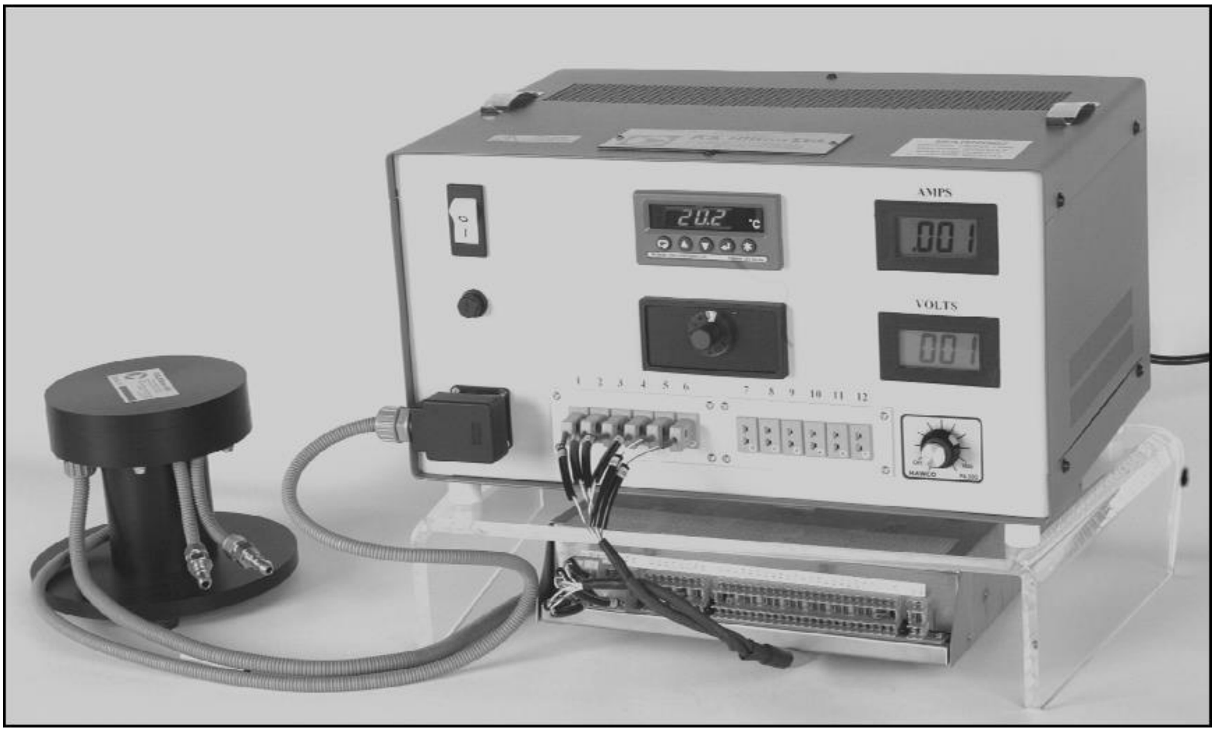
Experiment – 7 Radial Conduction Experiment

Aim of this Experiment

The Radial Heat Conduction experiments allows the basic laws of heat transfer by conduction through a cylindrical solid to be investigated.

Experimental Set – up

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 comprises an insulated solid disc of brass (3.2mm thick x 110mm diameter) with a brass core (14mm diameter) and an electric heater at the centre. The brass disc is water cooled around its circumference.

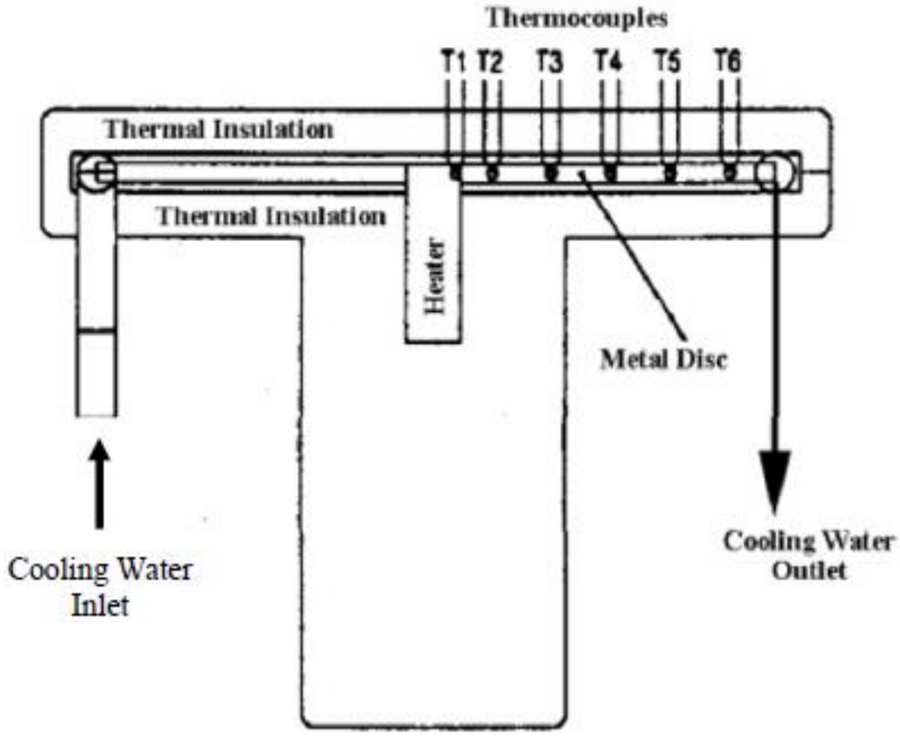
The central heater is nominally rated at 100Watts (at 240 V AC) and an integral high temperature cut out (with automatic reset) prevents overheating. Power is supplied to the heater from the Heat Transfer Service Unit H112 via an 8-pole plug and lead.

Six thermocouples T1, T2, T3,...T6 are located at increasing radii from the heated centre to record the temperature distribution across the disc. The thermocouple sensing tips are located in drilled holes so that in each case the measured point is the centre of the disc thickness. Each thermocouple is fitted with a miniature plug for direct connection to the Heat Transfer Service Unit H112 and an edge connector for use with HC112A Data Acquisition Upgrade.

Water for the cooled circumference 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 disc, the water is allowed to run to a drain via the outlet hose.

Schematic Representation of Linear Conduction Experiment Unit



Capabilities Of The Radial Heat Transfer Unit

1. To measure the temperature distribution for steady state conduction of heat energy through the wall of a thick cylinder (Radial energy flow) 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 for steady state conduction of heat energy through the wall of a thick cylinder (Radial energy flow) and using the equation to determine the constant of proportionality (the thermal conductivity k) of the disc material.

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

Operating Procedure Of Radial Heat Transfer Unit

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

2. Turn the voltage controller anti-clockwise to set the AC voltage to minimum. Ensure the Radial Heat Transfer Unit H112B has been connected to the Heat Transfer Service Unit H112.

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 100W only.

4. 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 centre of the disc. Rotate the voltage controller to increase the voltage to that specified in the procedure for each experiment.

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

6. Allow the system to reach stability, and take readings and make adjustments as instructed in the individual procedures for each experiment.

7. 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.

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

Experiment -7.1

To measure the temperature distribution for steady state conduction of heat energy through the wall of a thick cylinder (Radial energy flow) and demonstrate the effect of a change in heat flow

Aim of this experiment

This experiment aims to determine the temperature gradient during radial heat transfer by conduction along the wall.

Procedure

Follow the basic **OPERATING PROCEDURE**

Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to approximately 100 volts. If however the local cooling water supply is at a high temperature (25-35 ºC or more) then it may be necessary to increase the voltage supplied to the heater.

This will increase the temperature difference between the hot centre and cool circumference of the disc.

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

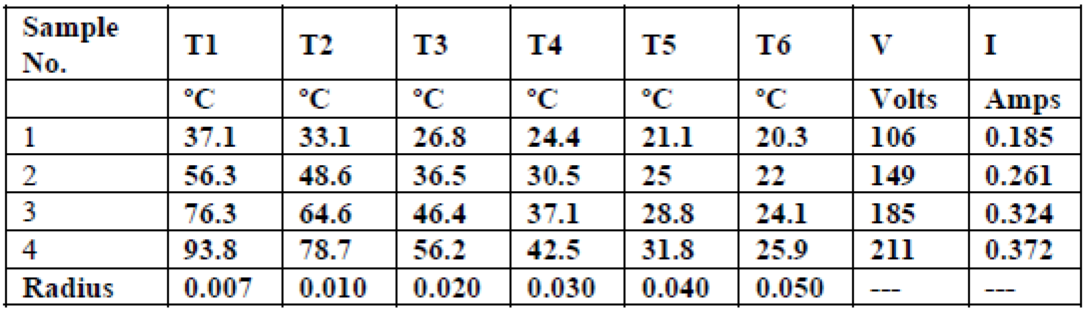
When the temperatures are stabilised record:T1, T2, T3, T4, T5, T6, V, I.

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

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

If time is available, the procedure may be repeated further noting that the maximum safe temperature for T1 is 100ºC When completed, if no further experiments are to be conducted reduce the heater voltage to zero and shut down the system.

Sample Test Results



Sample No.	T1	T2	T3	T4	T5	T6	V	I
	°C	°C	°C	°C	°C	°C	Volts	Amps
1	37.1	33.1	26.8	24.4	21.1	20.3	106	0.185
2	56.3	48.6	36.5	30.5	25	22	149	0.261
3	76.3	64.6	46.4	37.1	28.8	24.1	185	0.324
4	93.8	78.7	56.2	42.5	31.8	25.9	211	0.372
Radius	0.007	0.010	0.020	0.030	0.040	0.050	---	---

Experiment -7.2

To understand the use of the Fourier Rate Equation in determining rate of heat flow for steady state conduction of heat energy through the wall of a thick cylinder (Radial energy flow) and using the equation to determine the constant of proportionality (the thermal conductivity k) of the disc material.

Aim of this experiment

This experiment aims to determine the temperature gradient during linear heat transfer by conduction along the wall and find the thermal conductivity coefficient k of solid material.

Procedure

Follow the basic **OPERATING PROCEDURE.**

Again following the above procedure ensure the cooling water is flowing and then set the heater voltage V to approximately 100 volts. If however the local cooling water supply is at a high temperature (25-35 ºC or more) then it may be necessary to increase the voltage supplied to the heater.

This will increase the temperature difference between the hot centre and cool circumference of the disc.

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

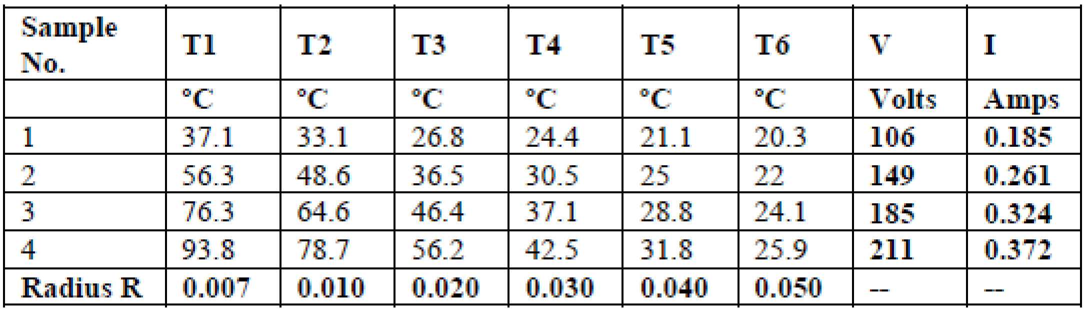
When the temperatures are stabilised record:T1, T2, T3, T4, T5, T6, V, I

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

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

If time is available, the procedure may be repeated further noting that the maximum safe temperature for T1 is 100ºC When completed, if no further experiments are to be conducted reduce the heater voltage to zero and shut down the system.

Sample Test Results



Sample No.	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**V**	**I**
	°C	**°C**	**°C**	**°C**	**°C**	**°C**	**Volts**	**Amps**
1	37.1	33.1	26.8	24.4	21.1	20.3	**106**	**0.185**
2	56.3	48.6	36.5	30.5	25	22	**149**	**0.261**
3	76.3	64.6	46.4	37.1	28.8	24.1	**185**	**0.324**
4	93.8	78.7	56.2	42.5	31.8	25.9	**211**	**0.372**
Radius R	**0.007**	**0.010**	**0.020**	**0.030**	**0.040**	**0.050**	--	--

Experiment -7.3

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

Aim of this experiment

This experiment aims to observe the heat transfer phenomenon take place durinh the the time to reach unstable conditions to stable conditions

Procedure

Follow the basic **OPERATING PROCEDURE.**

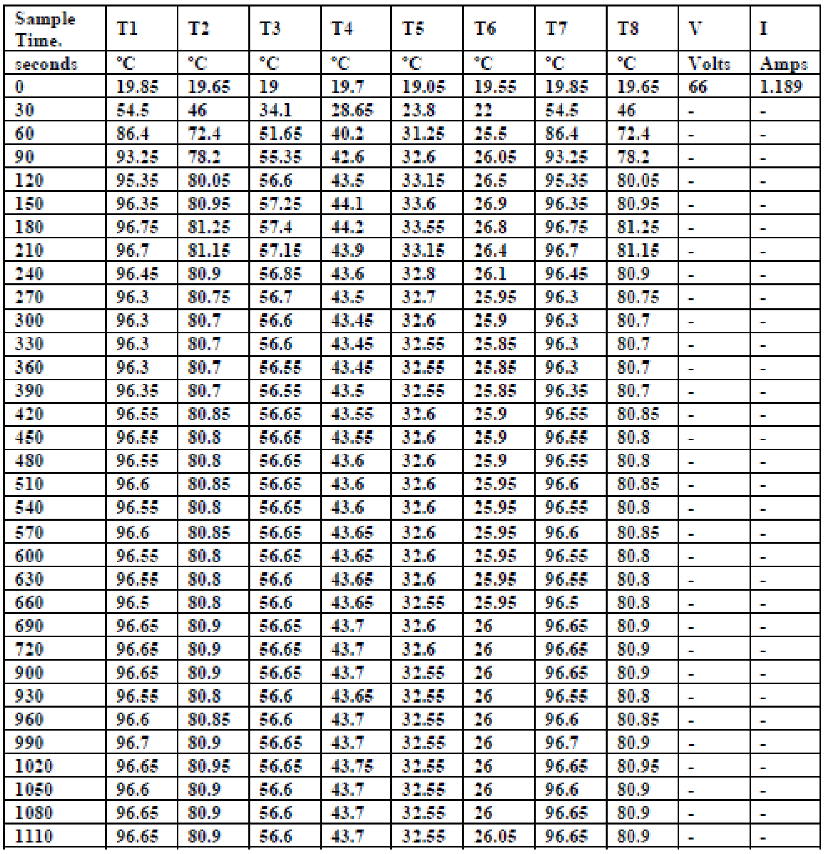
Again following the above procedure, ensure the cooling water is flowing. **Disconnect the heater plug** and then set the heater voltage V to approximately 66 volts but do not reconnect the heater plug at this stage.

Start a stopwatch or alternatively use a clock to record regular time intervals and then re-connect the heater plug with the voltage still set at approximately 66 volts.

Record T1, T2, T3, T4, T5, T6 at regular intervals of say 30 seconds.

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

Sample Test Results



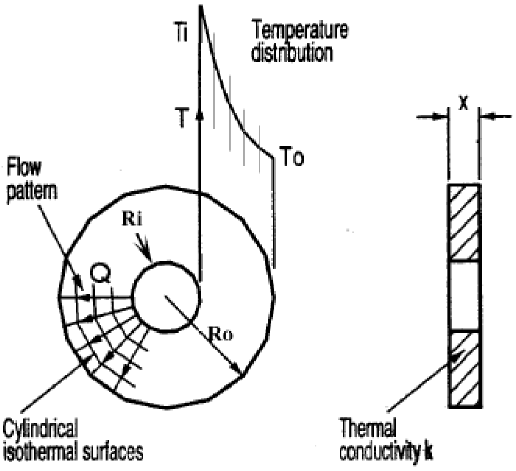
Sample Time.	T1	T2	T3	T4	T5	T6	T7	T8	V	I
seconds	°C	°C	°C	°C	°C	°C	°C	°C	Volts	Amps
0	19.85	19.65	19	19.7	19.05	19.55	19.85	19.65	66	1.189
30	54.5	46	34.1	28.65	23.8	22	54.5	46	-	-
60	86.4	72.4	51.65	40.2	31.25	25.5	86.4	72.4	-	-
90	93.25	78.2	55.35	42.6	32.6	26.05	93.25	78.2	-	-
120	95.35	80.05	56.6	43.5	33.15	26.5	95.35	80.05	-	-
150	96.35	80.95	57.25	44.1	33.6	26.9	96.35	80.95	-	-
180	96.75	81.25	57.4	44.2	33.55	26.8	96.75	81.25	-	-
210	96.7	81.15	57.15	43.9	33.15	26.4	96.7	81.15	-	-
240	96.45	80.9	56.85	43.6	32.8	26.1	96.45	80.9	-	-
270	96.3	80.75	56.7	43.5	32.7	25.95	96.3	80.75	-	-
300	96.3	80.7	56.6	43.45	32.6	25.9	96.3	80.7	-	-
330	96.3	80.7	56.6	43.45	32.55	25.85	96.3	80.7	-	-
360	96.3	80.7	56.55	43.45	32.55	25.85	96.3	80.7	-	-
390	96.35	80.7	56.55	43.5	32.55	25.85	96.35	80.7	-	-
420	96.55	80.85	56.65	43.55	32.6	25.9	96.55	80.85	-	-
450	96.55	80.8	56.65	43.55	32.6	25.9	96.55	80.8	-	-
480	96.55	80.8	56.65	43.6	32.6	25.9	96.55	80.8	-	-
510	96.6	80.85	56.65	43.6	32.6	25.95	96.6	80.85	-	-
540	96.55	80.8	56.65	43.6	32.6	25.95	96.55	80.8	-	-
570	96.6	80.85	56.65	43.65	32.6	25.95	96.6	80.85	-	-
600	96.55	80.8	56.65	43.65	32.6	25.95	96.55	80.8	-	-
630	96.55	80.8	56.6	43.65	32.6	25.95	96.55	80.8	-	-
660	96.5	80.8	56.6	43.65	32.55	25.95	96.5	80.8	-	-
690	96.65	80.9	56.65	43.7	32.6	26	96.65	80.9	-	-
720	96.65	80.9	56.65	43.7	32.6	26	96.65	80.9	-	-
900	96.65	80.9	56.65	43.7	32.55	26	96.65	80.9	-	-
930	96.55	80.8	56.6	43.65	32.55	26	96.55	80.8	-	-
960	96.6	80.85	56.6	43.7	32.55	26	96.6	80.85	-	-
990	96.7	80.9	56.65	43.7	32.55	26	96.7	80.9	-	-
1020	96.65	80.95	56.65	43.75	32.55	26	96.65	80.95	-	-
1050	96.6	80.9	56.6	43.7	32.55	26	96.6	80.9	-	-
1080	96.65	80.9	56.6	43.7	32.55	26	96.65	80.9	-	-
1110	96.65	80.9	56.6	43.7	32.55	26.05	96.65	80.9	-	-

Theory of Experiments

If the inner surface of a thick walled cylinder is at a temperature higher than its surroundings then heat will flow radially outward.

If the cylinder is imagined as a series of concentric rings, each of the same material and each in close contact, then it can be seen that each cylinder presents a progressively larger surface area for heat transfer.

If the heat input at the centre remains constant then the heat transfer per unit area must reduce as the heat moves towards the outside diameter. Therefore, the temperature gradient will decrease as the radius increases.

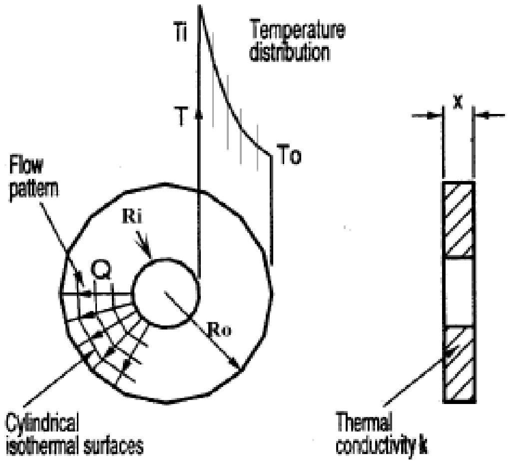


When the inner and outer surfaces of a thick walled cylinder are a uniform temperature difference, heat flows radially through the cylinder wall.

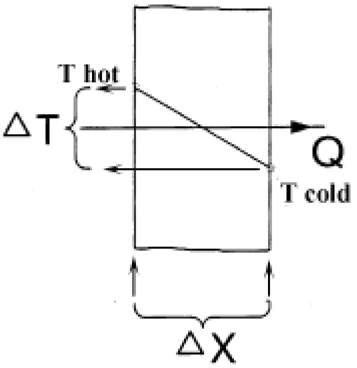
Due to symmetry, any cylindrical surface concentric with the central axis of the tube has a constant temperature (is isothermal) and the direction of heat flow is normal (at right angles) to the surface.

For continuity, the radial heat flow per unit length of tube through these isothermal surfaces must remain steady. As each successive layer presents an increasing surface area with radius the temperature gradient must decrease with radius.

The temperature distribution will be of the form shown below.



Considering a plane section of flat surface, according to Fourier's law of heat conduction**:**

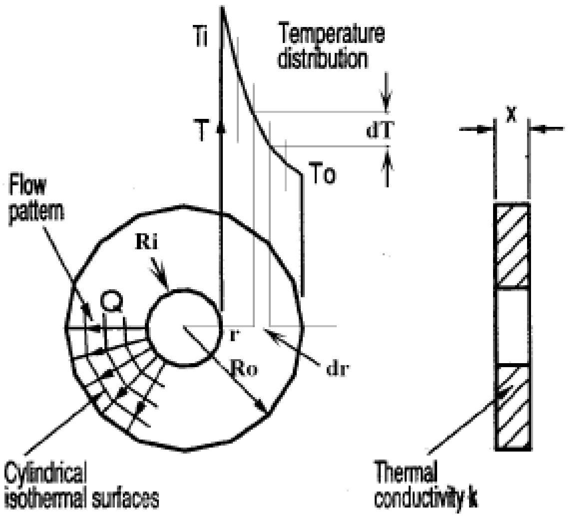


If a plane section of thermal conductivity **k,** thickness Δ**x** and constant area **A** maintains a temperature difference Δ**T** then the heat transfer rate per unit time $\dot{Q}$by conduction through the wall is found to be:

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

The negative sign follows thermodynamic convention in that heat transfer is normally considered **positive** in the direction of temperature **fall**.

Returning to the thick walled cylinder, if an elemental thickness of **dr** is considered then the area of this length of cylinder **x** can be considered as **2πr x**. The temperature gradient normal to the elemental thickness is **(dT/dr)**.



Applying Fourier's law to this elemental cylinder:

$$\dot{Q} = -k\,2\pi\,r\,x\left(\frac{dT}{dr}\right)$$

Since **Q** is independent of **r,** by integration between Ri and Ro it can be shown that

$$\dot{Q}\ \ln\left(\frac{Ro}{Ri}\right) = -2\,\pi\,kx\,(To - Ti)$$

Where **ln = log$_e$**

By rearranging the equation

$$k = -\frac{\dot{Q}\ \ln\left(\frac{Ro}{Ri}\right)}{2\,\pi\,x\,(To - Ti)}$$

For the purposes of the experiment, the negative sign in the above equation may be ignored.

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

Heat transfer through a solid material is not instantaneous. If heat is introduced at the centre of a disc 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 through the material away from the heat source towards any area of lower temperature.

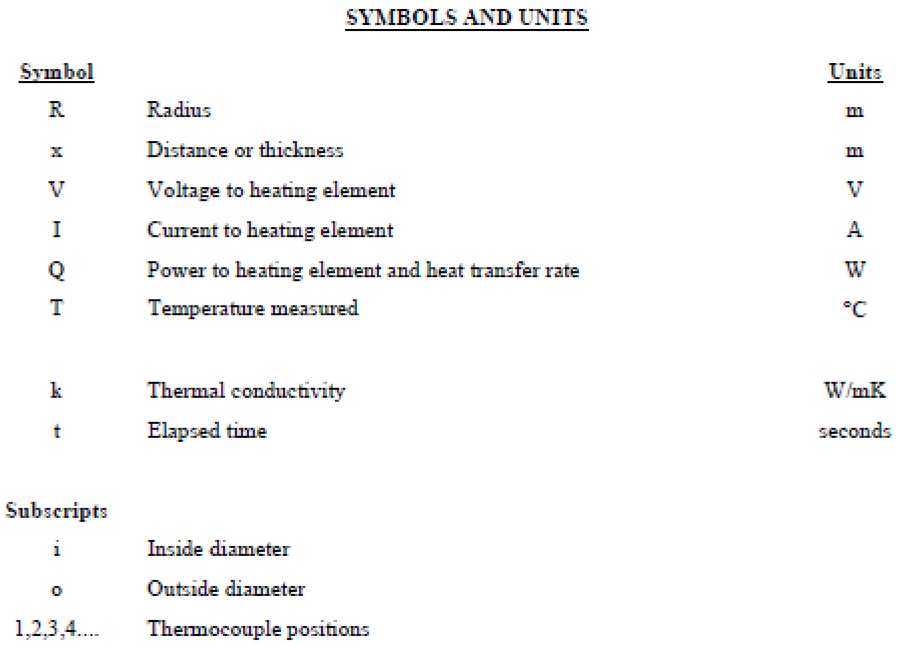
The rate of heat transfer through the disc and the subsequent temperature rise will not only depend upon the thermal conductivity (W/mK) of the bar but also the material specific heat (J/kg K), the material density (kg/m3) and the bar dimensions.

The heat will transfer through the disc and the temperatures at various points along the radius 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 2) 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 to T6 with time.

Appendix – I Symbolas and Units

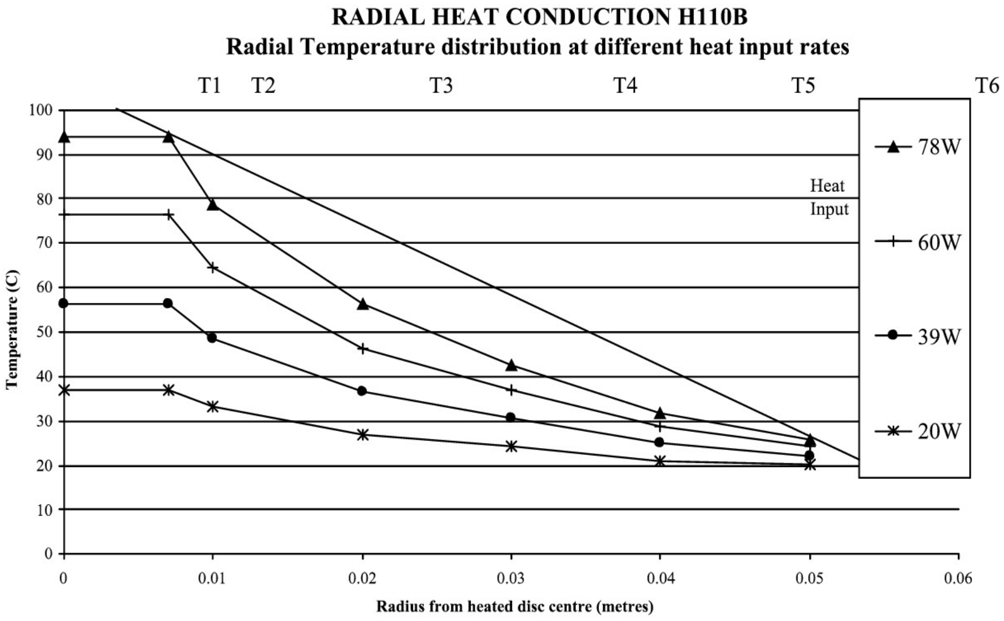


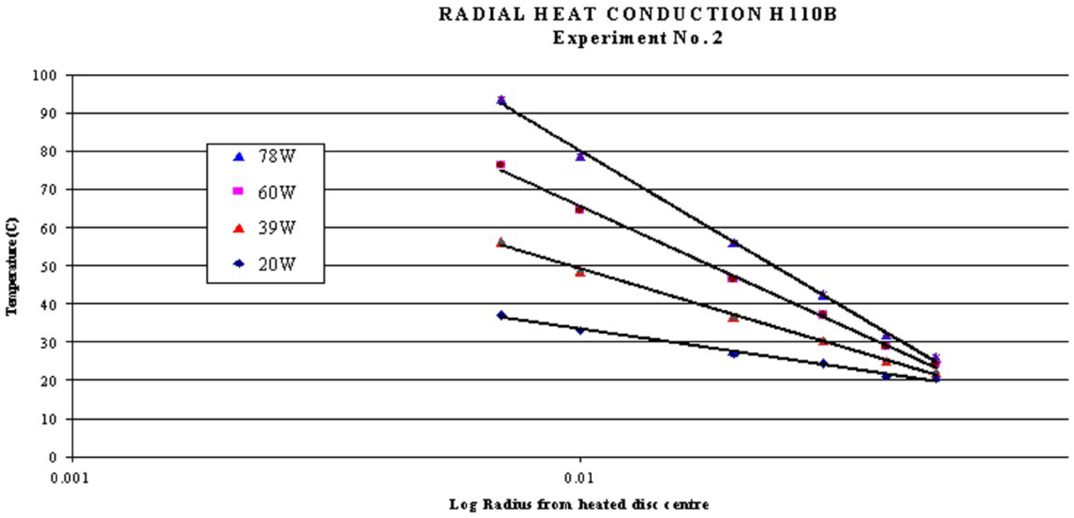
SYMBOLS AND UNITS

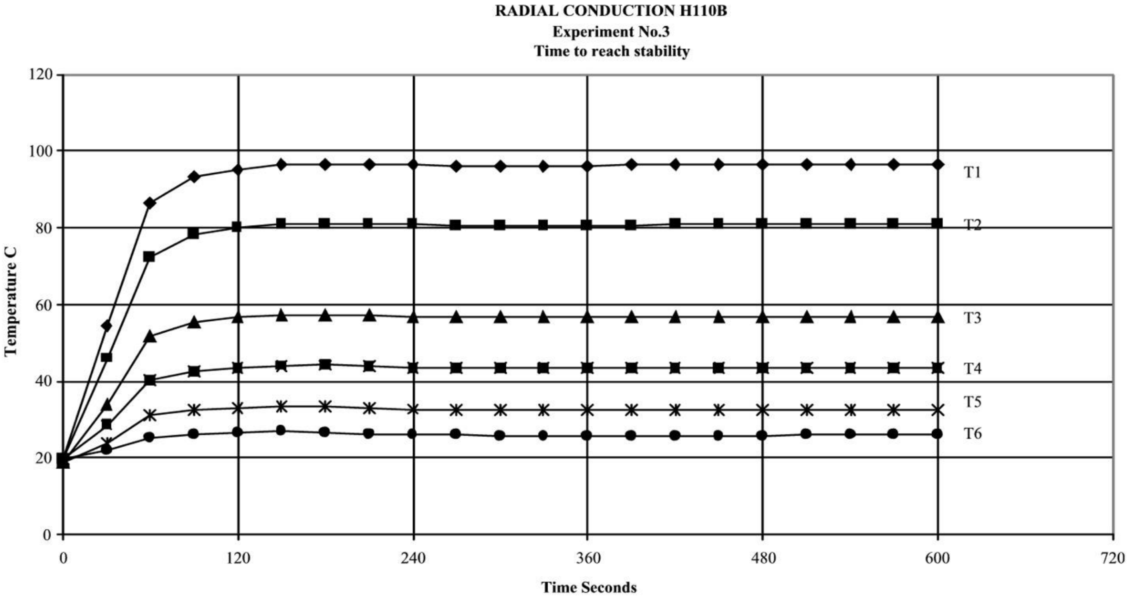
Symbol		Units
R	Radius	m
x	Distance or thickness	m
V	Voltage to heating element	V
I	Current to heating element	A
Q	Power to heating element and heat transfer rate	W
T	Temperature measured	°C
k	Thermal conductivity	W/mK
t	Elapsed time	seconds

Subscripts	
i	Inside diameter
o	Outside diameter
1,2,3,4....	Thermocouple positions

Appendix – II Some Useful Data






RADIAL CONDUCTION H110B
Experiment No.3
Time to reach stability
Temperature C
0
20
40
60
80
100
120
Time Seconds
0
120
240
360
480
600
720
T1
T2
T3
T4
T5
T6