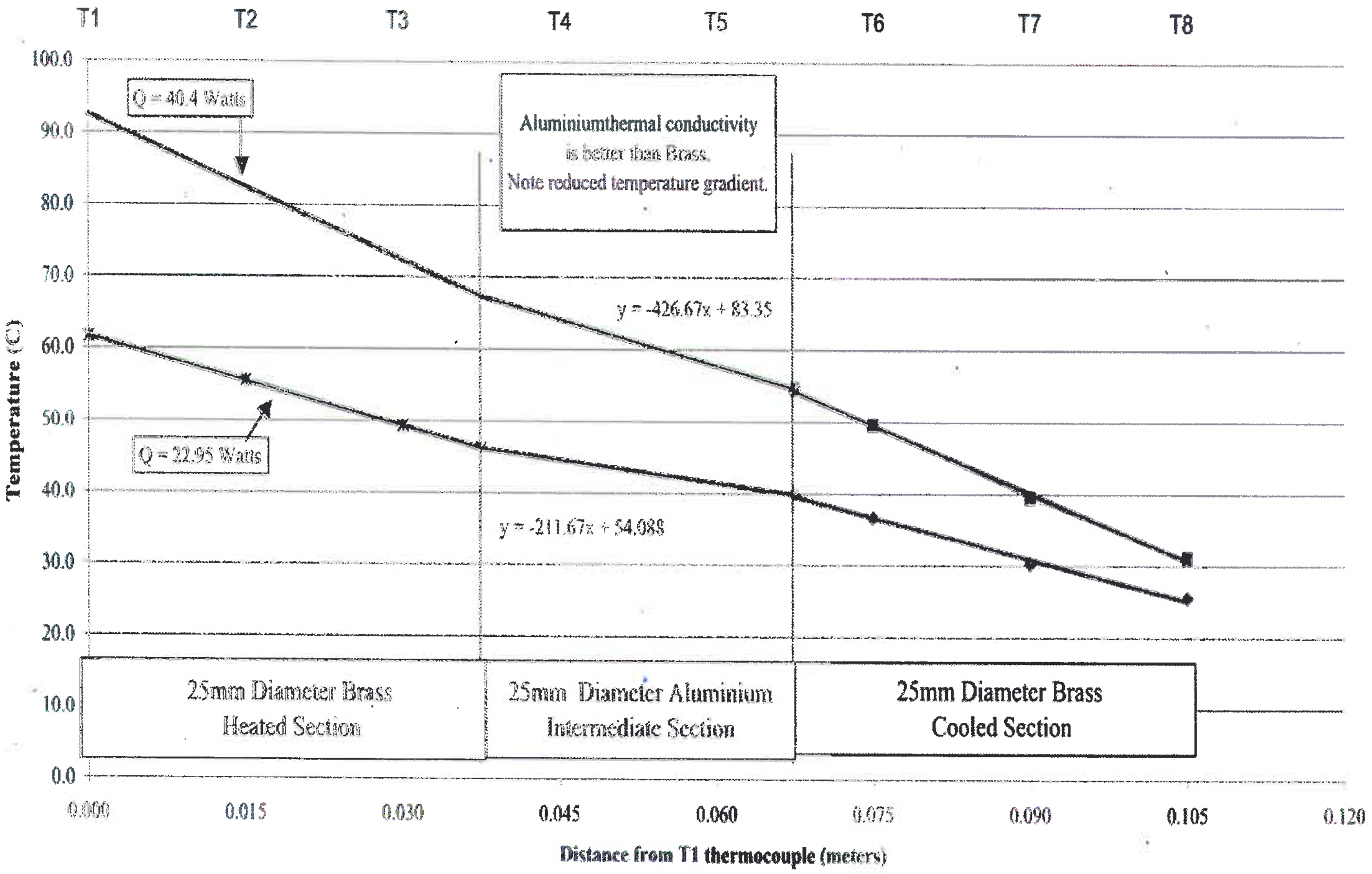
Hence

$$k_{int} = \frac{\dot{Q}}{A} \times \frac{\Delta T_{int}}{\Delta x_{int}}$$

$$= \frac{22.95}{0.00049} \times 211$$

$$= 221.5\ \mathrm{W/mK}$$

H110À LINEAR HEAT CONDUCTION
Experiment No. 4
Temperature Distribution when Q = 22.95 and 40.4 Watts



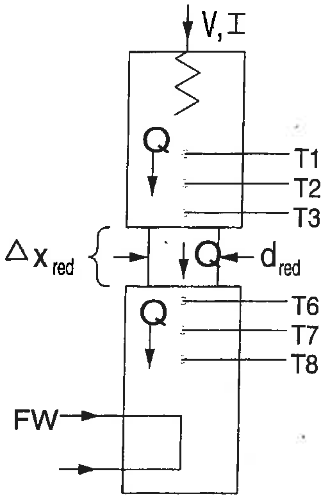
5. To demonstrate that the temperature gradient is inversely proportional to the cross-sectional area for one dimensional flow of heat in a solid material of constant thermal conductivity.

It is assumed that the **INSTALLATION AND COMMISSIONING** procedures for the linear heat conduction unit H112A have been completed as detailed on pages A4 to A6.

PROCEDURE

Following the basic **OPERATING PROCEDURE** on page A7 smear the faces of the heated and cooled sections with thermal conducting paste and clamp them together **with the reduced diameter brass intermediate specimen** in place.

Schematically this produces a system as shown below



Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to approximately 90 volts. This will provide a reasonable temperature gradient along the length of the bar. If however the local cooling water supply is at a high temperature (25-35 °C or more) then it may be necessary to increase the voltage supplied to the heater. This will increase the temperature difference between the hot and cold ends of the bar.

Monitor temperatures T1, T2, T3, T6, T7, T8 until stable.

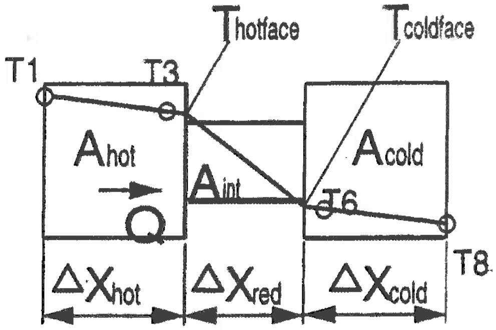
When the temperatures are stabilised record:
T1, T2, T3, T6, T7, T8, V, I

Increase the heater voltage by approximately 30 volts and repeat the above procedure again recording the parameters T1, T2, T3, T6, T7, T8, V, I when temperatures have stabilised.

When completed, if no further experiments are to be conducted reduce the heater voltage to zero and shut down the system as detailed in the operation section on page A7.

THEORY

If the heated and cooled sections are clamped tightly together so that the end faces are in good thermal contact with the stainless steel intermediate section a composite bar of the form shown below is formed.



Assuming that the energy entering the heated end is conducted **without loss to the surroundings** through to the cooled end, the heat flow through each section must be equal.

From Fouriers's law (ignoring the negative heat flow convention)

$$\dot{Q} = k\,A\,\frac{\Delta T}{\Delta x}$$

or

$$\Delta T = \left(\frac{1}{A}\right)\frac{\dot{Q}\,\Delta x}{k}$$

Hence, ΔT is inversely proportional to area A

For the heated section re-arranging the formula

$$\frac{\Delta T_{hot}}{\Delta x_{hot}} = \frac{\dot{Q}}{k_{hot}\,A_{hot}}$$

For the intermediate section

$$\frac{\Delta T_{int}}{\Delta x_{int}} = \frac{\dot{Q}}{k_{int}\,A_{int}}$$

For the cooled section

$$\frac{\Delta T_{cold}}{\Delta x_{cold}} = \frac{\dot{Q}}{k_{cold}\,A_{cold}}$$

If the thermal conductivity **k** of the heated, cooled and intermediate sections are all equal (the same material and material properties) then for a constant **Q** the only parameter that will affect the temperature gradient along the assembly will be the area **A**.

Hence

$$\frac{\left(\dfrac{\Delta T_{int}}{\Delta x_{int}}\right)}{\left(\dfrac{\Delta T_{hot}}{\Delta x_{hot}}\right)} = \frac{\left(\dfrac{\dot{Q}}{k_{int}\,A_{int}}\right)}{\left(\dfrac{\dot{Q}}{k_{hot}\,A_{hot}}\right)}$$

If Q and k are constant along the bar,

$$\frac{\left(\dfrac{\Delta T_{int}}{\Delta x_{int}}\right)}{\left(\dfrac{\Delta T_{hot}}{\Delta x_{hot}}\right)} = \frac{A_{hot}}{A_{int}}$$

A similar equation can be derived for the cooled section of the bar.

Overleaf are sample test results and illustrative calculations showing the application of the above theory.

OBSERVATIONS

Sample test results

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
	°C	°C	°C	°C	°C	°C	°C	°C	Volts	Amps
1	43.8	41.5	39.2			21.7	19.4	18	87	0.099
2	65.0	61.2	57.3			26.3	22.5	20	116	0.128
3										
4										
Distance from T1	**0.000**	**0.015**	**0.030**	**---**	**---**	**0.045**	**0.060**	**0.075**	**---**	**---**

CALCULATED DATA

Heated and cooled sections cross sectional Area A= 0.00049m^2

Reduced diameter intermediate section cross sectional Area, A_{int}= 0.00013m^2

Conductivity of Brass heated, cooled and reduced section = 121 W/mK

Sample No.	$\dot{Q}$	$T_{hotface}$	$T_{coldface}$	ΔT_{int}	k_{int}
	Watts	°C	°C	K	W/mK
1	8.46	46.15	39.8	6.35	220.85
2	14.88	67.35	54.55	12.80	192.87
3					
4					

For sample No.1 the example calculations are as follows:

Heated and cooled section cross sectional Area

$$A = \frac{\pi D^2}{4}$$

$$= \frac{\pi \times 0.025^2}{4}$$

$$= 0.00049 \text{ m}^2$$

Reduced diameter intermediate section cross sectional Area A_{int}

$$A_{int} = \frac{\pi D_{int}^2}{4}$$

$$= \frac{\pi \times 0.013^2}{4}$$

$$= 0.00013 \text{ m}^2$$

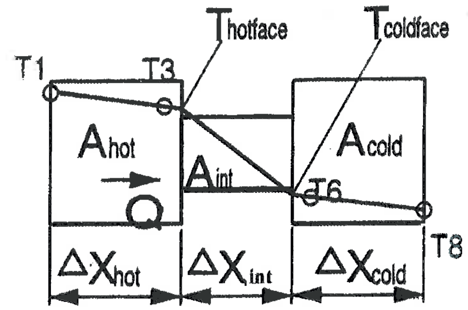
Heat transfer rate from the heater

$$\dot{Q} = V \times I$$

$$= 87 \text{ x } 0.128$$

$$= 8.46 \text{ Watts}$$

Note that the thermocouples T3 and T6 do not record the **hot face** and **cold face** temperatures as they are both displaced by 0.075m from T3 and T6 as shown below.



If it is assumed that the temperature distribution is linear, as is shown in experiment 1, then the actual temperature at the hot face and cold face may be determined from the following equations.

$$T_{hotface} = T3 - \frac{(T2-T3)}{2}$$

and

$$T_{coldface} = T6 + \frac{(T6-T7)}{2}$$

Hence in sample No.1

$$T_{hotface} = 39.2 - \frac{(41.5-39.2)}{2}$$
$$= 38.05\ °C$$

and

$$T_{coldface} = 21.7 + \frac{(21.7-19.4)}{2}$$
$$= 22.85\ °\ C$$

Hence

$$\Delta T_{int} = T_{hotface} - T_{coldface}$$
$$= 38.05 - 22.85$$
$$= 15.2\ °C$$

The temperature gradient in the section of reduced area

$$\frac{\Delta T_{int}}{\Delta x_{int}} = \frac{15.2}{0.03}$$
$$= 506.6\ K/m$$

The temperature gradient in the heated section

$$\frac{\Delta T_{hot}}{\Delta x_{hot}} = \frac{(T1-T_{hotface})}{0.030 + 0.0075}$$
$$= \frac{43.8 - 38.05}{0.0375}$$
$$= 153.33\ K/m$$

The ratio of the temperature gradients in the heated and reduced diameter bar are as follows

$$\frac{\left(\frac{\Delta T_{int}}{\Delta x_{int}}\right)}{\left(\frac{\Delta T_{hot}}{\Delta x_{hot}}\right)} = \frac{506.6}{153.3}$$

$$= 3.304$$

This compares with the area ratio

$$\frac{A}{A_{int}} = \frac{0.00049}{0.00013}$$

$$= 3.6982$$

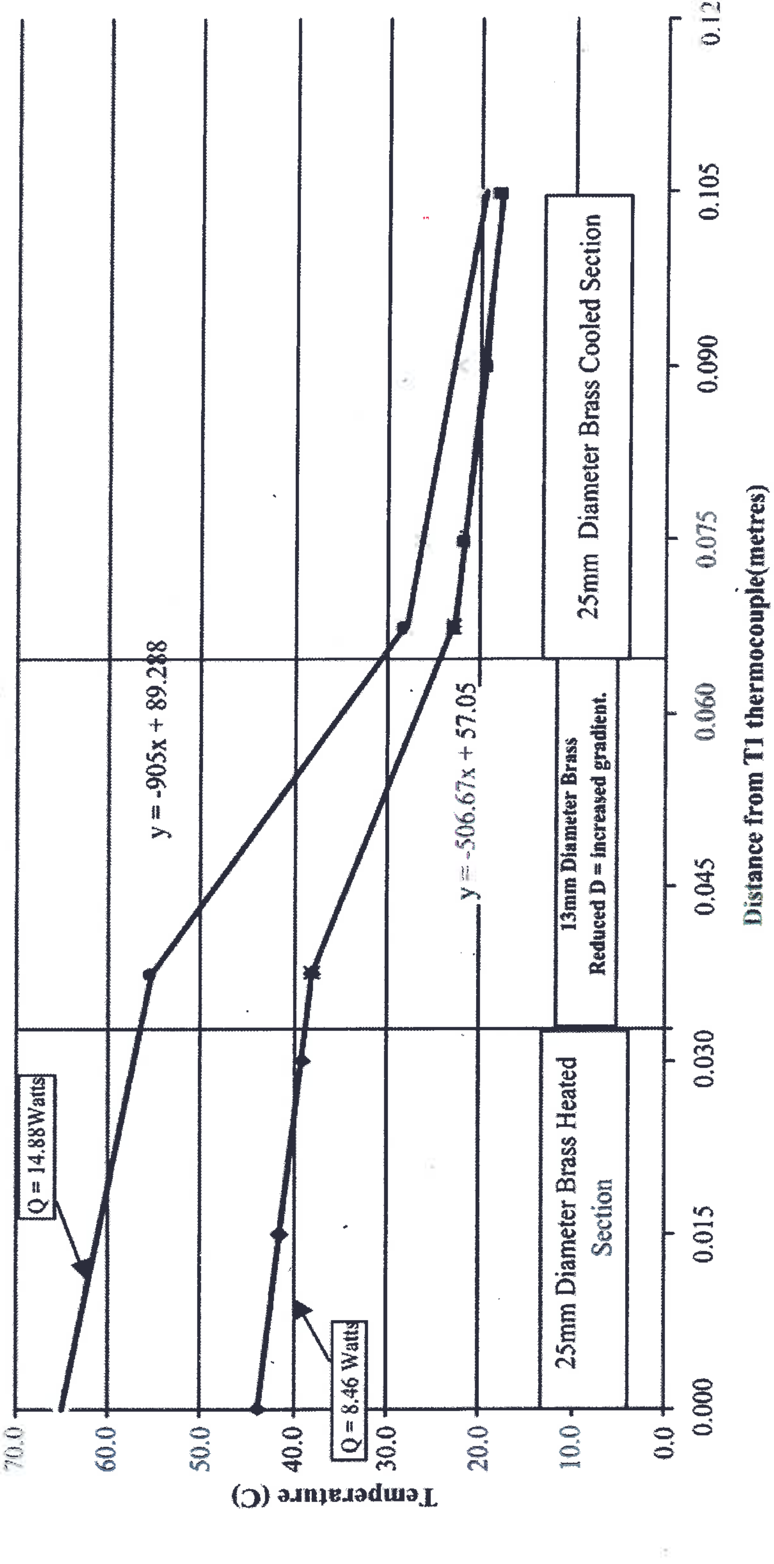
The differences may be attributed to measurement errors and the assumption that the heat transfer through the bar **Q** is without loss to the surroundings.

The data may also be plotted on a graph. This allows the $T_{hotface}$ and $T_{coldface}$ to be determined by extrapolating the line back from T3 and T6 to the hot face and cold face positions on the graph.

The data is plotted on the following page.

The graphical data may then be used to determine the above gradients and confirm the relationship with the area ratio.

H110A LINEAR HEAT CONDUCTION
Experiment No.5
Temperature Distribution when Q = 8.46 and 14.88 Watts



6. To demonstrate the effect of contact resistance on thermal conduction between adjacent materials.

It is assumed that the **INSTALLATION AND COMMISSIONING** procedures for the linear heat conduction unit H112A have been completed as detailed on pages A4 to A6.

PROCEDURE

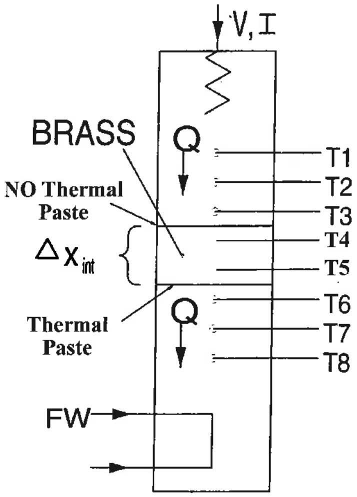
Following the basic **OPERATING PROCEDURE** on page A7. Ensure the faces of the heated and cooled sections are cleaned of thermal conducting paste and that the brass intermediate section is also similarly cleaned.

Lightly coat the mating faces between the cooled section and the brass intermediate specimen with thermal paste and assemble them together.

Do not coat the mating faces of the heated section and the brass intermediate specimen with thermal paste and assemble.

Finally, DO NOT clamp the assembly together as normal but leave the clamps open.

Schematically this produces a system as shown below



Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to approximately 120 volts. This will provide a reasonable temperature gradient along the length of the bar. If however the local cooling water supply is at a high temperature (25-35 °C or more) then it may be necessary to increase the voltage supplied to the heater. This will increase the temperature difference between the hot and cold ends of the bar.

Monitor temperatures T1, T2, T3, T4, T5, T6, T7, T8 until stable.

When the temperatures are stabilised record:
T1, T2, T3, T4, T5, T6, T7, T8, V, I

Increase the heater voltage by approximately 50 volts and repeat the above procedure again recording the parameters T1, T2, T3, T4, T5, T6, T7, T8, V, I when temperatures have stabilised.

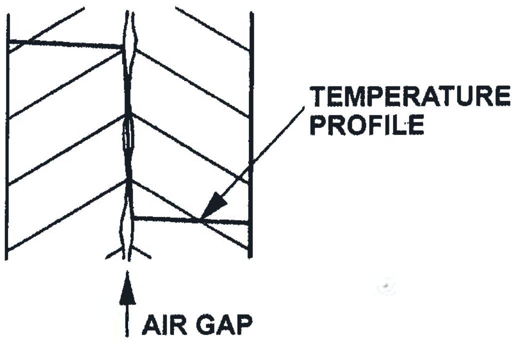
Leave the voltage setting at 17 volts and clamp the sections together on the unit. Monitor temperatures T1, T2, T3, T4, T5, T6, T7, T8 until stable and then repeat the above readings.

When completed, if no further experiments are to be conducted reduce the heater voltage to zero and shut down the system as detailed in the operation section on page A7.

THEORY

When two surfaces are in contact, paths of thermal conduction only exist where points of physical contact exist on a microscopic scale.

The degree of conduction will depend on surface finish, contact pressure, alignment and the presence of any intermediate material. If the surfaces are clean and in air then any air trapped between the surfaces will act as an insulator.



The addition of a good thermal conducting material that will fill the microscopic gaps will improve the effective thermal contact and improve conduction. This is the function performed by the thermal paste supplied. This contains an effective thermal conducting powder mixed in a semi-fluid carrier.

If used correctly most of the thermal paste will be squeezed from between the surfaces and only at the microscopic level will paste remain between the surfaces. However, if too much paste is applied or the surfaces are not brought together under firm pressure the paste can act as an additional resistance and effectively reduce heat transfer.

OBSERVATIONS

Sample test results:
Sample 1 **Not clamped**
Sample 2 **Not Clamped**
Sample 3 **Clamped**

Sample No.	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**V**	**I**
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**Volts**	**Amps**
1	54.7	50.8	47.1	34.8	31.0	27.2	23.5	20.6	117	0.128
2	91.7	84.6	77.4	53.6	46.6	38.2	31	25.4	164	0.182
3	86.2	79.1	71.7	53.3	45.9	38.9	31.5	25.7	164	0.182
4										
Distance from T1	**0.000**	**0.015**	**0.030**	**---**	**---**	**0.045**	**0.060**	**0.075**	**---**	**---**

CALCULATED DATA

Heated, cooled and intermediate brass sections cross sectional Area A= 0.00049m^2
Conductivity of Brass heated, cooled and reduced section = 121 W/mK

Sample No.	$\dot{\mathbf{Q}}$
	Watts
1	14.76
2	29.41
3	29.41
4	

For sample No.1 the example calculations are as follows:

Heat transfer rate from the heater

$$\dot{Q} = V \times I$$
$$= 117.0 \times 0.128$$
$$= 14.76 \text{ Watts}$$

The data is best analysed graphically and has been plotted on the following page for this purpose.

The lower graph lines are the test at 14.76 W heat input with the assembly not clamped. Note that the continuation of the T6, T7 line matches the slope and magnitude of the T4, T5 line in all three test results, even when the assembly is not clamped. This is the effect of the heat conducting paste.

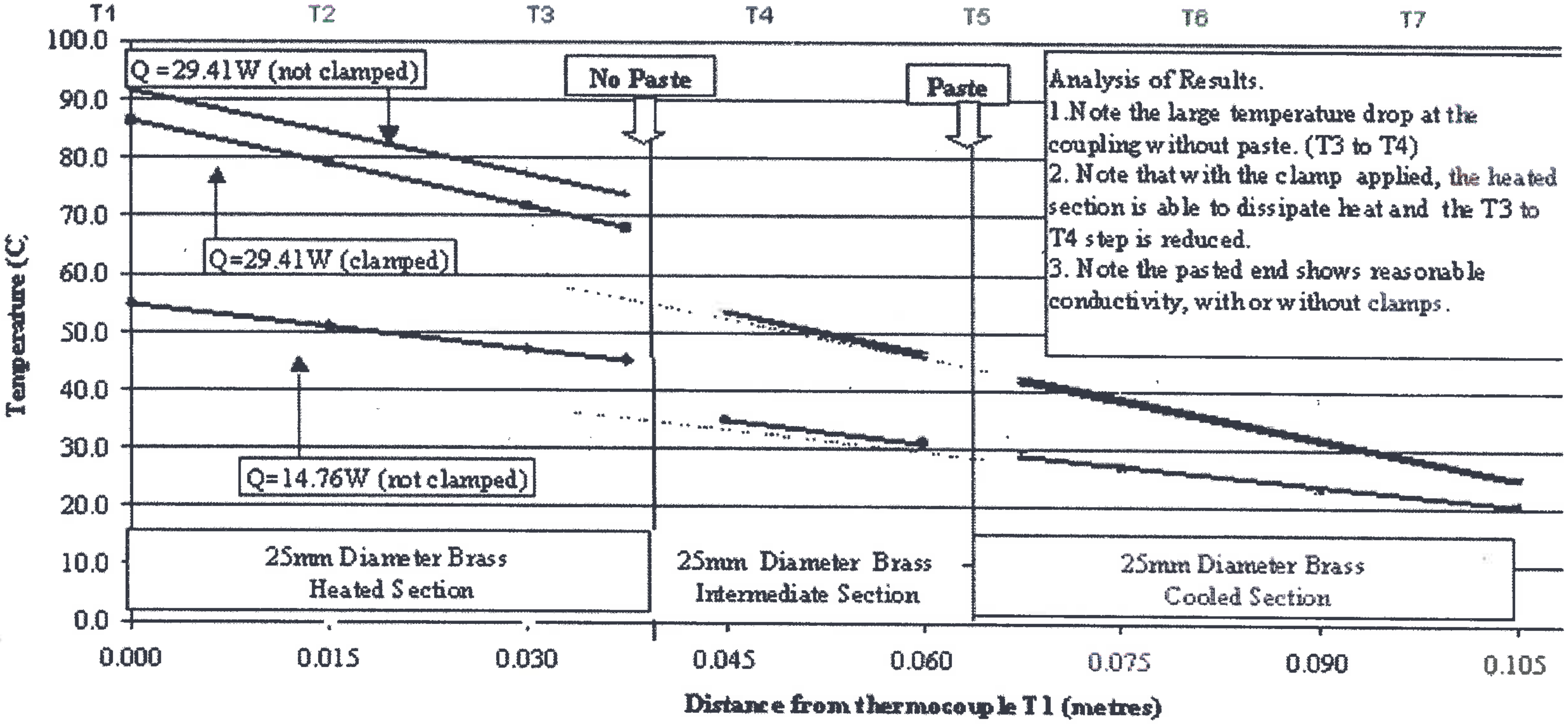
Note also that the largest temperature difference is across the surface without paste (between T3 and T4) even when the assembly is clamped.

Note that clamping the non-pasted assembly does reduce the temperature difference between T3 and T4, but only by a small amount.

H110A LINEAR HEAT CONDUCTION

Experiment No. 6

Demonstration of contact resistance.



Analysis of Results.

1. Note the large temperature drop at the coupling without paste. (T3 to T4)

2. Note that with the clamp applied, the heated section is able to dissipate heat and the T3 to T4 step is reduced.

3. Note the pasted end shows reasonable conductivity, with or without clamps.

7. To understand the application of poor thermal conductors and determine the thermal conductivity k of a poor thermal conductor.

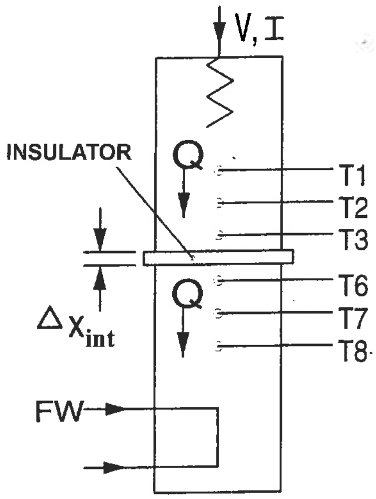
It is assumed that the **INSTALLATION AND COMMISSIONING** procedures for the linear heat conduction unit H112A have been completed as detailed on pages A4 to A6.

PROCEDURE

Following the basic **OPERATING PROCEDURE** on page A7. Ensure the faces of the heated and cooled sections are cleaned of thermal conducting paste.

Select the thin cork disc provided, measure and record the thickness Δx_{int} of the disc as accurately as possible (A vernier gauge or micrometer is suitable). Place this between the heated and cooled sections then clamp the assembly together.

Schematically this produces a system as shown below



Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to approximately 90 volts. This will provide a reasonable temperature gradient along the length of the bar. However care should be taken as the heat transfer rate will be reduced due to the insulator and the temperature T1, T2, T3 can rise higher than in other experiments.

Monitor temperatures T1, T2, T3, T6, T7, T8 until stable.

When the temperatures are stabilised record:
T1, T2, T3, T6, T7, T8, V, I

Increase the heater voltage by approximately 30 volts and repeat the above procedure, again recording the parameters T1, T2, T3, T6, T7, T8, V, I when temperatures have stabilised.

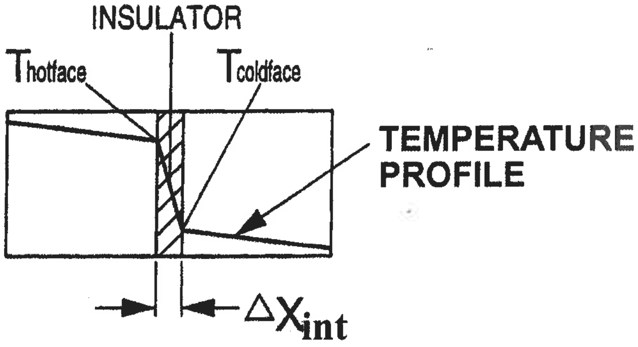
If time permits, the procedure may be repeated with the paper disc provided.

THEORY

Thermal insulators such as paper and cork have low thermal conductivity relative to metals and this means that only a small amount of heat will pass through the material even though a high temperature difference may exist across it.

This property may be utilised to reduce heat loss (or gain) to or from a body to its surroundings. Alternatively, the large temperature difference across an insulator may be the prime function, as in the case of an insulated handle on a cooking utensil.

If a thin section of insulating material is clamped between a heated and cooled surface then a temperature profile of the form shown below will result.



Assuming that the energy entering the heated end is conducted **without loss to the surroundings** through to the cooled end, the heat flow through each section must be equal.

Hence, by applying Fourier's law to each section

$$\frac{\dot{Q}}{A} = \frac{k_{cold}\,\Delta T_{cold}}{\Delta x_{cold}} = \frac{k_{int}\,\Delta T_{int}}{\Delta x_{int}} = \frac{k_{hot}\,\Delta T_{hot}}{\Delta x_{hot}}$$

Note that in this example the area **A** is constant

From this
$$k_{int} = \frac{\dot{Q}}{A}\left(\frac{\Delta x_{int}}{\Delta T_{int}}\right)$$

Where
$$\Delta T_{int} = T_{hotface} - T_{coldface}$$

Therefore
$$k_{int} = \frac{\dot{Q}}{A}\left(\frac{\Delta x_{int}}{T_{hotface} - T_{coldface}}\right)$$

Overleaf are sample test results and illustrative calculations showing the application of the above theory.

OBSERVATIONS

Sample test results

Measured thickness of cork sample $\Delta x_{int} = 0.00079m$

Sample No.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
	°C	°C	°C	°C	°C	°C	°C	°C	Volts	Amps
1	31.3	30.5	29.7			17.7	16.9	16.8	87	0.099
2	62.7	60.7	58.8			20.9	19	18	116	0.128
3										
4										
Distance from T1	**0.000**	**0.015**	**0.030**	---	---	**0.045**	**0.060**	**0.075**	---	---

CALCULATED DATA

Heated and cooled sections cross sectional Area A= $0.00049m^2$

Assumed Thermal Conductivity of cork composite material = 0.4 W/mK

Sample No.	$\dot{Q}$	$T_{hotface}$	$T_{coldface}$	ΔT_{int}	k_{int}
	Watts	°C	°C	K	W/mK
1	8.46	46.15	39.8	6.35	220.85
2	14.88	67.35	54.55	12.80	192.87
3					
4					

For sample No.1 the example calculations are as follows:

Heated and cooled section and cork sample cross sectional Area A

$$A = \frac{\pi D^2}{4}$$

$$= \frac{\pi \times 0.025^2}{4}$$

$$= 0.00049 \text{ m}^2$$

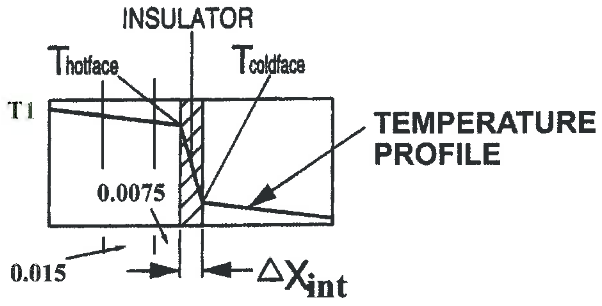
Heat transfer rate from the heater

$$\dot{Q} = V \times I$$

$$= 87 \times 0.099$$

$$= 8.46 \text{ Watts}$$

Note that the thermocouples T3 and T6 do not record the **hot face** and **cold face** temperatures as they are both displaced by 0.075m from T3 and T6 as shown below



If it is assumed that the temperature distribution is linear, as is shown in experiment 1, then the actual temperature at the hot face and cold face may be determined from the following equations.

$$T_{hotface} = T3 - \frac{(T2-T3)}{2}$$

and

$$T_{coldface} = T6 + \frac{(T6-T7)}{2}$$

Hence in sample No.1

$$T_{hotface} = 29.7 - \frac{(30.5-29.7)}{2}$$

$$= 29.3\ °C$$

and

$$T_{coldface} = 17.7 + \frac{(17.7-16.9)}{2}$$

$$= 18.1\ °C$$

Hence

$$\Delta T_{int} = T_{hotface} - T_{coldface}$$

$$= 29.3 - 18.1$$

$$= 11.2\ °C$$

From the parameters overleaf the thermal conductivity of the cork sample may be calculated.

$$k_{int} = \frac{\dot{Q}\Delta x_{int}}{A_{int}(T_{hotface} - T_{coldface})}$$

$$= \frac{\dot{Q}\Delta x_{int}}{A_{int}\Delta T_{int}}$$

$$= \frac{8.46 \times 0.00079}{0.00049 \times 11.2}$$

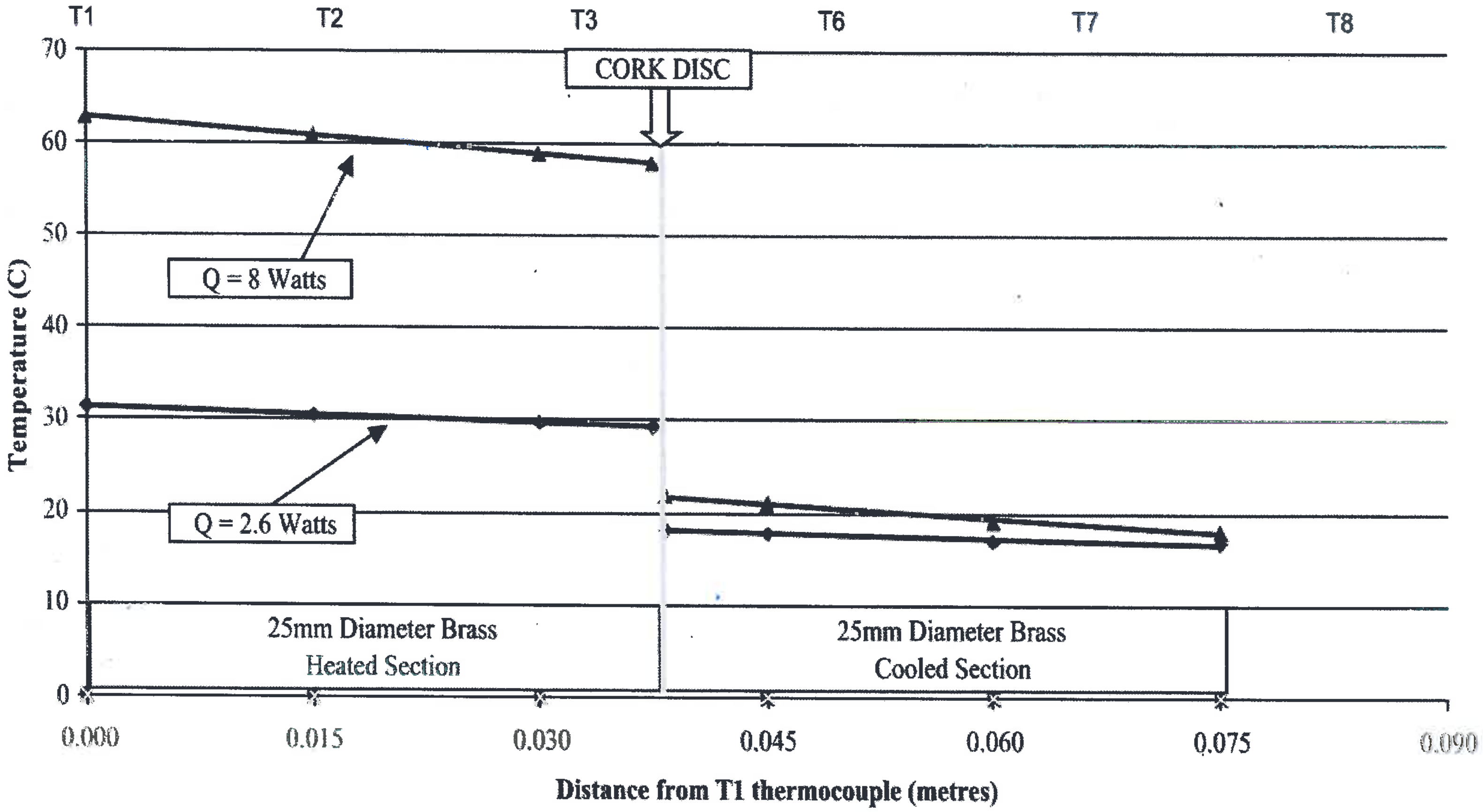
$$= 0.374\ W/mK$$

The data is plotted overleaf to illustrate the large thermal gradient between the hot face and cold face due to the effect of the insulation.

The hot face and cold face temperatures are determined graphically by drawing the best fit line between the data points available and then extending to either the hot face or cold face as appropriate.

Note that the temperature difference across the brass sections is much smaller than across even the thin section of cork insulation due to the difference in thermal conductivity.

H110A LINEAR HEAT CONDUCTION
Experiment No. 7 (Cork Disc)
Temperature Distribution when Q = 2.6 and 8.28 Watts



8. To observe unsteady state conduction of heat and to use this in observation of the time to reach stable conditions

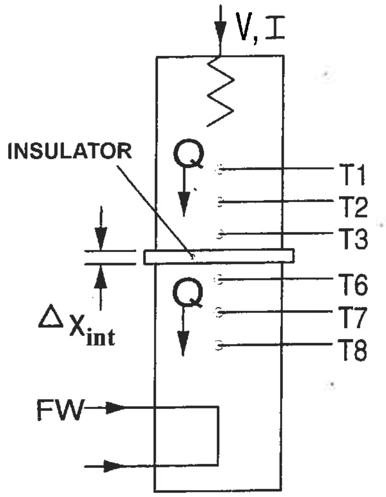
It is assumed that the **INSTALLATION AND COMMISSIONING** procedures for the linear heat conduction unit H112A have been completed as detailed on pages A4 to A6.

PROCEDURE

Following the basic **OPERATING PROCEDURE** on page A7. Ensure the faces of the heated and cooled sections are cleaned of thermal conducting paste.

Select the thin cork disc and place this between the heated and cooled sections then clamp the assembly together.

Schematically this produces a system as shown below



Again following the above procedure, ensure the cooling water is flowing.

Disconnect the heater 8-pole plug and then set the heater voltage V to approximately 90 volts but do not re-connect the heater at this stage.

Start a stopwatch or alternatively use a clock to record regular time intervals and then re-connect the heater with the voltage still set at approximately 90 volts.

Record V, I and T1 at regular intervals of say 5 minutes.

Note that the experiment can take up to 90 minutes to reach stability.

Note that if the Data Acquisition Upgrade HC112A is available then more temperatures may be recorded simultaneously.

THEORY

Heat transfer through a solid material is not instantaneous. If heat is introduced at one end of a solid at a constant rate Q the temperature closest to the heat source will begin to rise as soon as the heat input starts. Due to conduction, the heat will transfer along the solid away from the heat source towards any area of lower temperature.

The rate of heat transfer along the bar and the subsequent temperature rise will not only depend upon the thermal conductivity (W/mK) of the bar but also the material specific heat (J/kg K), the material density (kg/m^3) and the bar dimensions.

The heat will transfer along the bar and the temperatures along the bar will rise until a steady state condition exists where all intermediate temperatures are constant. As long as the heat input and the sink temperature are constant, the system will remain in equilibrium. It is under these conditions that all previous experiments (1 to 7) have been undertaken.

The subject of unsteady state heat transfer is beyond the capabilities of this unit but the procedure allows the concept unsteady state heat transfer to be introduced.

Overleaf are sample test results showing the temperature rise of T1 with time.

OBSERVATIONS

Sample test results

Sample Time .	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**V**	**I**
Minutes	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**	**Volts**	**Amps**
0	**18**								**86**	**0.097**
5	**31.3**								**86**	**0.097**
10	**41.3**								**86**	**0.097**
20	**52.40**								**86**	**0.097**
32	**57.5**								**86**	**0.097**
38	**59.00**								**86**	**0.097**
47	**60.3**								**86**	**0.097**
56	**61.3**								**86**	**0.097**
70	**62.0**								**86**	**0.097**
96	**62.7**								**86**	**0.097**
Distance from T1	**0.000**	**0.015**	**0.030**	**---**	**---**	**0.045**	**0.060**	**0.075**	**---**	**---**

CALCULATED DATA

For all of the above sample points the heat input Q was constant.

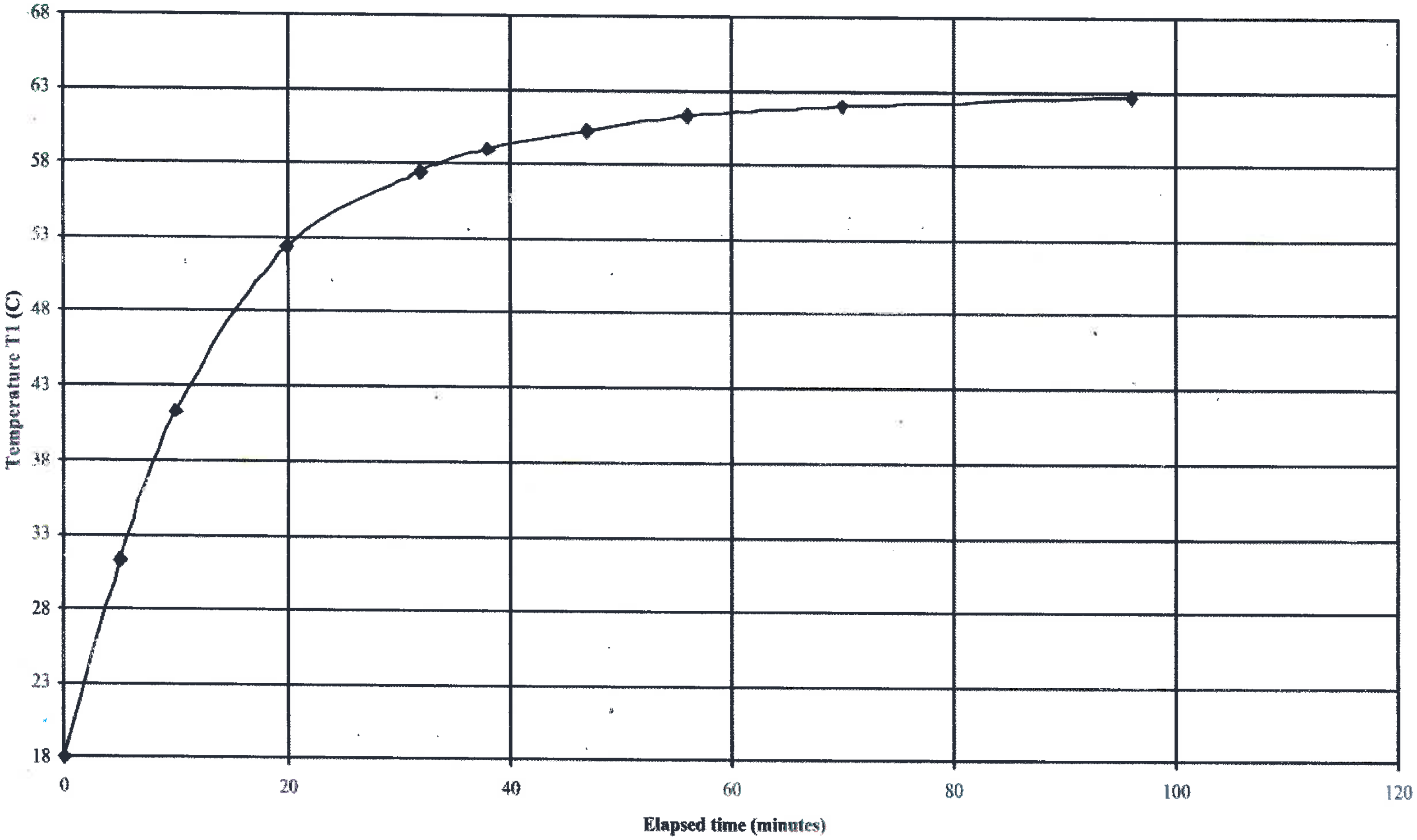
Heat transfer rate from the heater

$$\begin{aligned}\dot{Q} &= V \times I \\ &= 86 \times 0.097 \\ &= 8.3 \text{ Watts}\end{aligned}$$

The data is plotted overleaf.

The data illustrates that with small heat inputs the time for all of the system temperatures to reach stable conditions can be longer than expected. This emphasises the need to monitor temperatures with time until stability is assured.

H110A LINEAR HEAT CONDUCTION
Experiment No. 8
Temperature T1 variation with time when Q = 8.3 Watts



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