7. This difference, which is hardly to be accounted for by the ordinary theory of the relation between conduction and absorption, may be due to some imperfection of the experimental method used by H. and R. On the other hand, it is worth noting that the dual theory of conduction requires a difference of the kind and of the order of magnitude here observed. For this theory makes the paths of the few free electrons last so long that the rapidly alternating fields of even the longest light-waves would have no net effect on them. Therefore it confines the conduction-absorption power of metals to the action of the "associated," or "transit," electrons, and for metals in general the conductivity due to these electrons is about 8 or 10% less than the total conductivity. For bismuth κ_a is exceptionally small, about 67% of the total κ.

[1] Meier, *Inaugural Dissertation*, Barth, Leipsic, 1909.

[2] Hagen and Rubens, *Ann. d. Physik*, **11**, 873–901 (1903).

[3] Meier's paper gives $\rho\nu' \div \nu$ in the numerator within the summation sign, but I think it should be $\rho\nu'\nu$.

[4] Hagen and Rubens, *Ann. d. Physik*, **11**, 873–901 (1903).

[5] Loc. cit., p. 886.

[6] Their κ is the reciprocal of the resistance, in ohms, of a piece of the metal 1 m. long and 1 sq. m. in area of cross-section.

THE SPECTRAL ERYTHEMIC REACTION OF THE HUMAN SKIN TO ULTRA-VIOLET RADIATION

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Introduction.—At present the physician has neither a unit of dosage nor a meter for accurately measuring the amount of ultra-violet radiation used for healing purposes.

In the absence of an inanimate dosage-meter the patient is used as an indicator, and the dosage is estimated by the erythema produced on the inner forearm. This method is in common use as a guide in ultra-violet radiation therapy. Furthermore, in view of the wide variation in erythemic susceptibility of pigmented and unpigmented skin (brunette and blonde), and in view of the fact that irradiation cannot be continued safely beyond skin tolerance, it is highly probable that any unit of dosage or any inanimate dosage-meter, that may be adopted, will have to take this physiological effect into consideration.

Hence, in connection with the question of the unit of dosage, and particularly in connection with methods of standardizing the dosage, an important problem is the determination of the spectral erythemic reaction of the untanned human skin, and the energy required to produce a mild erythema.

Previous determinations of the erythemic response of the human skin when exposed to ultra-violet radiation of different wave-lengths were made by Hausser and Vahle[1] and more recently by Luckiesh[2] and his collaborators. In their determination of the energy required to produce a minimum perceptible erythema, Hausser and Vahle exposed the arm to single emission lines, which passed through a slit (3 cm. long) in a cardboard attached to the arm. Based upon their preliminary observations of the approximate magnitude of the erythemal dose for each wave-length, by making the exposure through the whole length of the slit, then through $^2/_3$ and finally through $^1/_3$ of the length, for different time intervals (3 exposures with each line), the exposure-time for producing a distinctly perceptible erythema was determined.

Instead of using isolated spectral lines, Luckiesh[2] and his collaborators exposed small areas of the subject's back to the total radiation from a quartz mercury arc lamp, shining through filters that shut off successively increasing wave-lengths of ultra-violet radiation, and noting the dosage necessary to produce a minimum perceptible erythema. For this purpose the time was varied so that the shortest exposure gave no visible results, and the longest exposure produced a definite erythema, as observed after a lapse of approximately 24 hours.

Experimental Procedure.—In the present investigation isolated spectral lines from a large quartz monochromator[3] were used as stimuli, and the time of exposure to produce a minimum perceptible erythema (one that lasted less than 24 hours) was determined. As found by others, the difficulty lies in defining the minimum perceptible erythema, especially the highly transitory erythema produced by wave-lengths less than 270 mμ (millimicrons) which, for a weak dosage, increases to a maximum redness and then disappears in the course of 2 to 5 hours.

The source of ultra-violet radiation used in the present work was a quartz mercury vapor lamp, operated on a constant voltage, under which condition the intensities of the spectral lines, measured at different times with a linear thermopile[5] calibrated in absolute value,[6] were constant to 5%.

The exit slit (of metal 0.1 mm. in thickness, with beveled edges turned away from the incident light[4]) was mounted upon a rigid support which, after focusing upon the desired spectral line, was securely attached to the spectrometer arm.

To facilitate setting on a spectral line the slit was given a thin coat of turpentine upon which was dusted a thin deposit of anthracene, which was then rubbed smooth. Starting with the slit closed this method of applying the fluorescent material produces a sharp knife-edge which, on opening the slit (0.3 mm. wide, 10 mm. long), permits an accurate isolation of closely adjoining emission lines.

The arm to be exposed to ultra-violet radiation rested upon a movable support directly back of, and within less than 0.3 mm. from the front surface of, the exit slit. The difference in focus of the radiation incident upon the exit slit, and incident upon the skin directly back of the slit,

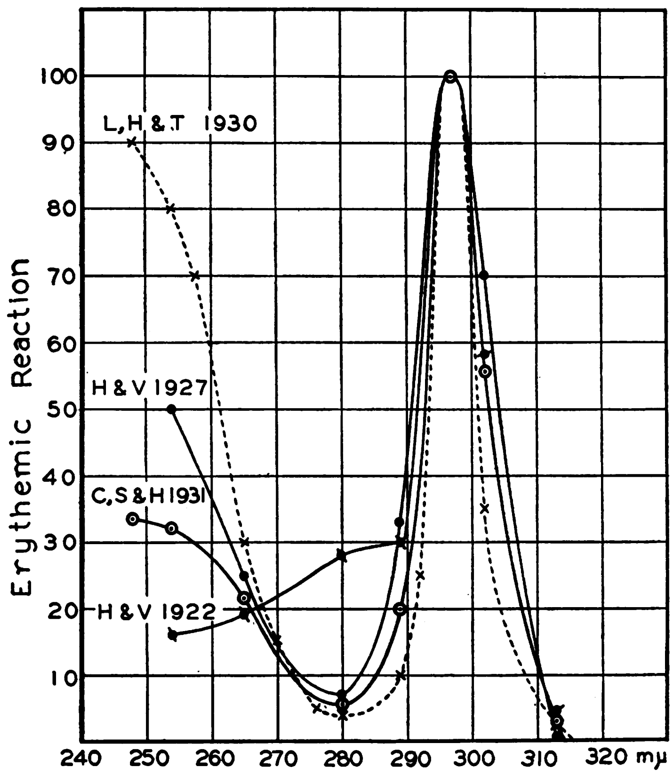

FIGURE 1

Spectral erythemic response of the human skin; H & V, Hausser and Vahle; L, H & T, Luckiesh, Holladay and Taylor; C, S & H, Coblentz, Stair and Hogue.

was therefore negligible. By moving the arm-support laterally, different parts of the arm (usually at intervals of 4 to 6 mm.) could be exposed to radiation.

In practice the exit slit was adjusted to intercept a given emission line (e.g., 297 mμ) and a series of irradiation exposures was made, ranging from 1.5, 1.75, 2.0, 2.25, 2.50 and 3.0 minutes. From such a series of exposures the time for producing a minimum perceptible erythema (1.75, 2.0 and 2.5 min., respectively, for the three writers) was easily established.

When making irradiation tests in the region of 254 mμ, where the observations of the erythemic reaction are in disagreement with previous experimenters, check exposures were made on the 297 mμ line alongside with the exposures to the emission line (e.g., 248 mμ) under observation. Since the minimum perceptible erythema for the 297 mμ line was produced in the usual time (1.75 min.; 2 min. produced an erythema lasting 2 days for W. W. C.) it is assumed that this disagreement is real.

The Spectral Erythemic Reaction.—As illustrated in figure 1, the wave-length range of the erythemogenic rays begins at about 315 mμ, and extends to an undetermined wave-length shorter than 240 mμ. The erythemic response curve rises abruptly to a maximum at 297 mμ, descends less abruptly to a minimum at about 280 mμ, then rises to a less intense maximum in the region of 250 mμ.

The disagreement in the spectral response curve in the region of 250 mμ is partly owing to the method of defining the minimum perceptible erythema, which is very transitory for short wave-lengths. However, this appears to be of minor importance in view of the increased practice of covering artificial light sources with a glass that intercepts ultra-violet radiation of wave-lengths less than 280 mμ, thus reducing the erythemogenic range of wave-lengths to agree more nearly with that of the sun.

The erythemogenic power of ultra-violet radiation depends upon the intensity of the rays and upon the susceptibility of the skin to different wave-lengths. But unlike the spectral sensibility curve of the eye which is different for different persons, from the limited data available it appears that the spectral erythemic response curve of the human skin is practically the same for different persons, in spite of the fact that the total energy required to produce an erythema is markedly different.

One difficulty in devising a suitable dosage meter is the fact that a long over-exposure to radiation at 254 mμ produces only a superficial burn, whereas a slight over-exposure to the more deeply penetrating radiation of wave-lengths 313 mμ produces a painful blister. For example, in one case it was found that an exposure to the wave-length 313 mμ for 14 min. produced a barely perceptible erythema (estimated exposure 15 min.); 16 min. was somewhat longer than required for a minimum perceptible erythema; and an exposure of 18 minutes produced a painful blister.

Reciprocity Law.—According to Luckiesh[7] the reciprocity law holds for biological effectiveness over a wide range of exposures.

In the present experiments the intensity of the emission line at 297 mμ was reduced by $^1/_2$, and by $^1/_4$, by means of glass filters, and the corresponding time of exposure was doubled and quadrupled. Within the experimental errors involved in making the test, the erythema produced by using $^1/_4$ of the unit intensity and exposing for 4 times the unit time, was not appreciably different from that produced by exposing the subject to unit intensity (430 microwatts per cm.[2]) for the unit time (2 min. for R.S.) required to produce a minimum perceptible erythema.

On the basis of the limited number of subjects tested in this work, the energy required to produce a minimum perceptible erythema upon 1 square centimeter of untanned skin, using monochromatic radiation of wave-length 297 mμ (the wave-length of maximum of erythemic susceptibility) is of the order of 500,000 ergs. The actual values for the three observers are, respectively, 452, 516 and 645 kiloergs per cm.[2]

When one considers the ever-increasing number of ultra-violet radiators sold for healing purposes, in some of which about 97% of the total erythemogenic radiation, of wave-lengths 200 to 315 mμ is contained in the highly germicidal but non-penetrating rays at 254 mμ (the resonance line in a so-called "cold" quartz mercury lamp), while other lamps contain practically no ultra-violet radiation of wave-lengths shorter than 310 mμ but emit longer wave-lengths that are more penetrating and more potent in causing burns, the urgent need of a means of standardization of the dosage seems apparent.

[1] Hausser, K. W., and Vahle, W., *Strahlentherapie, Berlin,* **13,** 41–71 (1921), and **28,** 25–44 (1928).

[2] Luckiesh, M., Holladay, L. L., and Taylor, A. H., *Jour. Opt. Soc. Amer.,* **20,** 423–432 (1930).

[3] Coblentz, W. W., and Kahler, H., *Bur. Stds. Sci. Papers,* **16,** 233–248 (1920).

[4] Coblentz, W. W., *Jour. Franklin Inst.,* **175,** 151–153 (1913).

[5] Coblentz, W. W., *Bur. Stds. Bull.,* **11,** 131–187 (1914).

[6] Coblentz, W. W., *Ibid.,* **11,** 87–100 (1914).

[7] Luckiesh, M., "Artificial Sunlight," p. 77 (1930); *Trans. Illum. Eng. Soc.,* **26,** June-July (1931).