P.A. HILTON LTD.

EXPERIMENTAL

OPERATING

AND

MAINTENANCE MANUAL

THERMAL RADIATION UNIT

H960

= 2,3,6

H960M/E/4/034

MAR 90 (4)

SAFETY IN THE USE OF EQUIPMENT

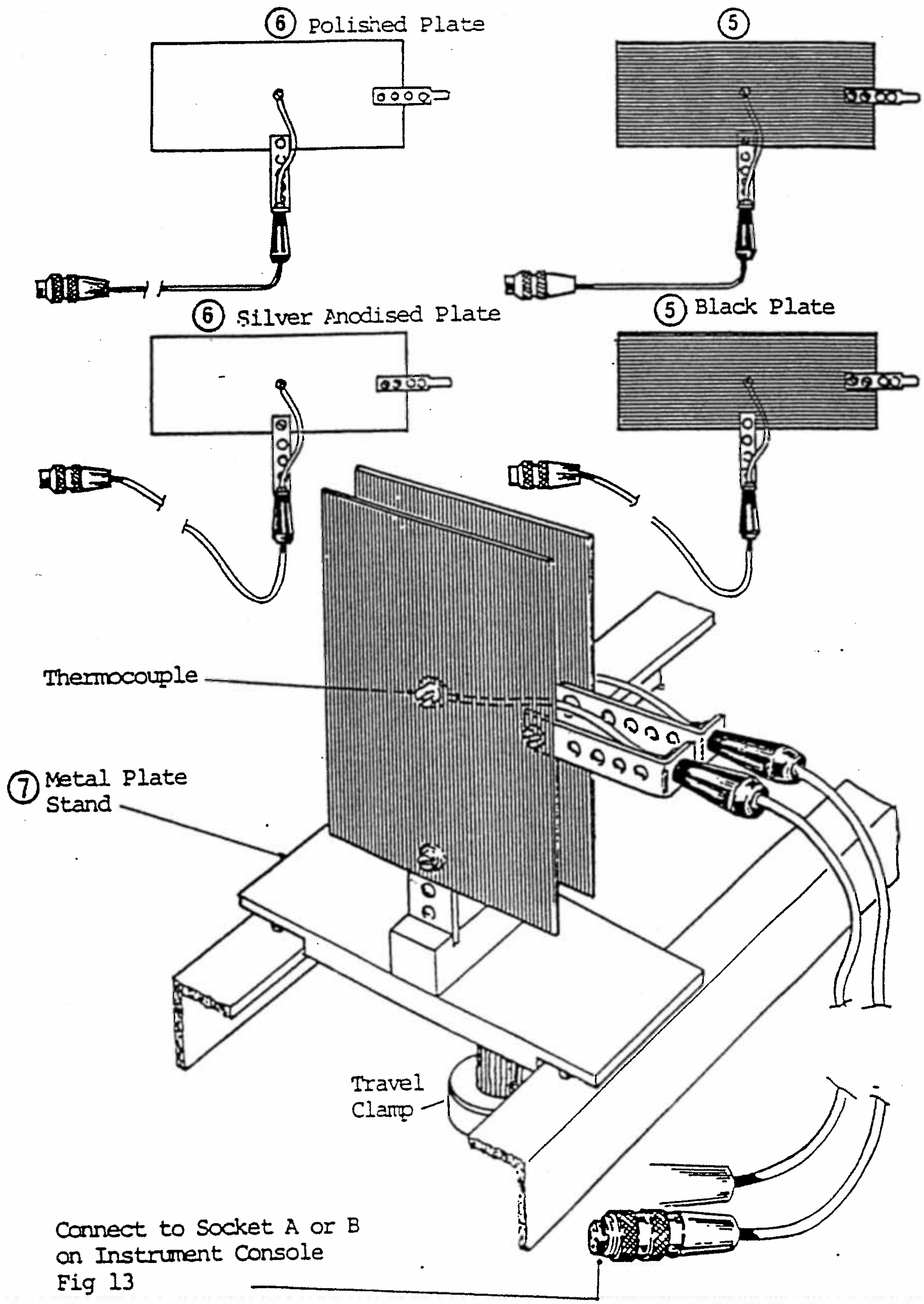
Before proceeding to install, commission or operate the equipment described in this instruction manual, we request you to read the following notes to alert you to potential hazards so that they may be avoided.

Although designed for safe operation, any laboratory equipment may involve processes or procedures which are potentially hazardous. The major potential hazards are listed below. Those particularly relevant to this item of equipment are highlighted for your information by the following symbol - ●

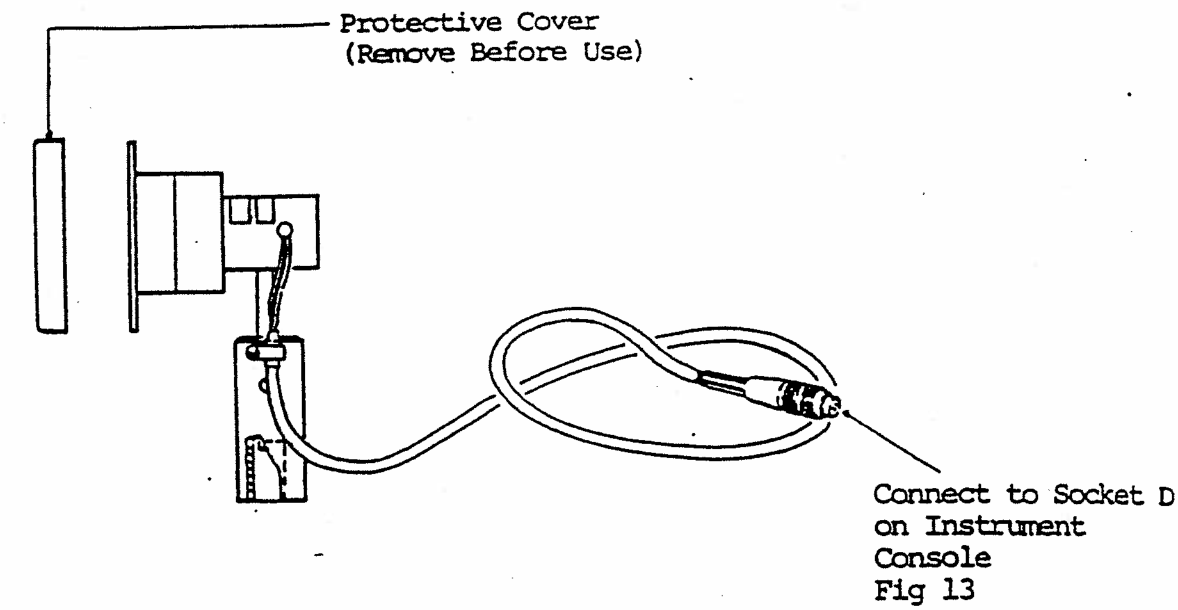
- ● INJURY THROUGH MISUSE
- ● INJURY FROM ELECTRIC SHOCK
- O FIRE OR EXPLOSION FROM HIGHLY INFLAMMABLE LIQUIDS OR VAPOURS (e.g. KEROSENE)
- O POISONING FROM TOXIC MATERIALS (e.g. MERCURY)
- O INJURY FROM HANDLING LARGE OR HEAVY COMPONENTS
- O INJURY FROM ROTATING COMPONENTS
- ● BURNS FROM COMPONENTS AT HIGH TEMPERATURES
- O SCALDING FROM BOILING LIQUIDS OR HOT VAPOURS (e.g. STEAM)
- O INJURY FROM FAST MOVING AIR STREAMS OR HIGH PRESSURE AIR HOSES
- O INJURY FROM CORROSIVE LIQUIDS
- O DAMAGE TO EYESIGHT
- O DAMAGE TO HEARING
- O DAMAGE TO CLOTHING

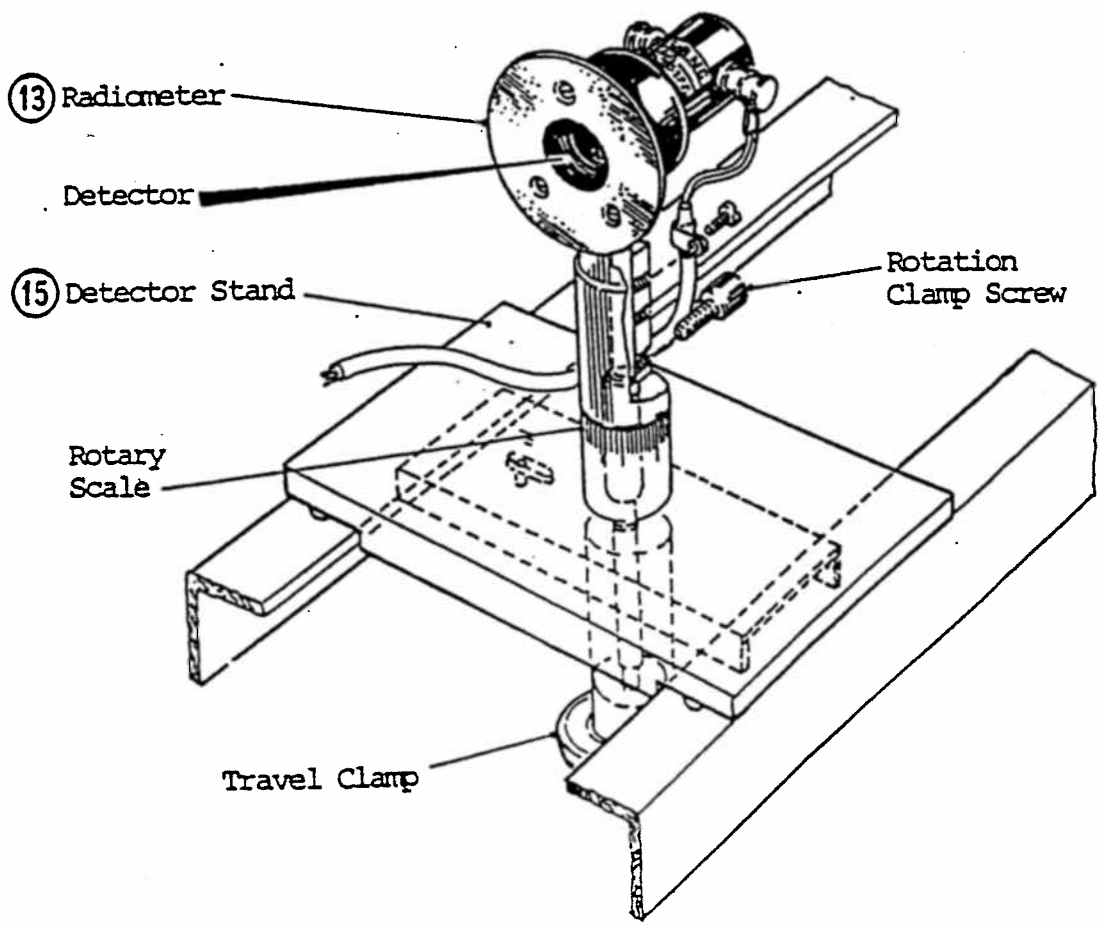
ACCIDENTS CAN BE AVOIDED provided that equipment is regularly maintained and staff and students are made aware of potential hazards. A list of general safety rules is included on Page 2 to assist staff and students in this regard.

The list is not intended to be fully comprehensive, but for guidance only.



METAL PLATES WITH STAND FIG 6





RADIOMETER ON DETECTOR STAND FIG. 8.

H960 THERMAL RADIATION UNIT

Experiments:

1. **Inverse Square Law for Heat**
   To show that the intensity of radiation on a surface is inversely proportional to the square of the distance of the surface from the radiation source.

2. **Stefan-Boltzmann Law**
   To show that the intensity of radiation varies as the fourth power of the source temperature.

3. **Emissivity I**
   To determine the emissivity of different surfaces (polished, silver anodised, matt black).

4. **Emissivity II**
   To demonstrate how the emissivity of radiating surfaces in proximity to each other will affect the surface temperatures and the heat emitted.

5. **Kirchoff's Law**
   To determine the validity of Kirchoff's Law which states that the emissivity of a grey surface is equal to its absorptivity of radiation received from another surface when in a condition of thermal equilibrium.

6. **Area Factors**
   To demonstrate that the exchange of radiant energy from one surface to another is dependent upon their interconnecting geometry, i.e. a function of the amount that each surface can 'see' of the other.

7. **Inverse Square Law for Light**
   To show that the illuminance of a surface is inversely proportional to the square of the distance of the surface from the light source.

8. **Lambert's Cosine Law**
   To show that the energy radiated in any direction at an angle with a surface is equal to the normal radiation multiplied by the cosine of the angle between the direction of radiation and the normal to the surface.

9. **Lambert's Law of Absorption**
   To show that light passing through non-opaque matter is reduced in intensity in proportion to the thickness and absorptivity of the material.

RADIOMETER DATA SHEET

Sensitivity	50mV W^{-1} cm^2 (5.0μV W^{-1} m^2)
Calibration Source Temperature	1000°C
Calibration Accuracy	±3%
Angle of Complete Vision	±25°
Cut-off Angle	±40°
Internal Resistance	46 ohms at 20°C
Ambient Temperature Compensation	0 to 70°C
Measuring Range	0 to 1 W cm^2
Thermopile Aperture Diameter	6.4mm
Measuring Circuit Resistance	<100000 ohms

Notes:

1. The digital meter associated with the radiometer is calibrated to give direct readings of the intensity of infra-red radiation in units of Watts per square meter (W m^{-2}), i.e. the signal produced by the radiometer is amplified by a factor of 20 times to produce calibrated readings on the 199.9 millivolt meter installed in the H960 console.

2. The digital meter indicates the intensity of the radiation received by the radiometer and not the radiation emitted by the appropriate heated surface.

   Several of the experiments in this instruction manual require the measurement of radiation emitted from the heated surface. It can be proved mathematically (beyond the scope of this manual) that the relationship between radiation received and radiation emitted is:

$$R = q \sin^2\theta$$

where R is the radiometer reading (W m^{-2})
Q is the half angle of the radiometer window (complete vision)
q is the energy emitted by the heated surface (W m^{-2})

Therefore, since $\theta = 25°$, $\sin^2\theta = 0.179$

Therefore $q = 5.59R$ W m^{-2}

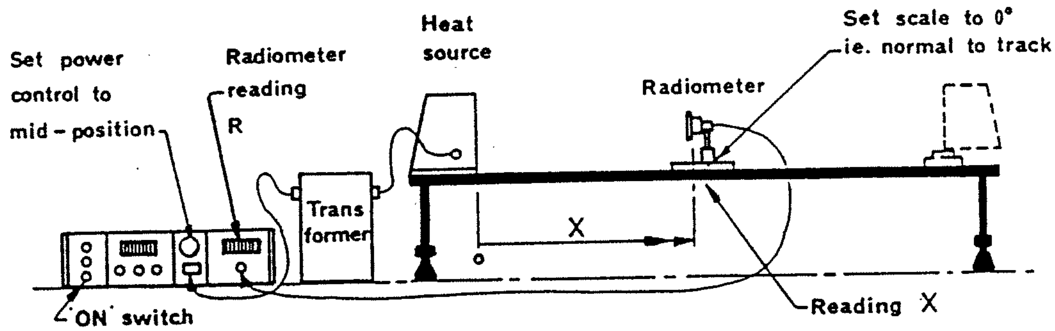
This relationship will be used in the appropriate experiments.

1. INVERSE SQUARE LAW FOR HEAT

Experiment

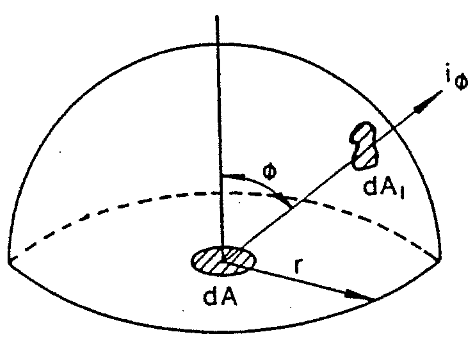
To show that the intensity of radiation on a surface is inversely proportional to the square of the distance of the surface from the radiation source.

Equipment Set-Up



Allow time for radiometer reading to stabilise (at steady heat source temperature) before noting radiometer reading.

Summary of Theory



The total energy dQ from an element dA can be imagined to flow through a hemisphere of radius r. A surface element on this hemisphere dA_1 lies on a line making an angle ϕ with the normal and the solid angle subtended by dA_1 at dA is $dw\phi = dA_1/r^2$.

If the rate of flow of energy through dA_1 is $dQ\phi$ then $dQ\phi = i\phi dw\phi dA$ where $i\phi$ is the intensity of radiation in the ϕ direction.

Initial Values of Variables to be used

Distance from heat source (X) = 100mm

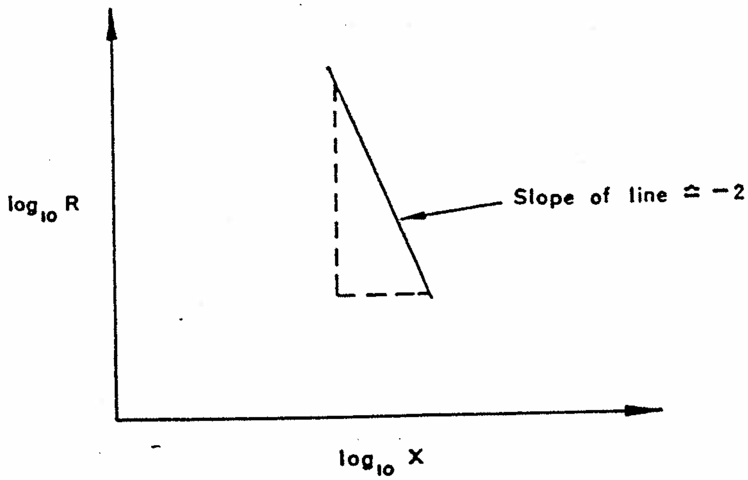
Readings to be taken

Record the radiometer reading (R) and the distance from the heat source (X) for a number of positions of the radiometer along the horizontal track.

Results

Distance	X (mm)	100						
Radiometer Reading	R (Wm^{-2})							

Log_{10}	X	2.000						
Log_{10}	X.							



A log-log plot of radiometer reading against distance will result in a straight line having a negative slope of -2 thus verifying the inverse square relationship between distance and radiation intensity.

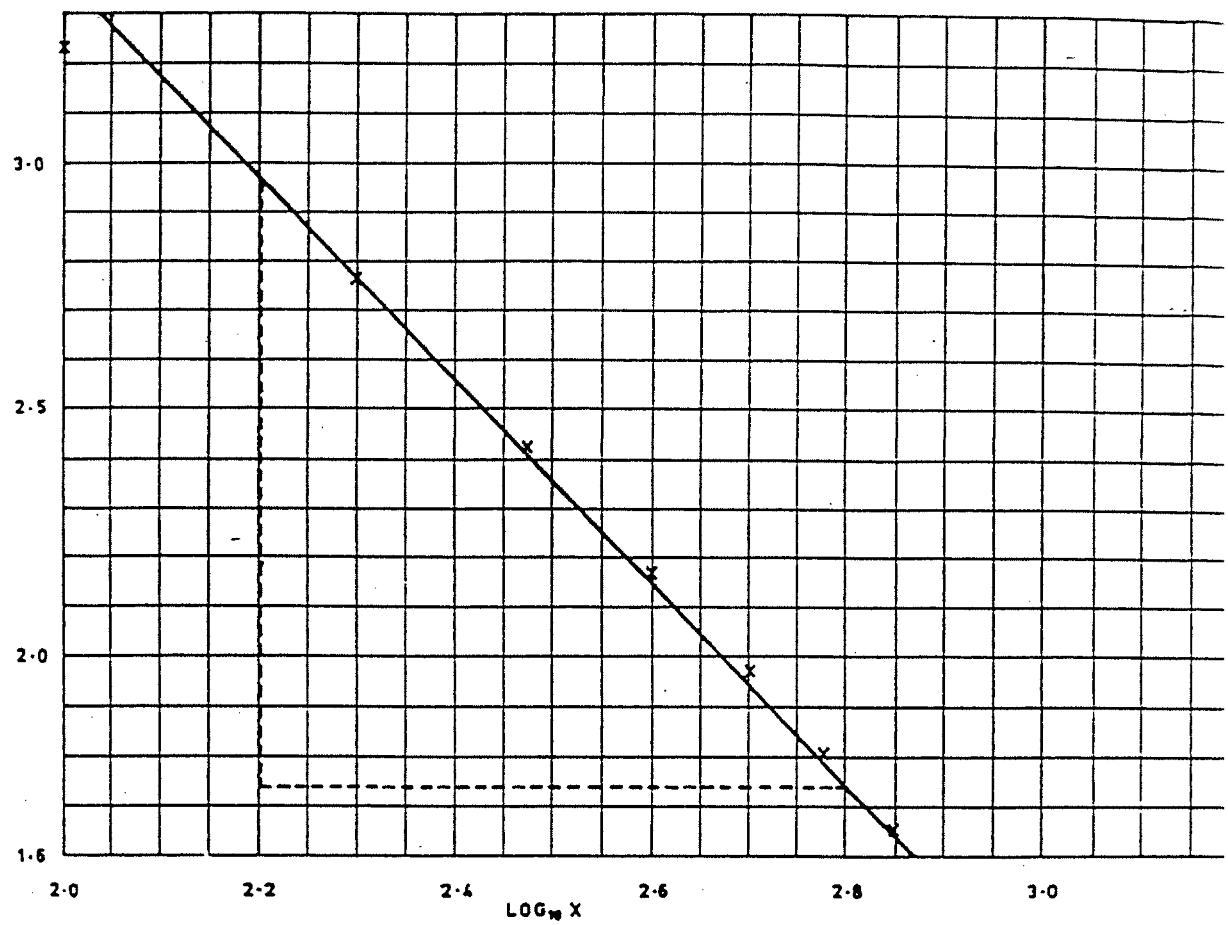
TYPICAL RESULTS

Distance X (mm)	100	200	300	400	500	600	700
Radiometer Reading R (Wm^{-2})	1725	582	268	147	95	63	45

Log_{10} X	2.000	2.301	2.477	2.602	2.699	2.778	2.845
Log_{10} X	3.237	2.765	2.428	2.167	1.978	1.799	1.653

See graph, Page 26.

INVERSE SQUARE LAW FOR HEAT



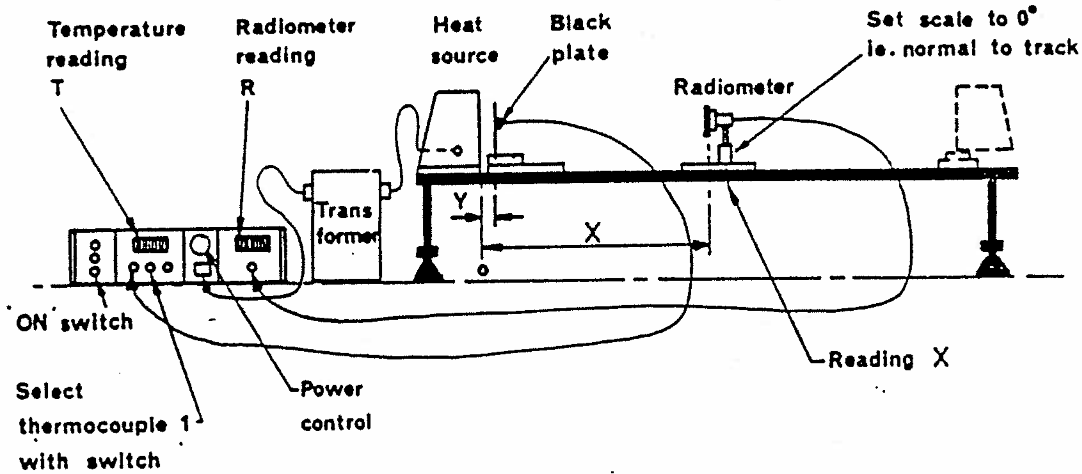
$$Slope = \frac{1.74 - 2.98}{2.8 - 2.2} = \frac{-1.24}{0.6}$$

Slope = <u>-2.06</u>

2. STEFAN-BOLTZMANN LAW

Experiment
To show that the intensity of radiation varies as the fourth power of the source temperature.

Equipment Set-Up



The power control on the instrument console should be set to maximum for this experiment.

Summary of Theory
The Stefan-Boltzmann Law states that: $q_b = \alpha(T_S^4 - T_A^4)$

where: q_b = energy emitted by unit area of a black body surface (W m^{-2})
(Note: Energy emitted by surface = 5.59 x reading from radiometer R - refer to Page 23 for explanation.)
α = Stefan-Boltzmann constant equal to 5.67 x 10^{-8} (W m^{-2} K^{-4})
T_S = Source temperature of radiometer and surroundings (K)
T_A = Temperature of radiometer and surroundings (K)

Initial Values of Variables to be used
Distance from radiometer to heat source (X) = 110mm
Distance from black plate to heat source (Y) = 50mm

Readings to be taken
Record the temperature reading (T) and radiometer reading (R) at ambient conditions then for selected increments of increasing temperature up to maximum within a practical range. Both readings should be noted simultaneously at any given point.

Results

Where K = °C +273 and $\sigma = 5.674 \times 10^{-8}$ W m^{-2} K^{-4}
Ambient temperature = °C

READINGS				CALCULATIONS	
Temperature Reading (T_s).	Radiometer Reading (R)	T_s	T_A	qb = 5.59 x R	$qb = \sigma(T_S^4 - T_A^4)$
°C	$W\ m^{-2}$	K	K	$W\ m^{-2}$	$W\ m^{-2}$

Compare calculated values for qb. If the emissivity of the black plate is unity and the Stefan-Boltzmann relationship holds true (i.e. temperature to the fourth power) then the calculated values should be the same.

TYPICAL RESULTS

Where K = °C +273 and σ = 56.74x10-9 W m-2 K-4
Ambient temperature = 18°C = 291K

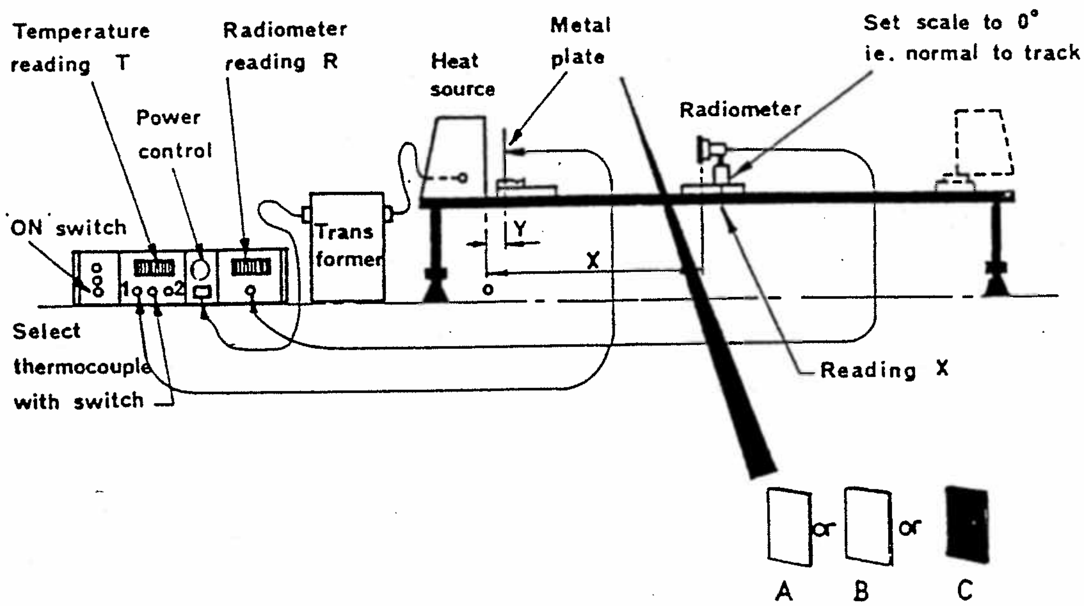
READINGS				CALCULATIONS	
Temperature Reading (T_s)	Radiometer Reading (R)	T_s	T_A	qb = 5.59 x R	$qb = \sigma(T_S^4 - T_A^4)$
°C	$W\ m^{-2}$	K	K	$W\ m^{-2}$	$W\ m^{-2}$
205	485	478	291	2711	2553
180	355	453	291	1984	1981
155	262	428	291	1465	1496
130	189	403	291	1057	1089
105	130	378	291	727	750
80	75	353	291	419	473

The correlation between the two independent calculated values for qb shows that the intensity of radiation varies as the fourth power of the source temperature (Stefan-Boltzmann Law has been verified).

3. EMISSIVITY I

Experiment
To determine the emissivity of different surfaces (polished, silver anodised, matt black).

Equipment Set-Up



Summary of Theory
Emissivity (θ) is defined as the ratio of the total energy emitted by a surface to the total energy emitted by a black surface at the same temperature. For real bodies θ is a function of the radiation wave-length, the angle of incidence, the surface temperature and even the surface finish, but it is generally practical to assume averaged values when making calculations. Tabulated values of typical emissivities for various materials are to be found in published tests dealing with this subject. Usually the emissivity is introduced as a multiplication constant in heat transfer calculations, as, for example, in the Stefan-Boltzmann Law which is re-written:

$$q = E\sigma(T_S^4 - T_A^4)$$

where $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

Note q = 5.59 reading from radiometer (R). (Refer to Page 23 for explanation)

Initial Values of Variables to be Used
Distance from radiometer to heat source (X) = 110mm
Distance from heat source to nearest metal plate (Y) = 50mm

Readings to be taken
Install the polished plate in the carrier.

Vary the power to the heat source and record the temperature of the metal plate (TS) and radiometer (R) at various settings.

Repeat the procedure for the silver anodised plate and matt black plate.

Results

For each plate in turn:
where K = °C + 273
Ambient temperature = 19°C

READINGS				CALCULATIONS	
Temperature Reading (T_S)	Radiometer Reading (R)	T_s	T_A	qb = 5.59 x R	$E = \frac{qb}{\sigma(T_S^4 - T_A^4)}$
°C	W m^{-2}	K	K	W m^{-2}	

TYPICAL RESULTS

For the Polished Plate:

READINGS				CALCULATIONS	
Temperature Reading (T_S)	Radiometer Reading (R)	T_s	T_A	qb = 5.59 x R	$E = \frac{qb}{\sigma(T_S^4 - T_A^4)}$
°C	W m^{-2}	K	K	W m^{-2}	
110	28	383	291	156.5	0.19
90	17	363	291	95.0	0.17
70	10	343	291	55.9	0.15
50	5	323	291	28.0	0.13
30	2	303	291	11.2	0.16

Average value for E for polished plate is 0.16.

For the Silver Anodised Plate:

READINGS				CALCULATIONS	
Temperature Reading (T_S)	Radiometer Reading (R)	T_S	T_A	qb = 5.59 x R	$E = \frac{qb}{\sigma(T_S^4 - T_A^4)}$
°C	W m^{-2}	K	K	W m^{-2}	
160	250	433	291	1397.5	0.88
035	183	408	291	1023.0	0.88
110	130	383	291	726.7	0.89
85	85	358	291	475.2	0.90
60	42	333	291	234.8	0.81

Average value of E for anodised plate is 0.87.

For the Matt Black Plate:

READINGS				CALCULATIONS	
Temperature Reading (T_S)	Radiometer Reading (R)	T_S	T_A	qb = 5.59 x R	$E = \frac{qb}{\sigma(T_S^4 - T_A^4)}$
°C	W m^{-2}	K	K	W m^{-2}	
205	485	478	291		1.06
180	355	453	291		1.00
155	262	428	291		0.98
130	189	403	291		0.97
105	130	378	291		0.97
80	75	353	291		0.88

Average value for E for matt black plate is 0.98.

Note that although the anodised plate is silver, it behaves more like a black plate than a polished plate due to the irregular surface finish.