CONSTRUCTION AND CALIBRATION OF A LOCAL PYRANOMETER AND ITS USE IN THE MEASUREMENT OF INTENSITY OF SOLAR RADIATION

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ABSTRACT

Using locally available materials, we have successfully constructed a pyranometer. This pyranometer has been calibrated against a standard Eppley pyranometer at the University of Nigeria, Nsukka and then used in measurement of intensity of solar radiation in Enugu which lies on latitude 6.20^{0}N-- and longitude 7. 30^{o}E. The investigation was carried out between October and December 1984. Our investigations show that the maximum mean instantaneous insolation for the months of October November and December in Enugu were 565.6 Wm^{-2} , 600.6 Wm-^{2} and 580.4 Wm $^{-2}$ respectively. The maximum instantaneous insolation for the period usually occured between 11.30 a.m. and 1.00 p.m. Our results also reveal that the sudden appearance of harmattan haze drastically reduced the mean hourlyinsolation. These results compare favourably with similar investigations using other techniques.

1. INTRODUCTION

The electromagnetic radiation emitted by the sum (solar radiation) covers a wide wavelength spectrum. However, 99.512 per cent of the radiation is in the wavelength range O.115 to 5.00 m[1]. The intensity of s6lar radiation just outside the earth's atmosphere (the extraterrestrial radiation) integrated over the entire wavelength spectrum, is known as the solar constant. The solar constant has an annual mean value of 1.37 Kw/m^2. Owing to the eccentricity of the earth's orbit round the sun, the intensity of extraterrestrial radiation varies between the limits of 1.32 kw/m^2 in early July to 1.42 kw/m^2 in early January[2]. [4]Barbaro et al[3] and Thek ekara have given an analytic .mod for representing this variation. This model is of the form: $1=J_0$ (1+0.035cos(2π(N-4)/366) where I is the solar constant and N is the day number from January 1 of the year.

As the solar radiation enters the earth's atmosphere its intensity and spectral distribution are altered due to absorption and scattering by different atmospheric constituents. Water vapour absorbs solar radiation in the infrared region while ozone absorbs in the ultraviolet region; the terrestrial solar radiation is therefore deficient of radiation in these bands. Gas molecules, water droplets and other atmospheric particles are the main scattering agents. Cloud covers absorb and reflect incoming solar radiation back into space in an unpredictable manner.

Several authors [5,6,7] have made detailed analysis of the absorption and scattering processes. However the attenuation of the solar radiation due to the interaction with the atmosphere is usually represented by Beer's law exponential decay model.

$$I_{B,\lambda} = I_{0,\lambda} e^{-c_\lambda m}$$

where $I_{b,\lambda}$ is the beam irradiance on a terrestrial surface at wavelength λ ;C_λ is the atmospheric insolution coefficient, and m is and air mass,(defined as the ratio of the path length of radiation through the atmosphere at any given angle to the sea level path straight through the atmosphere at any given angle to the sea level path straight through the atmosphere (vertically). $I_{0,\lambda}$ is the monochromatic extraterrestrial irradiance.

The intensity of solar radiation reaching a terrestrial surface has two components; namely the beam (or d1rect) component I_b and the diffuse component I_d• The beam component is the solar radiation reaching a surface in the atmosphere without significant change in direction, while the diffuse component is the solar radiation flux which is scattered by different constituents of the atmosphere and reaching a terrestrial surface without a specific angle of incidence. The total or global insolation on a terrestrial surface is the sum of these two components, "i.e.

$$I_g = I_b + I_d$$

The global insolation at any location depends on the geographical location (the latitude), the time of the day, the time of the year and the prevalent atmospheric conditions. The relative amount of the direct and diffuse components depends on the atmospheric conditions. Under clear sky conditions, the amount of diffuse radiation is relatively small while in the presence of total cloud cover the solar radiation reaching the earth's surface is purely diffuse.

Although some theoretical models have been proposed for the calculation of insolation by some authors[3,8], solar radiation data are best obtained by direct measurement. pyranometers are used for measurement of global insolation while pyrheliometers measure only the beam component. Generally these devices detect solar radiation either by photovoltaic conversion or by a combination of photothermal conversion and the - - - - electric effect. The pyranometer constructed detects solar radiation by photothernal conversion and thermoelectric effect.

EXPERIMENTAL DETAILS

(i) CONSTRUCTION OF PYRANOMETER:

The pyranometer constructed consists of the radiation sensor a protective Perspex box and a glass dome; the readout device is an EDSPOT longrange galvanometer. The radiation sensor is a set of four locally - made copper-constantan thermocouples connected to a set of five copper' plates. Four of the copper plates measure 2cm x 1cm x O.05cm each, while the fifth plate measures 1cm x 2cm x O.05cm. One junction of each thermocouple was soldered to one small plate; the other set of the junction was soldered to the large plate. The four small plates were blackened with a mixture of black paint and lampblack. The large plate was painted white and then covered with aluminium foil. The plates were then screwed onto a pair of 9cm long T-shaped wooden upright stands attached to a wooden base measuring 25cm x 25cm x 1cm; the large plate was screwed onto one of the stands while the other four were screwed to the other stand in such a way that they do not touch one another. This is shown in plate 1.

PLATE 1: MOUNTED COPPER PLATES & THERMOCOUPLES

Due to high absorptance of black surfaces and high reflectance of shiny metal surfaces, the small black plates absorb most of the incident solar radiation, while the large shiny plate reflects most of the radiation. At any given time therefore there is a temperature difference between the black plates and the shiny plate. The thermocouple junctions soldered to the black plates therefore act as the 'hot' junction while the other junctions at the shiny plate are the 'cold' junctions. A thermoelectric electromotive force (e.m.f.) is therefore generated in the thermocouples. The current flowing is measured by a sensitive galvanometer and is proportional to the intensity of solar radiation.

The assemblage is encased in a Perspex box measuring 25cm x 25cm x 8cm; the wooden base onto which the T-shape upright stands are screwed, form the base of the box. The box has a round hole at the top, over which a glass dome of diameter 16cm is fitted by means of car windscreen plasticine. The glass dome is made from a 2-litre round bottom flask. The assemblage is shown in plate 2.

ii) CALIBRATION OF THE PYRANOMETER

The constructed pyranometer was calibrated against a standard Eppley pyranometer (model PSP 17361 F3) at the University of Nigeria Nsukka. During the calibration, the constructed pyranometer was mounted side by side with the Eppley pyranometer on a horizontal concrete roof. The constructed pyranometer was connected to an EDSPOT long range galvanometer. The galvanometer deflection increases and decreases with the intensity of insolation.

The Eppley pyranometer records the cumulative insolation over a time period. Readings for cumulative insolation for two-minute period were recorded; the galvanometer deflections were also recorded simultaneously at the end of each two-minute period. The values of the instantaneous insolation were calculated from the cumulative values. The readings obtained during the calibration are shown in table 1.

Mean galvanometer deflection (cm)	Mean instantaneous insolation (wm-2)
4	30
7	90
11.5	180
13.8	210
16.5	240
20.5	270
24.4	300
24.5	330
26.8	360
29.0	384
28.5	390
31.8	420
33.0	450
36.0	480
43.8	570
47.0	600
52.0	630
54.5	660
59.5	690
70	900
82	960
85	990
85	1050
95	1140

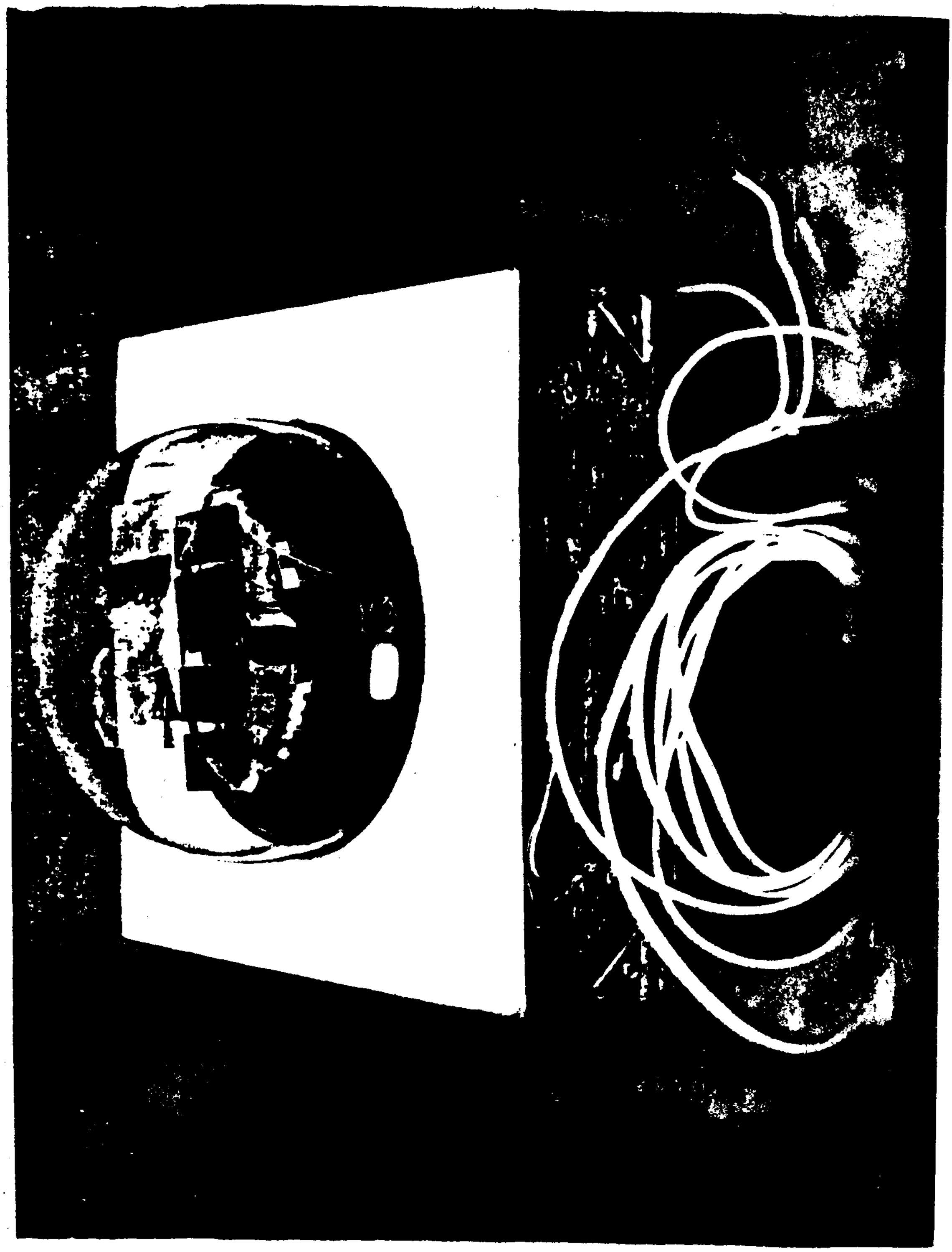


PLATE 2: LOCALLY CONSTRUCTED PYRANOMETER

The calibration curve is obtained by plotting the galvanometer deflection against the instantaneous insolation as measured by the Eppley pyranometer. The calibration curve is shown in figure 1.

(iii) MEASUREMENT OF INSOLATION

The solar radiation in Enugu was measured for October, November and December 1984, using the constructed pyranometer. The pyranometer was mounted on a horizontal concrete roof at the Campus 11 of the Institute of Management and Technology (I.M.T.), Enugu. Hourly (or half-hourly readings of the galvanometer deflection were recorded. The hourly (or half-hourly) instantaneous insolations were then interpolated from the calibration curve.

RESULTS

Figure 2 snows a graph of instantaneous insolation (measured by the Eppley pyranometer) versus time of the day. Also shown on the same set of axes is a graph of galvanometer deflection versus time of the day. The graphs show that the galvanometer deflection follows the same trend as the intensity of insolation. Figure 3 compares performance of our pyranometer with Eppley pyranometer.

The maximum mean instantaneous insolations for the period were as follows:-

October 564.6 wm^{-2}
November 606.6 Wm^{-2}
December 580.4 Wm^{-2}'

The reduction of insolation by clouds in October and thick harmattan haze in December are well revealed by these results.

For a given hour of the day the instantaneous insolation was most consistent in December and least consistent in October. For instance, in October the insolation at 1.00 p.m. range from 162 Wm^{-2} in 17 October 1984 to 922 Wm^{-2} on 9 October 1984, while in December the instantaneous insolation for the same time varied from 5000 $Wm-^{2}$ on 20 December 1984 to 547 wm^{-2} on 15 December 1984. This may be attributed to broken clouds which usually occur in an irregular manner in October.

The highest single intensity for each of the months was:

October 968 $wm-^{2}$
November 799 $Wm-^{2}$
December 603 $Wm-^{2}$

The relatively low value for December was again due to the effect of harmattan haze which was almost permanent in the atmosphere. In October the sky was usually clear whenever there was no cloud; therefore the insolation could at times be very high.

CONCLUSIONS

We have successfully demonstrated that using greater percentage of locally available material, we can construct fairly reliable pyranometers. Our home made pyranometers compare

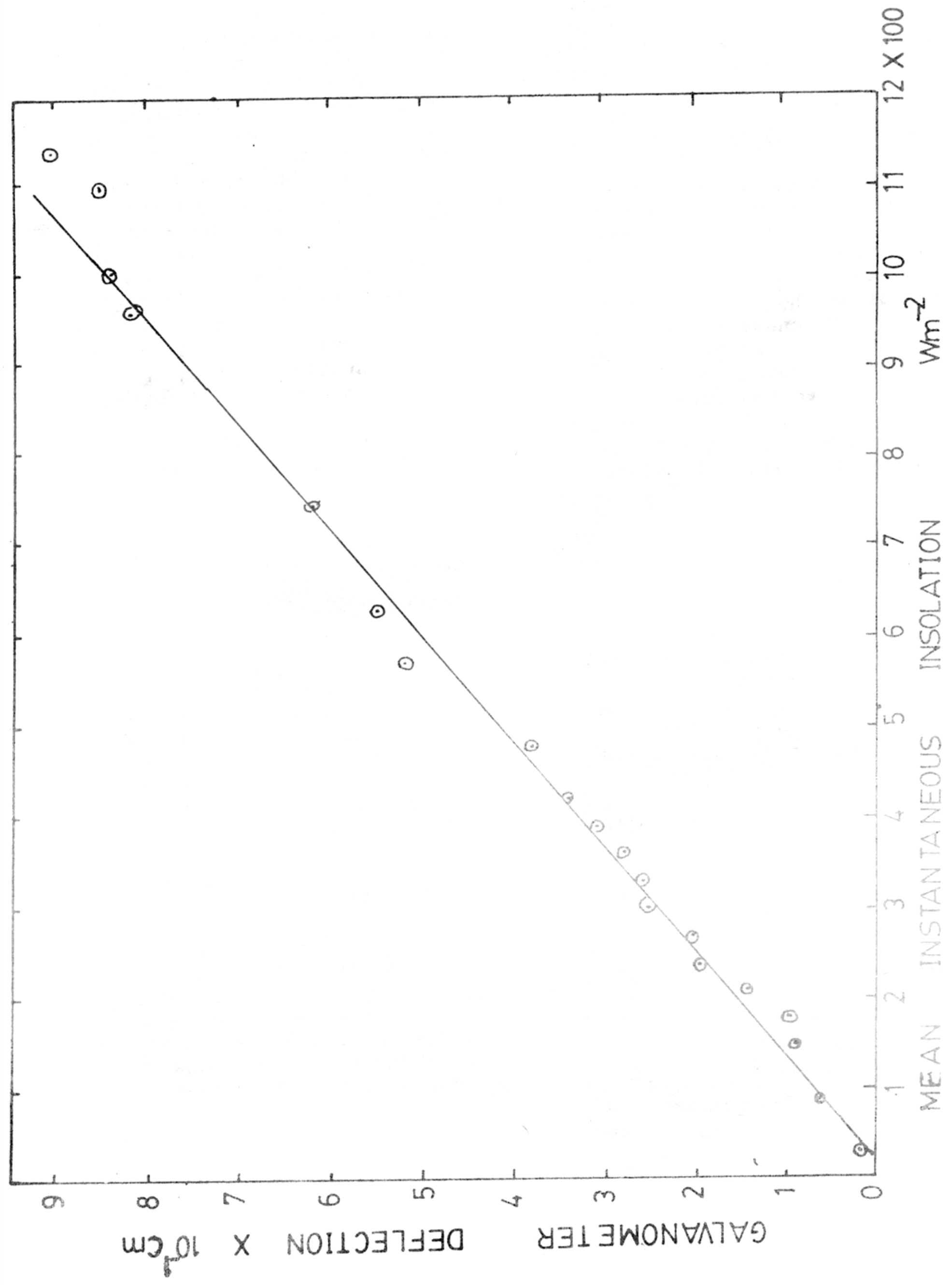


Fig.1. Calibration Graph for Pyranometer

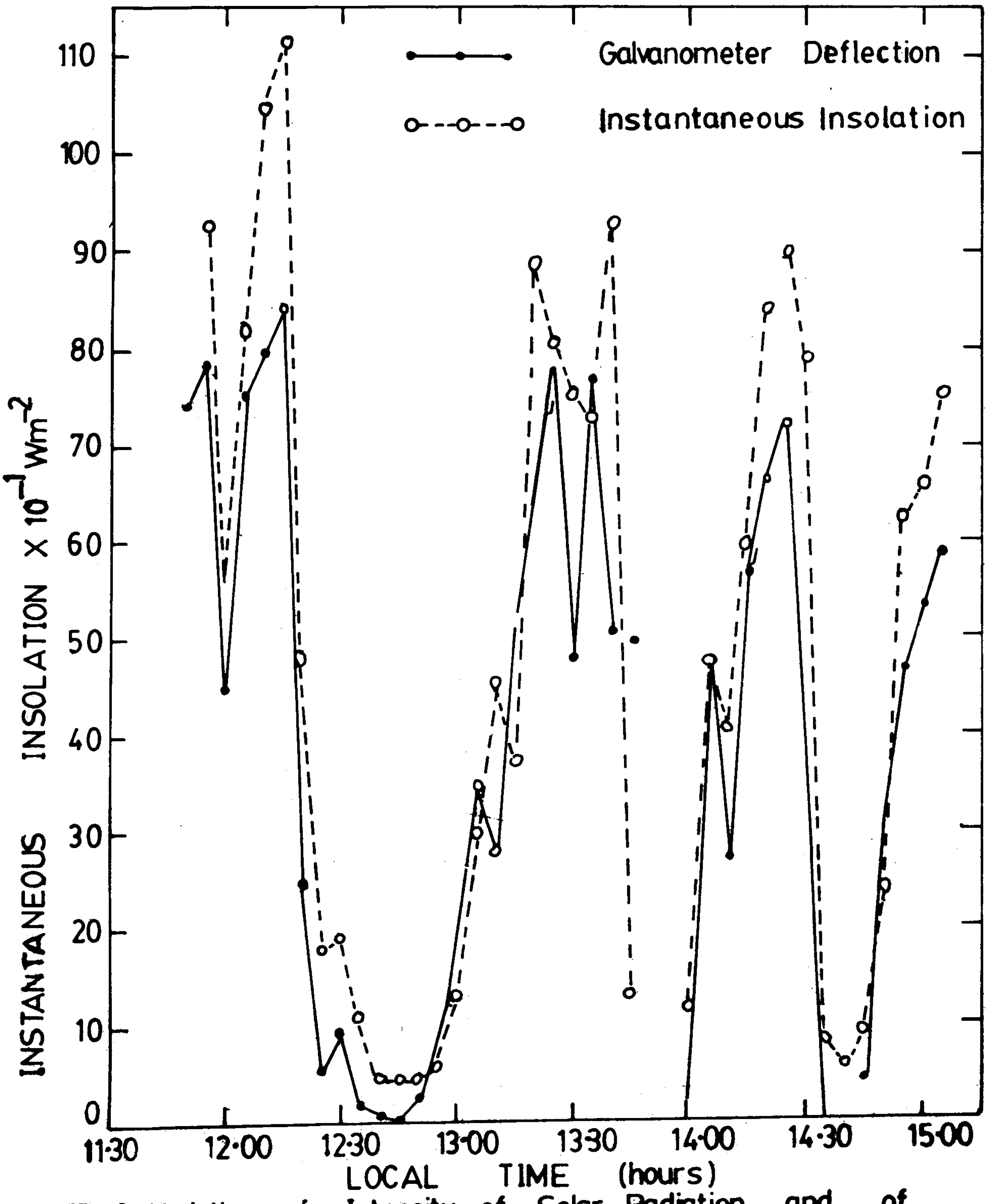
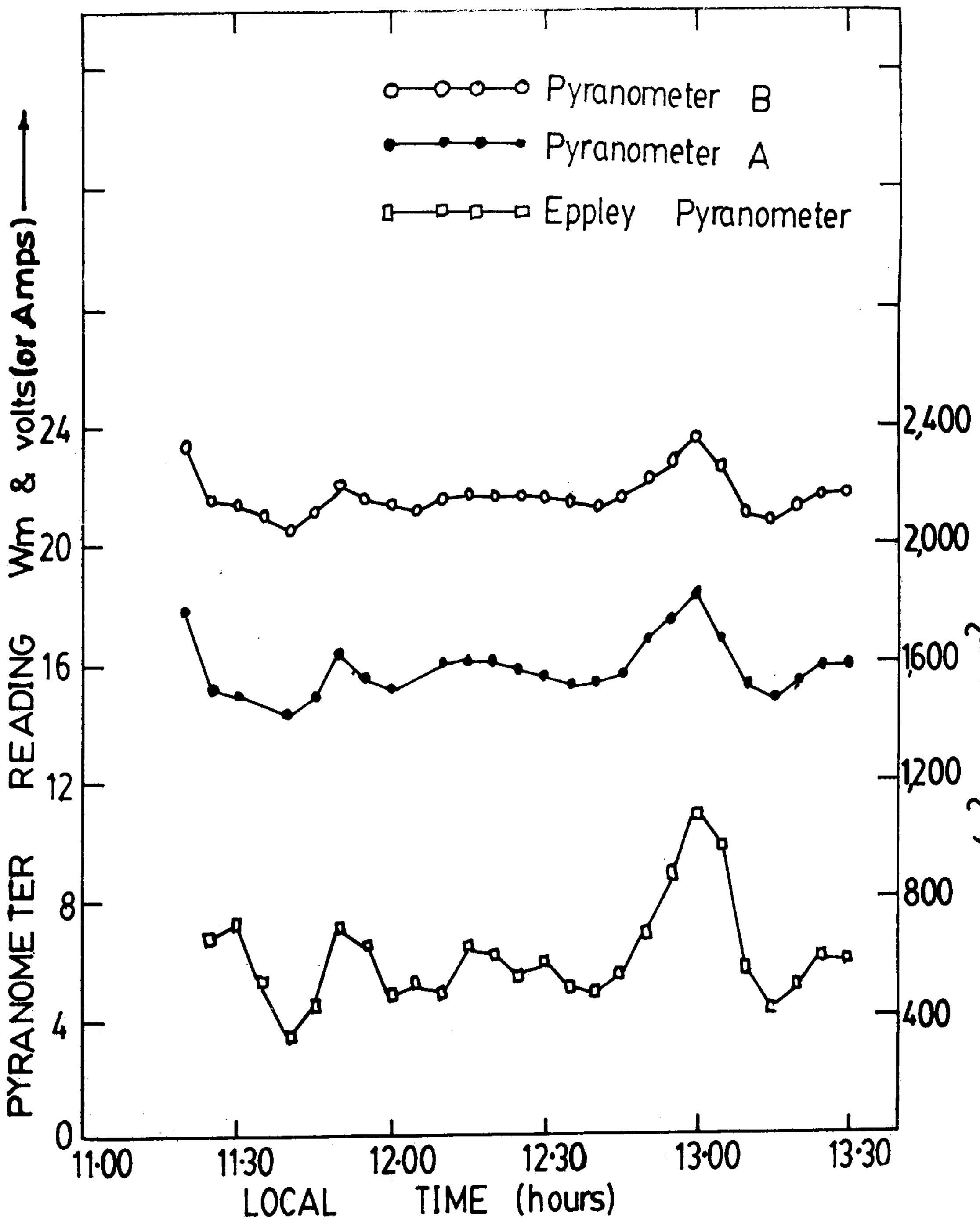


Fig.2, Variation of Intensity of Solar Radiation and of Galvanometer Deflection With Time



Fig·3, Variation of Intensity of Solar Radiation and of Amplified Output Voltage With Local Time favourably with imported Eppley pyranometer. We have also successfully used our instrument to measure highest instantaneous, and highest mean instantaneous insolation for Enugu-Nigeria for a period of three months.

With improved technology and better choice material, it is hoped that the efficiency of our locally constructed pyranometer might be improved. This can be achieved by using a material with low specific heat capacity (e.g. platinum) for making the sensor; and also by making the surface area to thickness ratio of the sensor as high as practicable.

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