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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE

A Radiation Calorimeter for the Absolute Measurement of Radiation Intensities between 0.4 and 12.5 watts/cm^2

by

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Summary

A continuous flow radiation calorimeter is described in which a radiation flux produces a temperature difference, detected by a thermistor bridge, between the inlet and outlet of the water circuit. The rate of flow of water through the calorimeter is self-stabilizing. The radiation intensity is measured by replacing the radiant heating by an equivalent rate of electrical heating.

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2. Introduction

In studying the ignition of materials, it has been found necessary to standardize measurements of radiation intensities of the order of at least 10 watts/cm^2. Several investigators (1) (2) have designed absolute instruments for lower levels of radiation, but no apparatus could be obtained to cover the required range of intensities. The continuous flow radiation calorimeter described in this note was therefore developed to make absolute measurements in the range 0.4 - 12.5 watts/cm^2.

2. Description of apparatus

The apparatus (Fig. 1 and Plate 1) consists of a "constant flow" calorimeter surrounded by a water-cooled guard ring which ensures that the incident radiation, the intensity of which is to be measured, falls only on the front face of the calorimeter.

Water flows through the calorimeter at a rate of about 1 cc/sec from the self-stabilizing water circuit illustrated in Fig. 3. The constant flow of water is developed from the aspirator bottle illustrated on the left. The only substantial resistance to flow in the aspirator is offered by a glass orifice and this is fed by the constant pressure head of the system. The rate of flow is therefore a function only of the liquid and of the dimensions of the orifice through which it is flowing.

This constant output of water is fed into the calorimeter system and the equilibrium flow must remain constant irrespective of changes in the hydraulic resistance of the calorimeter and its feed system as there is no continuous accumulation of water in any part of the circuit.

Radiation incident upon the calorimeter produces a temperature difference between the water inlet and outlet and equilibrium is established in approximately a minute, the temperature difference being registered by a thermistor bridge as illustrated in Fig. 2 [x]. To ensure that the warm water from the calorimeter is properly mixed i.e. is of uniform temperature, a long length of 38 S.W.G. wire is fed into the outlet tube of the calorimeter as illustrated in Fig. 1.

An electrical heating element consisting of a length of about 40 inches of 24 S.W.G. nichrome wire is placed behind the receiving surface of the calorimeter.

3. Method of use

With water flowing through the calorimeter but with no radiation incident upon it, the micro-ammeter in the thermistor bridge circuit is set approximately to zero. Radiation is allowed to fall on the calorimeter and in order that the instrument shall operate at its maximum sensitivity the voltage across the bridge is adjusted such that the deflection on the meter is nearly full scale. Equilibrium is established in approximately a minute and the deflection is then noted.

Electrical heating from the supply mains is substituted for the radiant heating and its level adjusted until the previous micro-ammeter reading is reproduced. Measurement of the input electrical power gives the value of the incident radiation intensity.

A correction has to be applied due to the fact that the emissivity factor of the front surface is not unity. The surface is coated with carbon black and previous workers give the emissivity of such a surface, within the relevant temperature range, as 0.952 (3) and 0.95 ± 0.01 (4).

4. Sources of error

4.1) Thermistor characteristics

The characteristics of any two thermistors taken from any one production batch are found in practice to differ a little and as a result the bridge zero may be expected to be slightly dependent on the temperature of the inlet water. This does not appreciably affect the accuracy of measurements however as the temperature of the inlet water is substantially constant during the course of an observation.

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x Type F 1512/300 thermistors were used, manufactured by Standard Telephones and Cables Limited.

Apart from possible changes of zero, the sensitivity of the bridge is slightly dependent on the temperature of the inlet water, but here again the effect is not important as the temperature is substantially constant during the course of an observation.

4.2) Effect of cooling by radiation, convection and conduction and of variation in ambient room temperature.

Apart from the heat given to the water, heat will be lost from the calorimeter by radiation, by convection and by conduction along the calorimeter supports and leads etc. It is important that these losses shall not vary sufficiently to introduce errors during the course of a measurement. To ensure that the losses are similar, irrespective of whether electrical or radiant heating be used, the electrical heater has been installed so that it produces heat almost uniformly near to the front surface, thereby producing a temperature distribution similar to that produced by the radiant heating.

To reduce further the importance of variations due to the above and to slight variations in ambient room temperature during the course of a measurement, the order of rate of flow of water selected (1 cc/sec) is such that the losses constitute only about 5 per cent of the cooling by the water flow. Variations therefore become only of second order importance.

5. Variability of readings

In order to assess the variability of the readings given by the radiation calorimeter, the measured values of intensity I were compared with the relation $I = f(\sigma T^4)$ where T is the temperature of a radiator. A pyrometer which had been previously calibrated against a black body furnace was used to measure the temperature of the one foot square radiant panel fed with a gas/air mixture at a steady rate. The radiation was measured for different fuel supplies and therefore for different panel temperatures.

The range of the intensities used was extended by removing the radiation calorimeter to a greater distance from the radiant panel. The ratio of the configuration factors at the two distances was known experimentally from comparative measurements made by the radiation calorimeter itself, and it was thus possible to normalise the black body temperatures to one distance of separation between radiant panel and calorimeter. This procedure is permissible as the only assumption is that the electrical calibration is proportional to the intensity.

The relationship between the radiation intensity at the calorimeter and the normalised black body temperature T_B was not immediately taken as

$I = a_1(\sigma T_B^4)$ but as $I = a_0 + a_1(\sigma T_B^4) + a_2(\sigma T_B^4)^2$

By this assumption it was possible to check that results were not being misinterpreted due to neglect of such factors as inaccuracy in the calibration of the pyrometer, or variation, with mean temperature, of the temperature distribution over the surface of the furnace.

Using the results for I given by the radiation calorimeter, the "best fitting" values of the constants were found by the method of least squares. It was found that a_0 approximated closely to zero and that the ratio a_2/a_1 lay between zero and -0.05. Comparing a linear graph with that of the expression $I = a_1(\sigma T_B^4)[1 - 0{\cdot}05(\sigma T_B^4)]$

it was found that the difference between the two was never greater than $\pm 1\frac{1}{2}$ per cent. The second term was therefore ignored and the "best value" of

a_1 was chosen to fit the expression $I = a_1(\sigma T_B^4)$

A set of eleven consecutive results is given in Table 1 and from them, taking the definition of R.M.S. percentage deviation σ' as

$$\sigma' = \frac{100}{\sqrt{n-1}} \sqrt{\sum_{1}^{n} \left(\frac{I_{R_r} - I_{P_r}}{I_{R_r}} \right)^2}$$

where I_R is the intensity as measured by the radiation calorimeter

I_P is the intensity deduced from the pyrometer readings.

a value of 2,8 per cent is obtained. This value has been confirmed by subsequent results.

TABLE 1

Deviations in a typical set of readings

Calculated Intensity I_P (from pyrometer reading) (cal/cm^2/sec)	Intensity given by radiation calorimeter. I_R (cal/cm^2/sec)	% Deviation %
0.986	0.978	-0.8
0.840	0.833	-0.8
0.634	0.646	1.9
1.080	1.120	3.7
0.940	0.916	-2.6
0.360	0.357	-0.8
0.403	0.421	4.5
0.314	0.311	-1.0
0.276	0.266	-3.6
0.319	0.308	-3.5
0.253	0.258	2.0

6. Conclusions

An absolute radiation calorimeter has been described which allows the absorbed radiation to be measured with a probable error of 1.8 per cent. The error in measuring the incident radiation is dependent on the adsorption factor of the calorimeter face; this factor has been taken from the results of two observers as being 0.95. (3) (4)

Possible improvements in future apparatus would be first a reduction in the thermal capacity of the system to give a faster response; several minutes are required for a reading with the present instrument. Second it would be desirable to include some system of air venting on the calorimeter as the air dissolved in the water flowing through the calorimeter gradually comes out of solution during the course of an experiment and the apparatus at present has to be cleared about every hour during use by flushing through with water.

7. Acknowledgement

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8. References

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VHM

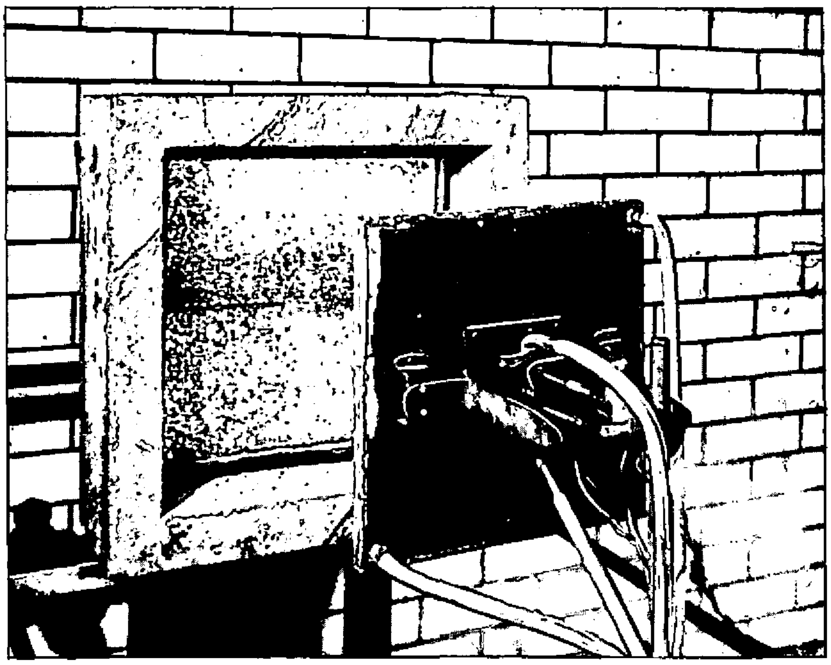

PLATE. I. REAR VIEW OF RADIATION CALORIMETER

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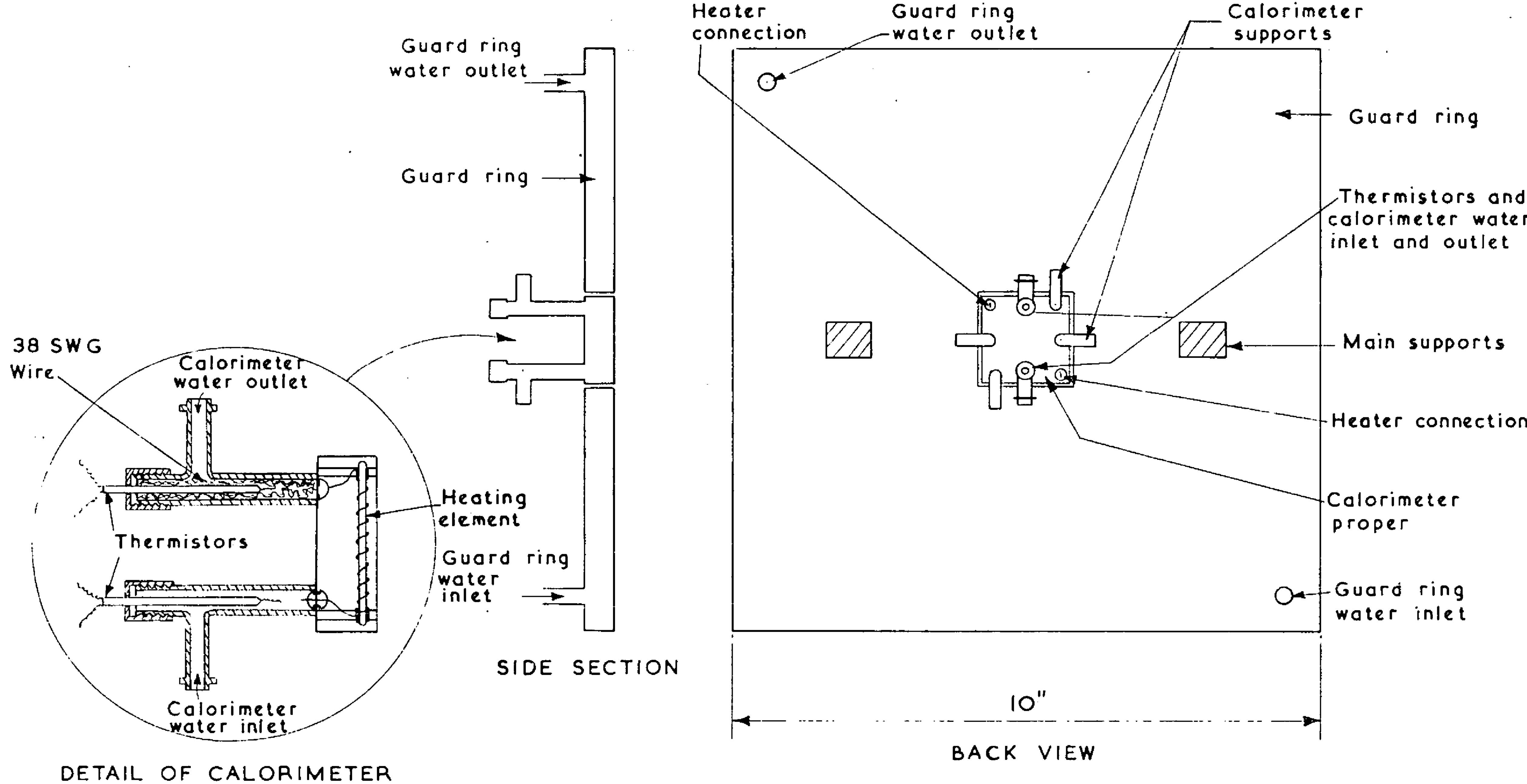

FIG. I. RADIATION CALORIMETER

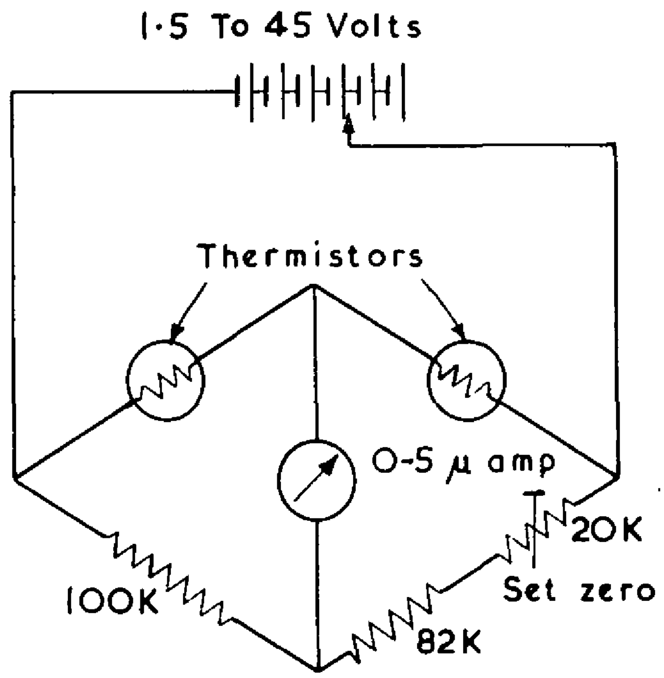

FIG. 2. THERMISTOR BRIDGE CIRCUIT

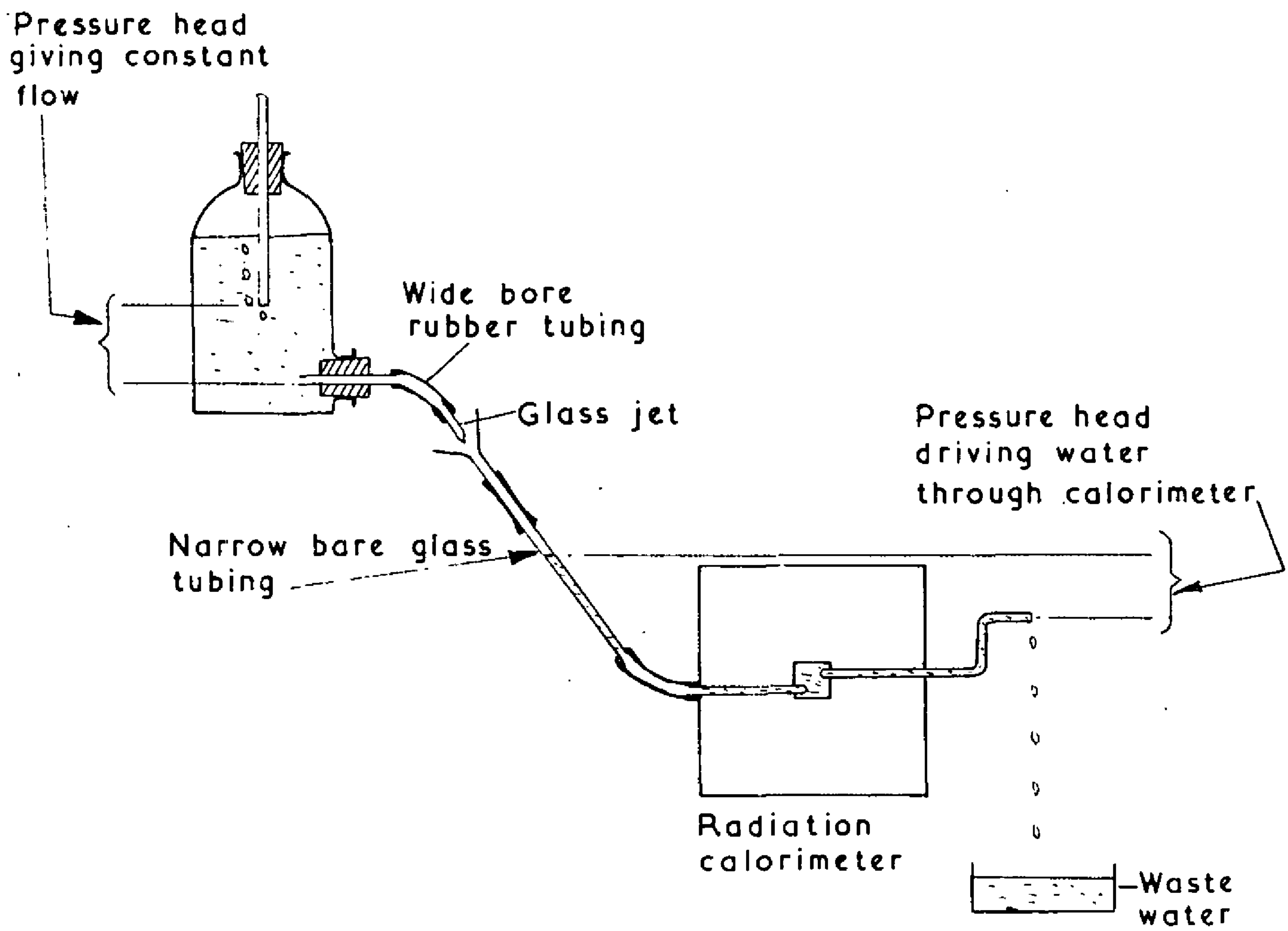

FIG. 3. SELF STABILISING WATER CIRCUIT