*Citation:*

Groot, H., On the Effective Temperature of the Sun, in:
KNAW, Proceedings, 22 II, 1920, Amsterdam, 1920, pp. 615-620

**Physics.** — *"On the Effective Temperature of the Sun."* (2nd Communication). By H. GROOT. (Communicated by Prof. H. W. JULIUS).

(Communicated at the meeting of September 27, 1919).

In a previous article of March 1919 it was demonstrated that the determination of the effective solar temperature by the application of PLANCK's radiation formula to the data of ABBOT, does not lead to a same temperature, independent of the considered kind of light, as estimated by A. DEFANT, but on the contrary that the value of $T$ determined in this way varies systematically as $\lambda$.

The meaning of the results so found will be examined in this article.

It is necessary beforehand to define as strictly as possible what we mean by the term "effective temperature", as the same meaning is not always attached to this expression.

The reason that we cannot simply speak of the sun's temperature is, first, that the sun has not the same temperature at all depths (thermodynamics show that for an extensive gas-mass — we must consider the sun as such — the temperature varies from layer to layer), and secondly that we cannot either indicate the temperature of a definite layer nor know the way in which the temperature depends on the distance from the centre of the sun.

We *can* however find what temperature we should have to assign to the sun, so that, if it were an absolutely black body, it would behave *in a definite respect* exactly in the same way as we observe in reality.

We may ask for example, what temperature an "absolutely black sun" must have if the position of maximum intensity in its spectrum is to be the same as in the real spectrum; or if the solar constant is to have the same value as the constant that has been determined experimentally. The first question may be answered by the aid of WIEN's law; the second question by the application of the formula of STEFAN-BOLTZMANN.

The temperature thus found is called "effective" temperature.

Since, however, the sun is not an absolutely black body, we need not be surprised that the effective temperatures of the sun, which are found in these different ways, are not equal. It is, therefore, necessary when indicating the effective temperature of the sun, to state clearly beforehand from what condition imposed on the temperature of the absolutely black body which we think as taking the sun's place, it has been determined.

In what follows the condition has been chosen that the distribution of energy in the spectrum of the black body, calculated according to the law of PLANCK, will agree as closely as possible with that in the sun's spectrum, as has been derived by ABBOT from bolograms.

Accordingly, the temperature which we should have to assign to such a "black sun", if this condition is to be fulfilled, is the effective temperature, which will be discussed in this article, and which, we have found, appears to be dependent on the chosen $\lambda$.

The relation between $T$ and $\lambda$ is once more given below in table 1.

TABLE I.

| $\lambda_1$ | $\lambda_2$ | $T$ |
|---|---|---|
| 0.4 m | 0.5 | (6400) |
| 0.5 | 0.6 | 9000 |
| 0.6 | 0.7 | 10.000 |
| 0.7 | 0.8 | 9600 |
| 0.8 | 1.0 | 8000 |
| 1.0 | 1.2 | 5500 |
| 1.2 | 1.5 | 3800 |
| 1.5 | 1.8 | (5400) |
| 1.8 | 2.0 | — |

The way in which the values of $T$ have been calculated is briefly as follows.

From PLANCK's formula:

$$f \cdot I_\lambda = \frac{7{,}211 \cdot 10^8}{\lambda^5 \left(10^{\frac{2{,}1562 \times 2890}{\lambda T}} - 1\right)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

is obtained for any value of $T$, and with any choice of the units (factor $f$), a definite curve $I_\lambda = \varphi(\lambda)$, which represents the distribution of intensity in the spectrum of the absolutely black body.

Conversely $f$ and $T$ can be found when $I_\lambda$ is known for two values of $\lambda$.

The observed energy spectrum of the sun does not agree, however, with that of the black body, so that if we do apply PLANCK's formula for the calculation of $f$ and $T$ from the experimentally determined $I_\lambda$, the value of $T$ will depend on the place where we choose $I_\lambda$.

In table I the 1[st] and 2[nd] columns give the values of $\lambda$ from whose corresponding $I_\lambda$ the $T$ of the third column has been calculated. It seems to me that the application of PLANCK's formula to the experimentally determined energy spectrum of the sun's radiation has not much sense, unless we could really consider this as almost agreeing with the spectrum of an absolutely black body — the criterion of which would consist in finding the same $T$ from arbitrarily chosen combinations of $I_\lambda$.

I wrote already in my previous article:

"The assumption that all kinds of light come to us from one photospheric surface, in other words that light of various wave-lengths should come from the same depth of the sun, appears more and more untenable.....

If, however, in reality light of different wave-lengths originates from different parts of the sun, it becomes very questionable whether we shall be allowed to apply PLANCK's formula, as we saw DEFANT do".

Instead of imagining one photospheric surface, as did DEFANT, we might try, what the supposition leads to that the sun is built up of a number of concentric "partial photospheres", each of them radiating as an absolutely black body, so that the total observed radiation is considered as built up of a number of partial radiations originating from different layers. In my previous article I pronounced the expectation that on this supposition, considering the fact that it seems to follow from the work of SPIJKERBOER and VAN CITTERT that in general we must look deeper into the sun for red light than for violet, the effective temperature would increase with the wave-length.

This expectation has proved erroneous. And on closer consideration it was, indeed, unfounded. The effective temperature of a layer can, in fact, only be derived from the distribution of energy in its spectrum — and the said result of SPIJKERBOER and VAN CITTERT teaches us nothing about this. It is, however, worth while to examine the hypothesis of the "partial photospheres", because this may, perhaps, make it clear how the effective temperatures determined according to PLANCK, are nothing but calculated quantities to which a physical sense can hardly be attached, and which certainly do not give an insight into the actual temperatures of the sun

If we possessed a means to consider exclusively light that reaches us from this photospheric scale, then, according to our supposition, every photosphere would possess its own energy spectrum, which would vary from photosphere to photosphere, and this for two reasons

1. The real temperature in the inner layers is different from that in the outer.

2. The radiation, reaching us from the inner layers has undergone a greater loss through absorption and scattering (and, so far as the latter cause is concerned, to a much greater degree for the shorter wave-lengths than for the longer), in consequence of which, even if the real temperature of the different layers were the same everywhere, the observed energy spectrum would still be different in the different layers.

What we do observe, however, is not the spectrum modified by scattering etc. of every layer separately, but the combination of all these spectra together.

To try and derive an effective temperature from this spectrum, which is far from "black" seems to be absolutely unpermissible; because the fundamental condition itself, that the energy spectrum used would in its main points resemble that of an absolutely black body, has not been fulfilled.

*If*, however, we do apply this procedure, it is not surprising that the found values of $T$ appear in a high degree, to be dependent on $\lambda$.

The latter may be shown more clearly by the following method. Let us imagine an energy spectrum formed by the superposition of only two spectra, originating from two really "black" bodies, which contribute about an equal amount to the total radiation, but whose temperatures differ greatly. Such a case is represented in figure 1.

Let the curve 1 correspond to the absolute temperature 3000°, the curve II to 1500°. Then the maxima lie respectively at $\lambda = 1\ \mu$ and $\lambda = 2\ \mu$. Summation of these yields the curve III, but by halving the ordinates curve IV has been derived from this, whose area is again equal to the area of each of the component curves, i.e. we reduce all the cases to *equal total radiation.*

It is now easy to see that when we derive the temperature from the shape of a small part (*ab* or *cd*) of the summation curve, at the same time considering this part as belonging to an energy curve of a black body, for *small* values of $\lambda$ a temperature would

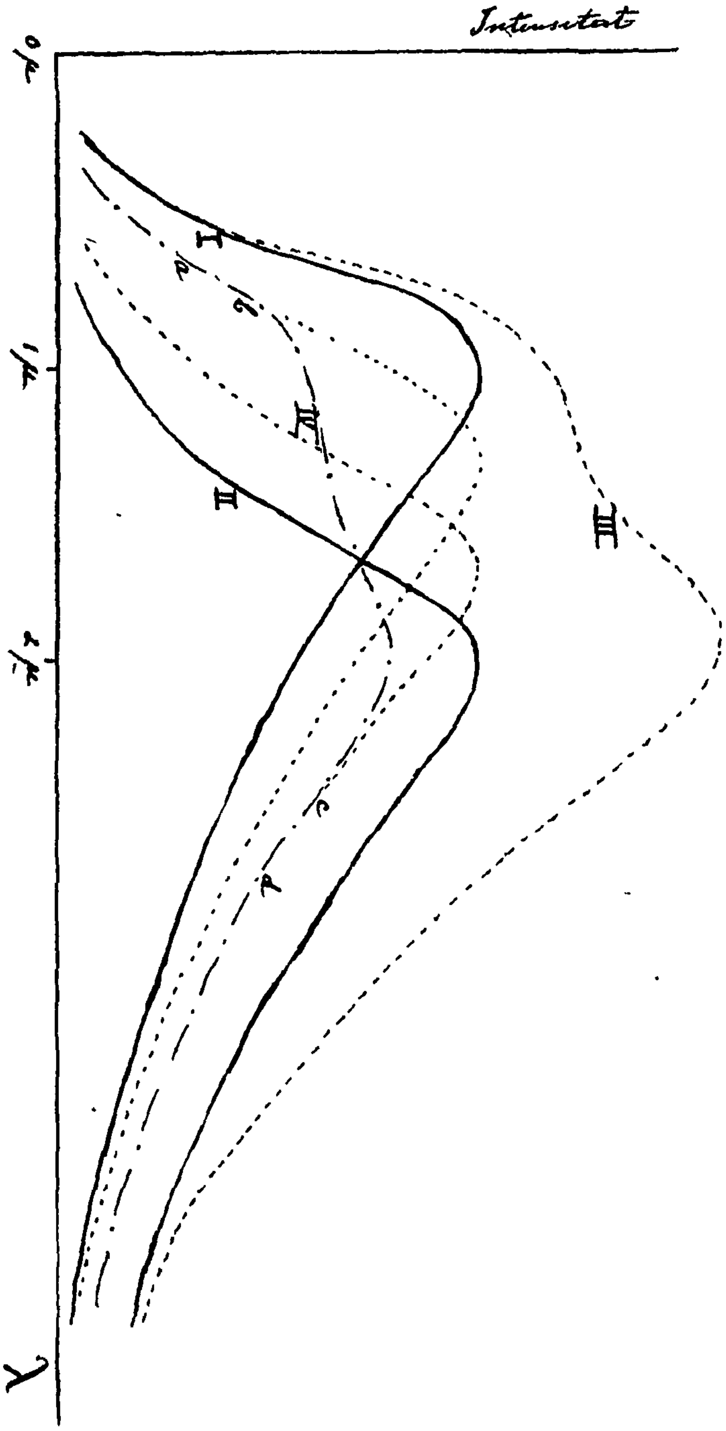


Fig. 1.

be found lying between 3000° and 1500°, but nearer 3000°; whereas on the other hand, for large values of $\lambda$, an intermediate temperature would be found lying more to the side of 1500°.

(The two imagined intermediate curves of radiation of black bodies have been drawn dotted, so that each of them again embraces the same area).

The temperatures calculated for different values of $\lambda$ would have been still more divergent, if I had not been the original energy curve of a black body, but had presented a much greater slope towards the violet side on account of molecular scattering

Though for the sun everything is of course much more complicated than in these examples, the conclusion remains valid that $T$ must be found dependent on $\lambda$, if our supposition should be justified that every layer radiates as a black body. But though this hypothesis accounts to a certain extent for the variation of the found values of $T$ with $\lambda$, and is preferable in so far to the undoubtedly untenable supposition of DEFANT and others, that the radiation of the sun would issue from one single absolutely black photospheric surface — yet the hypothesis of the "partial photospheres" cannot be considered either as satisfactory.

Until by other means, some insight has been obtained into the power of emission of the successive layers of the sun's mass, and the degree in which they scatter and absorb the different kinds of light, hardly anything can be derived from the distribution of energy in the solar spectrum concerning temperatures on the sun.

The conception "effective temperature of the sun" has little value. This temperature varies in fact greatly according to the way in which it is defined, and none of the definitions warrant in any way, that by means of them an approximation is found of temperatures that actually prevail on the sun.