# PLATES SENSITIZED TO RECEIVE INFRARED RADIATION

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The examinations of the emission of infrared radiation usually start out from the laws of radiation of a black body, with the Planck formula as a critical starting point. The Planck formula expresses the relation between density with wave length $\lambda$ and the absolute temperature $T$ [1]. A graphic

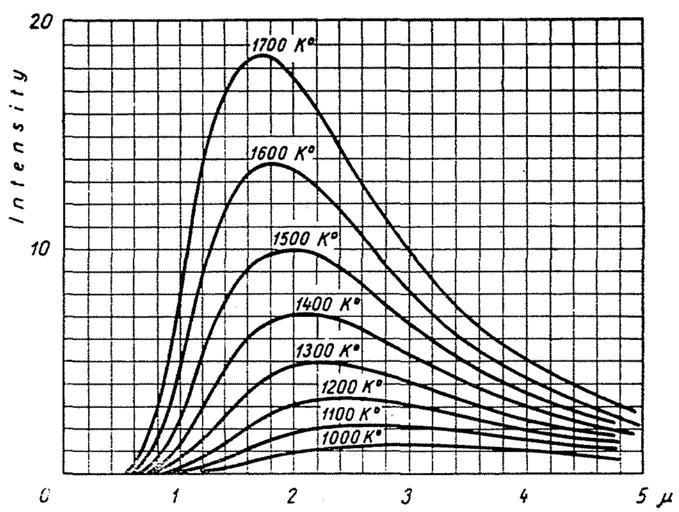


*Fig. 1*

representation of this law reveals the displacement of the radiation peaks towards the smaller, shorter wave lengths, as temperatures are being raised (Fig. 1).

If, now, the Planck formula

$$W(\lambda, T) = \frac{8\pi hc}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

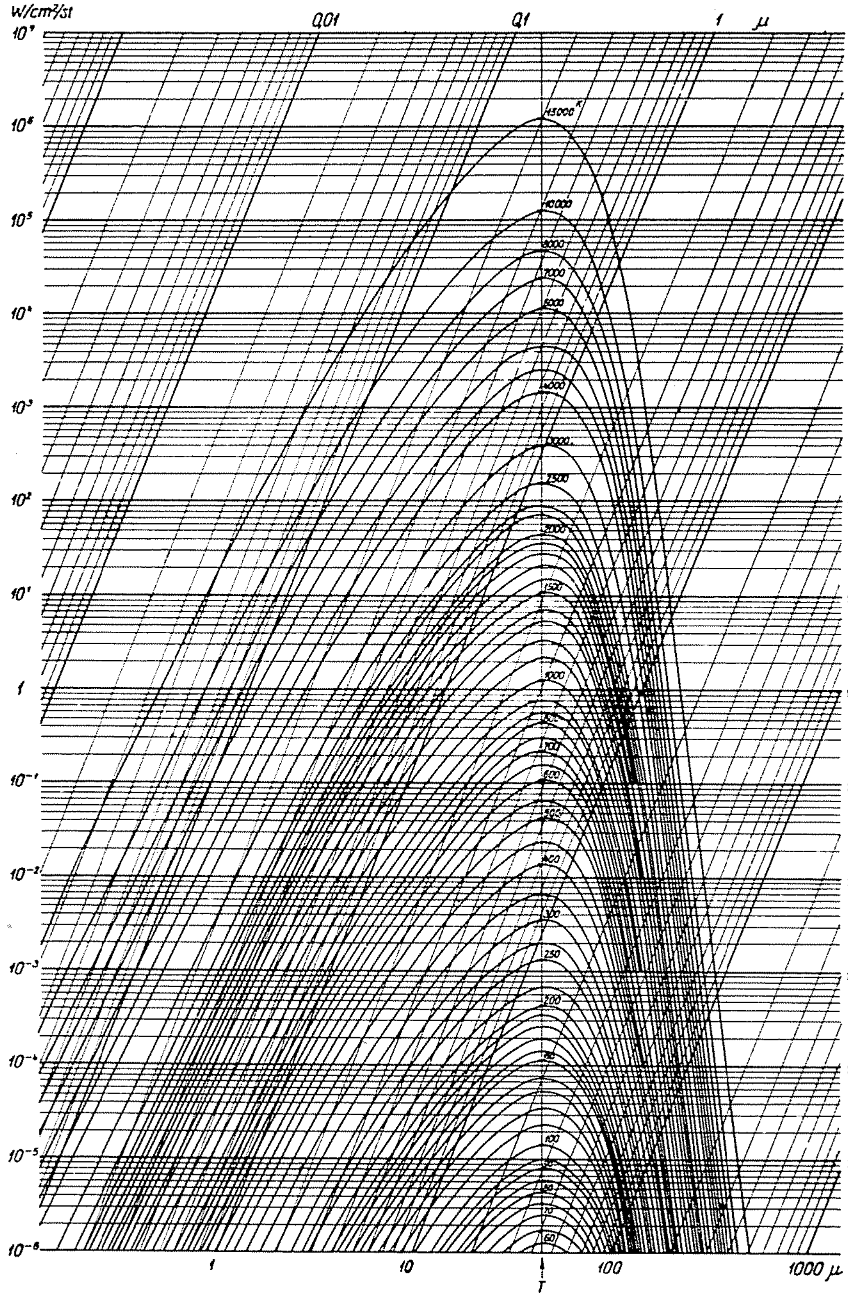


Fig. 2

where $h$ stands for Planck's constant, $k$ for Boltzmann's constant and $c$ for the speed of light, is represented as a relation between the wave lengths and the absolute temperatures, one obtains the relative energy distribution of the radiant body. In order to give a good survey of the spectral distribution of radiation energy, we have plotted the wave length against the spectral intensity on a logarithmic chart of oblique angle. Such a representation shows that all curves may be derived from each other by means of a translation along the straight line joining the radiation peaks. Fig. 2 indicates that the laws

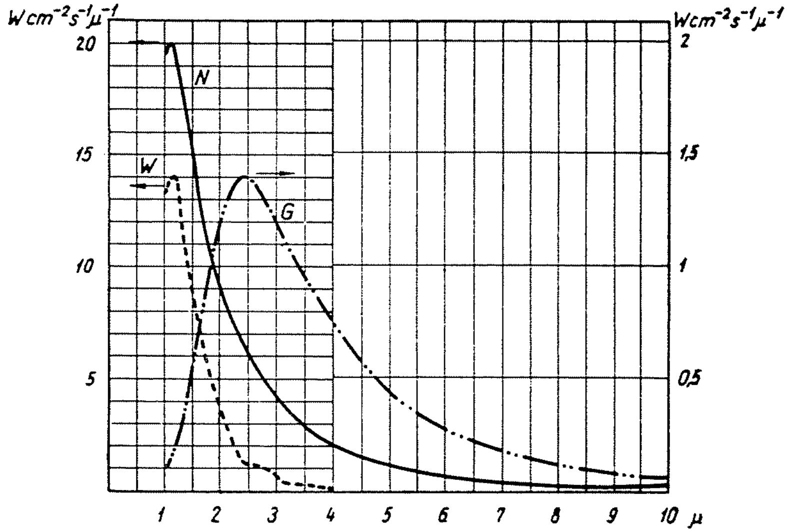


*Fig. 3*

of radiation can be still more distinctly observed in this way. It will be noted that when the curve $W(\lambda, T)$ of an emitting body, with respect to a certain temperature may be derived by affinity from the curve of a black body — where the direction of the affinity is identical with the axis of the ordinates — then the body in question is termed a grey body. That is, the temperature of the grey body is the temperature to which a black body must be brought in order to make the two curves congruent. A great many bodies, such as wolfram-filament lamps, globar light sources, etc. behave like grey bodies.

When the bodies emitting infrared radiation are considered, it has to be remarked that, in addition to grey bodies, there are a great many light sources which do not follow the laws for black bodies. The most important of such bodies of selective emission are the Nerst filament, the Auer-burner, the hydrogen gas arc, the zirconium vapour arc, etc. Fig. 3 represents the spectral energy distribution of a common wolfram filament lamp (10 volts, 15 amperes, 150 watts) of a globar light source (28 volts, 3.4 amperes, 95 watts) and of a Nerst filament (100 volts, 0.85 amperes, 85 watts) for the interval between 1 $\mu$ to 10 $\mu$.

It is not our intention in this paper to treat in detail the different infrared radiators, as their description can be found in any manual, but the energy magnitudes to be reckoned with, in sensing infrared radiations, had to be pointed out [2]. As an anticipation, let it be mentioned here that while a near infrared radiation is due to photons having still a relatively rather high radiation energy, distant infrared radiation involves photons of relatively very low radiation energy. For this reason, it is increasingly difficult to sense rays as we depart from the limit of the visible spectrum. Hence, prior to discussing the reception of the radiation on sensitized plates, the sensitivity and selectivity of the receiving systems for infrared radiation has to be discussed.

The sensing systems for infrared radiation can be classified into two groups : selective and non-selective receivers.

The first group comprises non-selective receivers, since in these systems the resolving of radiation energy on a given surface is not selective, so that they are sensitive to all sorts of electromagnetic radiations. Fine sensing of infrared radiation is not possible with such receivers, as they will record other incoming radiations together with the infrared radiation.

The receivers classified in the second group are characterized by the dependence of their sensitivity on the wave length. By using such receiver systems, the rays to be tested can be resolved in the various ranges of infrared radiation. The present paper will mainly deal with the sensitive receiver plates or films employed in this type of selective receivers, particularly emphasizing the methods for sensitizing such plates or films to infrared radiation in general, or to certain ranges of infrared radiation. Certain processes will be described, by which the sensitivity of such plates or films may be extended to supersensitivity.

It is not the aim of the present paper to treat in detail the procedures taking place in solids on the action of infrared radiation. However, before investigating the sensitive plates receiving infrared radiation, it is necessary to point out some changes occurring in solids upon the introduction of certain substances. This is a highly important phenomenon which is to be taken into account in the construction of receivers for infrared radiation, since the receiving plates often have to be sensitive to infrared radiation of very low radiation energy.

The quantum theory discloses that the possible energy levels are determined by the solutions of the Schrödinger equation. The number of these solutions is known to be finite, and the solutions are divided into groups. Let us represent existing energy level groups by horizontal groups of straight ines, and examine *e.g.* zinc sulfide, in which the possible energy level groups are $A$ and $B$ (Fig. 4). If traces of salt are introduced into the sulfide, one of the salt's possible energy level being $C$, it will act as a primary activator. In this case, the electrons of the $A$ level will jump, upon the action of high-energy photons, to the $B$ levels. When they drop to lower energy levels — after having spent a certain time at the $C$ level — energy is liberated in the form of radiation. Let us now introduce into the sulfide some other impurities of $D$ energy level, close to the $B$ energy group. Now when the above-described phenomenon occurs, among the electrons dropping to lower levels some will drop to the level $D$. Let us now expose the material to the effect of infrared radiation. — This will enable the electrons to jump from the $D$ energy level to

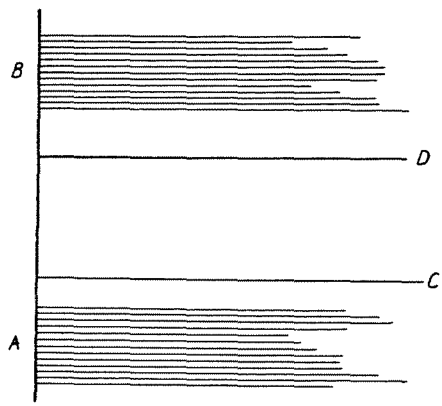


*Fig. 4*

the $B$ level on the action of very low-energy photons, whence they return to $C$ or $A$ respectively, with simultaneous radiation. Hence, the introduction of the latter impurity has made the layer supersensitive to the infrared radiation of very low-energy photons, and in this manner layers which would otherwise not react to such radiation will be rendered responsive to it.

There are also secondary activators whose energy level is in the $D$ group, very close to the $B$ group ; in this case, even the weakest infrared radiation suffices to bring about the phenomenon referred to above.

A prerequisite of attaining these phenomena is to produce highly purified sulfides : a purity degree in the magnitude of $10^{-8}$ is required. The suitably chosen primary and secondary activators can be introduced into such pure sulfides, and the sulfides so contaminated are highly sensitive to infrared radiation.

Among selective infrared receivers a special role is assigned to photographic plates. It is known that plates coated with silver bromide can be made highly infrared sensitive by the addition of dyes to their coating. Such dyes largely consist of heterocyclic carbon rings separated by methane groups [3].

Empirical results have confirmed that the length of the methane chains is related to the sensitivity expressed in term of wave length, that is, the addition of each methane group displaces the sensitivity by 0,1 $\mu$ in the infrared region. It is to be noted that the life of the plates so prepared with respect to infrared radiation, rapidly decreases with the number of the methane groups added.

Fig. 5 represents the sensitivity of a normal infrarapid film in the region of the spectrum and of the near infrared radiation region. In addition to the above sensitizing method of adding methane chains, there are further methods for sensitizing these dyes.

Before describing these further methods, it has to be pointed out that next to sensitivity, gradation is an important characteristic of infrared plates

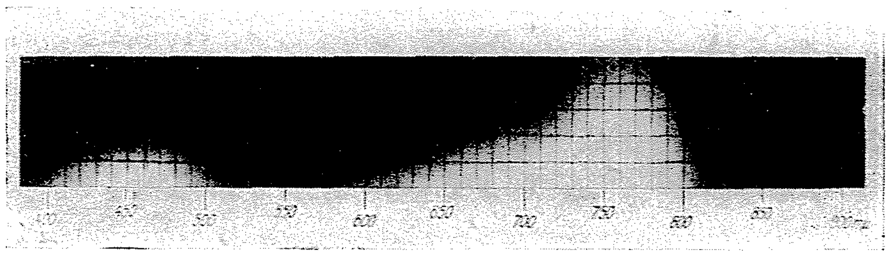

*Fig. 5*

and films [4]. Gradation depends on the steepness of the blackening curve of the investigated layer.

$$\gamma = \frac{dS}{d \log I t}$$

Fig. 6 below shows a photograph of the spectrum, made on an Agfa-Rapid 750 infrared plate, as well as its curve of blackening, that is, the changes of darkening arising with the modification by units of the logarithm of illumination. The tan of the inflexion tangent of the curve, the so-called gamma value, is a characteristic of sensitivity, as it will determine the proper tone to be achieved (Fig. 7).

In addition to sensitizing with various methane groups, reference is made to the classical Schumann-method, by which the plate can be rendered supersensitive, if, prior to the exposure, it is immersed in a 4% ammonia liquid and then dried with alcohol at 12° C.

The infrared-sensitivity of silver bromide layers can be substantially increased if in the above process an 8% ammonia solution is used, containing an equiponderate amount of sodium carbonate. Fig. 8 portrays a spectrum photographed on a plate so sensitized. It is possible in this manner to increase sensitivity to 1100 m$\mu$, and the factor of multiplication for the spectrum of constant energy to 8.

Plates and films can be made supersensitive to infrared radiation if placed in a larger, firmly closable vessel containing some drops of mercury.

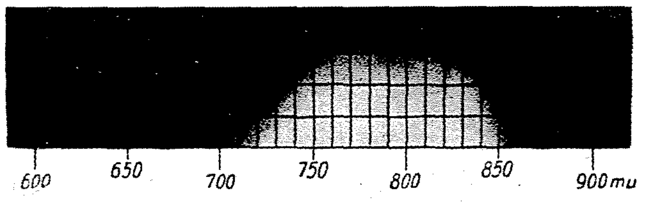


*Fig. 6*

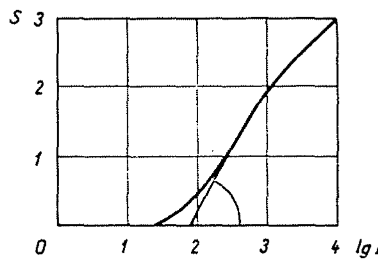


*Fig. 7*

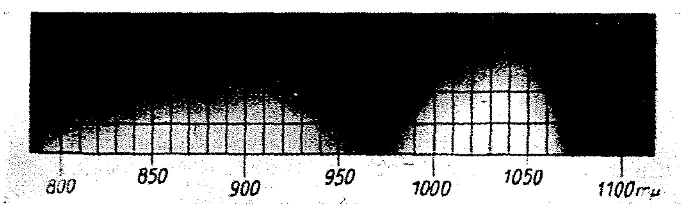


*Fig. 8*

Upon being exposed to the action of mercury vapour for 2 to 3 days at room temperature, the plates will become highly infrared sensitive. The supersensitivity so acquired will last to about 2 to 6 weeks.

In addition, the use of adequate filters plays an important part in increasing sensitivity. Such filters will transmit certain regions of infrared radiation, without weakening it. A very efficient filter can be obtained by inserting a layer of coloured gelatin between two glass-plates. Fig. 9 shows the transmission curve of such a filter. It is to be noted that the visible spectrum is totally absorbed by the filter, whereas only a poor absorption takes place with regard to the nearly infrared rays, up to a wave length of 0,8 $\mu$. A number of filters is widely used. They have the common characteristic of transmitting only the desired part of the radiation. Fig. 10 shows a filter suppressing radiations below the 900 m$\mu$ wave length. The filter is of the Nr. U. G. 8 Jena-type, with a thickness of 2 mm, and is of dark wine colour.

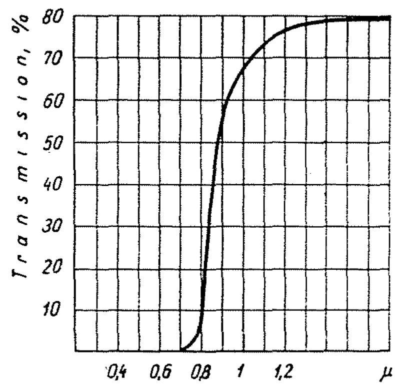


*Fig. 9*

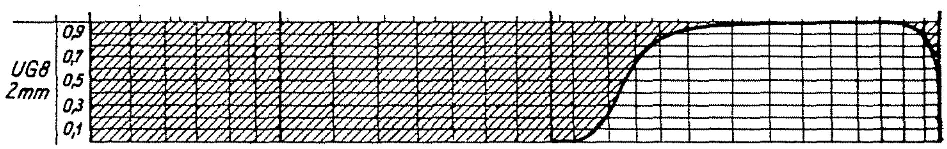


*Fig. 10*

It should be noted in connection with the application of filters that polarization foils are ineffective on the limit of the visible spectrum. It is usual to employ two parallel polarisators by which radiations of varying wave lengths can also be filtered. The infrared-sensitivity of receiver plates or films can thus be still further increased [5].

We shall not discuss now the various well-known examples of infrared photography, by which the visibility of distant, foggy landscapes up to 30—40 kilometres can be improved, but we should like to call attention to a less common example. It is a known fact that in infrared photos freshly cut branches can be distinguished from bushes. It is possible to prepare dyes which will behave in a predetermined manner with respect to infrared radiation. The following figures show photos of such a net. The net has first been photographed in visible light (Fig. 11) and has then been placed on a certain base whereupon it became invisible in infrared light (Fig. 12). This theory of infrared ray photography is only possible on the basis of the preceding theoretical consideration.

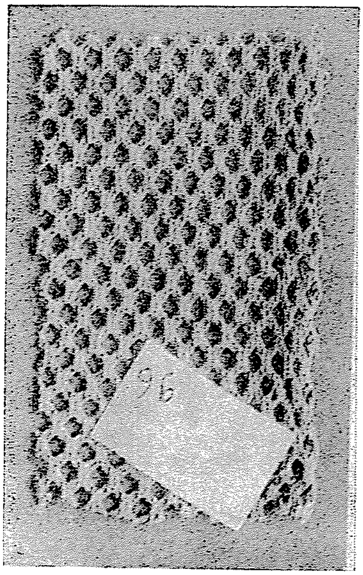


Fig. 11

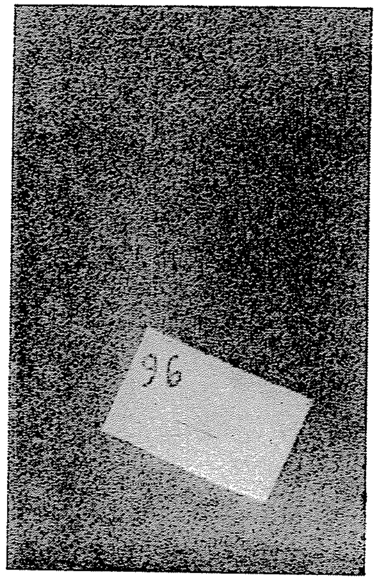


Fig. 12

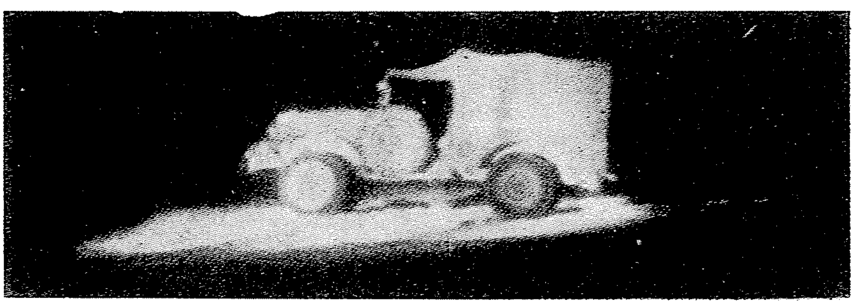

Fig. 13

As another field of application of near infrared radiation, reference is made to the images produced with electronic telescopes, where the theoretical considerations set forth above are also encountered. The image so produced is projected on a phosphorescent screen by means of an electronic optical arrangement. Photographs with infrared rays can only be made on layers containing various impurities, in order to achieve the sensing with proper intensity of photons having a relatively low energy [6]. It is therefore necessary in this case to introduce the required impurities into the phosphorescent matter, in order to achieve conversion of even very low-energy infrared radiation into visible light energy. Fig. 13 shows a photo produced in this manner. The image made with the infrared radiation is projected on the sensitized layer by means of a conventional optical lens systems. The sensing of the phosphorescent image is also done with the usual eyepiece lens [7].

It can be said, on basis of the foregoing, that the recording of photographs and observations made with the aid of infrared radiation usually requires the recording of a low-energy radiation. In these cases it is of basic importance to supersensitize the sensing system, the plate or film receiving the infrared rays, with a view to permit fixing of the phenomenon.

## Summary

As a preliminary for the consideration of plates or films sensitized to infrared radiation, one has to be acquainted with the emission of the infrared radiation in question, and with the spectral energy distribution of radiation. It is particularly important to have a thorough knowledge of the various radiators to be sensed, with a view to sensing the radiated photons of small energy, and for properly sensing infrared radiation it is just as important to know the selective and non-selective receivers. This is how the infrared rays of various wave lengths can be resolved and sensed. For fixing the sensation on plates or films, these latter have to be rendered sensitive or super-sensitive. In addition to theoretical considerations, the paper sets forth a wet and a dry method. The use of filters as a means for further sensitizing is also referred to. Finally, a few photographs taken with infrared radiation are presented.

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