57. *Effect of Light on Pigments and Dyestuffs.*

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The present paper deals with the experiment to examine the effect of light on pigments and dyestuffs used in old Japanese fine arts. Almost all of precious pictures and silken fabrics, handed down to us from some hundred years ago, and kept in our museums and conservatories, have suffered considerable damages in their colors owing to chemical, biological and other agencies acting incessantly upon them. There is no doubt that the most active one among these agencies is light. Our study aims not at the exposition of physical laws governing the bleaching of these coloring matters, but it forms the first step in the investigation to find out some hints about the best method for the preservation of these costly articles of old fine arts.

Materials tested. Such being our object, the materials to be tested are confined (1) to pigments used in Japanese paintings, and (2) to dyestuffs employed in dyeing silken textiles in olden times. Many sheets of genuine Japanese papers, exactly equal to those used in old pictures, were uniformly brushed over with 25 different kinds of pigments, using gelatine as the binding material, by skilled artists of the Tokyo Imperial Museum, and they formed the first class of our test objects. The second class of test objects were prepared by dyeing silken fabrics with 27 different sorts of stuffs, following exactly the traditional process by specialists. It is to be mentioned that the peculiarities of these coloring matters are that, pigments used in our paintings are mostly of mineral origin, such as powders of malachite, azurite, cinnabar, mica, and natural oxides of metals, while the dyestuffs for textiles belong exclusively to those of vegetable origin, such as decoctions of roots of *Rubia cordifolia* and *Lithospermum erythrorhizon*, and flower of *Carthamus tinctorius*, using proper mordants. These colors are all marverously stable in comparison with modern chemical coloring matters like aniline dyes. In our previous studies on the fading of modern colors, we made use of Zimmermann colored papers, much used in psychological experiments, and they were found to be pretty unstable. Wishing to compare the stabilities of these modern colors with those of our old pigments, we took 17 kinds of Zimmermann papers as the third class of test objects. Besides these, we included as the fourth class of the test objects 7 grades of malachite powders of different sizes of grains, without any cementing materials. These powders were kept in small shallow receptacles, covered with optically good glass plates. The reason of the use of such test objects is to make clear the influence of cementing materials and substrata of pictures on the fading of pigments. Thus our test objects numbered 76 in all.

Exposure to light. These test objects were exposed to the direct sun light with their surfaces horizontal. The exposure was restricted to times of cloudless sky, and even in fine days, it extended from a time

not earlier than 9 o'clock and to a time not later than 4 o'clock.

Now the action of light on the fading of colors depends clearly on the integrated value of illumination I of the sun light with respect to time, or on the total exposure $\int Idt$. Wishing to know this magnitude, we designed a suitable integral photometer, but soon its use was found to be too troublesome, and we abandoned its use. It was sufficient for us to utilize the observation at the Central Meteorological Observatory of Tokyo, where solar energy is continuously recorded by Robitzsch actinograph, measuring the amount of total solar radiation falling on the unit area of a horizontal plane. Assuming a standard illumination I_0 , we can reduce the total exposure to a form $\int Idt = I_0 \int dt = I_0 \cdot T$. Then as the measure of the total exposure, we may simply take $\int dt = T$ expressed in hours, and call it the *reduced time* of exposure. As I_0 , we may take, for the sake of convenience, the solar constant, which when expressed in gramcalorie, centimeter, and hour, is approximately 116.

The average number of fine days in a year in Tokyo is about 60. And in such fine days, the time of cloudless sky suited for the exposure of our test objects is generally pretty short. Our observations were begun in Feb. 1934 and continued to Nov. 1935, the actual exposed time amounting to about 150 hours with reduced time of exposure of 84.3 hours, the total integral exposure being 9885 gr. cal., cm., hour. During this interval, we measured and traced the change of colors at several stages, and the law of decay was made known, so that by the total exposure of more than 80 hours, the changes of our test objects may be looked upon as fairly reached to their final states.

Ostwald color system. There are many systems in vogue to describe the color sensation of a given color. We consider that the system developed by Ostwald as the most suitable one to be adopted in the present case. In this system, a color is expressed by 3 parameters. The first parameter is the specification for its hue, whether red or green. All different hues are arranged round a circumference of a circle according to a special rule. Any particular hue is specified by the first parameter (1-100) indicating its position on the hue-circle; e. g. yellow (0-10), red (20-30), purple (30-40) and so on. The other two parameters are the white (w) and the black content (s) expressed in percentages. Here a color is considered to be composed of a certain amount (r) of ideally pure hue mixed with white and black, so that

$$r + w + s = 100.$$

Any color having a given hue may be represented by a point within an equilateral triangle RSW , with sides equal to 100. The instrument most suited for the color measurement to determine these 3 parameters is Pulfrich's cascade photometer, which needs not be described here.

Observation. All test objects were examined by this photometer, and their hue numbers and their w , r were determined before and during the exposure. The reports about the values of parameters in

in its white content, and the latter, on the contrary, suffers a remarkable change in its hue, and almost no change in the other parameters.

The colors of the third class test objects, or Zimmermann colored papers, are very unstable, as was already known to us by our previous experiment. The colors Z 5 and Z 7, though practically of the same hue initially, show changes in hues in opposite senses, the former turning to orange and the latter to purple.

In conclusion, the authors wish to express their sincere thanks to the authorities of "Harada Sekizenkwai," by the aid of whose fund, the present experiment was conducted.