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THE EPPLEY LABORATORY, INC.

SCIENTIFIC INSTRUMENTS

NEWPORT, R.I.

U.S.A.

STANDARDIZATION

OF

EPPLEY ÅNGSTRÖM PYRHELIOMETER

NO. 16843 *

The radiation intensity is determined by the equation

$$I = ki^2$$

where I is the intensity expressed in cal cm^{-2} min^{-1}, i is the electrical compensation current expressed in amps and k is a constant. This constant has the following value:

$$k = 7.04$$

IPS 56

This value was established, at Newport, through comparison with Eppley working standard Ångström pyrheliometer No. 8420 using Eppley Ångström readout unit No. 4506 (i.e. incorporating a potentiometric controlled milliammeter). The results of this comparison are given below. Each tabulated value represents the mean of at least 10 readings.

N.B. after Calibrating: Carpentras

$k = 487,6\ mW \cdot cm^{-2} \cdot A^{-2}$ SI scale 1981

(7.04 ~ 491.5 $mW \cdot cm^{-2} A^{-2}$) IPS 56

7,041 (IPS 56) ~ 7,189 (WRR 81) cal cm^{-2} min^{-1}

487,6 " ~ 6,984 cal cm^{-2} min^{-1}

*Element No.

Control Box No. 5425

THE EPPLEY LABORATORY, INC.
12 Sheffield Ave., Newport, R. I. 02840, U.S.A. Telephone 401 847-1020

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The K factor listed on this calibration certificate is referenced to the International Pyrheliometric Scale of 1956 (IPS 1956). To effect a conversion to the Absolute Scale (SI), the K factor should be multiplied by 1.021. This conversion is derived from Eppley standard Ångström No. 7644 as compared at the fourth International Pyrheliometric Comparisons at Davos, Switzerland in October 1975.

Date	I (λ.8420) cal cm-2 min-1	i^2 (λ. 16843) amp^2	k	
28 Dec 77	1.267	0.1798	7.047	
28 Dec 77	1.251	0.1775	7.048	
28 Dec 77	1.261	0.1792	7.037	0,010
29 Dec 77	1.202	0.1705	7.049	
29 Dec 77	1.207	0.1715	7.038	
29 Dec 77	1.209	0.1717	7.041	0,011
3 Jan 78	1.245	0.1770	7.034	
3 Jan 78	1.243	0.1768	7.031	
3 Jan 78	1.240	0.1761	7.041	0,010

Mean 7.041
Mean Deviation 0.1±%

The radiation reference employed is the International Pyrheliometric Scale (1956).

F. Griffin

The Eppley Laboratory, Inc. **IN CHARGE OF TEST:** F. Griffin

W. Scholes
By: W. Scholes

Newport, R. I.

Shipped to: **Date:** 4 Jan 78 **S.O.** 35687

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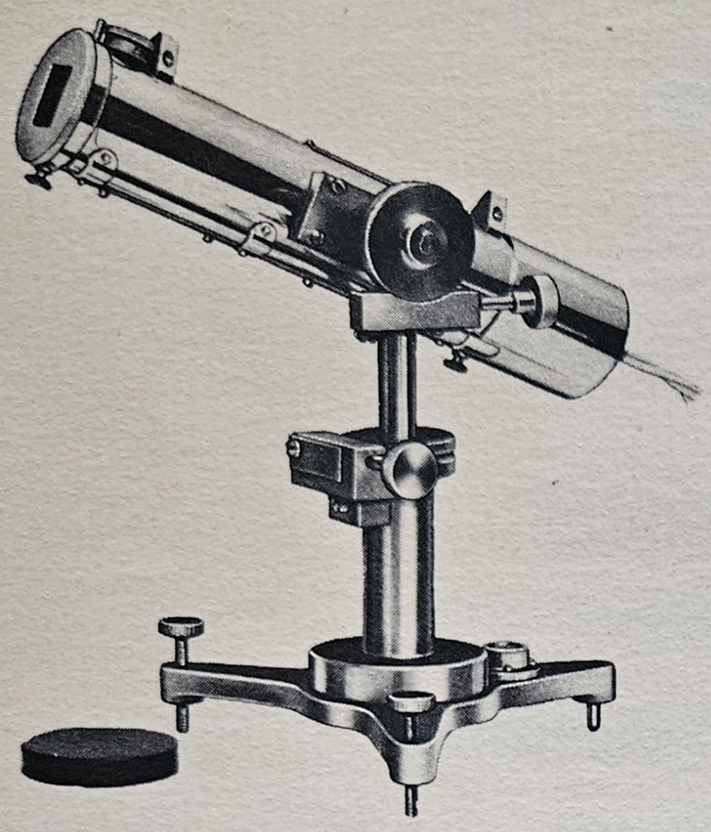


EPPLEY ÅNGSTRÖM PYRHELIOMETER

FOR THE ACCURATE MEASUREMENT OF DIRECT SOLAR RADIATION

Model ANG The electrical compensation pyrheliometer introduced by K. Ångström is one of the best-known and most reliable instruments for measuring the intensity of the sun's radiation. One of the principal uses of the Ångström pyrheliometer is as a primary working standard for the calibration of secondary pyrheliometers and pyranometers.

The Eppley model is a special development introduced in collaboration with Dr. Anders Ångström. The principal improvements over the earlier European models are as follows:

(a) **Tube length is increased to a maximum commensurate with obtaining the smallest practical aperture angles (effective aperture 5.0) and minimizing the effect of air currents within the system;**

(b) **Element is of permanent soldered construction and the leads to readout instrumentation (see below) are continuous;**

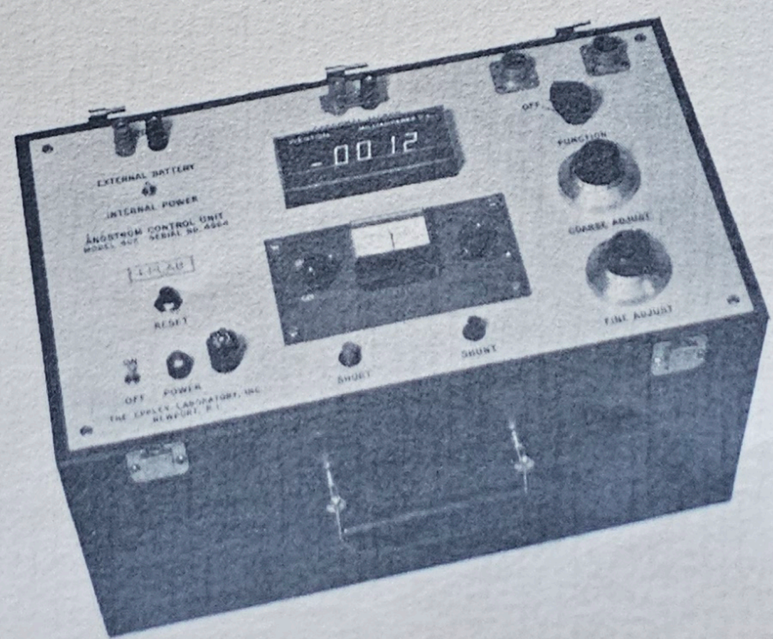
(c) **Conical shield behind the manganin strip receivers minimizes reflection and emission effects;**

(d) **Strips and shield are coated with Parsons' optical black lacquer;**

These instruments are calibrated by comparison directly against the Eppley group of primary pyrheliometric standards. The latter are periodically compared, on an international basis, to ensure the most accurate reproduction and maintainence of the International Pyrheliometric Scale. Individual pyrheliometer calibration (absolute) accuracy is better than ±0.5 per cent.

Model 402 If employed with the associated Eppley control unit, repeatability of ± 0.1 per cent, with steady sky conditions, is readily obtained in the pyrheliometer indications. This control unit comprises a 4½ digit bipolar digital panel meter with a precision shunt resistor of 0.1 ohm (accuracy 0.01 per cent) an electronic null detector and associated circuitry to permit near simultaneous operation of two pyrheliometers.

Ångström Pyrheliometer Model ANG
Control Unit with Digital Meter Model 402



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THE EPPLEY-ÅNGSTRÖM COMPENSATION PYRHELIOMETER AND ASSOCIATED D.C. ELECTRICAL INSTRUMENTATION

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THE EPPLEY-ÅNGSTRÖM COMPENSATION PYRHELIOMETER AND ASSOCIATED D.C. ELECTRICAL INSTRUMENTATION

1. Description of the pyrheliometer

The electrical conpensation pyrheliometer introduced by K. Ångström is one of the best known instruments for measuring the intensity of solar radiation and one of the most reliable. Although it is capable of being used absolutely, it is practically always employed as a high-precision relative instrument. Its principal use is as a primary working standard for the calibration of secondary pyrheliometers. Figure 1 shows the instrument.

This Eppley model of the Ångström pyrheliometer is a special development introduced in collaboration with Dr. Anders Ångström, and consists of a cyclindrical metal tube, 9.0 inches in length (including the circuit compartment), so diaphragmed inside that the rectangular aperture of each of the two radiation receivers has plane angles of 4.2° and 10.6° (mean 7.4°). If allowance is made for the effect of diffuse sky energy irradiating both strips (see below) differently, there is a partial compensation effect reducing

Fig. 1 Eppley Ångström electrical compensation pyrheliometer

the mean acceptance angle to an effective one of 5.0°. The tube is equipped with sights and is readily aligned in the solar beam by means of the azimuth and elevation adjustments provided. Both of these adjustments may be easily disengaged to permit rapid alignment when required.

The radiation sensitive element is located at the rear of the main tube. By loosening the clamping screw on the bottom of the tube and removing the circuit compartment cover. the element is accessible for inspection and may be removed from the tube by unscrewing the flat head screw located on the rear side of the tube and unsoldering the color coded wires from the rear terminals. When removing or replacing the element, care should be taken to avoid damaging the receiver strips. Essentially, the sensing element comprises two very thin almost identical manganin strips (20.0 x 2.0 x 0.02 mm in dimensions), mounted parallel side by side, the upper surfaces being blackened with Parsons' black optical lacquer (sprayed). These strips are denoted S_L and S_R in Fig. 2 (electrical circuit diagram). On the under surfaces of the strips, two copper-constantan thermocouples (T_L and T_R) are attached in series opposition and in good thermal contact with, but electrically insulated from, the strips. These

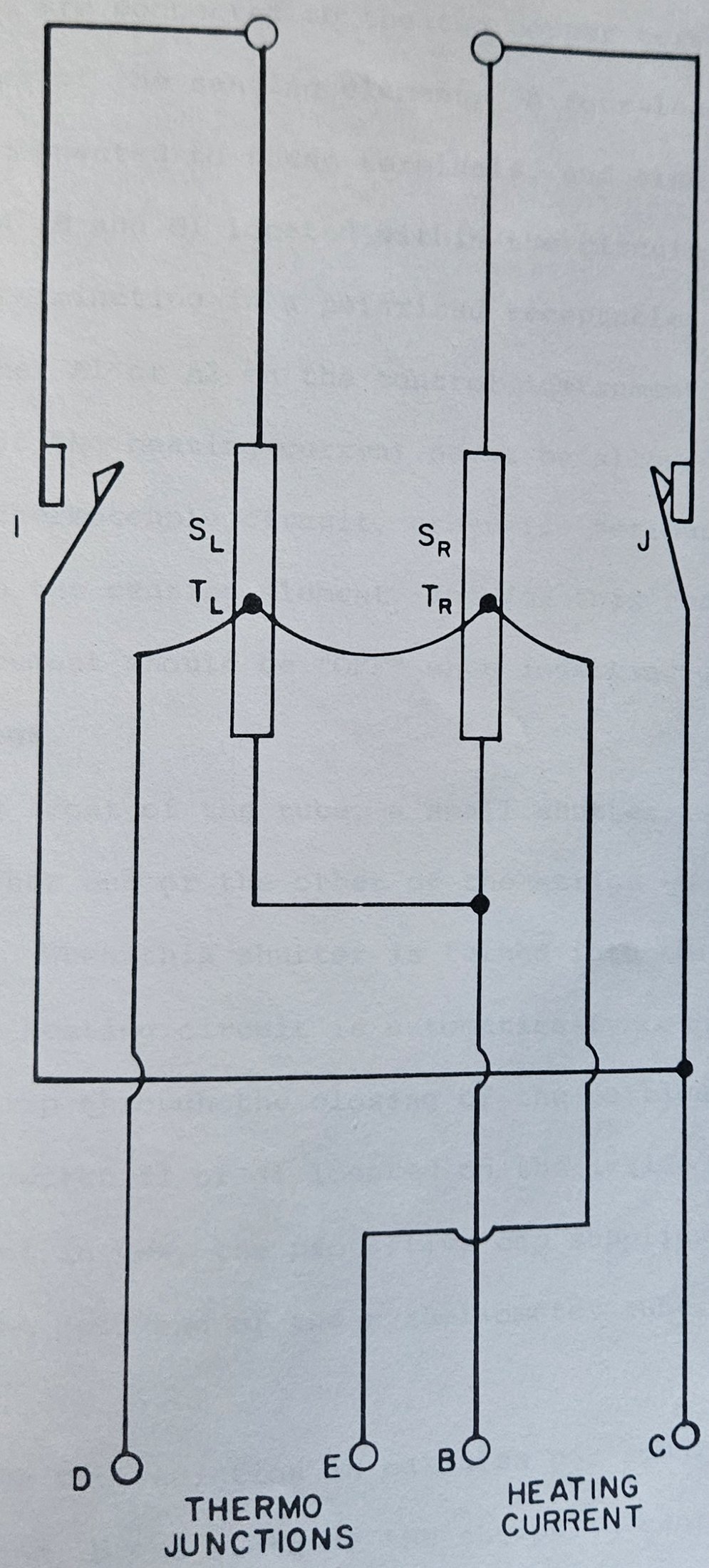

Fig. 2. Electrical circuit diagram of Eppley-Ångström pyrheliometer (when S_R strip is shaded)

thermocouples are connected to the two copper terminals (D and E) on the base of the sensing element. A four-lead cable is permanently connected to these terminals, and also to the current posts (B and C) located within the circuit compartment. This cable, terminating in a polarized receptacle, should be mated to either A1 or A2 on the control instrument. It is essential that the heating current never be allowed to pass through the thermocouple circuit, otherwise serious damage will occur to the sensing element, and for this reason, the control instrument should be "OFF" when inserting or removing the cable plugs.

At the front of the tube, a small shutter is provided to enable either one or the other of the strips to be screened from the sun. When this shutter is turned into the desired position, the heating circuit is automatically connected to the shaded strip through the closing of the particular gold contact microswitch (I or J) located on the inside of the tube.

When not in use, the protective cap supplied should be placed over the open end of the pyrheliometer tube.

2. Theory

Let I be the radiation in calories per square centimeter per second, b the width of the strips in centimeters,

a the absorption coefficient of their blackened surfaces (usually taken as 0.985 for Parsons' black), r the resistance in ohms per centimeter of the strips, and i the electrical compensation current in amperes. The electrical heat equivalent (J) is 1 cal sec^{-1} = 4.187 watts. We then have

$$baI = \frac{ri^2}{4.187} \tag{1}$$

from which

$$I = \frac{ri^2}{4.187ba} \text{ cal cm}^{-2} \text{ sec}^{-1} \tag{2}$$

or

$$I = \frac{60ri^2}{4.187ba} \text{ cal cm}^{-2} \text{ min}^{-1}. \tag{3}$$

In order to measure the radiation we have to determine b, a and r, a determination which has only to be made once. As the radiation intensity is generally expressed in cal cm^{-2} min^{-1}, we may put

$$\frac{60r}{4.187ba} = k \tag{4}$$

where k is the "constant" of the pyrheliometer. From a knowledge of the value of this constant and through a measurement of the compensation current, we may obtain the required radiation intensity from the equation

$$I = ki^2. \tag{5}$$

As the strips are exposed in practically the same manner to the air and as they have the same temperature, correc-

tions for cooling and convection are thus eliminated.

It is customary to determine the constant k by a relative comparison with a primary standard pyrheliometer.

3. Description of auxiliary instrumentation

This readout system consists of a 4 1/2 digit bipolar digital panel meter (accuracy ±0.05% of reading or ±1 digit), a precision 0.1 ohm, 0.01% shunt resistor, an electronic null galvanometer and associated potentiometers and switches to permit convenient operation of the system. The Eppley control instrument will permit the sequential operation of two pyrheliometers. The entire assembly is contained in a single unit, operating from 115V, 50-60 Hz power along with two 6.75V internal mercury batteries. Figure 3 is a schematic of the unit. The battery switch marked EXTERNAL BATTERY and INTERNAL POWER permits the use of an external source (6V D.C.), if desired. Such a source should be connected to the terminals marked 6V D.C., red denoting positive polarity.

4. Provision for alternate method of precision current measurement

For normal use, the internal digital meter provides sufficient accuracy for most measurements. However, should the user desire to employ an alternate method of current measurement, the copper shunt may be removed from the EXTERNAL

METER binding posts and an appropriate current measuring device placed across the terminals. The external device will essentially be in series with the internal digital meter. Therefore both devices can be read simultaneously. Control instrument functions will remain unchanged in their use. When an external measuring device is not used, the solid copper shunt must be replaced, and the binding posts firmly tightened before use.

5. Operation of the equipment

To insure proper operation and accurate results, the following operating procedure should be adhered to.

(1) Adjust coarse and fine potentiometers to their zero setting.

(2) INTERNAL - EXTERNAL power switched to INTERNAL position for 115V, 50-60 Hz operation and to EXTERNAL position for auxiliary 6V D.C. supply. If an external 6V D.C. power source is to be used, 115V, 50-60 Hz would still be required to power the digital meter. In this situation, it would be recommended to employ the EXTERNAL METER connections with an appropriate portable readout to make the control unit completely self contained and free of mains power.

(3) Place FUNCTION switch in OFF position.

(4) Turn primary power switch to ON position and allow approximately 15 minutes for warm up of the digital meter.

(5) Connect pyrheliometer to A1 input socket (pyrheliometer switch should be in M position).

(6) Turn null detector on and then turn SENSITIVITY knob to its full-clockwise position. This will provide adequate sensitivity for normal pyrheliometric calibration work.

(7) Turn FUNCTION switch to A1 position.

(8) The RESET button controls a 1A circuit breaker which is employed as an over current protection for the pyrheliometer heater strips. If the circuit breaker is actuated, simply turn both COARSE and FINE potentiometers to zero and push RESET button in.

This type of control system has been exposed to direct sunlight for a period of 3 to 4 hours during the test program, and it was found that stability held to within the calibration accuracy of the system.

The conventional method of observing is first to assure that the pyrheliometer is accurately aligned on the sun.

Then establish the zero position on the galvanometer scale by setting the pyrheliometer shutter in the neutral position (indicated M on the selector knob), and leaving the cap in place on the pyrheliometer tube. Then zero the null detector with the ZERO knob on the control unit. After zeroing the null detector, remove the cap and proceed with the measurement. The zero needs to be ascertained only once for each series of readings. One strip is then exposed alone (knob indication R or L) and the other heated usually by a current of the order of 0.4 amp) until the galvanometer pointer returns to the predetermined zero. Then, the other strip is exposed and the operation repeated with the roles of the two strips reversed. The first strip is again exposed and the reading quickly repeated; the radiation intensity can then be derived, as explained above, from the mean current compensation value. For the standardization of other radiometers, however, it is preferable to continue the series of readings over a period of 15-20 minutes when a set of at least 10 readings (i.e. 5 with each strip exposed to the sun) can be obtained: under conditions of steady radiation flux, the precision of such a mean determination is, generally, of the order of 0.5 per cent or better.

The alignment of the pyrheliometer, with respect to the solar beam, should be checked quickly before each reading is

made. When readings are completed, the null detector ON-OFF switch should be returned to the OFF position to conserve the batteries in the electronic galvanometer.

Tests have shown that the absolute current measuring accuracy of this new digital control system is 0.1% which is the same as was obtained with the former system, utilizing a potentiometric controlled milliammeter. The major advantage of the new system is the ease of operation and interpretation of current from a digital meter.

October 1976

TV/jc

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Att: Hr. civ.ing. Carsten Nielsen

dato/date 6 Marts 1978

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pos. nr/no	antal quant.		type type	pris pr. enhed price per unit	beløb amount
1	1	Precision Infrared Radiometer	PIR		
2	1	Solar Tracker (for 3 Pyrhel.)	ST-3		
3	1	Precision Spectral Pyranometer incl. WG-7 Hemispheres	PSP		
4	1	Angstrom Pyrheliometer	ANG		
5	1	Control Unit w. Digital Meter	402		

Med venlig hilsen
P A R A T R O N A/S

Torben Voldum

Modtaget: _____