ART. XXVIII.—*The Action of Sunlight on Glass;* by THOMAS GAFFIELD.

THE great attention now given to all the phenomena connected with light and heat may awaken some interest in the experiments in which I have been engaged for the past four years on the subject named at the head of this article. Perhaps I cannot better commence my essay, than by quoting from the "Proceedings of the Natural History Society," (vol. ix, p. 347) an account given before that Society, of my experiments in 1863, and after I had been engaged in them only a few months.

"He believed that his experiments in connection with the subject were original as to their method and their extent, although it had long been observed in Europe that colorless or light-colored plate-glass had turned to a purple hue by exposure to intense sunlight. One case* is cited of a change to a gold color; and one experiment recorded by Dr. Faraday,† some forty years ago, proving that a light purple changed to a darker hue after eight month's exposure.

"Other experiments are on record showing the action of glass of different colors as media in the transmission of light and of heat; but none, with the above exception, showing the effect produced on the glass itself.

"An experience of some twenty years in the window-glass business had only presented a few isolated cases of supposed change of color from this cause, which were attributed to some obvious defect in an article of inferior manufacture; but, within

* Journal of Society of Arts for Feb. 15, 1854.

† Dr. Faraday's Chemical Researches. London, 1859, p. 142.

a short time, he had heard of the change of color in an article of superior manufacture, in a quantity of white plate glass, of which some lights had been broken out of a window in which they had been exposed to the sun.

"This fact coming to his knowledge led him to try an experiment with several specimens of plate, crown, and sheet glass, during the month of July last; which proved that a month's exposure to a hot sun would change the best white French plate and all white sheet glass, such as is used for photographs and engravings, to a color containing more or less of a yellow hue. The dark green and dark blue or bluish green did not experience any change; but any hue which approached a white, whether bluish, greenish, or yellowish white, turned to a yellowish color.

A second series of experiments, commenced in July, and continued three months, on some thirty specimens from France, England, Belgium, Germany, and the United States, only confirmed the results of the first; and a daily examination at first, and afterward from week to week, and month to month, revealed the interesting fact, that, even after a single day's exposure to a July sun, the change of color will, in some instances of the lightest hues, commence.

"So remarkable was the change in a week, affecting nearly all the light-colored glasses, that he commenced a third experiment on the 6th of August which should speak for itself. He then exhibited to the Society ten pieces of French white plate-glass, four by two inches in size (all of which were cut from the same sheet), one of which showed the original colorless glass, and the others exhibiting the change of hue towards yellow, after exposure respectively of one, two, and four days; one, two, and three weeks; one, two, and three months.

"The changes in the first four days were slight; but the last specimens were so yellow as to exhibit a contrast very marked, and excited the interest of all the members present. That the color permeates the body of the glass, and is not confined to the surface, or produced by reflection therefrom, has been conclusively proved by grinding off about one-sixteenth of an inch from both surfaces and the four edges of a duplicate exposed specimen, which, after repolishing, still exhibited the same yellow color.

"The glasses exposed were all what are called colorless window-glasses, although they varied in tinge and hue from the whitest French plate to the darkest green English sheet-glass.

"An experiment for four months, from July to November, on really *colored* glasses, red, green, yellow, blue, and purple, showed no change except in the purple, which became slightly darker.

"The experiments were carried on upon a rough plate-glass roof, nearly horizontal, and which received the rays of the sun

during the greater part of the day. In all cases, strips corresponding to those exposed, and cut off from the same pieces, were placed in the dark, to be compared with the other specimens after exposure.

"It will be noticed that the dark green, blue, and bluish green did not change. The color of the Belgian sheet (called German or French by glass-dealers in America), a yellowish or brownish green, did not change; and these were the only exceptions. All plate-glasses changed, except an inferior blue quality, and a superior crystal plate of a greenish color, made in Germany, and at the only factory which has not given up the use of pot-ash for soda-ash.

"It is possible that a longer exposure of a year, or of years, might change every color in some degree.

"His inquiries, since he instituted these experiments, have brought out some fine specimens of Belgian sheet-glass from a house built three years ago, which had changed in some instances to a golden and in others to the well-known purple hue.

"It is his intention to pursue the experiments farther, with a view to ascertain the effects of sunlight during each month and season of the year; and also whether exposure to heat, air, or moisture alone, out of the direct action of the sun's rays, will produce any corresponding change.

"Mr. Gaffield does not propound any theory to explain these changes of color, which, under our sunny skies, probably take place much more rapidly than in the different and less clear atmosphere of England.

"Some writers point to the presence of oxyd of manganese in the original composition of window-glass, and some to the oxyd of iron, as a chief cause.

"Some writers have peculiar theories about the different classes of the sun's rays. Some may think the change referred to, a molecular or chemical one; and others, wiser than the rest, refrain from any explanation, waiting for a larger multiplication of experiments, and a greater accumulation of facts, before educing any satisfactory law of nature which governs these curious and interesting phenomena.

"Mr. G. makes no pretentions to any discoveries, unless it be to the very rapid change in glass observed in our climate in July, but only gives the result of his experiments, in the hope that the great interest now manifested in the subjects of light and heat may lead others to examine the matter, to repeat the same experiments in other countries, and to give the world the result of their researches, and enable the learned and scientific men of the age to explain this remarkable power and action of the sun's rays.

"It should be remembered that he submitted his specimens to

the most severe tests by placing them where they received reflected as well as transmitted light and heat. The change in glass, when glazed in the windows of our dwellings and stores, is so much more gradual, that it very rarely attracts the attention of observers, except in the marked variation from white to purple."

In accordance with the intention above expressed, I have continued my experiments on this interesting subject, and under different heads will now give some account of their method and results.

My first experiment was with pieces of glass four by six inches, placed in a sash six by sixty inches long, in the grooves of which the specimens were placed, the sash being fastened together by wooden pins, and placed on a nearly horizontal rough plate-glass roof, which received the direct rays of the sun during the greater part of the day. In my next experiment, I placed some of the specimens directly on the rough plate-glass. These were carried on in summer and autumn. It was necessary to make a different arrangement for winter, when the fall of snow and the formation of ice might interfere with the full success of the experiments. I concluded that the best size for specimens was four by two inches, and I made some wooden boxes about $\frac{3}{8}$ inches deep, $4\frac{1}{4}$ inches wide, and of a length to fit the sills of windows facing the south, in the upper story of a Boston house. One of the windows was three-sided, looking east, south, and west. In these boxes, painted white, my specimens were placed in a nearly horizontal position, side by side, and, (after the loss of a few pieces, blown away by hurricanes and squalls), were secured in their positions by cords of twine or slight copper wire fastened at each end. I have arranged boxes on the roof in front of this window also, some being of greater depth in which to place pieces of plate and rough plate about one inch in thickness. All of these boxes are provided with covers, which are placed over the glass, and fastened by buttons, on the occurrence at any time of a snow storm. At all other times, the glass is exposed. Holes in proper places in the boxes allow the rain which falls to pass off easily. Every piece of glass is carefully marked by a diamond in an upper corner with its name, and if necessary, with some abbreviation descriptive of the experiment to which it belongs. This precaution is necessary to prevent mistakes, when a comparison is to be made of several kinds and colors, of exposed and unexposed specimens. In all cases, where an experiment is to be made with any description of glass, the pieces (4×2 inches in size) must all be cut from the same sheet, as there is frequently a slight difference in the shade of sheets from the

same factory, arising from the difficulty of having the materials in their manufacture, and the circumstances attending the melting, blowing or casting precisely the same. Two pieces or more should be laid aside to show the original color, and to compare with the others, and thus to show the changes produced by exposure to sunlight for days, weeks, months or years. At the commencement of an experiment, say for instance, the exposure of white plate-glass for from one to twelve months, a neat paper box is provided, 4¼ inches long, 2⅛ inches deep and wide enough to hold fourteen pieces, (two of the original color, and twelve exposed specimens) and a description of the contents is marked on its cover on an adhesive label. At the end of each month, a piece is withdrawn from exposure, carefully cleaned, and marked either with a diamond or by an adhesive label, and placed in the box. As "order is heaven's first law," it is peculiarly necessary in all observations upon the actions of heaven's brightest luminary. By observing the above directions, much time will be saved, and at the conclusion of an experiment, everything is in shape for exhibition to friends at home, or students at a lecture room.

Of course a *perfect* arrangement could only be made when a perfectly flat roof or platform in an open field could be provided, and the sunlight could act with full force during every hour and minute of the day. But mine was sufficiently near this point to show very interesting results.

In one of my earliest experiments, I kept a record of the changes going on in the various kinds of glass, at first from day to day, and afterwards from week to week, and month to month. The following is a specimen:

Kinds of glass.	Original color before exposure.	Color after one day's exposure.	Here were inserted other columns to show effect of exposure for 2 and 4 days, for 1, 2 and 3 weeks, for 1 and 2 months.	Color at end of exp't. (3 mos.)
French white plate, English crown glass. French white sheet. Belgian sheet. American sheet.				

I might give the names of all the different kinds of glass which I have exposed to sunlight, but I refrain because for the reason given previously, I have found different specimens from the same manufactory of plate, of crown, and of sheet-glass, sometimes to differ in shade, sometimes in result of exposure, and sometimes in both.

I will, however, give below, (not naming the particular manufactories), a general description of my experiments in 1863, when an exposure of thirty-three specimens for a few months in summer and autumn showed the following results.

The first table shows that twenty-four kinds were found to be easily affected, and exhibits the time at which the change in color was first observed. The second table shows nine kinds which did not change in color during the same time.

Table of glasses easily changed.

Kinds of Glass.	Original color before exposure.
5 of French white plate.	White, with light bluish green tinge.
2 " German " "	White " " " " "
1 " English white plate.	White " " " " "
5 " " plate.	Yellowish green.
1 " Belgian rough plate.	White, with slight green tinge.
3 " French white sheet.	" with light bluish green tinge.
1 " Belgian " "	" " " yellowish green tinge.
4 " English " "	One light yellowish green and three light bluish green tinge.
2 " American " "	White, with light blue green tinge.
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The time at which change of color was first observed.									Color after exposure.
Days.			Weeks.			Months.			
1	2	4	1	2	3	1	2	3	
1		4							Yellow or yellowish green.
1				1					" "
1									" "
	4			1					Deeper yellow tinge.
		1							Yellowish green tinge.
3									" "
1									" "
	1		1	1		1			" "
1		1							" "
8	5	6	1	3		1			

Table of Glasses not changed in three months.

Kinds of glass.	Original color of glass.
1 kind of German crystal plate.	Light green.
1 " " " plate.	Dark blue.
1 " " English rough plate.	Dark green.
1 " " English crown.	Light green.
1 " " American "	Bluish green.
1 " " " sheet.	Dark bluish green.
1 " " English "	Dark green.
1 " " Belgian "	Yellowish or brownish green.
1 " " French "	" " " "
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Subsequent experiments with five of these kinds, (all which I could conveniently obtain), showed that an exposure of a year, or even less, would change all but an ordinary kind of American sheet, which was of a dark bluish green color.

The experiments which speak for themselves are the most satisfactory ones, that is to say, where one has not only the

record made at the end of each month, but a piece of glass taken in and laid aside at the same time to show the actual color produced, and the truth of the records. It is very interesting to witness any one of these series of specimens, showing, as in one of white plate, a gradual change, commencing in a day or a few days in summer, from greenish or bluish white to a yellowish white, or light yellow, a deep and deeper yellow, until it becomes a dark yellow or a gold color; and in some Belgian sheet specimens, a gradual change, commencing in a few weeks in summer, from brownish yellow to deeper yellow, yellowish pink, pink, dark pink, purple and deep purple.

There are several kinds of glass in which no perceptible change took place in three months, which were very sensibly affected by an exposure of a year.

Experiments.—I have given a general account of my first experiments in 1863, and a portion of the tables kept in my journal at that time. I might have given names and results in full and shown the actual effects and shades of color produced by exposure for a few months, on some thirty kinds of glass. But in my case, as in many novel and original investigations, the results of first experiments, and the theories based upon them, were modified by subsequent ones. I supposed that many kinds of glass not changed in three months would not change at all: that all which changed would take a yellowish color, unless by exposure of many years: that no color but some shade of yellow or pink would ever be produced in any kind by exposure to sunlight.

The experiments of 1864 and the two following years, proved to me that nearly every kind of window glass I had exposed, could be changed in one year; that a rose or pink color, (or some tint approaching them) could be produced in various kinds in a few months; and that some kinds of greenish white glass would, after exposure, assume a bluish tint or bluish white.

It may seem singular for one who has been a glass dealer and manufacturer like ourselves, thus to advertise what may be called a defect in his own wares. It might seem unkind to other manufacturers to expose the defects of their productions, literally before the light of day. But my scruples have been all removed, when I have noticed in a late communication of Pelouze (see Comptes Rendus, Jan. 14, 1867) the following statement: "I do not believe that there exists in commerce a single species of glass that does not change its shade in the sunlight." As all manufacturers are in the same category, it will do no harm for me to repeat what Pelouze says, as the result of my experiments, and to affirm that a longer or shorter exposure to the direct action of the sun's rays will probably change in some degree the color of all or nearly all kinds of window glass.

I subjoin an account of an experiment carried on for one year with nine different kinds of glasses. These represent plate, crown and cylinder glass, the manufactures of both hemispheres and almost every shade and color of what are called colorless glasses.

I name only the nationalities, and not the particular manufactories of the glasses in any of my tables. I have this information recorded in my journal, and shall be happy to communicate it to any who may desire it.

Memorandum of nine different kinds of glass exposed from Jan. 12, 1866, *to Jan.* 12, 1867.

Kind of glass.	Color before exposure.	Color after exposure.
French white plate.	Bluish white.	Yellowish color.
German crystal plate.	Light green.	Bluish tinge.
English plate.	" "	Yellowish green.
English crown.	" "	Light purplish color.
Belgian sheet.	Brownish yellow.	Deep " "
English sheet.	Dark green.	Brownish green.
American crystal sheet.	Light bluish white.	Purplish white.
" " "	Lighter bluish white.	Light yellowish green.
" ordinary "	Bluish green.	No change.

The colors named above are given from an observation of the glass edgewise, by which one can see a body of color two or four inches in depth, whereas the usual thickness of the glass varies from one-fourteenth to one-quarter of an inch, and shows its color easily only by placing a white curtain or paper behind it.

I have tried several experiments showing the effect of sunlight during each month and each season of the year. At the end of the year, by the comparative depth of yellow or purple color produced in the various specimens, one can see the comparative actinic power of the rays during each month and season. The results proved that the actinic effect increased from January to July, and decreased after that month. The greatest effect during any season was observed in the summer, the least in winter, and that in spring and autumn was about alike, and midway between that of summer and winter.

Crystal or lead glass, and a piece of optical glass having probably very little, if any, manganese, changed not in two years. Perhaps a longer exposure may produce some change.

A rough piece of light colored window glass metal changed to a yellowish color in a year.

Colored glasses after two or three years' exposure showed no perceptible change in any instance except a slight one in a single specimen of purple. Perhaps an exposure of many years may make a change in some other colors.

I have made experiments with artificial heat on glass in various ways, from exposure to the heat of a cooking range oven

to that of a glass stainer's kiln, without any change of color in the common colorless window glasses, while the same or similar specimens exposed to sunlight have been nearly all changed in a few months.

Specimens exposed in hot water for a month, in doors and out of sunlight, experienced no change of color, while similar ones exposed during the same length of time in the bottom of a dish filled with two or three inches of water out of doors, and to the direct rays of the sun, experienced a decided change, though only about half as much as when directly exposed, out of the water.

Being convinced that air, moisture, and artificial heat do not make any change of color, our experiments indicate that the change is effected by the actinic rays of the sun alone.

This actinic effect is cut off in some degree by every medium, by water as stated above, and even by clear glass, as a specimen exposed inside of a window or under another piece of thin colorless glass shows only about one-half as much change, as that exposed outside of the window or with no covering of glass over it. The amount cut off by colorless glass and by colored glass differs greatly with the difference of color.

[To be concluded.]