SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 87, NUMBER 8

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F. S. BRACKETT
Chief, Division of Radiation and Organisms,
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The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

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## GRAPHIC CORRELATION OF RADIATION AND BIOLOGICAL DATA

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In discussions of the relation of radiation to biological phenomena one frequently wishes to correlate transmission curves and the characteristics of common sources of light with the response curves of the biological phenomena. Although the facts involved are for the most part well known, they are scattered through the literature in such a way that it is difficult to form a clear picture of their interrelation without gathering this material together graphically. In order to meet this need the composite graph shown in Figure 1 has been developed. The accompanying explanation indicates the significance of each curve, and the bibliography at the end of the paper will enable anyone who wishes more detailed data to go immediately to the original sources.

As water is the chief constituent of most living matter, its transmission characteristics set definite limits for other than surface effects of radiation. It is perhaps significant that radiation therapy has found its effective wave-length regions in those ranges where transition takes place from negligible transmission to relatively great transmission. Such a region exists in X rays from 1Å to shorter wave lengths, and again in the ultra-violet for wave lengths immediately longer than $.18\mu$. Another region which has as yet been little studied occurs in the near infra-red for wave lengths shorter than $1.4\mu$. The transmission characteristics of water may perhaps most readily be indicated by plotting the absorption coefficients, that is $k$ in the expression $I = I_0 e^{-kx}$, as a function of wave length or frequency over the regions of interest. The full line curve *a* in the upper section indicates these values for the range from $10\mu$ to $.1\mu$ in wave length as indicated at the bottom of the graph, or .1 to 10, $\times 10^4$ wave number (waves per cm, *i. e.,* proportional to frequency) as indicated at the top. The values of the absorption coefficients are shown at the left outside the frame. Another convenient method is to indicate for each wave length or frequency the thickness of water which will reduce the light to one-half

## EXPLANATION OF FIGURE 1

Upper Section: ABSORPTION.

*a* ——— WATER, ultra-violet, visible, and infra-red.

Ordinates: Absorption coefficients $k$ in $I = I_0e^{-kx}$ (outside left).
Thickness transmitting half intensity in cm (inside left)
Transmission of 1-cm thickness (right).

Abscissae: Wave lengths in microns $\mu$ (bottom).
Wave numbers, waves per cm (top).

*b* - - - - - WATER, X ray (same ordinates).
Wave lengths in Angstroms (instead of $\mu$ as indicated at bottom).

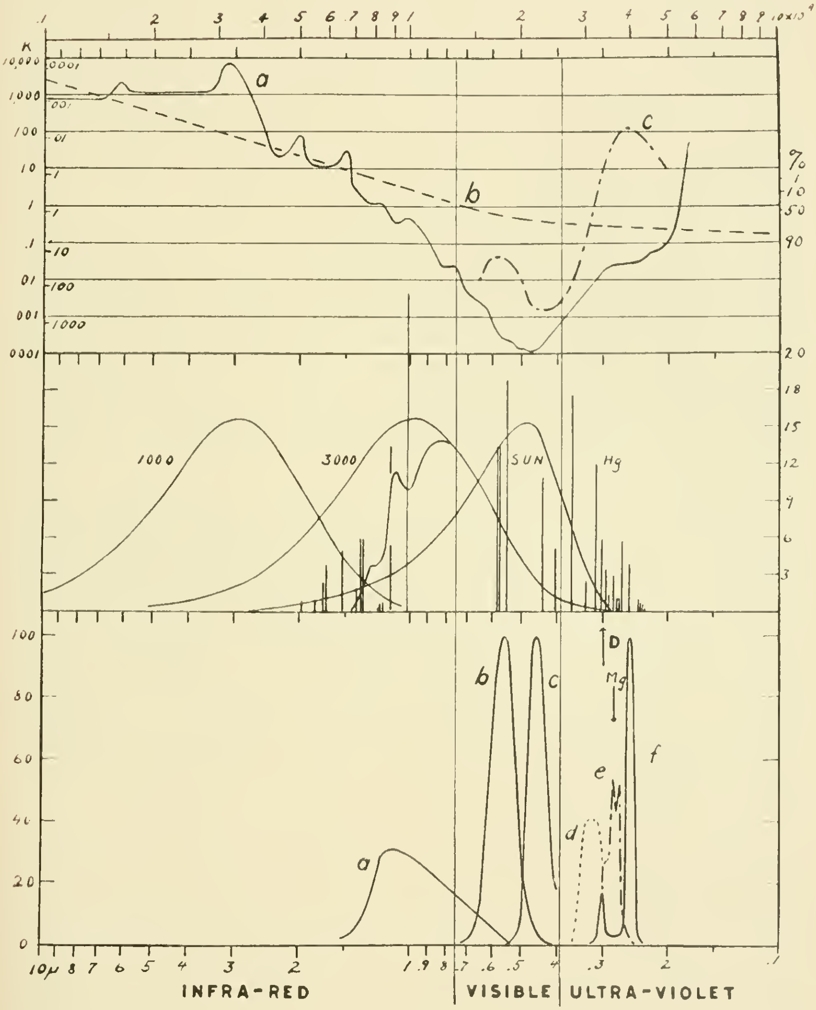
*c* -·-·-·- OZONE, (same coordinates as in *a*; gas at standard conditions).
Atmospheric transmission is equivalent to about 3 mm and can be found by shifting scale (right) up by approximately half a division.

Middle Section: RADIATION.

Relative emission from body at 1,000° K. (dull-red therapeutic lamp).
Relative emission from body at 3,000° K. (high-temperature Tungsten lamp).
Relative emission from sun.
Relative emission from mercury arc in quartz.

Lower Section: BIOLOGICAL PHENOMENA.

*a*, transmission of flesh (1/2 cm thick) in per cent.
*b*, relative visibility.
*c*, relative phototropism.
*d*, Vitamin A.
Absorption and vitamin value disappears when radiated.
*e*, Ergosterol.
Absorption disappears under radiation, which produces activation yielding therapeutic value of vitamin D.
*f*. Relative erythema effectiveness, zero degree (very light). For extreme erythema, fourth or fifth degree, the relative intensities of the the two maxima are reversed.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1000
3000
SUN
Hg
100
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60
40
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a
b
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e
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D
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5
4
3
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1
.9
.8
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.4
.3
.2
.1
INFRA-RED
VISIBLE
ULTRA-VIOLET

Figure I.

its incident intensity value. These may be found from the same curve by reference to the ordinates at the left within the frame.

Thus at the limit of the visible in the red we find that some 30-cm water path is required to reduce the intensity of light to one-half its original value, whereas at $1\frac{1}{2}\mu$ only .03 cm or .3 mm will produce the same result. As water cells are frequently used of 1-cm thickness it is convenient to indicate the wave-length range over which such a cell will yield appreciable transmission. The values of transmission for 1-cm path are indicated at the right of the upper section. These enable one to immediately estimate the wave-length range for the cut-off from such a cell.

In order to compare the absorption characteristics which are familiar to radiologists in the X-ray range with those exhibited in the visible range the X-ray values have been indicated by the dotted curve *b*, the wave lengths being found by reading Angstroms instead of $\mu$ at the bottom of the graph. It is interesting to note the relatively smooth transition from low to high transmission in the X-ray region compared with the highly selective characteristics exhibited in the infrared, visible, and near ultra-violet.

As the presence of ozone in the atmosphere plays an important rôle in limiting the light which reaches the earth, the transmission characteristics of ozone gas under standard conditions have been indicated by curve *c*. The transmission values at the right now apply to a cell of 1-cm thickness of ozone gas under standard conditions. Since, however, the whole absorption in the atmosphere is equivalent to about 3 mm, in order to estimate the absorption of atmospheric ozone it is necessary to shift the transmission scale bodily upward by one-half of one of the large spaces indicated. We thus find the transition from 90 per cent to 1 per cent occurring in a very narrow region from 3,200 A to 2,950 A respectively.

With these curves in mind we may now profitably turn to the matter of sources of radiation with which one has commonly to deal. For the sake of comparison we have assumed that lamps will be chosen of such a size and used at such a distance that a comparable amount of maximum energy is received. The curve at the left shows the relative emission per unit wave length of radiation at each wave length for a solid body at the absolute temperature of 1,000° K. Here we find most of the energy occurring for wave lengths longer than $1.4\mu$, or, in other words, in a region where practically all the energy will be absorbed in an extremely thin layer of water. The customary dull red therapeutic lamp has characteristics not greatly different from this curve. For that reason it must be regarded for the most part simply as a surface heater.

The next curve indicates the emission of a solid body at an absolute temperature of 3,000° K, where it is now seen that its maximum energy lies in a region which would be relatively well transmitted by water. Such a radiation might well be expected to penetrate somewhat into the living matter. It does, however, contain a considerable proportion of energy which will be absorbed in a thin layer, that is for wave lengths longer than $1.4\mu$. If one wishes radiation that is as nearly free as possible of this surface-absorbed energy, a light of this temperature should be used with a water filter. A modified curve is indicated terminating at approximately $1.4\mu$, which shows the type of radiation which one would receive from an ordinary high-temperature lamp such as the customary Tungsten light when equipped with a water cell of 1-cm thickness. Again, on approximately the same scale the relative distribution of solar energy is shown as it would be without atmospheric absorption. Owing to atmospheric ozone no appreciable ultra-violet reaches us from the sun beyond 2,950 A. As the amount of ozone fluctuates this limit varies considerably. Furthermore, large amounts of energy are absorbed in the infra-red by atmospheric molecules, particularly water vapor. This, again, is subject to extreme variations, depending upon the location, time of day, and amount of humidity. In the solar curve we see that the chief energy lies in the visible region, whereas our high-temperature lamp, even with a water filter, has the larger proportion of its energy in the near infra-red. Since for therapeutic purposes the mercury arc is very widely used, its energy distribution has also been shown. As its light is radiated chiefly in a large number of restricted regions of practically monochromatic light, it can best be shown simply by vertical lines. The height of these lines is proportional to the intensity. Since, however, they differ widely for different conditions of excitation, they must be regarded at best as only a rough basis for estimation.

In addition to the blue and ultra-violet lines with which we are chiefly concerned, this arc shows not only strong yellow and green lines, but in most cases a line at $1.014\mu$ of an intensity which exceeds any other line. This great line in the near infra-red occurs in a region where it is readily transmitted by water and, as we shall see in a moment, to a great extent by flesh. This wave length of radiation is readily transmitted by the aqueous humor of the eye and will be chiefly absorbed in the retina. While undoubtedly ultra-violet effects would be noticed long before any danger would be incurred from this radiation in the case of a quartz mercury arc, on the other hand in the case of ordinary glass mercury arc caution should be used to avoid too great exposure as it may produce a lasting injury in the nature of an actual burn on the retina.

In order to be able to correlate these physical characteristics which we have indicated with the direct observations of biological material, the lower portion has been devoted to characteristics for which data is available. Curve *a* shows the transmission of flesh, having been corrected for surface absorption. On the long wave-length side undoubtedly water is most important in setting the limit. On the short wave-length side other constituents of the living matter account for the fact that this transmission drops off rapidly on passing into the visible range. It will be noticed, therefore, that the region of the maximum transmission of flesh occurs roughly in the range emitted from a water-filtered high-temperature light. The near infra-red thus constitutes a region of relatively penetrating radiation for therapeutic purposes. Curve *b* shows relative visibility of light for the human eye. Curve *c* shows the relative phototropic response of an oat seedling to light. It will be noticed that it is insensitive to red and a considerable portion of the yellow, the maximum occurring in the blue. Curve *d* shows the absorption band that seems to be correlated with vitamin A. Radiation that is damaging to the vitamin value causes a weakening in this band. Curve *e* shows the absorption band that seems to be correlated with ergosterol and vitamin D. Radiation that seems to produce activation destroys this absorption. Curve *f*, the full line curve, shows the erythema response of the human skin in the case of a very light erythema (zero degree). Here it will be seen that a minor maximum occurs at $.298\mu$ and a great maximum in the region of $.253\mu$. In the case of extreme erythema, fourth or fifth degree, the relative effectiveness of these two regions is reversed, the great maximum occurring at $.300\mu$ and the smaller maximum at the region of $.253\mu$. It is, however, very significant and perhaps important from a therapeutic standpoint that a minimum of erythema occurs between these two ranges and that this minimum coincides with the chief ergosterol absorption. It may thus be possible to secure a maximum therapeutic dosage with a reduction in resulting erythema by the use of monochromatic light in this range. The magnesium spark lines at $.280\mu$ are promising for this purpose.

Another point of interest is that the lethal region for algae occurs in this same range as ergosterol absorption, the threshold for this effect being indicated by the arrow marked D. The solar energy falls off rapidly at this point.

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