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A SPHERICAL RADIATION METER

(MET EEN SAMENVATTING)

by

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§ 1. INTRODUCTION

Various types of ecological and horticultural work require unambiguous measurements of daylight in nature and under greenhouse conditions, eventually combined with artificial illumination. For this purpose barrier layer cells have been widely used. The reason for this is that they allow a relatively easy handling, and yield a high output of electric current so that a simple measuring device is sufficient. The fact that they are sensitive only in a restricted spectral region has not been taken too seriously yet; in connection with suitable calibrations they may be considered to give a fair estimate of the biologically active part of a given radiation.

The types of radiation meters used have been widely divergent, but they have in common that their receiving surface is flat (*cf., e. g.*, [1, 2, 3, 4, 5, 6, 7]). According to LAMBERT's cosine law this results in a preference in recording radiation incident in a direction normal to this surface. The present authors felt that the last mentioned circumstance is liable to yield data of an arbitrary nature. Moreover, they are of the opinion that it would be preferable if a value could be obtained representing in an unambiguous way the total influx of light into a certain space in which a plant grows, *e.g.*, a greenhouse, a certain location in a garden, an experimental room, or a plant community. Preferably, such a value should be obtained by one single measurement, which should be reproducible under the same external conditions. It seemed logical, therefore, in the first instance, to exclude any influence of the position of the photosensitive surface in relation to the direction of the influx of light to be measured. In other words, one would aim at the construction of a radiation meter which would not show a preferential sensitivity in relation to the direction of the influx. It is clear that a spherical sensitive surface would fulfil this requirement since it absorbs the light energy independent of the direction of the incoming flux of light. In practice it is difficult to use a real spherical receiving surface, since the instrument requires a handle and, moreover, the common barrier layer cells are flat. So the problem to be solved was to construct a receiving surface, which, in combination with flat cells, would absorb the light in the same way as a light-sensitive sphere.

The construction of such an instrument is described in section 2, a brief discussion of its application for the purposes mentioned above, is attempted in section 3; some examples of measurement are given in section 4.

§ 2. THE SPHERICAL RADIATION METER AND THE TYPE OF INFORMATION IT YIELDS

The apparatus (fig. 1) is built up of two circular selenium barrier layer cells, facing opposite directions. At about 9 mm in front of each cell an iris diaphragm is mounted; just below this diaphragm is a slightly convex piece of opaline glass. Bij variation of the opening of the diaphragms the amount of light energy reaching the barrier layer cells can be regulated. The two opposite sides of the system each are mounted with a somewhat more than halfspherical cover of opaline glass, inside this cover around the diaphragm is a small metal collar. The cells, the diaphragms, and the fitting for the hemispherical glass covers are mounted in a heavy metal ring connected to a hollow haft in which the wires from the photocells run. The dimensions of the apparatus are: diameter of the „hemispherical" covers 3.4 cm, height 2.6 cm, distance between the tips of the covers 8.2 cm, diameter of the metal ring 4.4 cm, height 2.9 cm (including the diaphragms and their mounting). Each diaphragm can be operated from outside by a small pin, moving simultaneously a loose metal ring so that no light enters through the slit in which the pin runs. In our present construction the pin snaps into holes at certain distances, fixing the diaphragm in a definite position. The place of these holes has been empirically chosen so that for the corresponding holes at each side the photoelectric current is independent of the position of the apparatus in the illuminated space. In order to achieve this, the following condition has to be fulfilled. Each separate half of the apparatus, when illuminated normal to the surface of the cell in a parallel beam of light (A, in fig. 1) should yield twice the current obtained in a unilateral exposition to the same illumination (B, in fig. 1). This may be achieved by a suitable choice of the height h of the fairly hemispherical covers in relation to their diameter. In connection with a micro-amp. meter of fairly low resistance it is possible to measure light intensities from very low values up to full sunshine, simply by variation of the diaphragms.

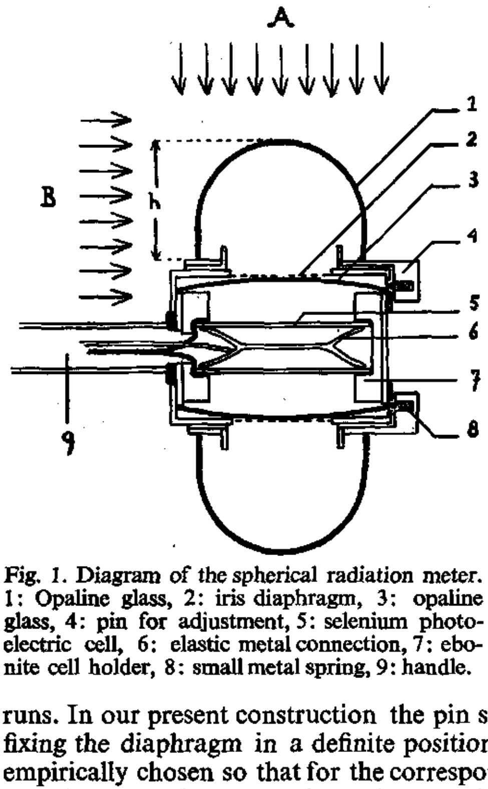

Fig. 1. Diagram of the spherical radiation meter. 1: Opaline glass, 2: iris diaphragm, 3: opaline glass, 4: pin for adjustment, 5: selenium photoelectric cell, 6: elastic metal connection, 7: ebonite cell holder, 8: small metal spring, 9: handle.

There are indications that the danger of damaging the photocells by high light intensities is considerably reduced as soon as the resistance in the external circuit is low, provided the temperature of the photosensitive surface does not rise too much. A low external resistance can be realized, *e.g.*, by shunting the μ-ammeter. Along this line the mountings of the spherical radiation meter probably can be simplified by omission of the diaphragms.

It was observed, moreover, that in order to obtain reproducible measurements the mounting of the photocells preferably should be airtight.

These viewpoints have not yet been materialized in our present construction; it does not appear necessary to lay special stress on them in this discussion which only is concerned with the principle of the spherical measurement.

With the construction outlined it is easy to realize that the position of the meter in the illuminated space does not affect the readings more than 5 %. On the contrary, a flat, unilateral radiation meter has a very high sensitivity towards the direction of the light. This may easily be noticed under natural conditions, when the cell either faces the sun or an indirectly illuminated part of the sky. Slight variations in the position of the cell and in the mounting as well as in the shape of the cover glass are liable to introduce uncertainties into the measurement. The spherical meter may contribute to arrive at a more definite estimation of the influx of radiation into a certain space.

It should, however, be realized that the type of information obtained differs from the one obtained in measurements with the flat meter. The information given by the spherical meter is concerned with the influx of radiation into a sphere. This brings about that we cannot deal any more with illumination of a flat surface and thus cannot use any measuring unit in which this quality is included.

So *e.g.*, we cannot use the lux, being one lumen *per square meter*. This unit, moreover, for plant irradiation purposes has the disadvantage of being based upon the human luminosity curve which property, however, does not concern us here (*cf. e.g.* [8]).

Using the spherical radiation meter, we propose to take as a unit the influx expressed in μ-watts incident into a sphere with a cross section of 1 cm^2, so with a radius of $\sqrt{1/\pi}$ cm.

The apparatus can be calibrated in a homogeneous, parallel beam of light of known intensity with a larger diameter than the light receiving parts. Owing to the differential sensitivity of the barrier layer cells for various wave lengths, each source of radiation requires a separate calibration of the meter in μ-watts/sphere of 1 cm^2 cross-section.

§ 3. DISCUSSION OF THE INFORMATION OBTAINED IN RELATION TO PHOTOBIOLOGICAL REQUIREMENTS

It has been presented as an advantage of the device described that it estimates the influx irrespective of its direction. Various uncertainties introduced by the extreme sensitivity to direction of most of the classical devices are thus avoided, and a much more unambiguous estimation of the „light climate" of a certain spot is obtained.

We will now ask whether the information will fit biological requirements better than that obtained with a flat meter. Little is known so far about the actual reaction of plants in relation to the different types of measurement under discussion. One would like to suggest that for the estimation of the light climate in a vegetation which has an appreciable vertical extension, the type of information given by the spherical meter probably answers more closely to what the plant actually receives than the type of information resulting from a measurement with a flat meter. This case will obtain, *e.g.*, especially when single plants are considered which grow in a greenhouse or inside a more or less dense vegetation, and thus receive light from all sides. A similar situation is found when the reaction of a plant upon various types of artificial illumination is considered. A plant will show a reaction upon one lamp hanging straight over it which differs from that upon several lamps in the surroundings also if a flat meter would measure the same illumination in a horizontal position in both cases. It can be expected that under the mentioned conditions the spherical meter will give a more suitable characterization of the irradiation than the flat one, because the flat meter underestimates the irradiation of the surrounding lamps.

If the growth of single plants under natural illumination (*e.g.*, in the open air or in a greenhouse) is to be compared with that under artificial illumination, it is important to measure both the natural and the artificial light with the spherical meter. The flat meter underestimates the illumination of the whole sky much more than the illumination of a lamp hanging straight above the meter. It is evident that there is no general conversion factor for the relation between measurements with the flat meter and the spherical one.

If, on the other hand, the light of a special direction is preferably absorbed by the plant material or any vertical component of the vegetation is minor to the horizontal extension, a measurement with the flat meter may meet the situation more adequately. This may hold for a film of algae, a layer of lichens or mosses, a field of grass, a field of uniform plants, a large and uniform wood. However, none of these vegetations – and increasingly less in the order mentioned – is exactly flat, and it requires detailed investigations to see in how far the individual plants react according to estimations of the light by the spherical meter. One would expect that the field as a whole behaves in accordance with light measurements obtained with the flat meter whereas individual plants receive the light more or less as indicated by the spherical meter.

This holds both in an open and a closed vegetation. Of course in a closed vegetation (*e.g.*, of uniform plants) the individual plants receive the light mainly from above. As the plant width increases, the condition of each individual plant will deviate more from a situation as recorded by a flat meter, and it will become increasingly important to estimate the influx into its space by a measurement with the spherical meter. The type of flat meter used is also of importance. We use one covered with a slightly convex opaline glass, yielding approximately a „cosine sensitivity". It was built according to a device obtained through the courtesy of the N.V. KEMA, Arnhem, and our instrument has been calibrated there.

Several investigators have drawn attention to the correction of flat light meters in order to approach the theoretical cosine sensitivity. So, *e.g.*, covers of diffusing opal perspex (9,10) and lenses, cemented to the cells (11), have been more or less succesfully applied.[1] In order to avoid misunderstanding it should be pointed out clearly that these corrections aim at yielding the theoretical response for angular incidence of light into a horizontal plane, and not the insensitivity towards angle of incidence, the purpose for which we constructed the spherical radiation meter.

Some confusion might arise, at first sight, in studying ref. 12, in which a.o. an integrating sphere is proposed for correction of deviations from cosine law (fig. 15e). This, however, is an opaque sphere, diffusing the light at its inner surface after it has entered the sphere by a flat opening parallel to the cell surface. A shield, again parallel to the mentioned planes, through

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[1] We are indebted to Dr G. A. W. RUTGERS, KEMA, Arnhem, for the supply of references on this point.

the centre of the sphere serves at protecting the cell from direct illumination. This construction, however, is essentially different from the proposal in the present paper; it aims at a correct estimation of the light incident upon the plane of the opening. The diameter of the sphere is suggested to be 4–5 inches (10–12 cm), essentially larger than the hemispheres used in our apparatus. By the time of its proposal the mentioned device does not appear to have been in operation; it was suggested as an improvement of a device by BARNARD who obtained a very good compensation of cosine-law errors by use of a circular opening in an opaque plate at a fixed distance above the cell surface (12).

The spherical meter, as can easily be seen, overestimates the influx on the horizontal surface. Whether this overestimation is operative wholly or partly also with regard to the photobiological activity of a flat vegetation, still remains to be established. It might be suggested that in a large number of cases this error would be less important than that introduced by the arbitrarity of the publication of one single figure obtained with a flat light meter. Of course, difficulties arising from the changed spectral composition of the light inside a vegetation are the same for the spherical radiation meter and for the flat one, and have to be considered separately.

In addition, it may be suggested that the spherical light meter will be advantageous in the estimation of light incidence in submerse vegetations, and also in mass cultures of algae. Unfortunately, we do not yet have data about such measurements.

§ 4. EXAMPLES OF MEASUREMENT

Some comparative measurements were made with the spherical meter and with our flat meter in the open air, in a greenhouse and inside some vegetations. The flat meter was exposed with its receiving surface directed upward, downward, and to the north, south, east and west. Alongside with this, measurements with the spherical meter were made in the same places. Some results are given in Table I. The measurements are given in μ-Watts per cm^2 for the flat meter, and in μ-watts per sphere of 1 cm^2 cross section for the spherical meter. For each measurement we reduced the numerical values of the readings obtained with the flat meter in its various positions according to the numerical value of the reading obtained with the spherical meter when the latter value was put equal to 100. In Table I the values thus obtained were put between brackets behind the values in μ-watts. The series of relative values in the various columns show very clearly that the data obtained with the flat meter differ widely, and in an irregular way so that each of them does not give an unambiguous characterization of the light climate in the space.

It would be expected that, upon addition of the relative values in the various columns of the single measurements, the sum values thus obtained will vary considerably less than those of the measurements represented in each column, since, in this way, the measurement with the spherical meter is approached. In column 11, we give the added values as such while the figures in column 12 represent $\sqrt{(4)^2 + (6)^2 + (8)^2} + \sqrt{(5)^2 + (7)^2 + (9)^2}$, in which (4), (5), *etc.* represent the relative values from column 4, 5, *etc.* It is very clear that the supposition made, holds indeed; the variation of the values in the column 11 and 12 is considerably smaller, in a relative measure, than that of the values in any of the columns 4–9 included. The values of column 12 should amount to 100. The deviations observed may have the following causes: 1) The 7 different measurements (col. 4–10) cannot be made at exactly the same moment and can hardly be made at exactly the same spot which is liable to introduce uncertainties especially inside vegetations. 2) Small short-time changes in sensitivity and

TABLE I.

Comparative measurements with the flat radiation meter and with the spherical one in various environments

	1	2	3	4	5	6	7	8	9	10	11	12
No	Date	Time of the day	Place	Exposition of the flat meter						Spherical meter	P[1])	Q[1])
				upward	downward	north	south	west	east			
	May '50											
1	11	15 h.	shadow between trees	3400 (74)	130 (3)	1050 (23)	1300 (28)	1200 (26)	1050 (23)	4600 (100)	177	118
2	12	10	shadow between trees	2950 (63)	125 (3)	920 (20)	1150 (24)	700 (15)	1050 (22)	4700 (100)	147	100
3	12	10	shadow between trees	3450 (76)	210 (5)	100 (24)	1100 (24)	680 (15)	1230 (27)	4550 (100)	171	118
4	11	15	sunshine between trees	60500 (73)	3100 (4)	1400 (17)	32000 (39)	15000 (18)	2300 (3)	83000 (100)	154	116
5	11	15	sunshine south side of hedge	72000 (72)	4100 (4)	2400 (2)	26000 (26)	53000 (53)	4100 (4)	100000 (100)	161	116
6	12	10	sunshine south side of hedge	58000 (58)	4500 (5)	2700 (3)	46500 (47)	6800 (7)	29700 (30)	100000 (100)	150	115
7	11	15	sunshine north side of hedge	59000 (59)	4100 (4)	6800 (7)	22300 (22)	43000 (43)	5500 (6)	100000 (100)	141	97
8	12	10	sunshine north side of hedge	59000 (60)	4500 (5)	7000 (7)	35000 (36)	5300 (5)	32300 (33)	98000 (100)	146	110
9	11	15	shadow north side of hedge	2430 (18)	600 (5)	7000 (53)	330 (2)	4400 (33)	2300 (17)	13300 (100)	128	83
10	12	10	shadow north side of hedge	5900 (48)	210 (2)	5700 (47)	340 (3)	3130 (26)	3080 (25)	12200 (100)	151	98
11	11	15	shadow in greenhouse	7000 (69)	1150 (11)	2500 (24)	2100 (21)	2950 (29)	2630 (26)	10200 (100)	178	112
12	12	10	shadow in greenhouse	8300 (66)	780 (6)	3400 (27)	1900 (15)	3130 (25)	3510 (28)	12600 (100)	167	108
	Aug. '50											
13	7	17	sunshine on lawn	23700 (58)	0 (0)	12700 (31)	5200 (13)	31700 (77)	4100 (10)	41000 (100)	189	118
14	8	16	in passage between Topinambour	8800 (69)	940 (7)	680 (5)	5500 (43)	4100 (32)	2700 (21)	12800 (100)	178	113
15	8	16	between Topinambour	1100 (64)	0 (0)	300 (17)	770 (45)	680 (39)	150 (9)	1720 (100)	174	123
16	8	15	under chestnut tree westside	920 (32)	230 (8)	300 (11)	490 (17)	2700 (95)	150 (5)	2850 (100)	168	121
17	8	15	under chestnut tree eastside	600 (33)	150 (8)	150 (8)	1400 (76)	150 (8)	600 (33)	1850 (100)	166	118

The measurements are given in μ-Watts per cm² for the flat meter and in μ-Watts per sphere of 1 cm² cross section for the spherical meter.

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[1]) $P = (4) + (5) + (6) + (7) + (8) + (9)$; $Q = \sqrt{(4)^2 + (6)^2 + (8)^2} + \sqrt{(5)^2 + (7)^2 + (9)^2}$ in which (4) means the value between ( ) in the 4th column, (5) means the value between ( ) in the 5th column, etc.

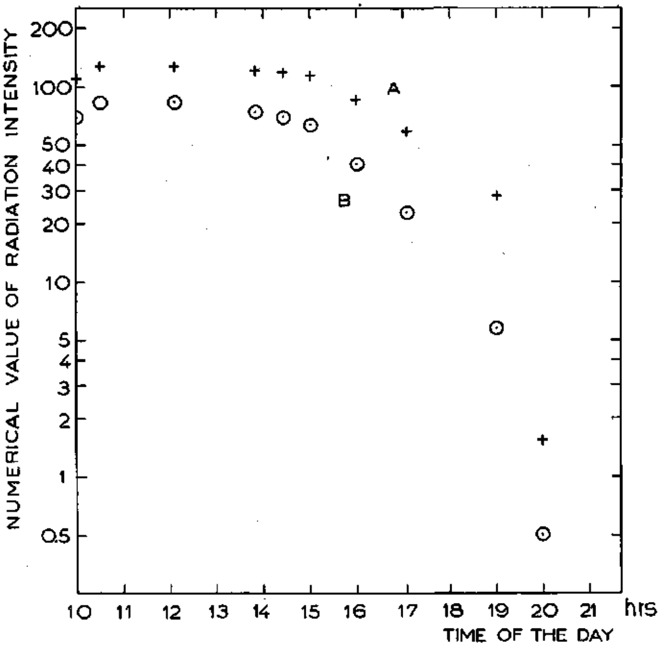

Fig. 2. Example of measurement of solar radiation.
A (+): with the spherical meter, in m-watts per sphere of 1 cm² cross section.
B (O): with the flat meter in horizontal position, in m-watts per cm².

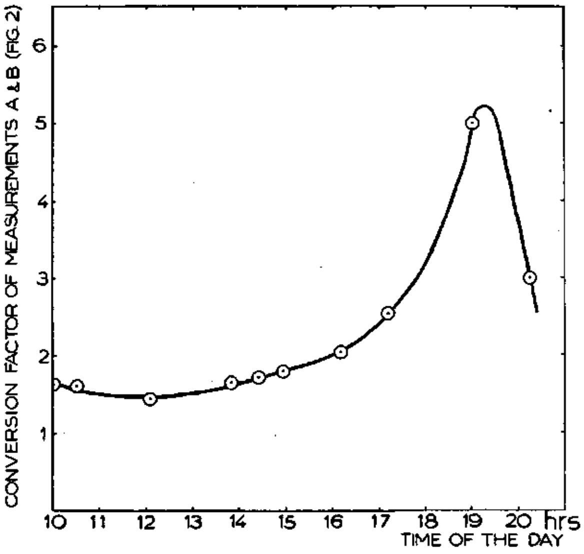

Fig. 3. Course of the conversion factor during the day, from the measurements A and B of Fig. 2.

differences in calibration between the two meters may well have been of some importance. The latter reason may be responsible for the tendency towards values somewhat above 100.

Fig. 2 shows the course of the radiation from sun and sky, 2nd June 1950, from 10 h. till 20 h., near the side of a wall in the sunshine. The measurements with the spherical meter are given in curve A, in m-watts per sphere of 1 cm^2 cross section. Curve B shows the m-watts per cm^2 arriving at the flat meter in a horizontal position. Since the intensity of the radiation is drawn in a logarithmic scale it can be seen clearly, that the ratio between the values given in curve A and B varies from 1,5 at noon to 5 at 19 h., just before the sun sets behind the trees in the surroundings. The course of this ratio during the day is given in Fig. 3. In the present measurements the variation of the conversion factor is mainly due to the variations in height of the sun during the day which leads to a concordant variation in the appreciation of the radiation intensity by the flat meter. Generally, however, any special feature of the light distribution in the space will reflect in the value of the conversion factor. It may be emphasized once more that the conversion factor only has a numerical interest, since the quality of the information is different for the two types of meters, as was expounded above.

SUMMARY

A „spherical radiation meter", composed of two flat barrier layer photocells mounted with fairly hemispherical opaline glass covers and two iris diaphragms, is described (fig. 1). This meter allows to estimate the influx of light into a certain space irrespective of the direction of the flux. The relation between measurements with this type of meter, and with the flat meter, is discussed. The unit in which the results of the measurements are to be expressed is different in both cases, since, essentially, the spherical meter is concerned with the influx into a sphere. The value of this meter for plant irradiation purposes is discussed. Its chief advantage appears to be the unambiguous estimation of the influx into a space (*e.g.*, a vegetation, a greenhouse, etc.). Plant units with an appreciable extension in the vertical direction may be expected to receive light rather like the spherical meter does, whereas units with a chiefly horizontal extension receive light more like a flat meter. Some examples of comparative measurements with a spherical meter and with a flat one are presented (Table I, fig. 2, 3) and discussed.

SAMENVATTING

Een spherische stralingsmeter, bestaande uit twee vlakke sperlaag photocellen, voorzien van ongeveer half bolvormige opaline glaasjes en twee iris diaphragma's, is beschreven (fig. 1). Met deze meter wordt de instraling van licht in een ruimte gemeten, onafhankelijk van de richting van de straling. De relatie tussen metingen met dit type meter en met vlakke meters, is besproken. De eenheid waarin de meetresultaten moeten worden uitgedrukt is verschillend voor beide gevallen, daar in wezen de spherische meter uitsluitsel geeft over de instraling van licht in een bol. De waarde van deze meter voor planten-bestralingsdoeleinden wordt besproken. Zijn voornaamste voordeel lijkt te zijn de ondubbelzinnige bepaling van de instraling van licht in een ruimte (b.v. een vegetatie, een kas, etc.). Planten of groepen van planten met een relatief grote uitbreiding in verticale richting zullen vermoedelijk licht opvangen op soortgelijke wijze als de spherische meter, terwijl vegetatieeenheden met een in hoofdzaak horizontale uitbreiding licht opvangen op soortgelijke wijze als een vlakke meter.

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