ULTRA-VIOLET RAYS AND THEIR USE IN THE EXAMINATION OF WORKS OF ART

FROM A PHOTOGRAPH COLORED TO SIMULATE THE APPEARANCE OF A XIV CENTURY IVORY UNDER ULTRA-VIOLET LIGHT. THE YELLOW SECTIONS ARE ORIGINAL, THE YELLOW AND VIOLET BACKGROUND DATES FROM THE XIX CENTURY, THE FRAME AND PLINTH ARE MORE RECENT

(see page 29)

THE METROPOLITAN MUSEUM OF ART

ULTRA-VIOLET RAYS
AND THEIR USE
IN THE EXAMINATION OF WORKS OF ART

BY JAMES J. RORIMER
Assistant Curator in the
Department of Decorative Arts

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". . . science . . . translates into a usable procedure what in the teaching of the sages has been an esoteric insight. Scientific method can be learned. The learning of it matures the human character. Its value can be demonstrated in concrete results."

WALTER LIPPMANN

PREFACE

THIS book is the outcome of experiments in the examination of works of art under ultra-violet rays, conducted in the Museum during the past three years by James J. Rorimer. Some of the early results of his studies were published in an article, "Marble Sculptures and the Ultra-violet Ray," in the *Bulletin of The Metropolitan Museum of Art* for July, 1929. Subsequently Mr. Rorimer has extended his investigations to other materials employed by the artist. So much interest has been expressed both here and abroad in the possibility of using ultra-violet rays as a means of determining the age and condition of works of art that the present publication would seem to meet a definite need. It is presented, however, not as an exhaustive study of the subject but rather as an introduction to the methods of using the rays, supplemented by observations on the examination by this means of numerous objects of art in many different materials. It is hoped that these results will induce others to carry on further experiments.

Science has placed at the disposal of the expert various aids for the examination of works of art, such as chemical analysis, micrography, photography, examination by x-rays, and the like. To these may now be added as of established value the ultra-violet rays. For the layman a word of warning is perhaps desirable. None of these aids, invaluable as it may be — when used by the trained observer — in helping to establish identity and in recognizing fraud and repairs, is of itself endowed with intelligence. These aids supplement the discerning eye; they do not replace it.

JOSEPH BRECK
Assistant Director, and Curator of the Department of Decorative Arts

ACKNOWLEDGMENTS

FORTUNATE indeed is the experimenter who receives early encouragement. From the very beginning of my experiments with ultra-violet rays the late Edward Robinson, as Director of the Museum, gave such encouragement and showed a keen interest in the studies undertaken. I am greatly indebted to Mr. Robinson for the results of my work.

The wide experience of many colleagues on the staff of the Museum and their unfailing coöperation have helped largely to promote these studies. I wish especially to thank Joseph Breck, whose discrimination and untiring interest were of inestimable value in the preparation of this book, and Gisela M. A. Richter and her associate, Christine Alexander, for continued collaboration in the laboratory and assistance in preparing the manuscript.

Outside of the Museum I have had the generous coöperation of many experts. Among those who have contributed notably to my knowledge of the subject and have given freely of their time to the discussion of various problems are the following: George K. Burgess, Director of the Bureau of Standards; Ernst Buschbeck, Curator of the Department of Paintings, Kunsthistorisches Museum, Vienna; L. J. Buttolph, Engineering Department of the General Electric Vapor Lamp Company; Fernand Cellérier, Director of the Laboratoire d'essais, Conservatoire national des arts et métiers, Paris; H. A. Elsberg; Harold D. Ellsworth; Edward Waldo Forbes, Director of the Fogg Art Museum, and his associate, George L. Stout, in Charge of Technical Research, Harvard University; H. P. Gage and O. A. Gage, Corning Glass Works; F. Jablonsky; Arthur Jaffé of Max Jaffé, Vienna; Ernst Kris, Kunsthistorisches Museum, Vienna; Karl Smital, Director of the Department of Manuscripts, National Bibliothek, Vienna; Thomas Whittemore of The Byzantine Institute; and Robert W. Wood, Department of Experimental Physics, Johns Hopkins University.

JAMES J. RORIMER

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ULTRA-VIOLET RAYS
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CHAPTER I

ULTRA-VIOLET RAYS AND THE APPARATUS REQUIRED FOR THEIR PRODUCTION

STUDENTS of art are well acquainted with the fact that white light if directed through a prism is broken up into its component parts, and that the resulting visible spectrum, which contains the purest of colors, is the physical equivalent for the artist's palette. The scientist, however, with apparatus far more sensitive than the human eye,[1] is able to study and measure waves of light which go in both directions far beyond the visible spectrum. If it were possible to construct a universal prism of such a nature that all wave lengths of light were able to pass through it and be thrown upon a screen, as can be done with the visible portion of light rays, we should have the results indicated in diagram 1. The particular rays of light which have been the subject of our investigations are the ultra-violet rays.

The ultra-violet rays extend from the violet rays of the visible section of the spectrum (diagram 2), or from about 3,900 angstrom units (a unit denoting one ten-millionth of a millimeter), to the rays which begin at the end of a gap extending from the longest x-rays. Millikan was able to study ultra-violet rays as short as one hundred angstroms, but the short ultra-violet rays are of no practical consequence for the examination of works of art and are only rarely used by the scientist. The line of demarcation between the violet and the ultra-violet is not a frontier, either from a technical or from a theoretical point of view,

[1] Various tests have shown that certain observers can see rays which are invisible to others; I have found intense bands of light at approximately 3669 to 3653 angstroms readily visible.

as there is virtually no difference in the two types of rays. We shall use the term ultra-violet rays to denote the radiations which are used for our experiments, but, as we shall see shortly when discussing the practical production and segregation of particular rays, the bands of light used would have to be spoken of in terms of measurement rather than in a word concept to be accurately described from a physical standpoint.

In figures 2 to 4 are shown spectrograms and a chart based on rays from a quartz lamp, a very powerful light source. From a study of diagram 2, the relative positions and wave lengths of the ultra-violet, the visible, and the infra-red rays will be readily understood. When rays in the near ultra-violet ranging approximately between 3,000 and 4,000 angstroms[2] are isolated from the remainder of the spectrum, an invisible but very powerful light results. This light, dependent largely on the bands of light having wave lengths of 3669-3653, 3349, and 3138-3132 angstroms respectively, has the property of rendering the invisible visible.[3] This type of visibility is largely dependent on the fact that certain substances possess the peculiar property of emitting light, without any appreciable rise in temperature, which is usually of a different color from that of the exciting radiation. If the emission ceases as soon as the exciting radiations cease to fall upon the substance, the phenomenon is called fluorescence.[4] Throughout this book we shall use the term fluorescence even when other factors (as, for instance, the reflection of incident

[2] In addition, as can be seen in figures 2 to 4, certain bands of light as short as 2537 angstroms have been used for our studies.

[3] To discuss the probable reasons for photochemical and other reactions is the province of the advanced physicist. It is sufficient for our purposes to know that substances have a different appearance (and photograph differently) under ultra-violet light from that which they have in visible light, because of reflection, refraction, absorption, and the like of the exciting rays coming in contact with them. For further discussion, cf. Wood, *Physical Optics*.

[4] Or phosphorescence if this condition continues after the exciting radiation is removed.

violet rays) are present. Our experiments are based to a great extent on the fact that most materials used in the production of

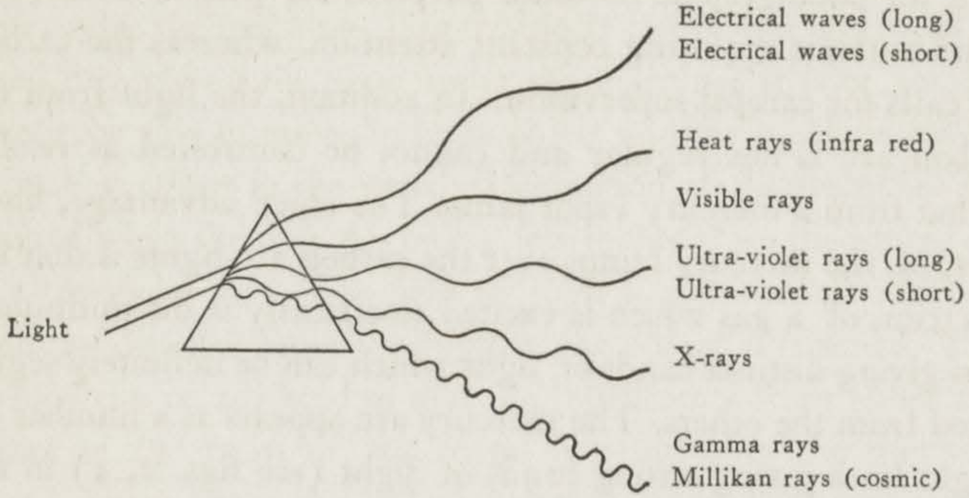

DIAGRAM 1. A DRAWING SUGGESTING THE PHYSICAL CONSTITUENCY OF LIGHT

works of art have individual fluorescences. In addition, most of these materials are changed by time and the elements (by physical and chemical disturbances), so that old substances tend to fluoresce differently from new ones. Inasmuch as the emitted

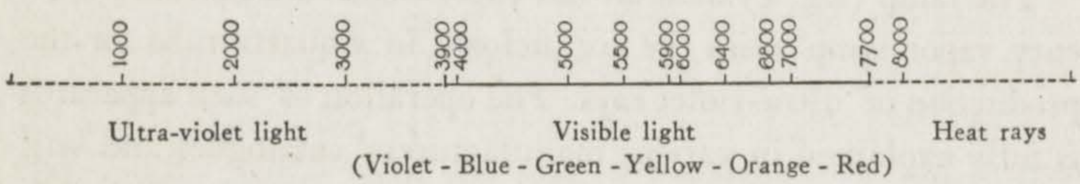

DIAGRAM 2. WAVE LENGTHS IN ANGSTROM UNITS INDICATE THE RELATIVE POSITIONS OF CERTAIN BANDS OF LIGHT

light is usually of a different color from that of the exciting ultra-violet radiation, we have here a most important basis for the examination and study of works of art.

The most common artificial sources of ultra-violet light are the carbon and the mercury vapor arcs. It has been our experience, as well as that of many scientists experimenting with ultra-violet light, that mercury vapor lamps are the most satisfactory for general use. They are particularly safe and may be left running for photographic or other purposes for periods of several hours without requiring constant attention, whereas the carbon arc calls for careful supervision. In addition, the light from the carbon arc is less regular and cannot be controlled as readily as that from a mercury vapor lamp. The chief advantage, however, of the mercury lamps over the carbon arc lights is that the spectrum of a gas which is excited electrically is discontinuous, thus giving distinct bands of light which can be definitely segregated from the others. The mercury arc appears as a number of bright lines giving strong bands of light (see figs. 2, 4) in the different parts of the spectrum. These concentrated lines are most effective for fluorescent and other ultra-violet ray studies.

Two types of mercury vapor lamps have come into use, but the efficiency and spectral distribution of the light evolved is essentially the same in both. Although the Museum cannot recommend any particular lamp, it seems advisable nevertheless to discuss the apparatus used for these experiments, so that the inexperienced person will have at least some starting point.

The lamp (fig. 1) used for our experiments is a standard mercury vapor lamp[5] with the arc inclosed in a quartz tube for the production of ultra-violet rays. The operation of such apparatus is fully explained in various manufacturers' catalogues and will not be discussed here. Before the lamp is used it should be allowed to run fifteen minutes for a maximum efficiency to be obtained. Ordinarily in visual examinations and always in the taking of photographs our machine is kept running at 85 volts and 5 amperes. We have adapted the lamp, as can be seen in figure 1, to Museum needs by constructing a bracket and shaft.

[5] There are several firms in America and in Europe which can supply suitable equipment. In Ellis and Wells, *The Chemical Action of Ultra-violet Rays*, several chapters are devoted to the subject of lamps.

Thus the lamp can be swung in all directions and can be raised and lowered so that it is usable for studying and photographing works of art of various kinds and sizes. Small objects can be placed on a table fitted with castors, and the table can be moved about under the machine; larger objects can be left on trucks or placed directly on the floor under the machine. It is of importance to be able to move both the object and the machine easily, for the best effects in the visual examination of fluorescences are obtained when the object is only a few inches from the source of the ultra-violet rays. The field of light is considerably reduced when the distance from the light to the object is lessened. The machine can be adjusted so that the light comes from either the bottom or the front of the metal box inclosing the mercury vapor burner; but as the light coming from the bottom is much stronger than that coming from the front of the burner, it is best to place objects in a horizontal position and use the front light only when an exceptionally large field must be covered, as for instance when one wishes to examine the entire surface of a large painting. It is important that ultra-violet ray observations be carried on in a very dark or, preferably, totally dark room. Besides, it has been found advisable in order to keep unfiltered rays from entering the dark room (and to safeguard the operator) to supplement the factory model of the machine by the addition of metal side pieces and cloth curtains, which allow for ventilation but restrict the stray light (cf. fig. 1). The upkeep, other than the cost of electricity, is practically negligible if the machine is properly handled and well oiled and the mercury burner washed in pure ethyl alcohol to keep it free from dust and dirt. For approximately the first five hundred hours there is no deterioration in the burner, but it is a matter of common experience that after the first thousand to fifteen hundred hours the burner loses from one-half to one-third of its initial efficiency. Burners with the proper accessories can be obtained for both direct and indirect electric currents.

We have already said that one must use isolated waves of light for the exciting of fluorescences and other ultra-violet ray reactions. To segregate these waves the most satisfactory method seems to be the use of glass filters containing fused oxide of nickel. These filters are placed in front of the source of light at the bottom or front of the box inclosing the mercury burner. The 5 mm. red-purple Corning Glass filter, Corex A, 986 A, and the Hanau filter have proven highly satisfactory for ordinary examinations (cf. fig. 2).[6] The former allows more visible violet light as well as more of the ultra-violet rays of short wave length to pass and is essential for many of the results which we have obtained. One of the reasons that European experimenters with ultra-violet rays have not arrived at certain of these results is that the filters they use do not segregate the same portions of the spectrum as does this valuable Corning Glass filter. The Hanau filter is especially useful for the examination of paintings, restored ceramics, and other painted surfaces. The table (pp. 51-53) referring to the photographs from which our illustrations were made will give a preliminary suggestion as to the filters used for the examination of various materials, but it is only as a result of individual experience that the need for different filters can be definitely appreciated. These filters ordinarily have unpolished surfaces, but for visual as well as photographic observations it is essential to have the rough surfaces polished. It is advisable also to have two filters of each kind available for comparison as to relative efficiency, for the filters are not absolutely stable, and a gradual deterioration is to be expected.

Objects of art may be examined visually under the ultra-violet rays, or they may be photographed. The value of photography comes not only from the permanence of photographic records and the possibility of indicating to others results which have been obtained visually, but also from the fact that certain re-

[6] For certain special examinations other filters may be used to advantage (cf. fig. 4).

actions are often recorded on the sensitive photographic plate more definitely than by the retina of the eye. In fact, some phenomena cannot be seen by the eye and therefore can be studied only in photographs. Ultra-violet light photomicrographs are often of great interest in special instances where results are dependent upon an examination of minute sections of material. It would be incorrect, however, to believe that photographic reproduction alone would serve in the examination of works of art with ultra-violet rays. It is very important in most instances that results arrived at photographically be confirmed by visual examination, for color, which is a most significant factor in ultra-violet ray reactions, is lost in the black and white photographs. Unfortunately color photographs are not possible and therefore the illustrations in this book are in many cases far less convincing than the results seen in the laboratory.

For the taking of ultra-violet light photographs, any camera can be used, although a view camera is preferable. All of the photographs reproduced in this treatise have been made with an F 4.5 anastigmatic lens. The use of a quartz lens has proved unnecessary in most of our work, for the most valuable results have been obtained with this ordinary, optically corrected glass lens. The relative transmissibility of a quartz lens and an anastigmatic lens is indicated in the spectrograms, figure 2. Panchromatic plates have been found in our experiments the most satisfactory[7] for photography in both incandescent and ultra-violet light. They have therefore been employed in the preparation of the photographs for this treatise.

For the photographing of reactions approximating those seen by the eye, it is necessary to filter out as many of the reflected, invisible ultra-violet rays as is practically possible — the photographic plate is extremely sensitive to these rays. Some of these

[7] An ordinary photographic plate is sensitive to wave lengths of light only up to about 5250 angstroms, whereas the photographic sensitivity of a panchromatic plate reaches about 7000 angstroms.

would be transmitted to the photographic plate even by the anastigmatic lens (cf. fig. 2), and consequently a filter is needed to cut off most of them.[8] Results with filters were far superior to those without. Two liquid filters among the many types and varieties experimented with have been found fairly satisfactory (cf. fig. 2). Two 10 mm. glass cells, one filled with a one per cent solution of ceriammonium nitrate in water, the other with a solution containing .5 gram of tryphenylmethane (obtained from the Eastman laboratories) to every 75 cc. of pure ethyl alcohol, were made. The table for photographs (pp. 51-53) shows which filter was used in each instance. The filter was attached to the board behind the lens. The table for photographs will also be of assistance in showing the actual timing, aperture openings, etc., used for the photographing of various materials.

We have frequently been asked if the ultra-violet rays, like the x-rays and radium rays, are harmful to the operator and if they cause damage to the objects submitted to examination. Ultra-violet rays having a wave length of about 3,000 angstrom units and less are deleterious, but as these are largely cut out by the filters used for ultra-violet light studies, there is little or no danger from burns and the other difficulties which are encountered when using light of short wave lengths. Burns are usually the result of lamps' being used carelessly without filters by inexperienced people desirous of obtaining sunburns. As there is some divergence of opinion as to the danger from burns carelessly incurred we may note that "Steinmetz observes that blood is practically opaque to the rays and on exposure of the body

[8] The Corning Glass filter, Noviol O (see fig. 3), cuts off rays shorter than approximately 3669 angstroms. As this filter is opaque to the most photographically active rays (as has been found in our experiments) it may be concluded that ultra-violet light photographs made with an anastigmatic lens (see fig. 2) are largely dependent on the action of rays of about 3669, 3660, and 3653 angstrom units on the photographic plate. This phenomenon accounts largely, in the writer's opinion, for the impossibility of recording on the photographic plate certain fluorescent effects.

thereto, the rays penetrate but slightly beneath the surface where they are absorbed by the blood. He also observes that complete recovery from ultra-violet burns may be extremely slow, taking months or even years for practically complete recovery and in some cases where the burn has been unusually severe some after effects, such as, for example, abnormal sensitivity to radiations of short wave length, may be practically permanent."[9] The Bureau of Standards in Washington has written us: "This Bureau does not attempt to advise on medical questions. We may say, however, that to our knowledge the ultra-violet rays do not injure the tissues permanently. In this connection, we would refer you to a recent publication by T. Howard Plank on *Actinotherapy and Allied Physical Therapy*." The Bureau of Standards further suggests "the use of greenish brown colored goggles (*e.g.*, Shade 2 or 3, Noviweld or Willsonweld glass) for protecting the eyes from ultra-violet radiation"; but goggles fitted with ordinary window glass[10] should afford some protection. Some people object to the strong smell of the ozone generated by the mercury lamp, and for this reason it is suggested that if the lamp is used considerably, an adequate ventilator or preferably an exhaust be placed in the laboratory dark room. Although the ozone is disagreeable, I cannot find, however, after thorough investigations, that ill effects have ever been experienced from a small quantity.

As the question of the possible injuries to works of art by ultra-violet rays is so vital, it seems advisable to discuss this subject in some detail. The effect of light on coloring matter and other unstable substances is, like other photochemical effects, very little understood. However, when ultra-violet rays are used in the examination of works of art there are certain definite, ascertainable conditions; with careful handling no injury what-

[9] Ellis and Wells, *The Chemical Action of Ultra-violet Rays*, p. 73.

[10] Unlike spectacles or eyeglasses made with so-called pebble or crystal lenses (*i.e.*, natural clear quartz).

soever should result. When a quartz mercury vapor arc is used, most of the ultra-violet rays of short wave length are cut off by filters and only wave lengths longer than approximately 2,500 angstroms (the bands below 3,000 angstroms, however, are very weak; cf. figs. 2-4) reach the object being examined. The ordinary examination lasts only three or four minutes, and the duration of a single exposure need never be longer than one hour and cumulatively not more than two or three hours.

In personal interviews, the following experts have definitely stated that they consider the use of filtered ultra-violet rays for the examination of works of art in no way harmful to the objects[11]: Dr. Colin G. Fink, Head of the Department of Electrochemistry, Columbia University, who is well acquainted with the science of ultra-violet rays; Dr. Ernst Buschbeck, Curator of the Department of Paintings, Kunsthistorisches Museum, Vienna, who at the present time is examining paintings under ultra-violet rays; R. Maurer, of the Academy of Art, Vienna, who has, for some time, been examining paintings in the Academy Museum under ultra-violet rays; Dr. Karl Smital, Director of the Department of Manuscripts of the National Bibliothek, Vienna, who has for several years been examining delicate manuscripts with ultra-violet rays and submitting them to exposures lasting several hours; Dr. Fernand Cellérier, Director of the Laboratoire d'essais, Conservatoire national des arts et métiers, Paris, who is examining paintings at the Louvre and has installed a laboratory in the museum for the examination of paintings belonging to the national museums of France; Professor Robert W. Wood, of Johns Hopkins University, who is an eminent pioneer in physical research; Dr. H. P. Gage, of the Corning Glass Works; and scientists and representatives of several companies experimenting and working with ultra-violet rays.

In the literature on ultra-violet rays it may be noted that Dr.

[11] Unless, of course, their colors are due to fugitive dyes which could be changed by a comparatively short exposure to sunlight.

P. W. Danckwortt, of the University of Hanover, in his recent and authoritative book, *Lumineszenz-Analyse in filtrierten ultravioletten Licht*, says that the second of the two chief advantages in the use of ultra-violet light is that the object examined is left absolutely unharmed.[12]

Edmond Bayle, Director of the Services de l'identité judiciaire de la France, and his coworker, Augustin Maché, Ingénieur E.P.C.I., in an article, "La Science au service de la vérité: L'Expertise scientifique des œuvres d'art," in *L'Illustration*, state that the use of optical and other radiations in general (including the ultra-violet rays) permits the observer to provoke certain phenomena which in no way alter the objects observed.[13]

L. J. Buttolph of the Engineering Department of the General Electric Vapor Lamp Company in a bulletin entitled *Uviarc Lamps and the Ultra-violet Ray* makes the following comment: "Ultra-violet light has been used for years in the routine testing of materials for their resistance to the destructive action of sun light. This component [the ultra-violet ray] is relatively much greater in the light of the carbon arc and the Uviarc[14] than in the light of the sun. . . . In general, materials are tested without the Uviarc filter and on the basis of one hour of exposure as equivalent to four days of direct sun light. In the case of the use of filters, three hours of filtered Uviarc exposure should be considered equivalent to one day of sun light."[15]

[12] See p. 69: "Zwei Vorteile sind es vor allen die diese neue Methode dem Gerichtschemiker empfehlenswert machen . . . . (2) Das zu untersuchende Objekt selbst bleibt vollkommen unversehrt."

[13] See the issue of September 28, 1929, p. 304: "Un point s'impose avant tout dans le choix des méthodes: la nécessité absolue de ne point détériorer l'objet expertisé. Le chercheur se trouvera donc naturellement dirigé vers l'utilisation de l'optique et des radiations en général, qui permettent d'observer et de provoquer certains phénomènes caractéristiques n'altérant en rien l'œuvre observée."

[14] A mercury vapor arc in quartz like the one used for our experiments.

[15] "Dyes and Dyed Materials," Item 34, p. 12.

In addition, samples of velvet were exposed to the ultra-violet rays created by our quartz mercury vapor lamp fitted with the red-purple Corning Glass filter, Corex A, 986 A, which allows rays as short as 2537 angstroms to pass. The samples were placed at a distance of six inches from the filter and exposed for a period of two hours. The upper part of each piece was covered by a piece of lead. The pieces were not in any way affected by this test, which was more severe than any examination to which works of art would be submitted. The colors were not absolutely sunfast, for with prolonged exposure to sunlight other samples of the same velvet had faded considerably.

With these preliminaries explained, we can now proceed to a study of the results obtained with the equipment described.

CHAPTER II

OBSERVATIONS ON THE EXAMINATION OF WORKS OF ART UNDER ULTRA-VIOLET RAYS

1. INTRODUCTION

SCIENTIFIC analysis is necessary in many cases for the determination of the condition and age of objects of art; it is also important in the study of technical processes. Magnification of what we see, either with a small pocket lens or with a microscope (or photomicrography for permanent record), and the obtaining of a completely different type of visual or photographic image by the use of light of various wave lengths (cf. diagram 1) are the most common physical methods for examining works of art.

Perhaps no method for the observation of widely varying phenomena is of such value as that using ultra-violet rays. Whereas in chemical and physiochemical processes it is necessary to remove particles of the substance of which the object is composed, in physical examinations this is not necessary. Besides, it is most useful and important to be able to study more than minute particles of the object to be examined. With such physical processes as those involving the use of ultra-violet rays it is possible to study not only small sections directly or photographically with a microscope but also large surfaces.

These rays cannot of course be used as a sort of magic to answer all kinds of questions, but they bring into view definite factors which are not to be observed in any other way and which, properly interpreted, can be used as evidence in arriving at conclusions. With practice and experience the experimenter perceives important phenomena which to the uninitiated may seem meaningless. As careful interpretation of the facts is requisite in order to obtain valid conclusions, it is most important to stress the need for laboratory experience. When unaccustomed to ultra-violet rays and their reactions, one should not attempt to make hasty or otherwise unqualified decisions. It must also be thoroughly understood that it is often necessary to carry out prolonged examinations in order to form definite and substantial opinions.

The use of ultra-violet rays does not supersede other methods of scientific analysis. While often the use of the ultra-violet rays is sufficient for the forming of conclusive decisions, it is also conceivable that the examination of a single object might involve the use of photomicrography, spectrophotometry, microchemistry, röntgenology, chemical analysis, and other processes.

Were it possible to devote even a few minutes to each reader of this book and to take him through several laboratory procedures, the following sections could be very much simplified. In describing the results to be obtained through examination by ultra-violet rays, we are definitely limited by the lack of accepted tables and measures and universal terms. As yet, accurate measurements of fluorescences and of reflected ultra-violet and color rays are not readily possible for the average experimenter. When we speak in terms of visible color, accuracy of definition is impossible.

We are largely dependent upon the visual observation of phenomena resulting from the exposure of works of art to ultra-violet rays rather than upon any formal physical measurement. In addition, the use of photography and photomicrography to aid in determining and comparing results is important. We cannot stress sufficiently, however, that the photographs which are used for the purpose of illustration in this book are frequently far less conclusive than are the visual examinations of the objects (cf. pp. 8, 9). In most instances color is the important factor, and black and white photographs[1] often give an erroneous impression of the situation (see notes 7, 8 on pp. 9, 10). For example, what is purple visually is usually white in a photograph, owing to the greater actinic activity of the shorter wave lengths. Conversely, reactions which appear as yellow or green are comparatively less active photographically and are dark in a photograph.

2. STONE

a. Marble

Perhaps no works of art through the ages have been so sought for and cherished as fine white marble sculptures. The temptation to produce forgeries, to copy, or to repair has attracted skillful artists and artisans. The forger either creates an object in imitation of the old with the intent to deceive or revamps an inferior old piece. The restorer sometimes exceeds the proper limits of his craft. Patinas are obtained by treatment with acid, with solutions of silver nitrate or of green vitriol, or perhaps by burying or baking.

Fortunately, the expert can base his judgment of marble sculptures on certain ascertainable conditions to be found in old marbles which it would seem impossible for the forger and restorer to duplicate. With continued exposure the surface of marble is changed. Gradually, because of penetration from the surface, a chemical and physical action proceeds a short distance into the body of the marble. It is this qualitative change, which varies according to the age and exposure of the piece, that we shall speak of as *penetration.*

[1] Color photography of reactions stimulated by ultra-violet radiations is practically impossible.

In this connection Professor A. P. Laurie writing on "Art Forgeries in Marble" to *The Times* (London) on December 5, 1928, made the following significant observations:

"A short time ago I had the opportunity of analyzing samples taken from a drill put into the interior limestone of Lincoln Cathedral. The analysis of these samples, taken at different depths, proved of considerable interest. In the first place, they showed the extent to which the sulphur gases in the air had converted the carbonate of lime into sulphate of lime, the percentages being 4.3 at one-quarter of an inch depth, 4 at one-half inch, 3.7 at three-quarters of an inch, and 2.4 at one inch. An analysis of the limestone fresh from the quarry, which was still being worked, out of which the cathedral has been built, showed that it was practically free from sulphate of lime. We get here, then, a change which must have taken a long time on the surface of the limestone which has been exposed to atmospheric conditions.

"It might be argued, however, that the extent of this change depended not so much on time as on the amount of sulphur acids present in the air owing to the burning of coal; but another change had also taken place due to the universally distributed carbonic acid gas, this being found in excess of the amount required to form carbonate of lime in the outer layers of the stone, being present in excess in the first quarter of an inch to an amount of 4.2 per cent, at the depth of half an inch 4 per cent, and one inch 1.1 per cent.

"It is evident then that the limestone has been slowly absorbing and combining with carbonic acid gas, which must be entering from the surface. It is therefore probable that, if drills were made into marble monuments of known age and the excess of carbonic acid gas present in combination at different depths were made (*sic*), an approximate indication would be obtained as to how long the changes took, and it should be quite easy to recognize a modern forgery by the absence not only of sulphate, but also of an excess of carbonic acid gas. There should be no difficulty in finding a place to make the drills which would in no way injure the statue."

Although the aging of marble and limestone (both are calcium carbonate, $CaCO_3$) may depend at times upon this chemical disintegration suggested by Laurie, or some similar one, it is more probable that the phenomenon of penetration is due largely to a physical change. Although this is an interesting problem, it is beyond the scope of this book.[2] Moreover, not only would the determination of the age of objects in marble by a method involving qualitative analytical chemistry be too difficult a procedure under ordinary conditions, but also the examination of an object would be restricted to a limited portion, whereas a physical examination of marble with ultra-violet rays permits a study of the entire surface. As a supplement to ultra-violet ray methods, chemical analysis is always available. Where it is desirable to study penetration, it is usually possible to examine breaks or fractures, which appear in almost all marble monuments. In rare instances it may be necessary to take a small and inconsequential chip from some unimportant part of the object (cf. fig. 14, which shows a piece of marble chipped so that the penetration could be studied).

Under ultra-violet rays (segregated by the use of the red-purple Corning Glass filter, Corex A, 986 A) old marble is different from freshly cut marble and from old marble which has been recut. Freshly cut marble exposed to this light appears a uniformly intense purple, whereas old marble is mottled white,

[2] The writer is indebted to Dr. F. Jablonsky for the investigations he has carried out along these lines. Dr. Jablonsky finds that the change in marble, as well as in other stone, is due to changes in crystalline structure. Therefore, he believes that the exterior surface of marble is gradually changed, owing to a release of what he calls "mountain pressure." When marble is removed from the mountains and comes in contact with light and other external influences, it tends to expand, the expansion beginning at the surface and proceeding towards the interior.

or white with yellow and blue tones. Organic and other substances on the surface of old marble may fluoresce or reflect the purple rays, thus interfering with normal conditions. For this reason it is often imperative to clean[3] small sections of the marble before completing a satisfactory examination.

A cross section of a block of Roman marble (fig. 5; an architectural fragment) resulting from a comparatively recent break (perhaps fifty years old) shows the condition of natural aging. Penetration, averaging about 3/16 of an inch, has occurred around the outside of the block. Although invisible in ordinary light, in ultra-violet light this is to be seen as a white band surrounding what was originally, before the break, the interior, unexposed part of the marble, which now appears as purple. The opposite end of the block (fig. 6) must have been broken many years ago, as the center of the field is no longer purple, but is more nearly white, like the band of penetration. By chipping a small corner of the block, the depth of the penetration from this more recent surface can be determined. The photograph reproduced in figure 6 shows approximately the penetration, but actual laboratory experience is necessary before a complete understanding of the phenomenon is possible.

To the eye the marble used for the head of Harmodios and for the female head, which are shown in figure 7a, appears virtually the same in ordinary light. When the marble is examined under ultra-violet rays the eye detects differences in color which are significant, confirming the conclusions reached on the basis of stylistic reasoning — that the Harmodios is a Roman copy of a Greek work of 477-476 B.C., the female head a forgery, or rather, a recut archaic head which has been so altered stylistically as to be in the same class as an outright forgery. The photograph of the two pieces under ultra-violet rays (fig. 7b), however, does not reveal this difference, for it shows a considerable penetration in both pieces. For evidence we must turn to the colored

[3] Preferably with pure water.

plate, figure 8, made from an ultra-violet light photograph of a three-quarters back view of the female head, colored to approximate what may be seen in the laboratory. The white band of penetration (running vertically) has been cut through, and in other parts of the head the outer shell of penetration has been cut away. This would indicate that such sections of the head as are approximately white are anciently cut, but that the neck, the part of the face shown in the photograph, and some of the hair have been recut. If this were the old surface, there would be no cutting through the exterior "shell," and the entire surface would be white. It was necessary to wash part of the surface to remove the "antiqued" dirt patina which is also purple under ultra-violet rays. The eyes, the forehead, the ears, the neck, and parts of the hair (fig. 8) have been recut, a fact which accounts for the stylistic discrepancies. Certain portions have their original surface, and the breaks of the nose, lips, and chin are antique breaks.

In a recent article entitled "One or Two Statuettes of Diogenes?"[4] Gisela M. A. Richter concludes upon stylistic and other grounds that the Diogenes (figs. 9, 10) in the Metropolitan Museum is the work of two different periods: the base, the two feet and parts of the left leg, the tree trunk, and the hind part of the dog being a Roman copy of a Greek original; the remainder a restoration executed before 1765 when the statue was published by Winckelmann in his *Monumenti antichi inediti.* As Miss Richter points out, when examined under ultra-violet rays "the parts which we consider ancient present a distinctly different appearance from the rest; they are more mottled and this mottling seems ingrained in the marble, not superficial as in the other portions. Thus both the physical and the stylistic examination indicate that the whole upper part of the statuette is of more recent date; only the base and the portions in one piece with it go back to ancient times."[5] A close study of the

[4] *Metropolitan Museum Studies*, vol. II, part 1, pp. 29-39.

[5] *Op. cit.*, p. 37.

ultra-violet light photographs (figs. 9, 10) indicates the difference in aging of ancient marble and marble cut sometime before 1765. It is interesting to note the difference in shade between the old left foot and the old portion of the left leg. They are part of the same piece of marble, but part of the old leg was chiseled away when it was joined to the new portion, which is considerably lighter in the photograph. To the eye those portions of the statue which photograph whitest are the most vividly purple under the lamp (cf. p. 17). If it had been possible, it would have been desirable to take off one of the arms and examine the cross section for the penetrations. As this was not practicable, we had to content ourselves with an examination of the penetration where some of the cement filling the joint could be removed. The penetration at this point was in keeping with our other conclusions.

A twelfth-century marble capital from the south of France (fig. 11) was compared with a freshly cut block of marble from the same region. The new block was almost completely purple (white in the photographic rendering), whereas the surface of the old block was mottled in shades of white and yellow and of blue interspersed with some purple tones. A new break in the recently cut marble showed no penetration; a break of comparatively recent origin in the capital showed the expected penetration.

Examined by the eye in ordinary light the Italian fifteenth-century marble bas-relief illustrated as figure 13a appears intact. When placed under ultra-violet rays one sees that the relief has been broken and skillfully repaired. The new portions under the ray are a vivid white, due to the fluorescence. The extent of the repairs is indicated by the areas outlined by black lines drawn on the ultra-violet light photograph, figure 13b. The relief, once removed from its wood frame, could be examined on all sides. As it had been broken, it was possible to examine the break minutely for penetration. A photomicrograph (four magnitudes) of the break from the side (fig. 14a) shows the condition of penetration. The repair had been made by actual piecing with marble, the surface then being finished with enamel paint to imitate the old surface. Under ultra-violet light the penetration of the marble relief (fig. 14b), as well as that of the small piece of marble used for the repair, was determined. It appears that this Renaissance marble relief was broken many years ago as the marble of the repair shows considerable penetration.

The above experiments are typical of several hundreds which cannot be described here in detail. As in the following sections, it must suffice to state that the experiments conducted have been sufficiently numerous and definite to warrant the statements made. In the case of marbles the recognition of forgeries, of reworkings of old marble, and of restorations has been possible.

b. Alabaster

Alabaster, which is a sulphate of lime ($CaSO_4 . 2H_2O$), has been used extensively for works of art. Like marble, alabaster tends to age with exposure to the elements. It loses the unpleasant white surface which it has when it comes from the quarry and gradually is mellowed, turning to a soft, yellow color. Alabaster undergoes a change which is physical rather than chemical. Moreover, alabaster, being a substance less dense than marble, ages much more rapidly. Although the phenomenon of penetration exists in old alabaster as in old marble and shows similarly under ultra-violet radiation, it is more difficult to decide what amount of penetration to expect in alabasters of given periods. In such objects as Egyptian alabaster vases and ointment jars, which were made with thin walls, penetration as such does not exist, for the entire body of the alabaster has been transformed with age. In these and similar cases breaks, whether ancient or recent, have the same tendencies to fluoresce white as the original surfaces.

A photograph of a fifteenth-century alabaster (fig. 12) taken under ultra-violet light shows that the lower part of the relief, which is a restoration of many years ago, has a different appearance from the upper part, which is original. To the eye, the relief when seen under ultra-violet rays is white to yellow in color in the upper part and approaches a purple tonality in the lower part. The lower portion of the relief has aged uniformly.

Ultra-violet rays are thus often useful for determining modern forgeries of objects in alabaster and for finding restorations. Often alabaster approaches the denseness of marble and even its chemical composition.[6] In such cases the procedure is similar to that indicated when examining marble.

c. Limestone

Limestone, because of its homogeneous structure and comparative durability and the ease with which it can be worked, has always been a favorite material of the architect and the sculptor. Like marble, it is a formation composed chiefly of calcium carbonate, though it is not in a crystalline state but is rather a sedimentary rock which has not undergone metamorphism. It must be remembered that there are many varieties of limestone differing widely in purity, texture, hardness, color, and the extent to which they exhibit their organic origin.

As in the case of marble, a gradual change (see p. 17), beginning at the surface and penetrating slowly towards the interior, takes place in limestone. With age an outer "shell" is formed, varying according to the exposure. Consequently in old limestone sculpture we can expect to find a characteristic penetration. This condition of penetration, although not always so easily distinguished in limestone under ultra-violet rays as in marble, is most important for the detection of restorations, recut surfaces, and forgeries. Restorations made with plaster, with

[6] Calcium carbonate ($CaCO_3$) although it is still called alabaster.

ground stone in a cement form, or with pieces of actual stone fitted to the original objects can be distinguished either under ultra-violet light or in ultra-violet light photographs, and sometimes in both. Restored parts and additions, even when the lines of joining are concealed by plaster or paint, become visible under ultra-violet rays, since the fluorescence of such restorations will usually vary considerably from that of the original stone. Certain kinds of restoration and their exact areas are not readily discerned even under the rays, but in such cases ultra-violet light photographs[7] give most satisfactory results.

In figure 15 the cross section of a sixteenth-century French limestone capital, from a known source, which was cut recently (1929) from a larger piece, is illustrated. This fragment affords an example of characteristic penetration in a piece of sculptured limestone which has been exposed for several hundred years, and is here used to show the phenomenon already demonstrated in the case of the marble block (fig. 5). As the penetration could not be photographed properly, we marked it with chalk while the block was under ultra-violet rays. To the eye the penetration appears as a white line similar to the chalk line in the photograph, and the other parts of the cross section as intense violet in color. The exposed parts of the capital were those indicated by the penetration, which averages ⅛ of an inch. The cross section itself represents the interior and shows no penetration from the unexposed parts of the capital. The break (on the left in the photograph), where the capital broke away from the pilaster of which it was a part, shows no penetration as this was not an exposed surface and did not undergo any change.

A limestone statue, illustrated in part in figure 16, was reconstructed in a peculiar manner. An examination with ultra-violet rays made definite conclusions possible. The section of the neck (fig. 16) marked by vertical lines on the ultra-violet light

[7] Owing to the action of the invisible ultra-violet rays on the photographic plate, which is more sensitive to these rays than the human eye.

photograph was first cleaned with benzine to remove the superfluous modern paint which had been applied by a restorer to cover the plaster joint, indicated by two horizontal lines. As is demonstrated in the ultra-violet light photograph, the head above the break is of a different and much darker stone than the lower portion of the body. It is not possible that this was an original break; stone does not break conveniently into two calcareous rocks which are different physically and chemically. It follows, therefore, that the two portions are not of the same period. Further examination of the cross sections of the break, following the theory already suggested in regard to the limestone capital (fig. 15), showed that a modern head had been added to an old figure — the lower part of the neck had the proper amount of penetration, which fluoresced more than the inner part of the stone, whereas the upper part of the neck was without any penetration whatsoever.

In figure 17, which shows part of a bearded head of the Chartres school, is illustrated a type of repair which, though visible in photographs made with ultra-violet radiation, cannot be seen either in ordinary white light or under ultra-violet radiation. The careful restoration is easily discovered in the ultra-violet light photograph, although even with a microscope and strong light the extent of the repairs cannot be determined. The nose, parts of the moustache, and the lips, as well as the upper part of the beard, are restored in a cement made from ground stone identical with that of the sculpture. The details were cut in the cement. In the ultra-violet light photograph the texture and the modeling of the restorations appear different from those of the original; in ordinary light these differences are not apparent. Color plays little part in this experiment. Variations in texture are accentuated under the ultra-violet rays sufficiently to indicate restorations. This is probably explained by differences in reflection and refraction (see p. 4, note 3).

d. Sandstone and Granite

Sandstone and granite undergo relatively very little change through exposure to the elements. They are composed mainly of such hard minerals as quartz and silica, and there is no apparent reason why one should expect a transformation on which a process of ultra-violet light examination could logically be based. In some cases, however, where the outer surface has changed (at times a slight penetration has also occurred) it has been found practicable to examine objects in these materials for recutting. Restorations can be discovered, just as in the case of other stone sculptures, owing to differences in chemical content or physical structure.

e. Precious and Semi-precious Stones

Our research has not been carried very far in this field. We have found, however, that jade, usually a greenish silicate, ages in much the same way as does marble or limestone. Recently cut jade is uniformly bright and intense under ultra-violet rays, but older specimens show definite signs of aging akin to those described in the discussion of marble sculpture.

A great deal has been written about the fluorescence of precious stones and the lack of fluorescent properties in imitations. Our superficial investigations have lead us to believe that the greatest care must be exercised in reaching decisions about this class of material on the basis of examination with ultra-violet rays. Precious stones vary considerably owing to impurities which are found in stones from one region and not in those from another. Some genuine diamonds, for instance, do not fluoresce, whereas others fluoresce brilliantly. The same situation seems to exist in the case of emeralds, rubies, and many other precious stones. As a rule, however, glass and paste products reflect ultra-violet rays, whereas precious stones have a tendency to fluoresce.

3. IVORY AND BONE

Ivory, because of its fine texture and its comparative stability, has been a favorite material of the artist since prehistoric times. In quality it rivals fine marble, and like marble it becomes mellow with age, ranging in color from light yellow to deep brown. Ivory, which is chemically between horn and bone, has an organic matrix richly impregnated with calcareous salts. The size of its tubes, or blood passages, which are smaller than those in bone, accounts for its finer grain. The pores are filled with an oily substance, which often dries up when ivories are not properly cared for.

Our only scientific approach to the dating of ivory objects must necessarily depend on phenomena of aging. Of course these vary according to the exposure, the kind of ivory, and numerous other factors. But we have found that the use of ultra-violet rays affords a method for determining both visually and photographically the relative degree of aging (appearing largely as a surface condition, the penetration being only very slight) of a particular piece, and consequently for distinguishing a recently carved ivory from one of greater antiquity. Although we do not know definitely the reason for the aging of ivory other than that some change, possibly analogous to that in the case of marbles, takes place, it appears that the condition of natural aging, whatever the cause, is identical for almost all ivories. In other words, we have a factor which, for ivories seen under the ultra-violet rays, causes distinctive reactions to occur. Ivories which have been artificially patinated with tobacco juice or bitumen or by being placed in manure, burned, carried under one's garments next to the skin, or even swallowed by turkeys, can readily be distinguished from naturally aged ivories under ultra-violet rays. (For the examination of ivories the same Corning filter as that used for the study of marble is recommended.)

The frontispiece is reproduced from a photograph which has been colored to suggest the actual appearance of an ivory plaque under ultra-violet rays. Both ordinary and ultra-violet light photographs are shown in figure 18 so that a thorough study of this representative piece can be made. The comparatively modern frame, though white in the ordinary photograph and in the original, is definitely purple under ultra-violet radiation. The background, including the crucifix, on which this superb fourteenth-century French relief carving has been mounted, is somewhat more yellow than the comparatively modern frame. The old ivory carving itself fluoresces vividly in mottled yellow tones. Those parts of the drapery which are blue-purple in the colored illustration, three finger tips and Joseph's left foot, are restorations contemporary with the background. The rosette was undoubtedly carved at this time from what was originally a skull; and part of the ground and the tip of Nicodemus's right shoe have been changed slightly by cutting. In this regard it must be remembered that unlike marble or limestone there is almost no penetration in old ivories, and as the patina is really only surface deep it can be scraped away. In black and white an ultra-violet light photograph (fig. 18b) of this piece shows the old sections to be very much mellowed, the surface photographing dark with more noticeable high lights than are found in the new pieces. This distinction can best be appreciated by a study of the other illustrations of old ivory objects photographed under ultra-violet rays.

To illustrate what can be accomplished with the photography of ivory objects under ultra-violet rays and to understand what is meant by the mellow quality which old ivory has in ultra-violet light photographs, it is important to study figure 19, a and b, very carefully. In the ordinary photograph (fig. 19a) the spurious ivory on the left which was inspired by a Byzantine ivory of the twelfth century in the Victoria and Albert Museum, London, and the South Italian ivory box of the eleventh to the twelfth century appear similar in color and surface quality. Under ultra-violet rays the forged plaque is intense purple in color; the genuine box becomes a mottled, yellow tone, for the ivory fluoresces brilliantly and reflects very few purple rays. In the ultra-violet light photograph (fig. 19b), the plaque photographs only slightly darker than in ordinary light; the box is much darker except where the high lights are strongest. An examination of a great many ivories indicates that this mellow quality in photographs, which is a yellow color to the eye, is characteristic of old ivories, although of course it varies with the exposure and the particular treatment of the individual piece. New pieces and freshly cut ivory are invariably purple under ultra-violet rays unless they have been superficially treated. In such cases, the patination can be removed with water or some other solvent. In the case of ivories of considerable age, a genuine patina cannot be washed off, although it can, as already shown, be scraped away.

Among the ivories examined was a French Madonna and Child of the fourteenth century. Figures 20 and 21 are from photographs of the upper part of this large ivory statuette under ultra-violet light. The Virgin's right hand and the Child's head and the upper part of His shoulders appeared purple under the rays, whereas the remainder of the group was primarily yellow in tonality. From this point definite conclusions were not difficult. The hand was a restoration. The Child's head and neck (fig. 21), which had been so securely and deftly attached to the body that it seemed impossible to believe that they were not all carved from a single piece of ivory, were seen to be restorations, as is evident as well on stylistic grounds. The upper part of the Child which photographs white and appears as purple under ultraviolet rays had been scraped, thus removing the old patina. This was undoubtedly done so that the neck and head and the upper part of the Child would seem identical in color and texture.

The Chinese ivories illustrated as figure 22 offer an interesting opportunity for comparisons. In the ordinary photograph they are all approximately the same color. The ultra-violet light photograph substantiates conclusions reached on the basis of other reasoning: that the brush holder is from the nineteenth century, the bottle from the seventeenth or eighteenth century, the two small figures from the twelfth century, and the Kuan Yin from the nineteenth or twentieth century. The holder, which is relatively modern, is a deep purple under the rays and thus photographs white; the bottle has not taken on the same "quality" of age as the two twelfth-century figures, which are yellow to the eye and mottled in the ultra-violet photograph. The Kuan Yin (on the right), which fluoresced an even brown color and photographed uniformly dark, is a nineteenth-century work which has been "aged" artificially by being dipped in some brownish liquid to imitate early pieces which would have turned dark through natural aging.

Bone generally reacts like ivory, but as its composition varies so decidedly with individual pieces none of the experiments with this material are illustrated. With sufficient precaution, ultra-violet rays can be used in determining the age of most objects carved in bone.

4. CERAMICS

The restorer of fragile ceramics is unequaled in cleverness. He can so put together a few small fragments with plaster as to suggest that no pieces are missing but merely that a broken object has been repaired. Skillful restorations of many kinds of ceramics may deceive even the best connoisseurs. In the detection of such restorations ultra-violet rays are of great value — at times indispensable.

The spurious piece is rather less of a problem than the restored one. An expert, knowing his particular ware, can generally determine without the use of ultra-violet rays whether a questioned piece is a reproduction. Usually he is able to compare a doubtful piece with unquestioned originals; also his knowledge of typical forms, decorations, and physical characteristics helps him to distinguish the genuine from the spurious. Generally, however, ultra-violet rays can be most helpful in making comparisons, as the imitations may differ in body and glaze from the originals and, consequently, may have a different appearance under ultra-violet light and in ultra-violet light photographs. Furthermore, there may be surface alterations, due both to age and usage, which cannot be duplicated in the imitation.

A thorough discussion of the various kinds of ceramics with their chemical compositions is not essential to a general understanding of the possibilities offered by ultra-violet rays for the examination of this class of material. The comparatively numerous illustrations with descriptions in this book should make it possible for any one, even without scientific knowledge, to study ceramics by ultra-violet light — by photography if necessary or simply by visual examination of their different fluorescences.

A sixteenth-century maiolica bowl (fig. 23a) was broken in three pieces, which were subsequently put together with the lines of joining concealed by paint. The colored ultra-violet light photograph (fig. 23b) shows the extent of the restorations, which appear as bright colors against the non-fluorescent purple luster of the original. Restorations in ceramics generally fluoresce brilliantly, as in this case, under ultra-violet radiation. In most instances restorations in ceramics can be studied better under the rays, because of the color factor, than in ultra-violet light photographs.

When the restorations have not been made with fluorescent materials, as in the case of the restored Persian bowl of the ninth century shown in figure 24, the use of ultra-violet light photographs is more satisfactory than is a visual examination under the lamp. It will be observed from the ordinary photograph that the restorations are not readily distinguishable, so perfectly has the restoration been carried out. The next illustration (fig. 24b) shows the bowl as recorded photographically under ultra-violet rays. The restored parts[1] and the background both appear a vivid purple to the eye but the restorations photograph as patches lighter than the background. It will be seen that the bowl was composed from many fragments, the missing areas having been filled in where necessary. The repaired parts were then painted to simulate the original surface, even the crackle being imitated by incised and painted lines.

Another example of restoration, as revealed by ultra-violet rays, is shown in figure 25. The lower part of the rim and of the body are restored in plaster, and the decoration is completed with painting.[2] To know definitely what parts are restored in such a piece as this, in which the inscription may be important, is of great value to the scholar, since a restored inscription, unless recognized, may lead to erroneous conclusions.

Less than one half of the fifteenth-century Italian bowl of glazed pottery (fig. 26), which has become iridescent with time, is old. The restorer has taken fragments of a bowl and built up the missing parts in plaster, carefully imitating the relief decoration and simulating the glaze with paint and varnish so skillfully that even a most careful examination fails to reveal the modern work. Under ultra-violet rays the bowl fluoresces brilliantly, but the old sections are a dark purple and photograph as light patches (fig. 26b).

A seventeenth-century Turkish tile had been broken[3] and was in the condition shown in figure 27a, except for the disfigured portion in the upper right-hand corner and the break which

[1] Metallic lusters are almost always non-fluorescent, whereas restorations, usually executed in plaster and paint, fluoresce brilliantly.

[2] The lack of sharpness is due to the reflection of the ultra-violet rays; the dark area on the upper rim is a shadow, not a restoration.

[3] When the tile was first examined under ultra-violet rays, the repairs were completely covered over with paint, but some of this was removed before the photograph was made.

passes through it. The exact condition of the restorations is shown in the ultra-violet light photograph (fig. 27b). These restorations appear against the purple background much as do the restorations in the maiolica bowl (fig. 23b). Figure 28 shows the tile after all the oil-paint restorations had been removed; the repairs are less extensive than might have been expected in view of the excessive restorations. The tile has now been restored (fig. 29) so that the damaged places do not destroy the general effect, but the actual state of the restorations is not concealed.

As already stated, ultra-violet rays are most useful for the comparison of ceramics of a given manufacture or period and for the consequent detection of spurious pieces. The possibilities of this kind of examination are virtually unlimited. A discussion of one of our experiments will suggest a method of study which, when applied to other cases, has proved most helpful. In the photograph (fig. 30) are four pieces of delftware which are superficially similar in color, texture, and the like, and purport to be of the seventeenth century. To begin with, an ultra-violet light photograph (fig. 30b) indicates that the large jug is slightly restored, as shown by the black patches on the handle and on the rim. In the ordinary photograph (fig. 30a), the three pieces to the right, which are genuine, are decorated with colors which photograph less intensely than do those of the large vase, which is spurious. On the contrary, in the ultra-violet light photograph (fig. 30b), the situation is reversed, and the decoration of the genuine pieces becomes more intense and uniform, that of the imitation pale and uneven.[4] The fluorescences of the white glaze and of the red, blue, yellow, and green colors in the decoration of the genuine pieces are conspicuously different from the fluorescences of the imitation. The individual colors can often, as in this case, be studied best by ultra-violet light photomicrography or directly under the rays with a hand magnifying glass.

[4] Note especially the blue colors as seen on the bulge of the stem.

5. TEXTILES

Reproductions, imitations, forgeries, and restorations make connoisseurship in textiles a most difficult problem. The fact that works of art in probably no other material are so subject to destruction largely accounts for the comparative rarity and poor state of repair of old textile fabrics and the consequent temptation to falsify them.

To attempt a thorough discussion of textiles and their reactions under ultra-violet radiation would, as in the case of ceramics, require more consideration than is possible here. There are so many types and varieties of textiles that it would seem preferable to discuss certain of our observations and the possibilities suggested thereby rather than to attempt an exhaustive study in a field which will perhaps at some time be the subject of investigation for a specialist in textiles. As the field is complicated from the point of view of techniques (*i.e.*, fabric weaves, dyestuffs, etc.), only the most general discussion is relevant. It is to be remembered when examining textiles under ultra-violet rays that the reactions may be influenced by immersion in or contact with foreign substances, which may destroy the evidence of age. As a rule, however, the ordinary processes of cleaning affect the situation but very little.

Under ultra-violet rays textile fabrics react variously depending on their chemical constituents and their physical[1] structure (threads, weaves, etc.). As a rule most old textiles, which have been used and exposed, fluoresce less than more modern ones, which fluoresce intensely since they still retain their original vitality. Although the disintegration of textile fabrics, including dyestuffs, is not fully understood, the chief factors causing the change in old pieces would seem to be light, air, heat, and humidity. These cause alterations which are partly chemical and partly biological, the chemical action being in the nature of oxi-

[1] Various weaves and surface structures reflect the waves of light differently (see p. 4, note 3).

dation, and the biological effects being brought about by bacteria and fungi. The weakening of cellulose threads in silk through oxidation is due chiefly to rays having wave lengths of less than 4,000 angstroms; changes in cotton and linen are also due to oxidation; but wool is less sensitive than cotton, linen, or silk to chemical change resulting from the action of light.

There are, then, definite conditions, although their causes are not always ascertainable, which we may expect to find in old textiles but not in more recent ones. The dyes, as a rule, will fluoresce less after exposure than before; there will be indications of wear on the surface; there may be repairs in an old piece; and so on. These conditions are not properly reproduced in an imitation. Under ultra-violet rays these characteristics are usually far more apparent to the eye, or to the camera, than in ordinary or artificial light. Restorations, often made with threads colored or dyed with aniline instead of mineral or vegetable dyes are easily distinguished from old sections by their different fluorescences.

A few specific illustrations of the results to be obtained with ultra-violet rays in the examination of textile fabrics will suggest the kind and variety of conclusions which may be reached by this process.

Two pieces (fig. 31) of silk[2] of identical pattern, in original factory condition, afforded an opportunity for making interesting comparisons. The smaller piece is an exceptionally well-preserved eighteenth-century original; the other is a reproduction made some years ago, as accurately and carefully as was possible with modern methods, in Lyons in commemoration of the factory's anniversary. The condition of the old piece is so fresh that any observer would have said that both pieces were probably made in the nineteenth or twentieth century, but under ultra-violet radiation a difference is readily perceived. The eighteenth-

[2] From the manufacturers' sample books.

century fragment fluoresces quite differently from the reproduction. Even the black and white photograph taken under ultra-violet rays (fig. 31b) shows clearly the dissimilarities. In the ordinary photograph (fig. 31a) the differences are practically indiscernible. In this case, since the early piece is so well preserved, it is not usage and exposure which cause dissimilarities in the two pieces, but inherent differences in the textiles.

Two of the three textiles illustrated in figure 32 are Spanish of the fifteenth or early sixteenth century. The third specimen, the bottom piece in the illustration, although similar in type, reveals a different handling of the design which may indicate a somewhat later origin, perhaps of the seventeenth century. Examination of the three specimens under ultra-violet rays would seem to confirm this belief. It will be noticed in the ultra-violet light photograph (fig. 32b) that the piece in question reacts differently from the other two. Its colors fluoresce for the eye much more vividly than the other two.

A frame containing six wool fragments, supposedly German and of the sixteenth or seventeenth century, is shown in figure 33. A study of these pieces under ultra-violet rays showed that three of them (those photographing without marked contrasts; fig. 33b) did not react as old pieces should. Further examination without the use of ultra-violet rays showed the diagnosis made with them to be correct, namely that these three pieces are of more recent date than the others. The three reproductions had all received the same treatment of dipping to "age" them. Although the pieces photograph uniformly from the point of view of tone, their colors are all dissimilar and their designs are not the same.

As has been previously stated, the ultra-violet rays are invaluable for determining restorations in this class of material, particularly as it is possible to photograph the object under ultra-violet light and in this way to obtain a more certain record of the position and extent of repairs than is procurable when examination is confined to the more usual methods (use of microscope and touch).

Figure 34 shows not only restorations in a sixteenth-century tapestry, but also the quality of an old tapestry under ultraviolet radiation. Some of the restorations had been marked on the tapestry before the photographs were taken, and, although the tapestries had been carefully brushed so that the traces of the chalk marks could not be seen under white light (nor are they to be seen in the ordinary photograph), they were brought out in the ultra-violet light photograph. New threads, both those used to reinforce the tapestry and those used in the restoration of entire sections, are lighter in the ultra-violet light photograph (fig. 34b) than the old threads and more purple to the eye under the rays.

In an ultra-violet light photograph (fig. 35b), the restorations in the border of an Oriental rug appear as light patches. For comparison an ordinary photograph is illustrated in figure 35a.

6. PRINTS, DRAWINGS, AND PALIMPSESTS[1]

a. Prints and Drawings

In estimating the value of a print or drawing, excellence of condition is often considered a primary requisite. The desire for perfection has given the restorer, with his paper patches and paste, pen and ink, bleaching powder and acids, not to mention many other materials, a reason for developing a masterly technique. Tempted by his successes, he may make unwarranted restorations, as for instance the improper insertion of a missing page in a rare book or the dishonest fabrication of a print by using a discarded block and old paper. Simple changes, such as pen and ink work to disguise faded or otherwise damaged lines

[1] In view of technical similarities, this discussion can be applied to postage stamps, bank notes, autographs, bookplates, printed books, etc.

of a print; additions of signatures either to replace less distinguished ones or to add to the value of a drawing which is not signed; the use of washes to enhance the appearance of a drawing; and mends and repairs of all kinds appear only too frequently.

Ultra-violet rays are most helpful in many instances for the examination and determination of the extent of such repairs and restorations, since the materials employed, as a rule, are chemically not the same as those used for the originals and consequently fluoresce differently. In the case of ink, however, the ultra-violet rays are not always of value, as ink ordinarily fluoresces very little. Old black ink, however, usually fluoresces more than modern ink, appearing somewhat brown in color under the rays, whereas new ink reflects the rays and is deep violet in color. In this way it is often possible to distinguish between inks of two different periods.

It is particularly interesting to be able to see with the aid of the rays, sometimes photographically as well as visually, "foxing" marks which have been removed chemically, indications of cleaning materials, and other substances which under ordinary light would not seem to be present, but which owing to slight chemical traces still fluoresce. Also, collectors' marks, indistinguishable imprints, and watermarks are frequently made legible under ultra-violet radiation. Old paper can generally be distinguished from new either because of extraneous substances or because of the difference in constituent elements. For example, old paper made of rags does not contain the sulphide found in modern pulp paper; pulp paper fluoresces less than rag. Certain conditions produced only by age and time, although not always to be seen in white light, are readily visible when they are subjected to ultra-violet radiation.

Turning from the question of repairs to that of forgeries, it is evident from the above that a suspected print can be compared to advantage with one or more genuine examples under ultra-violet rays. Similarities or dissimilarities, as the case may be, are often indicative. These are seen by the eye, but can rarely be recorded photographically.

Figure 36a shows how skillful repairs in an early sixteenth-century Florentine book are scarcely to be seen even when photographed with the aid of a filter and a sensitive panchromatic plate in ordinary light. Figure 36b, which is a photograph taken with ultra-violet rays, shows not only the restoration of the four corners, including the sections of the print which have been replaced, but also the spots which had been treated with chemicals so that they could not be seen in ordinary light. This photograph was most useful when studying the original page, for it made it possible to know exactly where to look for restorations.

When studying prints and drawings, it is most worth while to examine their reverse sides under ultra-violet rays, for the fluorescences of paper and restorations thereof are more readily discerned on the side where the printing or drawing does not appear. Often when paper has been reinforced on the back, it is necessary to place it between the ultra-violet rays and the eye. A print of the Dürer Large Horse of 1505 (fig. 37a) seems to be in perfect condition when examined in ordinary light on the printed side; under ultra-violet rays dark spots on the fluorescent paper are partially discerned. When the print is examined on the reverse side, where the non-fluorescent printed lines in no way interfere with the fluorescence of the paper, these dark areas (violet in color), three of which are outlined in the ultra-violet light photograph (fig. 37b), are more distinctly observed. Paste, which is always used in the making of restorations of this kind, does not fluoresce and as a result stands out quite vividly against the fluorescent paper. Once the restorations are located on the reverse side, it is a simple performance to study the corresponding areas on the obverse side.

In an ordinary photograph (fig. 38a) as well as in ordinary light, marginal rulings in a late fifteenth- or early sixteenth-century printed book cannot be seen. Under ultra-violet rays these lines are readily evident both visually and photographically (fig. 38b).

b. Palimpsests

The examination of palimpsests by ultra-violet rays is generally understood by librarians and scholars. The method we have used for the obtaining of photographic results is perhaps a divergence from the usual, but otherwise for the study of this material we are offering no innovations. A comparison of the ordinary and ultra-violet light photographs (fig. 39) of a page of the *Manuel Moschopoulus* manuscript[2] shows how clearly indecipherable writing which has been largely erased can be read under ultra-violet rays or in ultra-violet light photographs, and requires no further comment.

c. Japanese Prints

Ultra-violet rays have proved very useful for the examination of Japanese prints. Restorations have been revealed by examinations similar to those just described. When colors have been refreshed or additional colors added it has usually been possible to detect them by differences in fluorescences. The rays have also been used to compare colors which to the eye in ordinary light are identical, but which actually are different chemically.

In figures 40a and 41a two Japanese prints, the first by Harunobu and the other in the style of this master, are illustrated. On the right in each case are ultra-violet light photographs (figs. 40b, 41b) of the same prints. In the first example certain details which are not readily apparent in the ordinary photograph owing to fading of the original are brought out by the ultra-violet light photograph. Particularly noteworthy are the flower

[2] Photographed and reproduced through the courtesy of The Pierpont Morgan Library.

motives in the background and the actual condition of the printing, as for instance in the lower left-hand corner. The quality of the impression and the condition may thus be observed with the aid of ultra-violet rays. In figure 41, a and b, it will be noticed that the ultra-violet light photograph demonstrates that the print of the Lady on the Carp has been tampered with. This print was cleaned to remove spots and certain of the colors were retouched.

7. METAL

Only rarely have ultra-violet rays been useful for the examination of works of art in metal. Fluorescences do not occur, and metal surfaces reflect the rays almost completely. Metallographic microscopes and various devices[1] for measuring the metallic content of objects, which have been used commercially, are so satisfactory in this field that processes involving the measuring of reflected ultra-violet rays are not discussed here. When metal surfaces have been treated with varnishes or given artificial patinas[2] in one way or another, this condition can often be discovered with ultra-violet rays, owing to the fluorescences of otherwise ordinarily invisible substances.

8. GLASS AND ENAMEL

a. Glass

Glass, which is a compound of silica with metallic[1] oxides, is not the stable material which it is ordinarily supposed to be. Decomposition of the glass may appear as a fogging of the surface,

[1] At times used in conjunction with ultra-violet rays.

[2] As, for instance, in the case of gilding on picture frames and the like.

[1] For example, old Egyptian red glass was colored with copper, which turns the glass green or blue when surface decomposition sets in; white glass with manganese compounds turns to various shades of amethyst; etc.

or the surface may become iridescent or even pitted. At times the disintegration becomes even more serious, the glass decomposing entirely. This characteristic of glass, intensified in much old glass, which is generally softer than modern glass as it contains a larger proportion of alkali, has made it difficult to imitate glass having considerable age (several hundred years). Likewise it is almost always impossible to duplicate the exact formulae and conditions necessary for the accurate reproduction of old glass.

Ultra-violet rays may be used to compare genuine pieces of a particular variety with questionable ones. As with ceramics, the results can be most satisfactory, both because modern glass would not have aged and also because the constituent elements may vary chemically and consequently fluoresce differently. Modern glass reflects ultra-violet rays almost entirely, whereas old glass usually fluoresces, owing to decomposition or other change. Any foreign matter applied to the surface to give the effect of age can readily be detected.

The chief value, however — and this fact is important — of ultra-violet rays for the examination of glass is in the comparing of particular colors, which vary according to their physical and chemical composition, as well as in the comparing of the painted surfaces of the component parts of a given panel of stained glass. For instance, if several red pieces are of a supposedly identical shade in white light, their reaction to ultraviolet radiation should be the same. It is recommended that stained glass when being examined be held up in front of ultraviolet rays. Certain glass will allow rays to pass undisturbed, others will fluoresce, and still others are almost opaque to the invisible rays. In such instances the pieces of glass act as filters.

The usefulness of ultra-violet rays for the detection of forgeries in glass can perhaps best be demonstrated by an experiment performed with three pieces of Syrian glass. In daylight, as also in a photograph taken in white light (fig. 42a), the three pieces are very similar. The small vase (right) is known to be modern, and the mosque lamp (left) is genuine. The authenticity of the third piece (center), a large standing cup, had been questioned, but, as our experiments showed, without sufficient reason. It is a genuine piece of the fourteenth century. Under ultra-violet rays (fig. 42b), this piece reacted precisely as did the genuine mosque lamp; both pieces, owing to certain oxides in the glass, fluoresced with a yellow-orange color. The small modern vase, on the other hand, did not show this yellow-orange color. So also the reds[2] and the lapis lazuli blues on the two old pieces reacted quite differently from those on the modern vase. Although the three specimens appeared identical in the normal photograph (fig. 42a), in the ultra-violet light photograph the two genuine pieces can easily be distinguished from the spurious one. The genuine pieces photograph darker under ultra-violet rays than in ordinary light, largely owing to the oxides which fluoresce brilliantly, whereas the modern piece, which reflects the photographically more active invisible rays, appears lighter in the ultra-violet light photograph.

b. Enamel

Enamels may be examined under ultra-violet rays in much the same way as glass, paintings, and ceramics. Because of the chemical similarity of glass and enamels, there is no need for a further discussion. It should be understood, however, that visual examinations are often not as satisfactory as those dependent on photography, inasmuch as enamels tend to reflect a large proportion of violet and ultra-violet rays which can usually be recorded in a photograph but not by the eye, which is less sensitive to the shorter wave lengths of light.

A comparison of a and b of figure 43 shows how restorations are revealed by ultra-violet light photographs. The scratch on

[2] Best seen with a microscope under ultra-violet rays.

the head of Joseph and the dark patches of his garment and parts of the faces of the shepherds are among the restorations to be noted.

An enameled plaque, known to have been copied from an original on a twelfth-century shrine by Godefroid de Claire in Cologne, fluoresced and photographed differently from the five genuine plaques attributed to this enameler. The blue and red enamels of the copy reflected the incident rays without the occurrence of fluorescences, whereas these colors in the genuine pieces had identical fluorescences; the white enamel of the imitation fluoresced brilliantly, the white of the five genuine pieces very little.

9. WOODWORK, FURNITURE, AND WOOD SCULPTURE

The appearance of woods varies under ultra-violet radiation according to their age. In general, freshly cut, unfinished wood fluoresces but very little. The fluorescence of old wood is largely due to the patina it has received through the years. As a result it is particularly the surface finish — whether due to natural processes of age and exposure or to the painting, gilding, staining, varnishing, waxing, or other treatment which objects receive either originally or subsequently — which is to be examined under ultra-violet rays.

By this means it is usually possible to distinguish between artificial "aging" and natural aging. In the case of restorations differences in the age of the wood or in surface conditions are revealed by the difference in reactions to the ultra-violet rays. When a piece of furniture has been entirely refinished the problem becomes a more difficult one. In such cases the ultra-violet rays may be extremely useful in discovering traces of original patina or finish which are not to be seen in any other way.

A case in point was an English faldstool from about 1600. It was known to have been partly restored, but the new parts were so well disguised that it was difficult to distinguish them with certainty. Ultra-violet rays were helpful in determining the restorations. New and refinished sections of the stool appeared violet in color, as the comparatively new wood reflected the violet and ultra-violet rays and the surface varnish was transparent to the rays without fluorescing, while the old parts with their aged patinas fluoresced a whitish color.

Unfortunately attempts to record photographically what the eye is able to see with the aid of ultra-violet rays in the examination of wood have not been successful (see p. 10, note 8).

10. PAINTING

Last place in this discussion has purposely been reserved for paintings and other objects with painted surfaces. It is not that the definite value of ultra-violet rays for the examination of this type of material is doubtful. Their usefulness has been already well established by the work of other museums and individual research workers and is confirmed by our own experiences. But the possibilities of using this scientific method in the examination of other classes of material[1] have received hitherto little or no attention, and for this reason the possible results from the study with ultra-violet rays of material other than paintings have been given first place in this book.

The use of x-rays for the examination of paintings and the significant results obtained therefrom have so impressed themselves upon the amateur and even upon the expert that it is widely believed that no other methods for the examination of paintings are requisite. As already stated in the Introduction (pp. 15-

[1] An investigation conducted in America and in Europe indicates that experiments with ultra-violet rays for the examination of works of art have been limited almost entirely to paintings and palimpsests.

16), there is no occasion for limiting the ways and means which can be applied to the study of works of art. Of the many types of physical examination, including those using x-rays, various colored lights, infra-red rays, spectrographic analyses, and photographic and optical enlargements of all kinds, each has a definite place.

The usefulness of the x-ray in the study of paintings depends upon the fact that "under favorable conditions x-rays reveal the structure of pictures by penetrating the paint film and casting shadows of varying intensity, depending on the thickness and density of the pigment employed."[2] These powerful, penetrating rays reveal damages to original surfaces, but do not always indicate the extent of the repainted area, which often covers a much larger section of the old surface than is necessary. Moreover, slight surface damages or repainting of inconsiderable density may not be shown at all in the shadowgraph. It is therefore desirable in determining the condition of a painting to use both the ultra-violet rays and the x-rays.

Restorations, though perhaps not to be distinguished in ordinary light, are readily apparent under ultra-violet light, owing to the difference in fluorescence between the old and new paints. To the eye they may seem the same, but in reality they may be chemically different with consequently different reactions or they may be the same chemically with different reactions due to physical changes. In ultra-violet light photographs, the restorations generally appear light against dark, or the reverse. In some cases visual examination under ultra-violet rays is much more helpful than the use of photographs, but in other cases the eye is not sufficiently sensitive, and the photographic plate, with its sensibility different from that of the retina of the eye, is useful.

As many paintings are varnished and as varnishes fluoresce, more or less, restorations made over varnish are readily per-

[2] Burroughs, *Metropolitan Museum Studies*, vol. III, part 1, pp. 47-54.

ceived, since they break up the uniformly fluorescent varnished area. Sometimes the varnish, when it is too thick or has turned yellow, fluoresces to such a degree that the ultra-violet rays do not penetrate so as to react with the colors of the painting under the varnish. In such instances the properly qualified investigator can freshen the varnish with turpentine or some other substance, according to the individual situation, to obtain greater transparency.

In addition, it is probable that by comparing and analyzing under ultra-violet rays paintings of a particular period or by particular individuals it will be possible to arrive at conclusions about authenticity and attribution. But even the study of the work of a single painter would require experimentation beyond our present scope. In figure 44 are illustrated ordinary and ultra-violet light photographs of a fourteenth-century Italian panel painting in tempera by Ambrogio Lorenzetti (left) and of a copy (right) for which supposedly identical pigments and media were employed. The manner of working and the differences in the paints as brought out by the ultra-violet rays are significant. The visual examination of the two paintings in ultra-violet light disclosed much more vividly the discrepancies in the two paintings.

Figure 45a is from an ordinary photograph of a detail of a sixteenth-century oil painting, probably by Lucas Cranach. The ultra-violet light photograph (fig. 45b) shows the repairs which have been made. The surface has been disturbed in various places where the paint has either been refixed or where restorations have been made. The restoration of the long vertical crack is perfectly evident. In the laboratory the repairs over the highly fluorescent varnish appear as dark spots.

Two photographs (fig. 46) of a painting in tempera by Bartolo di Fredi illustrate further the possibilities of ultra-violet ray examinations. In the ultra-violet light photograph (fig. 46b) the restorations on the horse's hind quarters and tail are clearly seen as dark spots. The forelegs have been largely repainted and also the greater part of the head. Across the upper part of the illustration may be seen a horizontal strip where the surface has been filled in and completely repainted. In order to conceal this restoration the restorer carried his areas further than necessary. Among other restorations, we may note especially the shield and the lower part of the trappings and the tail of the black horse (partly seen behind the foot soldier).

The photographs of a detail of a seventeenth-century oil painting (fig. 47) suggest the actual visual impression one has when examining such a painting under ultra-violet rays. The spots which appear light in the ultra-violet light photograph are dark spots when seen visually.

TABLE GIVING INFORMATION FOR THE TAKING OF PHOTOGRAPHS

The ultra-violet light photographs described in this table were made with a quartz mercury vapor lamp (fig. 1) running on direct current at 5 amperes and 85 volts.

The ordinary photographs were made with a 500 watt tungsten filament spot light, equipped with a condenser lens and a blue glass filter. This incandescent light source has a maximum efficiency at about 4700 angstroms; it gives a band of light which goes to about 3400 angstroms in the ultra-violet section of the spectrum. Of course, the intensity in the ultra-violet region of such a light as this is relatively slight as compared with the powerful bands of ultra-violet light produced by a quartz mercury vapor lamp.

An F 4.5 anastigmatic lens open to an aperture of F 12 and Wratten and Wainwright panchromatic plates were used for all of these photographs, except where otherwise noted. Objects with highly reflecting surfaces were usually placed at a 45° angle to the ultra-violet light source.

Figure	Material	Light Source	Ultra-violet Light Filter	Distance of Source from Object	Lens Filter	Exposure
5	Marble	Mercury	Corex A[1]	35 in.	Tryphenylmethane[2]	4 min.
6	Marble	Mercury	Corex A	35 in.	Tryphenylmethane	4 min.
7a	Marble	Tungsten		72 in.	Tryphenylmethane	3 min.
7b	Marble	Mercury	Corex A	35 in.	Tryphenylmethane	6 min.
9	Marble	Mercury	Corex A	35 in.	Tryphenylmethane	8 min.
10	Marble	Mercury	Corex A	35 in.	Tryphenylmethane	8 min.
11	Marble	Mercury	Corex A	35 in.	Tryphenylmethane	8 min.
12	Alabaster	Mercury	Corex A	35 in.	Tryphenylmethane	8 min.
13a	Marble	Tungsten		72 in.	Tryphenylmethane	3 min.
13b	Marble	Mercury	Corex A	35 in.	Tryphenylmethane	3½ min.
14a	Marble	Tungsten		7 in.	(Microscope)	2 sec.

[1] See page 8. [2] See page 10.

Figure	Material	Light Source	Ultra-violet Light Filter	Distance of Source from Object	Lens Filter	Exposure
14b	Marble	Mercury	Corex A	16 in.	(Microscope)	8 min.
15	Limestone	Mercury	Corex A	30 in.	Ceriammonium[3]	7 min.
16	Limestone	Mercury	Corex A	35 in.	Ceriammonium	10 min.
17	Limestone	Mercury	Corex A	35 in.	Ceriammonium	10 min.
18a	Ivory	Tungsten		78 in.	Ceriammonium	3 min.
18b	Ivory	Mercury	Hanau[4]	35 in.	Ceriammonium	10 min.
19a	Ivory	Tungsten		78 in.	Ceriammonium	3 min.
19b	Ivory	Mercury	Corex A	35 in.	Ceriammonium	7 min.
20	Ivory	Mercury	Corex A	35 in.	Ceriammonium	7 min.
21	Ivory	Mercury	Corex A	35 in.	Ceriammonium	7 min.
22a	Ivory	Tungsten		78 in.	Tryphenylmethane	4 min.
22b	Ivory	Mercury	Corex A	35 in.	Tryphenylmethane	7 min.
23a	Ceramics	Tungsten		22 in.	Tryphenylmethane	14 sec.
23b	Ceramics	Mercury	Corex A	49 in.	Tryphenylmethane	15 min.
24a	Ceramics	Tungsten		58 in.	Tryphenylmethane	2 min.
24b	Ceramics	Mercury	Corex A	35 in.	Tryphenylmethane	15 min.
25a	Ceramics	Tungsten		30 in.	Ceriammonium	12 sec.
25b	Ceramics	Mercury	Corex A	35 in.	Tryphenylmethane	12 min.
26a	Ceramics	Tungsten		45 in.	Tryphenylmethane	9 sec.
26b	Ceramics	Mercury	Corex A	35 in.	Tryphenylmethane	20 min.
27a	Ceramics	Tungsten		78 in.		5 min.
27b	Ceramics	Mercury	Hanau	33 in.	Tryphenylmethane	35 min.
28	Ceramics	Tungsten		78 in.		5 min.
29	Ceramics	Tungsten		78 in.		5 min.
30a	Ceramics	Tungsten		78 in.	Ceriammonium	5 min.
30b	Ceramics	Mercury	Corex A	35 in.	Ceriammonium	10 min.
31a	Textiles	Tungsten		35 in.	Ceriammonium	11 sec.
31b	Textiles	Mercury	Corex A	55 in.	Ceriammonium	35 min.
32a	Textiles	Tungsten		78 in.	Ceriammonium	6 min.
32b	Textiles	Mercury	Corex A	40 in.	Ceriammonium	30 min.
33a	Textiles	Tungsten		78 in.	Ceriammonium	6 min.
33b	Textiles	Mercury	Corex A	40 in.	Ceriammonium	30 min.
34a	Textiles	Tungsten		74 in.	Ceriammonium	6 min.
34b	Textiles	Mercury	Corex A	35 in.	Ceriammonium	15 min.

[3] See page 10. [4] See page 8.

ULTRA-VIOLET RAYS

Figure	Material	Light Source	Ultra-violet Light Filter	Distance of Source from Object	Lens Filter	Exposure
35a	Textiles	Tungsten		72 in.	Ceriammonium	6 min.
35b	Textiles	Mercury	Corex A	36 in.	Ceriammonium	15 min.
36a	Prints	Tungsten		34 in.	Ceriammonium	9 sec.
36b	Prints	Mercury	Corex A	35 in.	Ceriammonium	7 min.
37a	Prints[5]	Tungsten		34 in.	Ceriammonium	10 sec.
37b	Prints[5]	Mercury	Corex A	35 in.	Ceriammonium	10 min.
38a	Prints	Tungsten		34 in.	Ceriammonium	9 sec.
38b	Prints	Mercury	Corex A	35 in.	Ceriammonium	8 min.
39a	Palimpsest	Tungsten		34 in.	Ceriammonium	9 sec.
39b	Palimpsest	Mercury	Hanau	35 in.	Ceriammonium	10 min.
40a	Prints	Tungsten		50 in.	Tryphenylmethane	10 sec.
40b	Prints	Mercury	Corex A	45 in.	Tryphenylmethane	10 min.
41a	Prints	Tungsten		50 in.	Tryphenylmethane	10 sec.
41b	Prints	Mercury	Corex A	45 in.	Tryphenylmethane	10 min.
42a	Glass	Tungsten		35 in.	Ceriammonium	14 sec.
42b	Glass	Mercury	Corex A	35 in.	Ceriammonium	14 min.
43a	Enamel	Tungsten		66 in.	Ceriammonium	4 min.
43b	Enamel	Mercury	Corex A	35 in.	Ceriammonium	15 min.
44a	Painting	Tungsten		(Details not recorded)		
44b	Painting	Mercury	Hanau	40 in.	Ceriammonium	13 min.
45a	Painting	Tungsten		78 in.	Ceriammonium	6 min.
45b	Painting	Mercury	Hanau	40 in.	Ceriammonium	13 min.
46a	Painting	Tungsten		78 in.	Ceriammonium	6 min.
46b	Painting	Mercury	Hanau	40 in.	Ceriammonium	13 min.
47a	Painting	Tungsten		78 in.	Ceriammonium	6 min.
47b	Painting	Mercury	Corex A	40 in.	Ceriammonium	12 min.

[5] Orthochromatic plate, seed 27.

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ILLUSTRATIONS

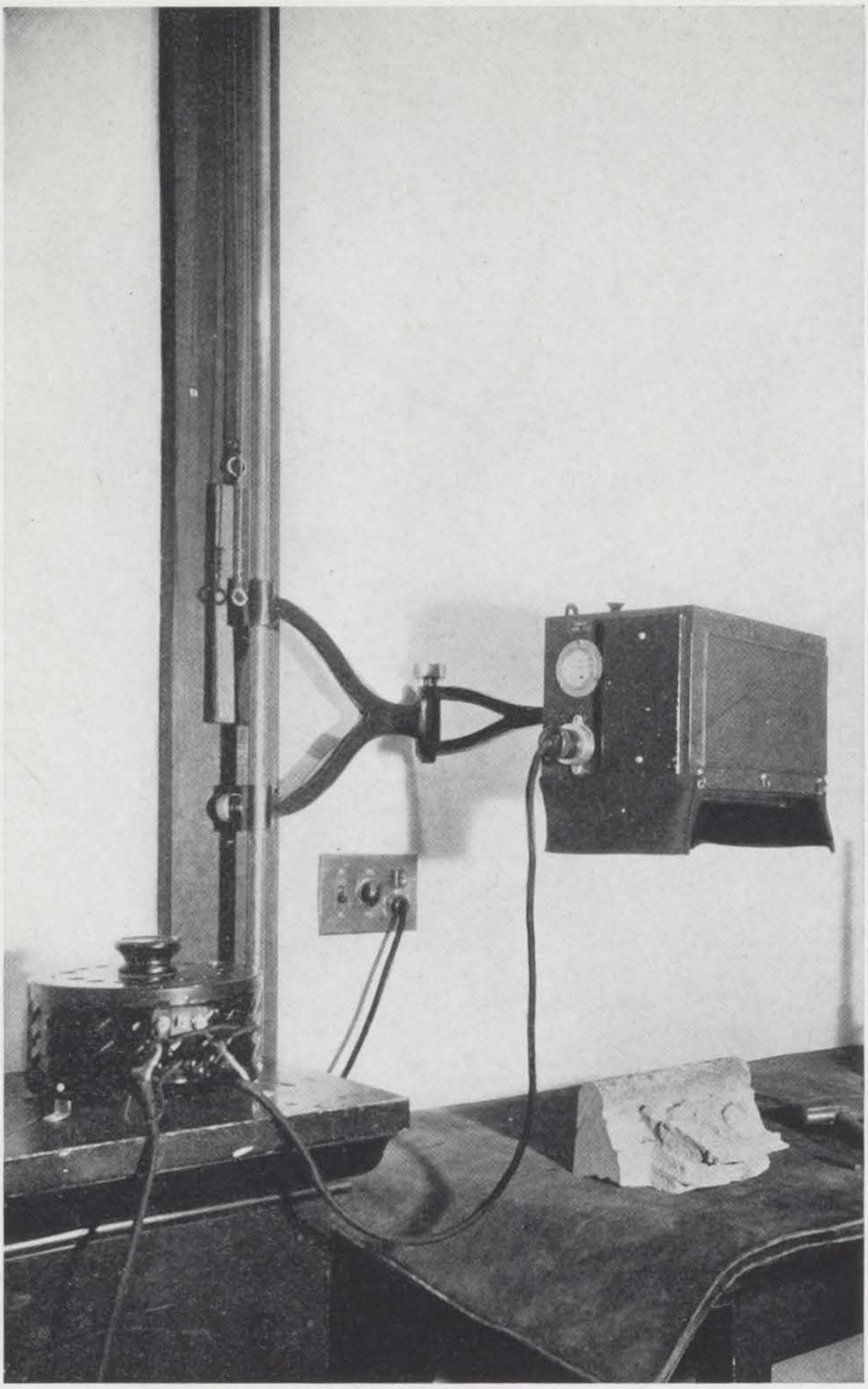


FIG. 1. THE ULTRA-VIOLET LIGHT APPARATUS USED IN EXPERIMENTATION

(see pages 6 and 7)

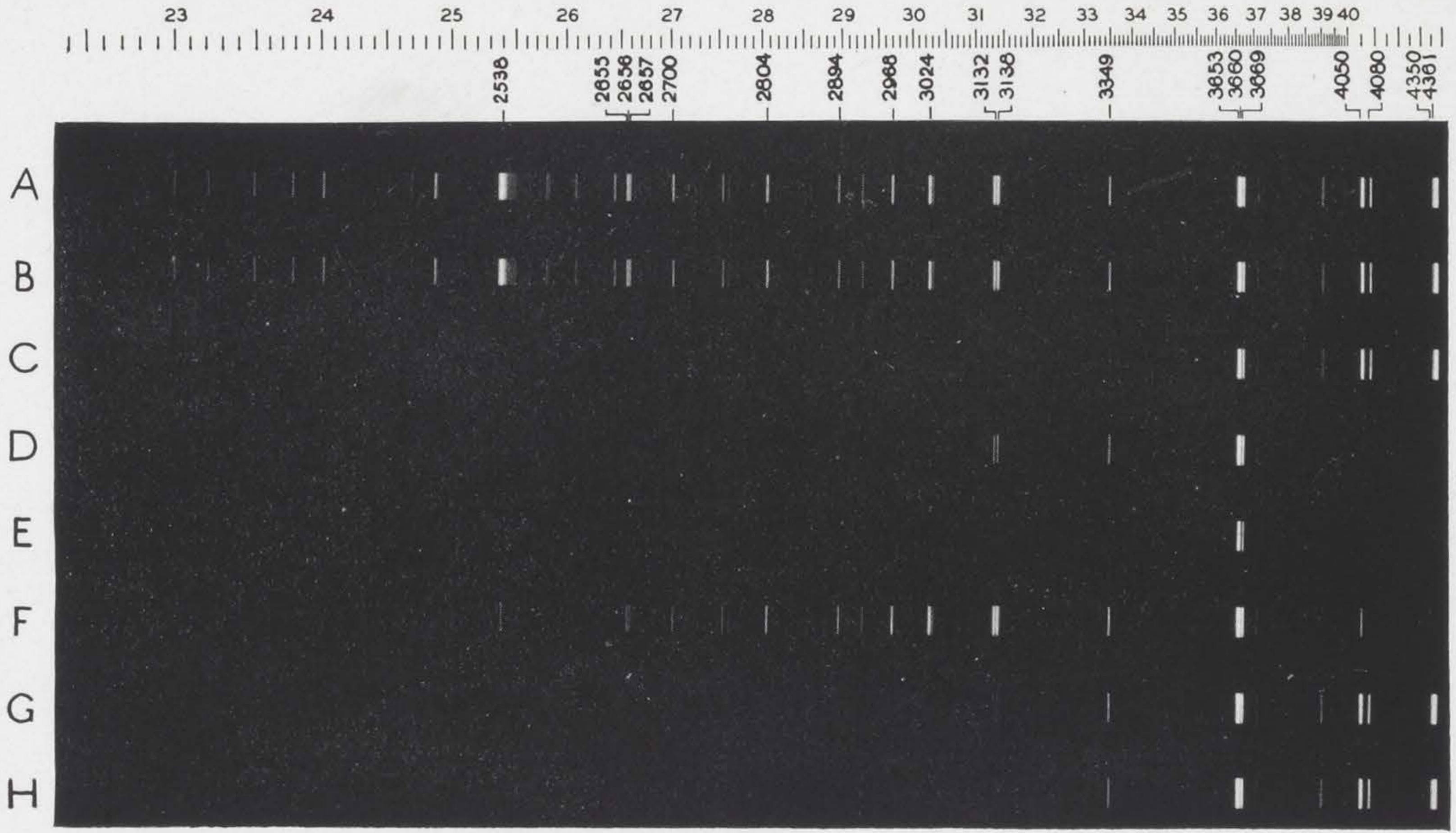
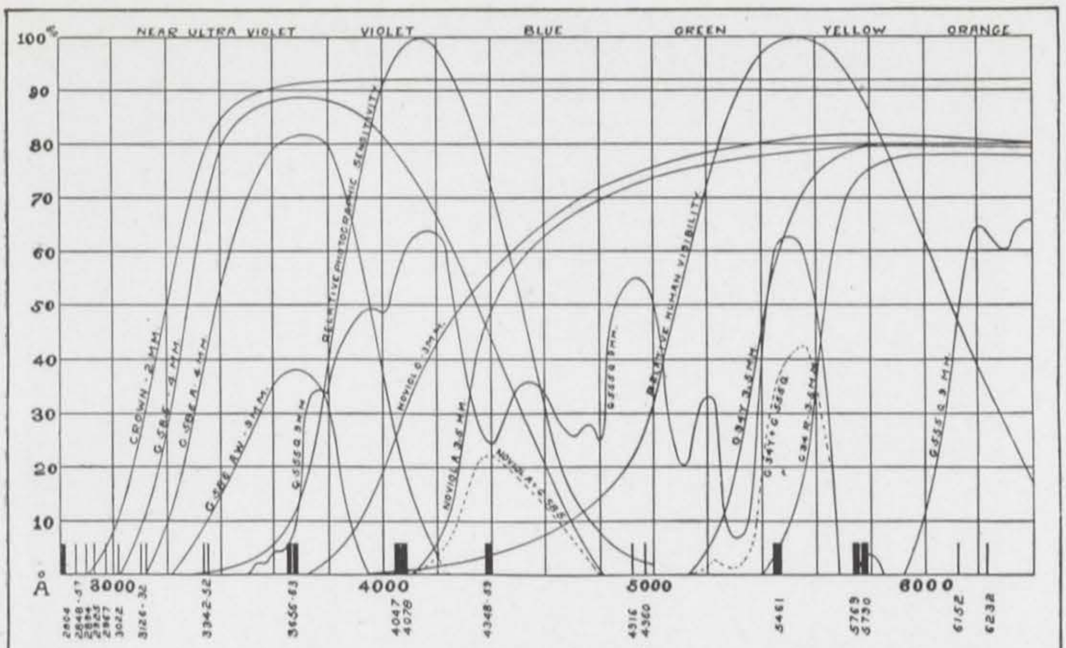


FIG. 2. SPECTROGRAMS OF VARIOUS MATERIALS USED FOR THE STUDY OF FLUORESCENCES AND FOR THE MAKING OF ULTRA-VIOLET LIGHT PHOTOGRAPHS

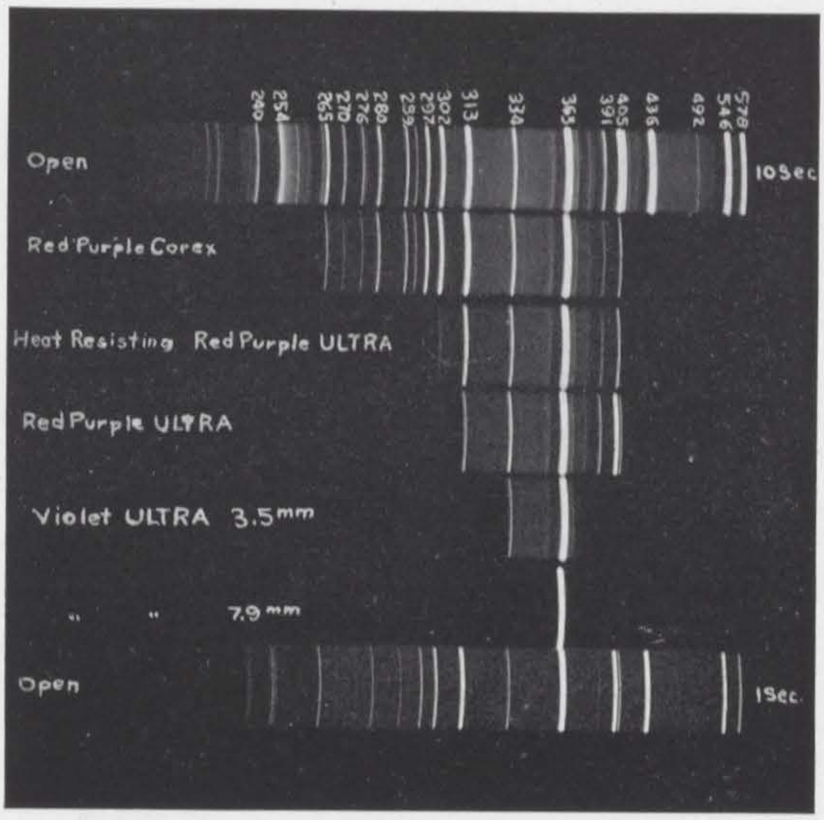
A. Quartz mercury vapor arc
B. Mercury arc through quartz lens
C. Mercury arc through anastigmatic lens
D. Mercury arc through Hanau filter
E. Mercury arc through French filter
F. Mercury arc through Corning Glass filter, Corex A, 986 A
G. Mercury arc through inorganic liquid (ceriammonium nitrate)
H. Mercury arc through organic liquid (tryphenylmethane in alcohol)



CORNING FILTERS - DATA FROM CORNING GLASS WORKS AND BUREAU OF STANDARDS.

COURTESY OF THE GENERAL ELECTRIC VAPOR LAMP COMPANY

FIG. 3
(see pages 3-12)



COURTESY OF THE CORNING GLASS WORKS

FIG. 4. SPECTROGRAMS OF ADDITIONAL FILTERS USED FOR FLUORESCENT STUDIES, MADE WITH A QUARTZ MERCURY VAPOR ARC

(see page 8, note 6)

FIG. 5. BLOCK OF OLD MARBLE. IN ULTRA-VIOLET LIGHT. THE COMPARATIVELY RECENT BREAK SHOWS THE PENETRATION. THE DARK SPOTS ARE DUE TO IMPURITIES IN THE MARBLE

(see page 20)

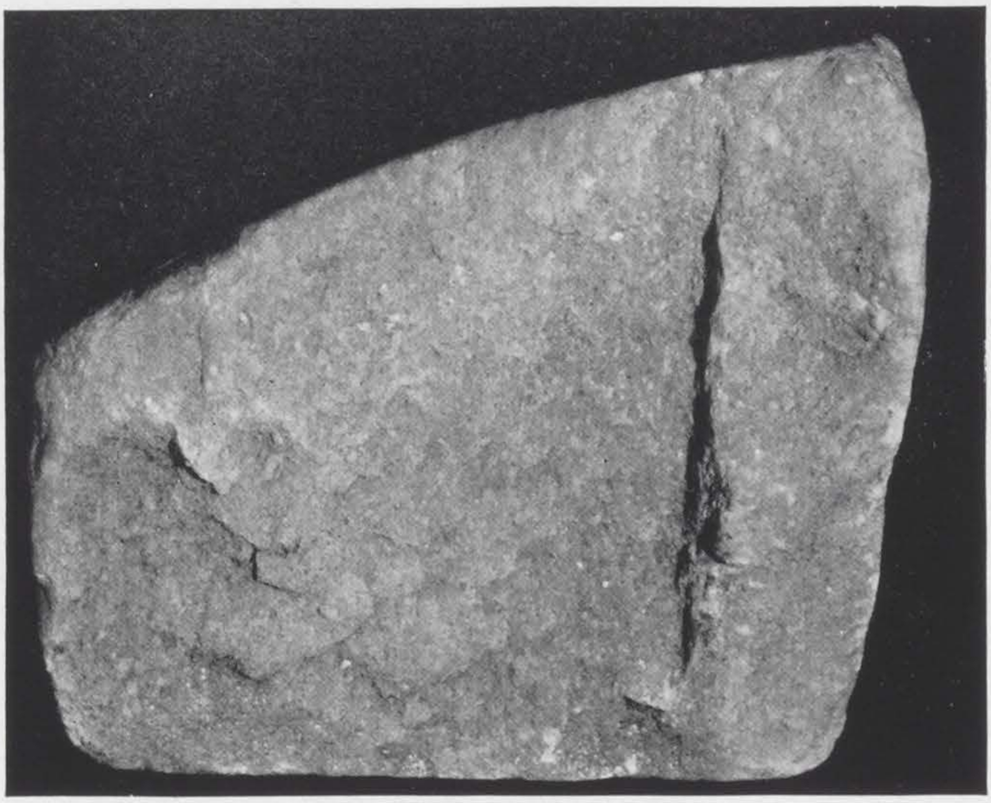
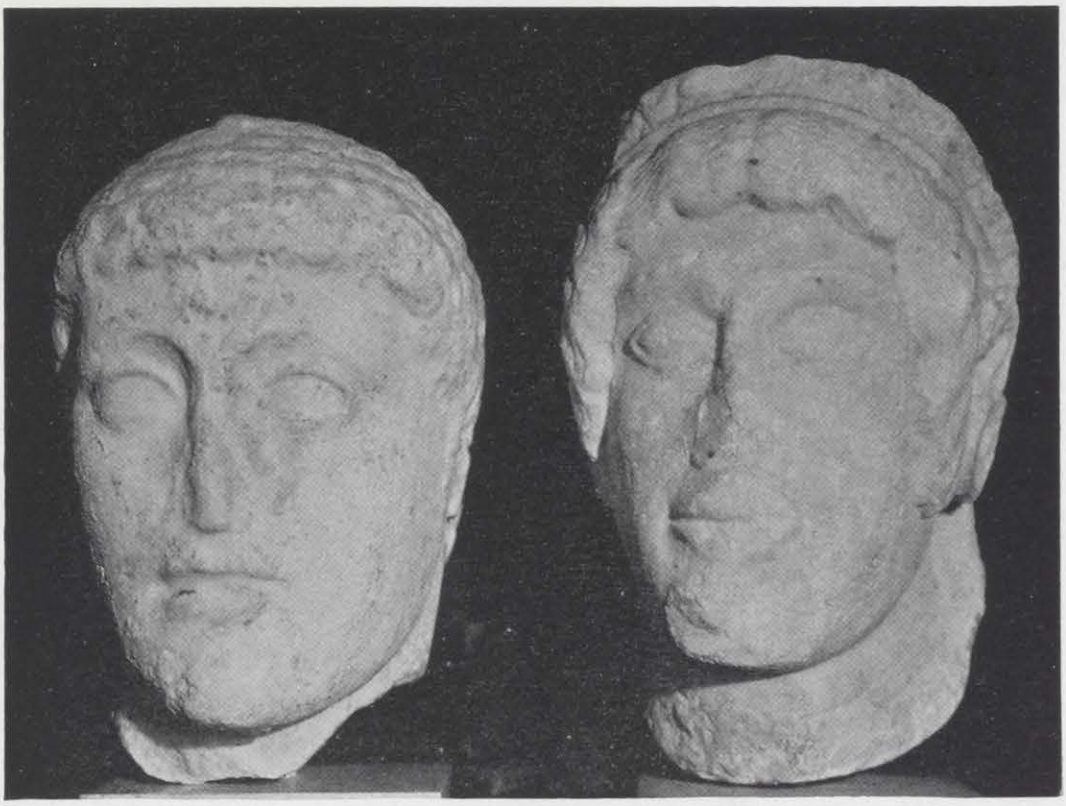


FIG. 6. OPPOSITE END OF THE MARBLE BLOCK SHOWN ABOVE. IN ULTRA-VIOLET LIGHT. THIS BREAK, BEING OLD, SHOWS A SURFACE CHANGE AS WELL AS PENETRATION

(see page 20)



A

B

FIG. 7. GENUINE ARCHAIC MARBLE HEAD OF HARMODIOS AND HEAD OF A MAIDEN RECUT IN MODERN TIMES FROM A DAMAGED CLASSICAL HEAD

A. In incandescent light
B. In ultra-violet light (see fig. 8)
(see page 20)

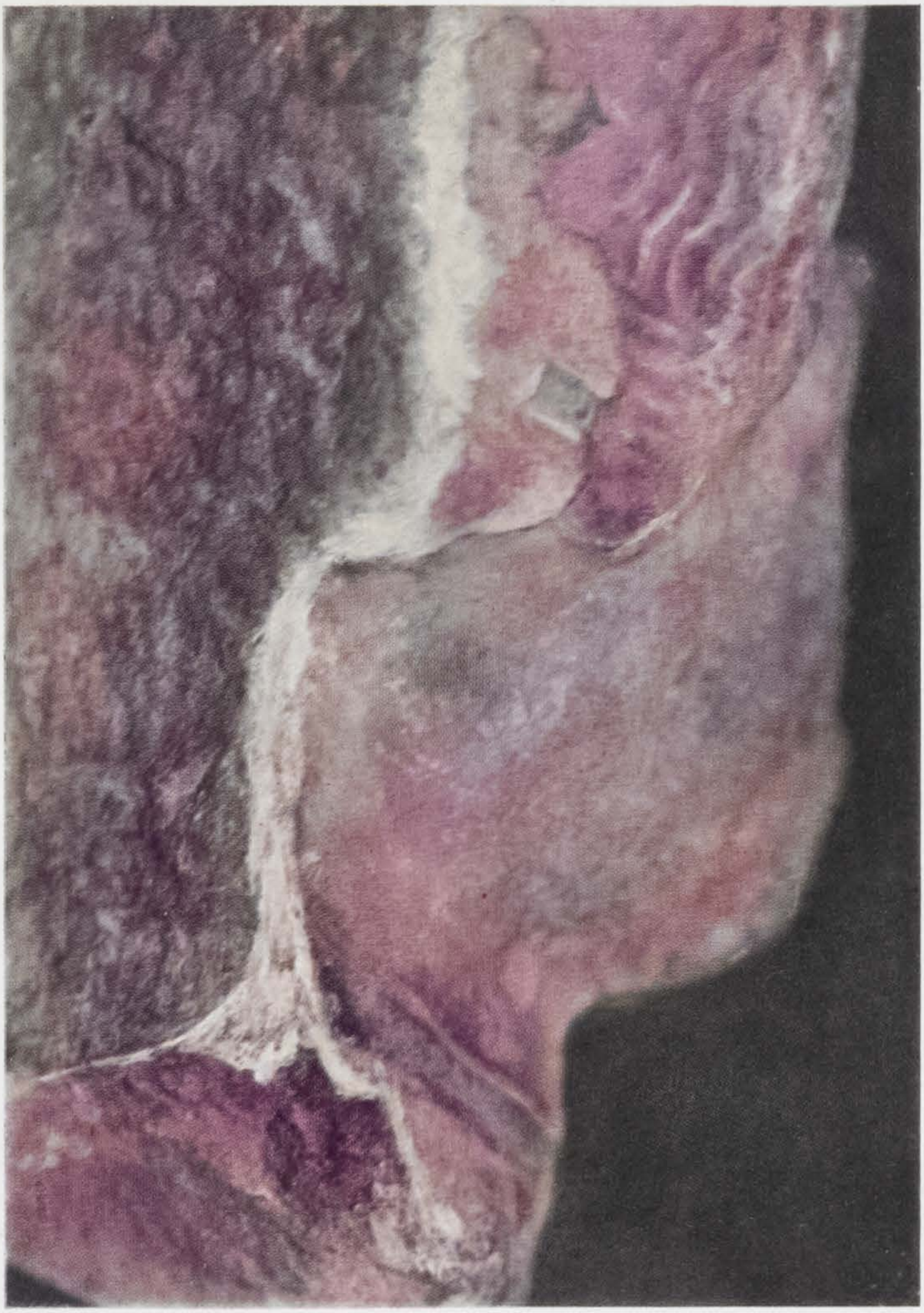
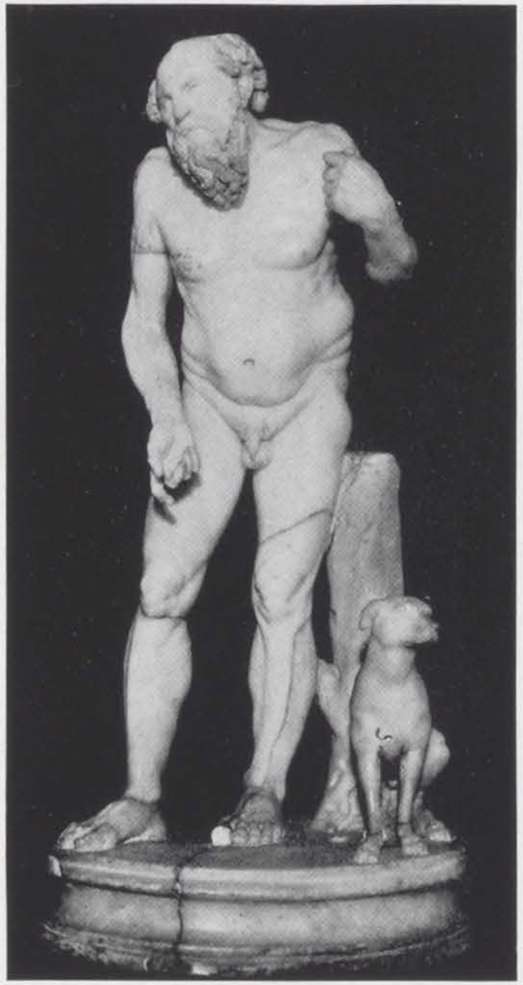


FIG. 8. FROM A PHOTOGRAPH COLORED TO SIMULATE THE APPEARANCE OF THE MARBLE HEAD OF THE MAIDEN (FIG. 7) UNDER ULTRA-VIOLET LIGHT

(see pages 20 and 21)

FIGS. 9 AND 10. THE BASE, DIOGENES' TWO FEET AND PART OF HIS LEFT LEG, THE TREE TRUNK, AND THE FOUR FEET OF THE DOG ARE FROM A ROMAN STATUE OF DIOGENES; THE OTHER PARTS DATE FROM BEFORE 1765. IN ULTRA-VIOLET LIGHT. (IN READING ULTRA-VIOLET LIGHT PHOTOGRAPHS CARE MUST BE EXERCISED LEST HIGH LIGHTS AND SHADOWS BE CONSIDERED AS RESTORATIONS)

(see pages 21 and 22)

FIG. 11. MARBLE FROM THE QUARRY OF ST.-BÉAT. IN ULTRA-VIOLET LIGHT. THE BLOCK HAS BEEN TAKEN RECENTLY FROM THE QUARRY; THE CAPITAL DATES FROM THE XII CENTURY

(see page 22)

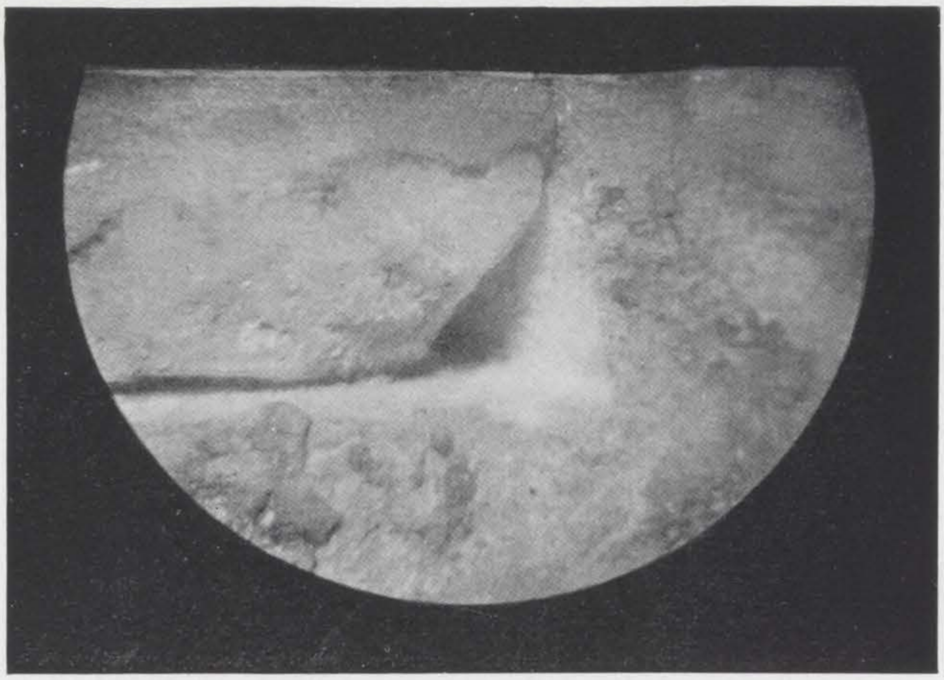
FIG. 12. MEDIAEVAL RELIEF IN EBRO ALABASTER. IN ULTRA-VIOLET LIGHT. THE LOWER PORTION IS A RESTORATION

(see page 24)

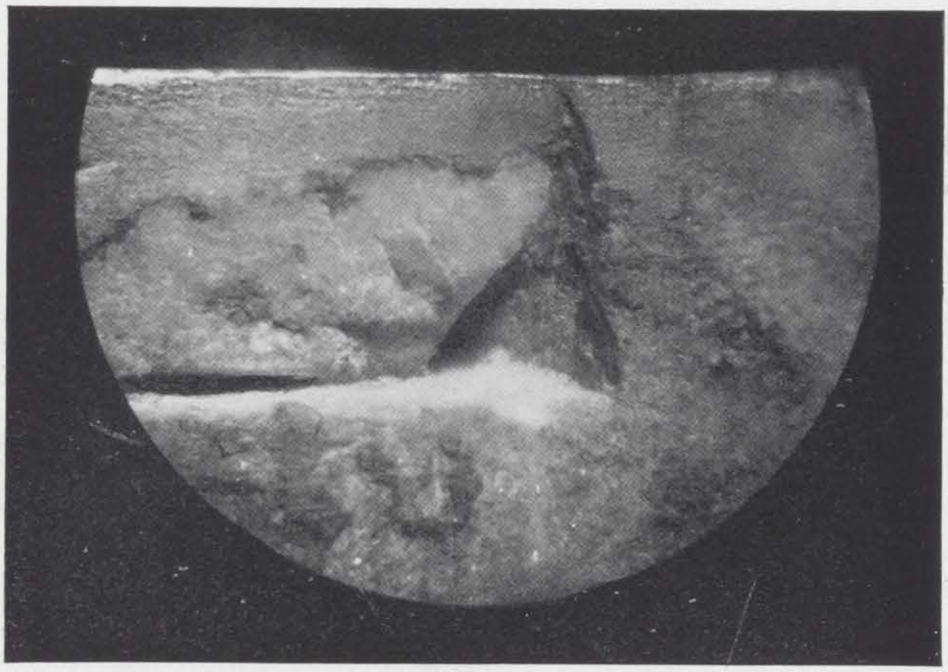
A B

FIG. 13. RENAISSANCE MARBLE RELIEF

A. In incandescent light
B. In ultra-violet light. Repairs are indicated by black lines
(see page 22)



A



B

FIG. 14. FROM PHOTOMICROGRAPHS OF THE REPAIRED BREAK IN THE MARBLE RELIEF SHOWN IN FIGURE 13

A. In incandescent light
B. In ultra-violet light. Penetration and fluorescences are clearly determined. The dark parts are paint used to conceal the joints

(see pages 22 and 23)

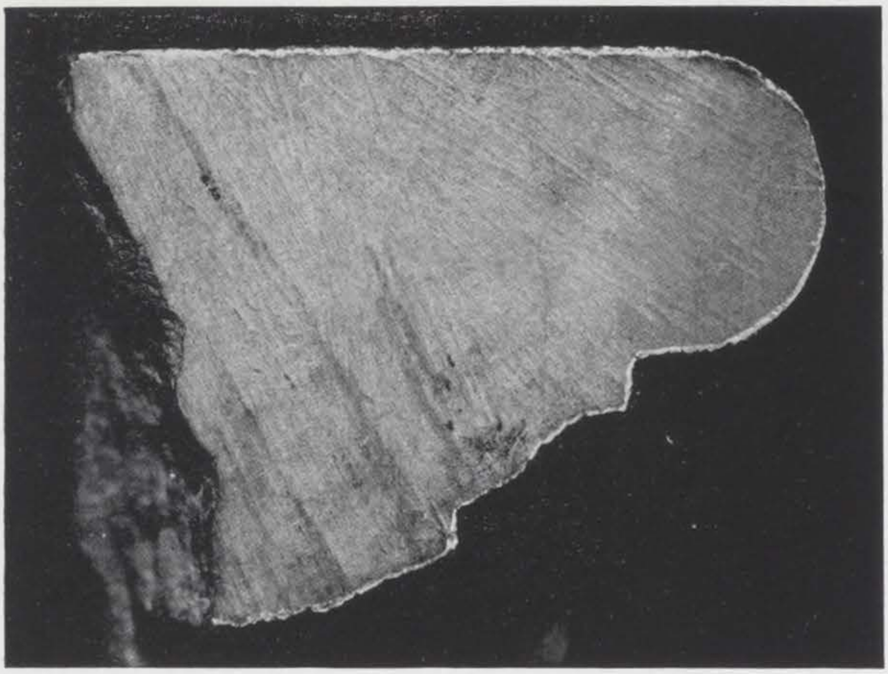


FIG. 15. FRENCH XVI CENTURY LIMESTONE CAPITAL. IN ULTRA-VIOLET LIGHT. THE WHITE LINE SUGGESTS THE PENETRATION FROM THE EXPOSED SURFACES

(see page 25)

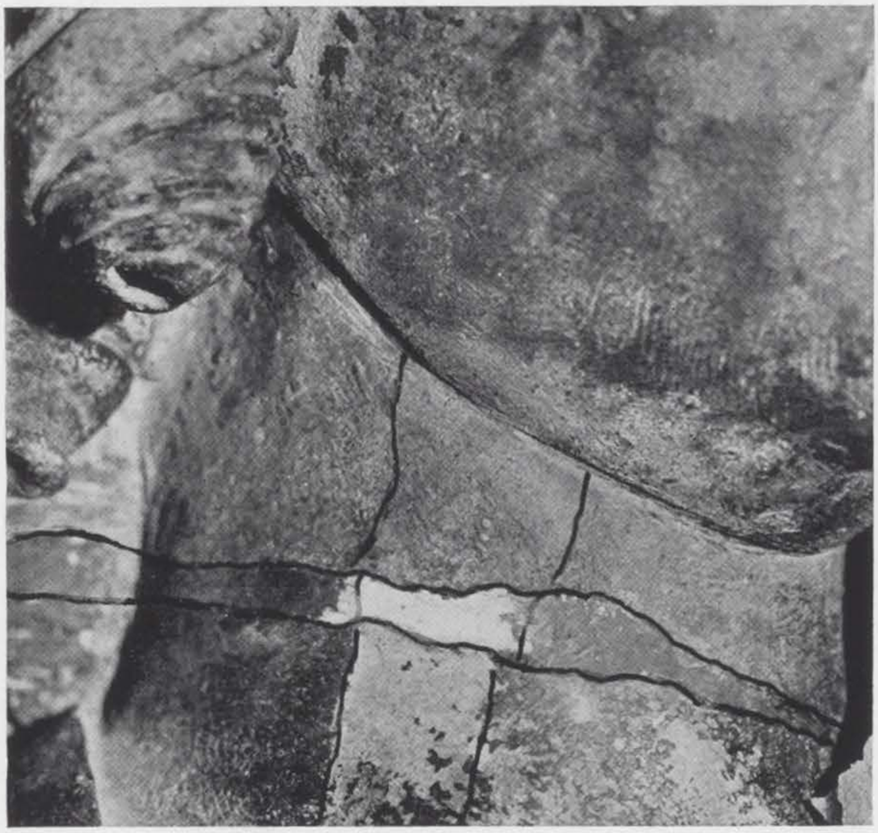


FIG. 16. DETAIL OF RESTORED XIII CENTURY STATUE. IN ULTRA-VIOLET LIGHT. THE HEAD AND BODY ARE MADE FROM DIFFERENT PIECES OF LIMESTONE; THE HORIZONTAL LINES SHOW THE PLASTER JOINT

(see pages 25 and 26)

FIG. 17. DETAIL OF RESTORED XIII CENTURY LIMESTONE HEAD. IN ULTRA-VIOLET LIGHT. THE RESTORATIONS, PARTICULARLY ABOUT THE MOUTH, CANNOT BE DISTINGUISHED IN ORDINARY LIGHT EVEN WITH A MICROSCOPE; DIFFERENCES IN TEXTURE, AS WELL AS IN COLOR, ARE BROUGHT OUT BY THE ULTRA-VIOLET RAYS

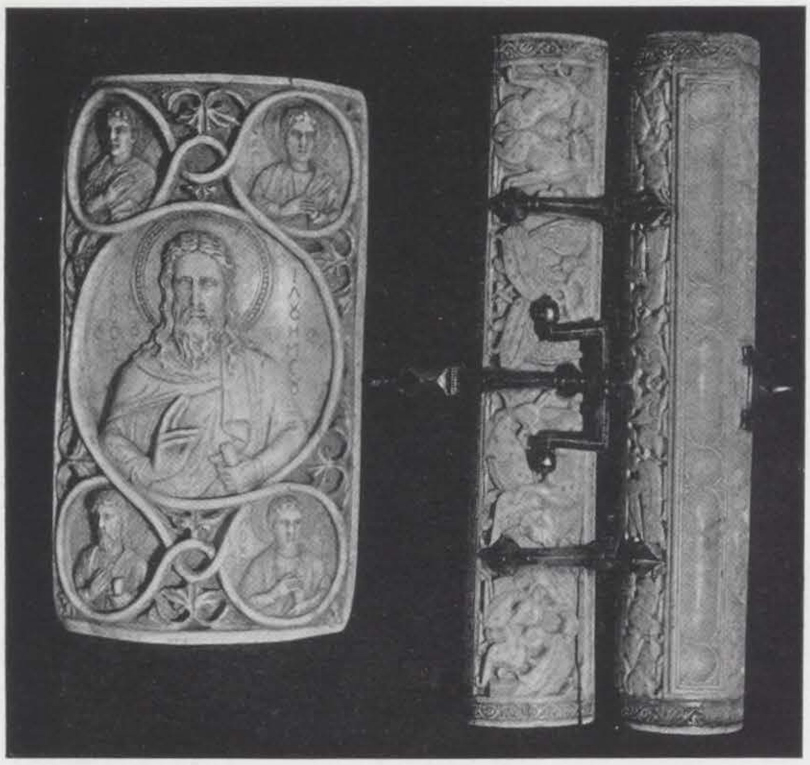
(see page 26)

A B

FIG. 18. XIV CENTURY IVORY (SEE FRONTISPIECE)

A. In incandescent light
B. In ultra-violet light. Compare the dark sections of the illustration with the yellow parts in the frontispiece

(see page 29)



A

B

FIG. 19. XIX CENTURY IVORY IN IMITATION OF A XII CENTURY BYZANTINE PLAQUE AND IVORY BOX, SOUTH ITALIAN, XI-XII CENTURY

A. In incandescent light
B. In ultra-violet light. The forgery photographs lighter in ultra-violet light as it appears purple under the rays; the old piece has a mottled yellow tone owing to natural aging and photographs darker than in incandescent light

(see pages 29 and 30)

FIG. 20. IVORY MADONNA AND CHILD, FRENCH, XIV CENTURY. IN ULTRA-VIOLET LIGHT. THE HEAD AND NECK OF THE CHILD AND THE RIGHT ARM OF THE MADONNA ARE RESTORATIONS

(see page 30)

FIG. 21. DETAIL OF THE IVORY SHOWN IN FIGURE 20. IN ULTRA-VIOLET LIGHT

(see page 30)

A B

FIG. 22. MISCELLANEOUS CHINESE IVORIES

A. In incandescent light
B. In ultra-violet light

(see page 31)

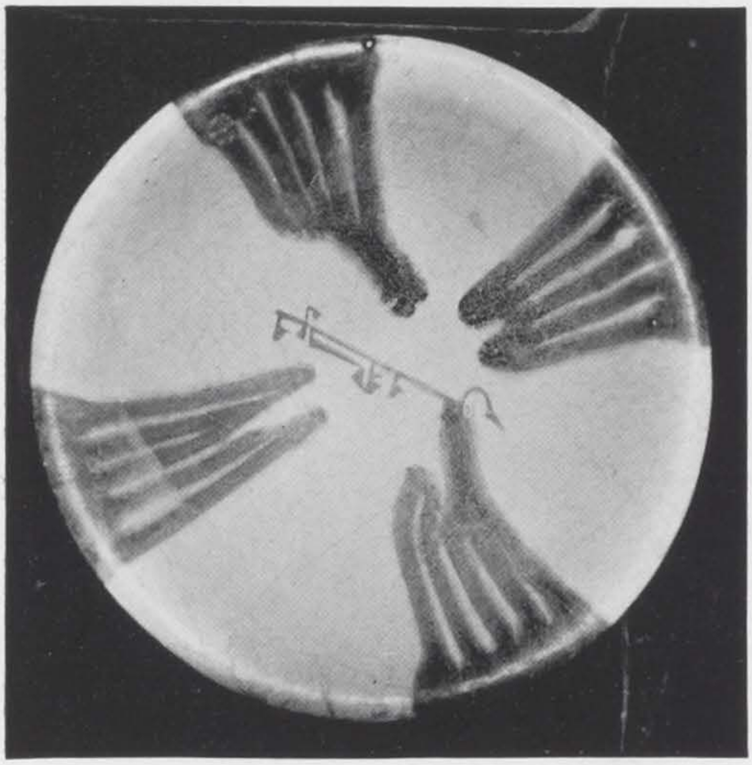
A

B

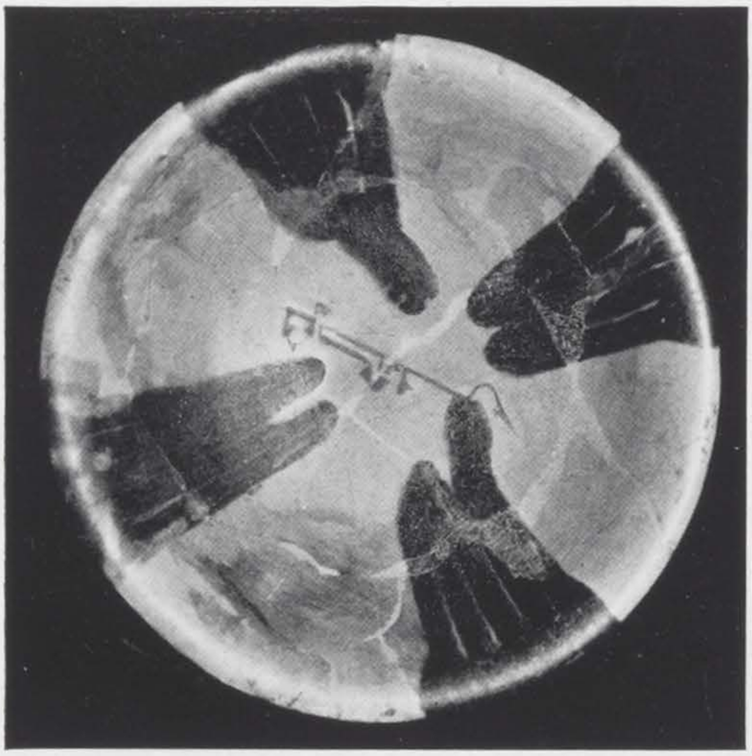
FIG. 23. XVI CENTURY ITALIAN MAIOLICA BOWL

A. In incandescent light
B. From an ultra-violet light photograph colored to simulate the appearance of the bowl under ultra-violet light. The yellow sections are restorations in paint

(see page 32)



A



B

FIG. 24. IX CENTURY PERSIAN BOWL

A. In incandescent light
B. In ultra-violet light. Skillful repairs not visible under ordinary conditions or with a magnifying glass are easily distinguishable

(see pages 32 and 33)

A

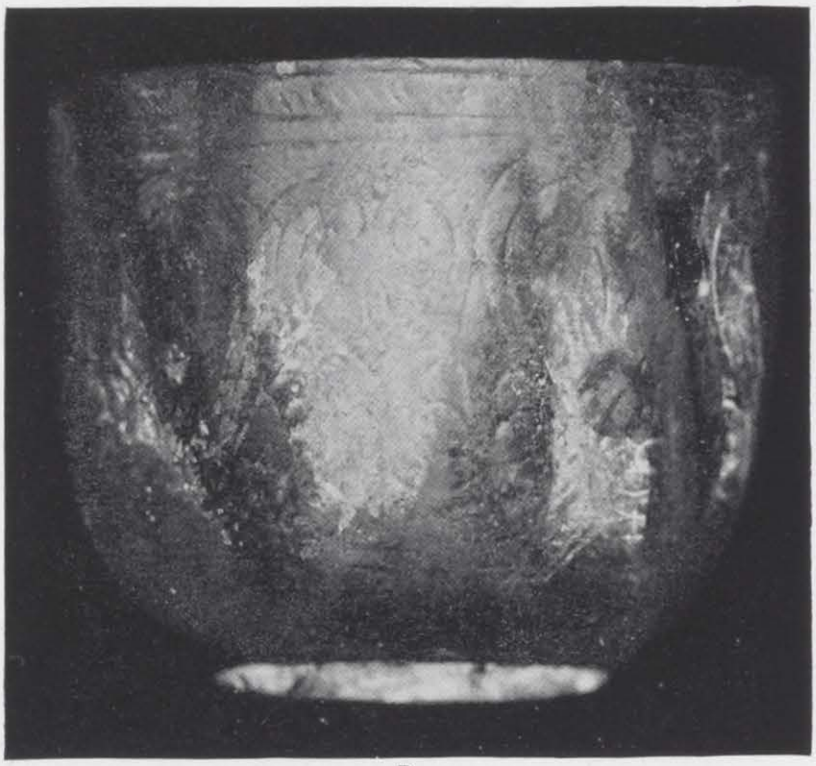
B

FIG. 25. XIII CENTURY PERSIAN BOWL

A. In incandescent light
B. In ultra-violet light. The lower rim and part of the inscription are restored

(see page 33)

A



B

FIG. 26. XV CENTURY ITALIAN BOWL

A. In incandescent light
B. In ultra-violet light. The white patches are original fragments; the remainder is plaster and paint

(see page 33)

A

B

FIG. 27. XVII CENTURY TURKISH (ASIA MINOR) TILE

A. In incandescent light
B. In ultra-violet light. The black patches are restorations (see pages 33 and 34)

FIG. 28. TILE AFTER UNNECESSARY PAINTED RESTORATIONS (SEE FIG. 27 B) HAD BEEN REMOVED. IN INCANDESCENT LIGHT

FIG. 29. TILE AFTER IT HAD BEEN PROPERLY REPAIRED. IN INCANDESCENT LIGHT

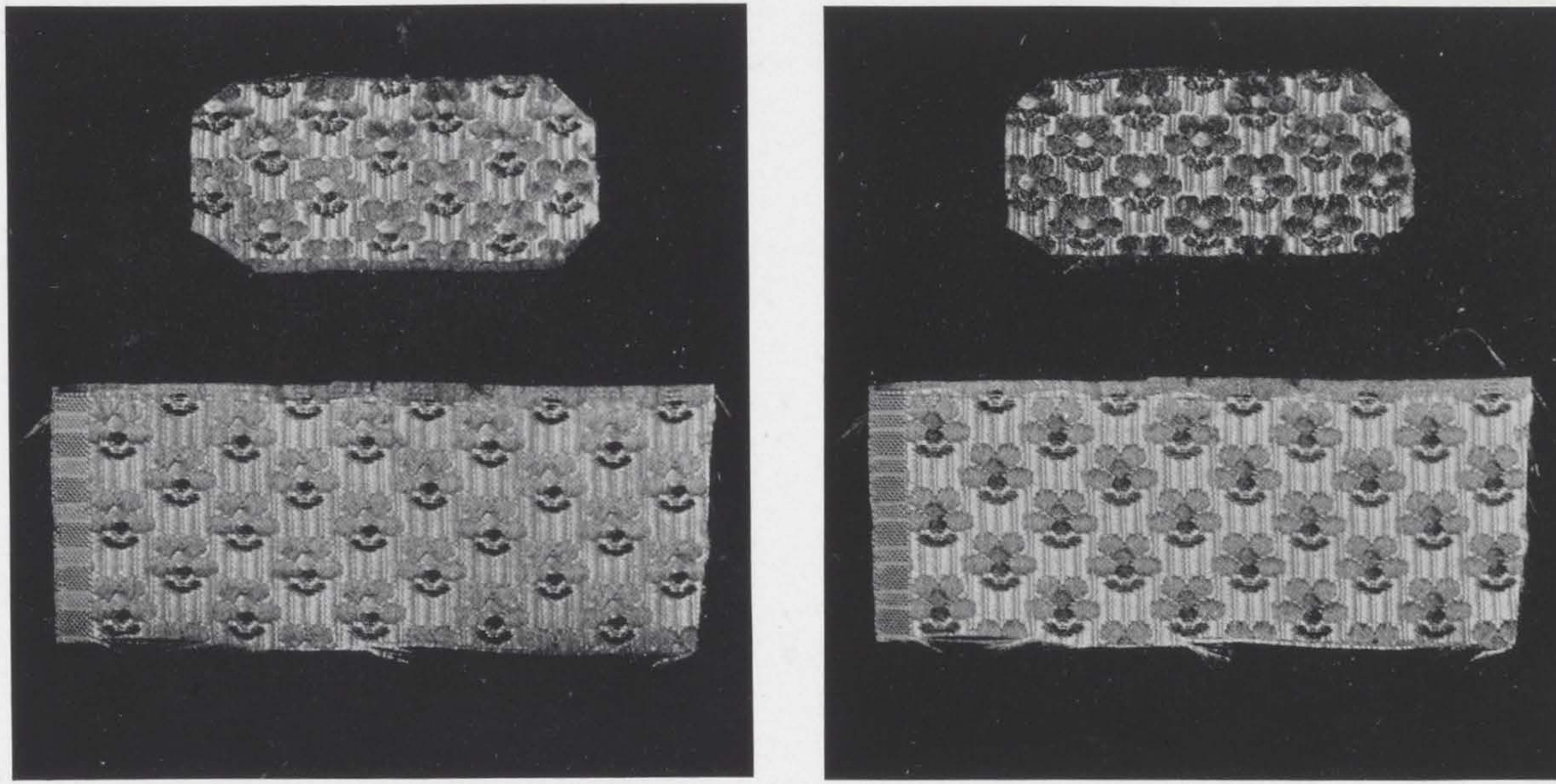
A

B

FIG. 30. MISCELLANEOUS DELFTWARE WITH RED AND BLUE DECORATION ON WHITE

A. In incandescent light
B. In ultra-violet light. The colors of the three genuine pieces (right) photograph darker under the rays; the colors of the imitation become lighter

(see page 34)



A B

FIG. 31. FRAGMENT OF XVIII CENTURY SILK (THE SMALLER PIECE) AND OF MODERN COPY (THE LARGER PIECE)

A. In incandescent light
B. In ultra-violet light. Colors which are chemically dissimilar react differently on the plate in ultra-violet light photography, although in incandescent light they appear the same

(see pages 36 and 37)

11.23

25.130.453

20.94.1

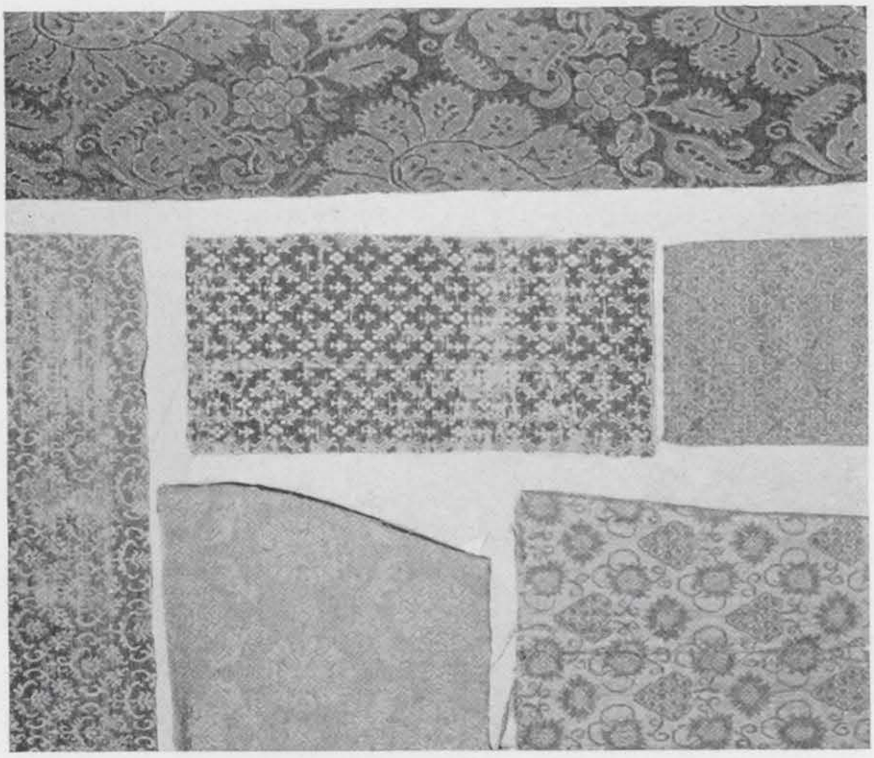
A B

FIG. 32. SILK TEXTILES, SAID TO BE XV CENTURY HISPANO-MORESQUE

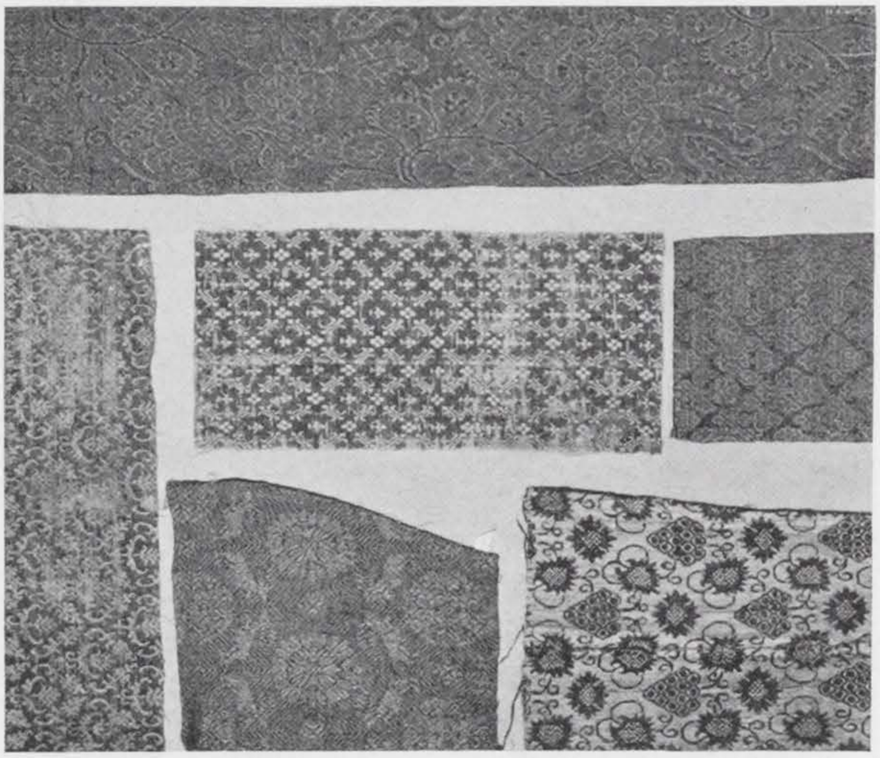
A. In incandescent light

B. In ultra-violet light. The two earlier pieces (above) are easily distinguishable in this illustration from the later reproduction (below)

(see page 37)



A



B

FIG. 33. WOOL FABRICS, SAID TO BE XVI OR XVII CENTURY GERMAN

A. In incandescent light
B. In ultra-violet light. The three pieces photographing uniformly dark are XIX century reproductions

(see page 37)

A B

FIG. 34. XVI CENTURY WOOL TAPESTRY

A. In incandescent light

B. In ultra-violet light. The restorations, somewhat lighter in color, are easily distinguishable (see page 38)

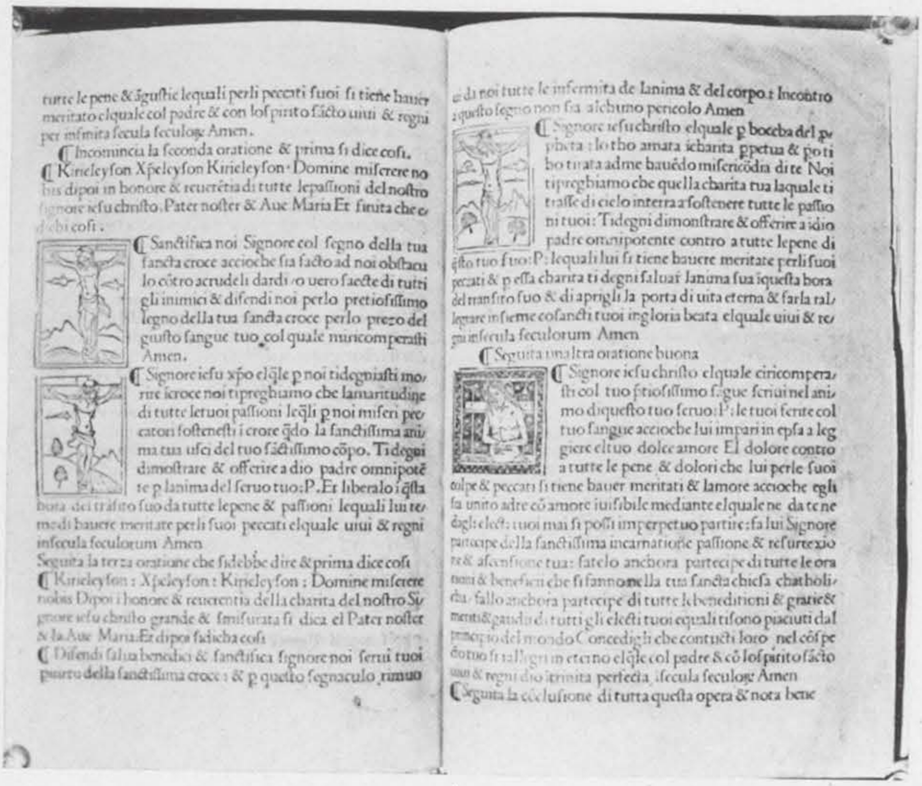
A

B

FIG. 35. XVIII CENTURY TURKISH (GHIORDES) RUG

A. In incandescent light
B. In ultra-violet light. The restorations appear as light patches

(see page 38)



A

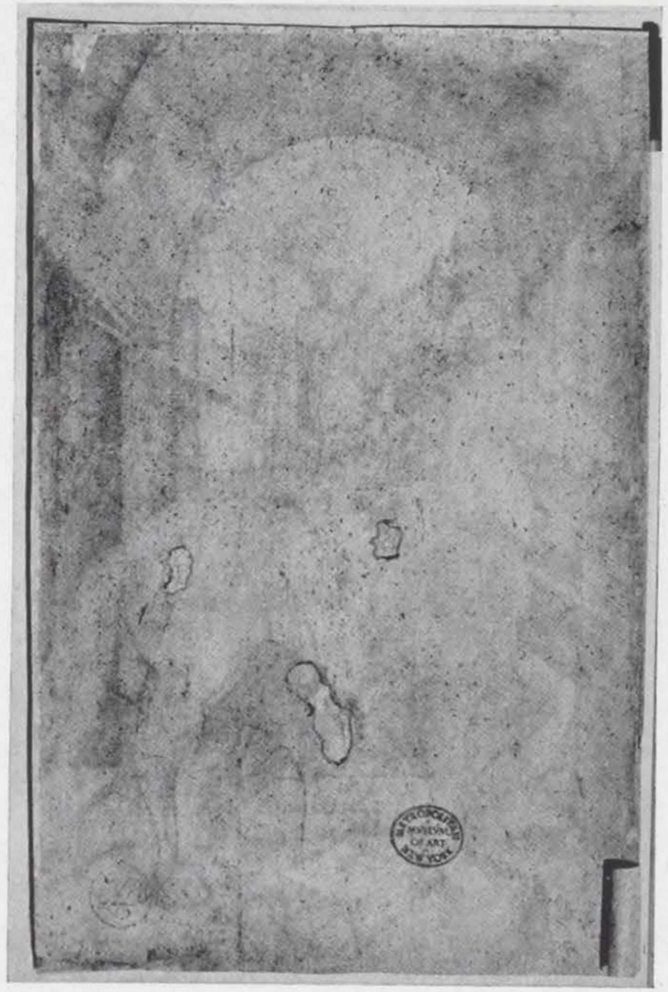
B

FIG. 36. XVI CENTURY FLORENTINE PRINTED BOOK

A. In incandescent light

B. In ultra-violet light. Note the restoration of the corners and the spots (see page 40)

A

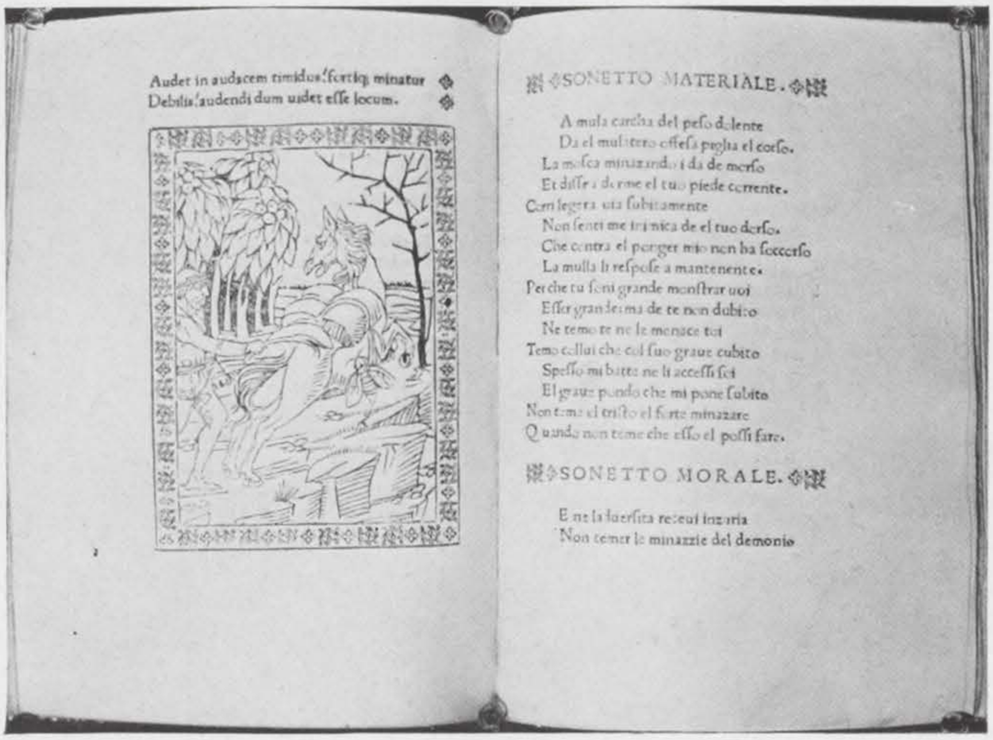


B

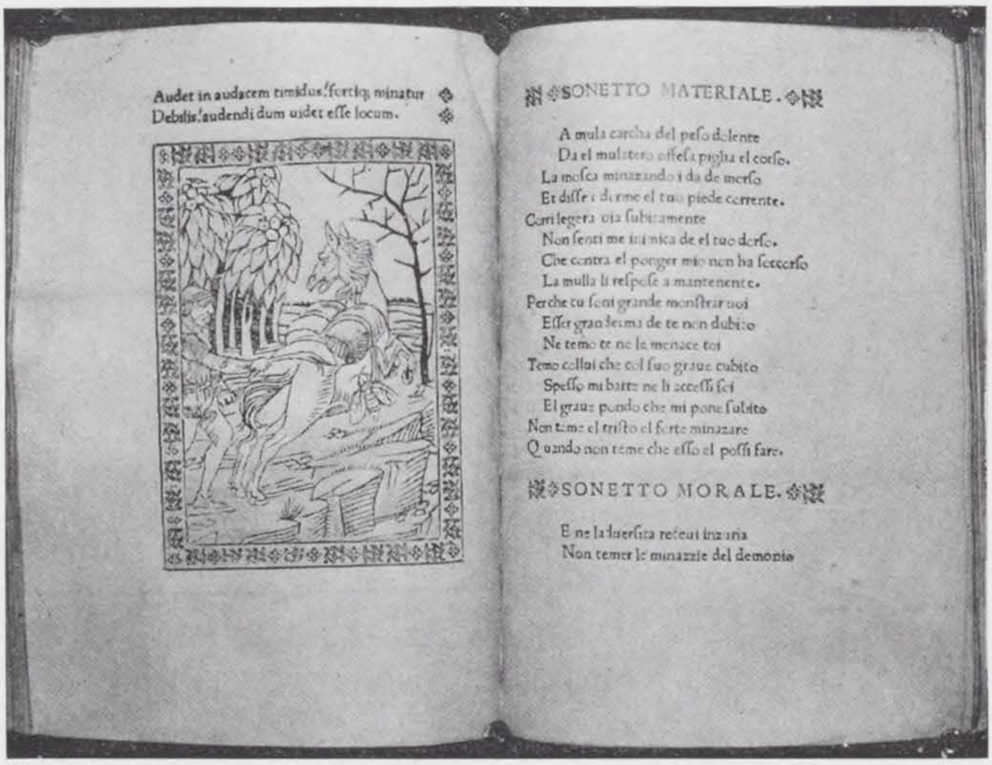
FIG. 37. ENGRAVING BY DÜRER

A. In incandescent light

B. Reverse of the engraving in ultra-violet light, showing repairs, three of which are outlined in black (see page 40)



A



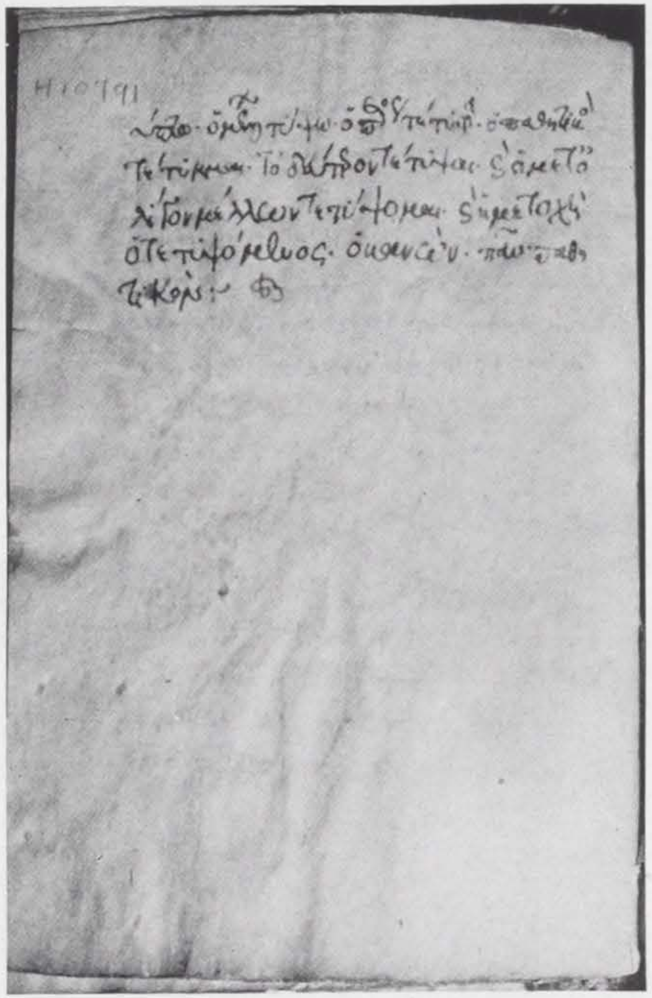
B

FIG. 38. PAGES OF A XV CENTURY EDITION OF AESOP'S "FABLES"

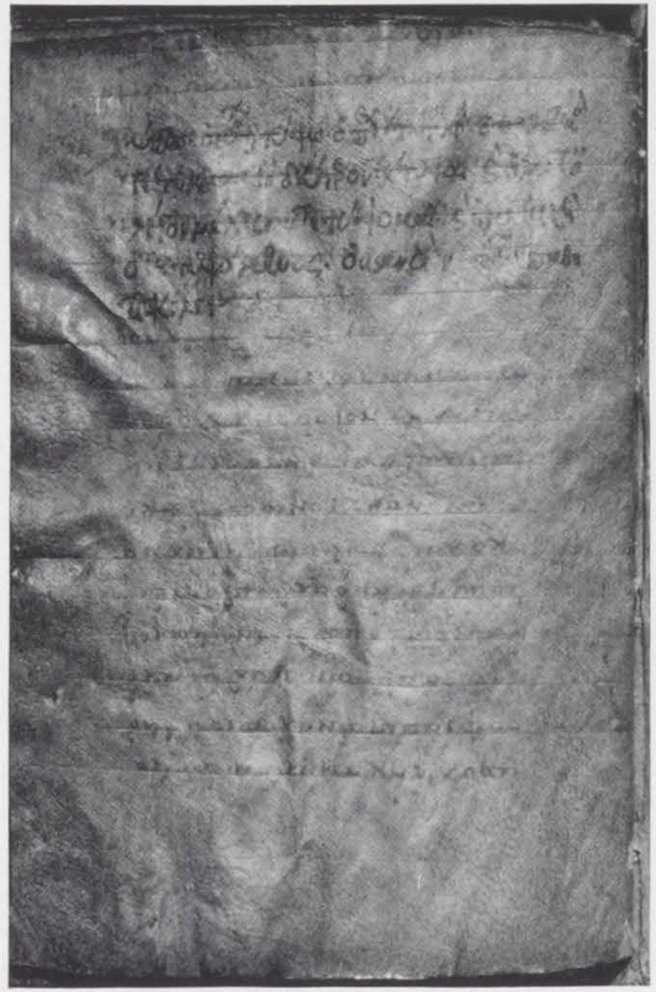
A. In incandescent light

B. In ultra-violet light. Note the rulings which were "removed" with chemicals

(see pages 40 and 41)



A



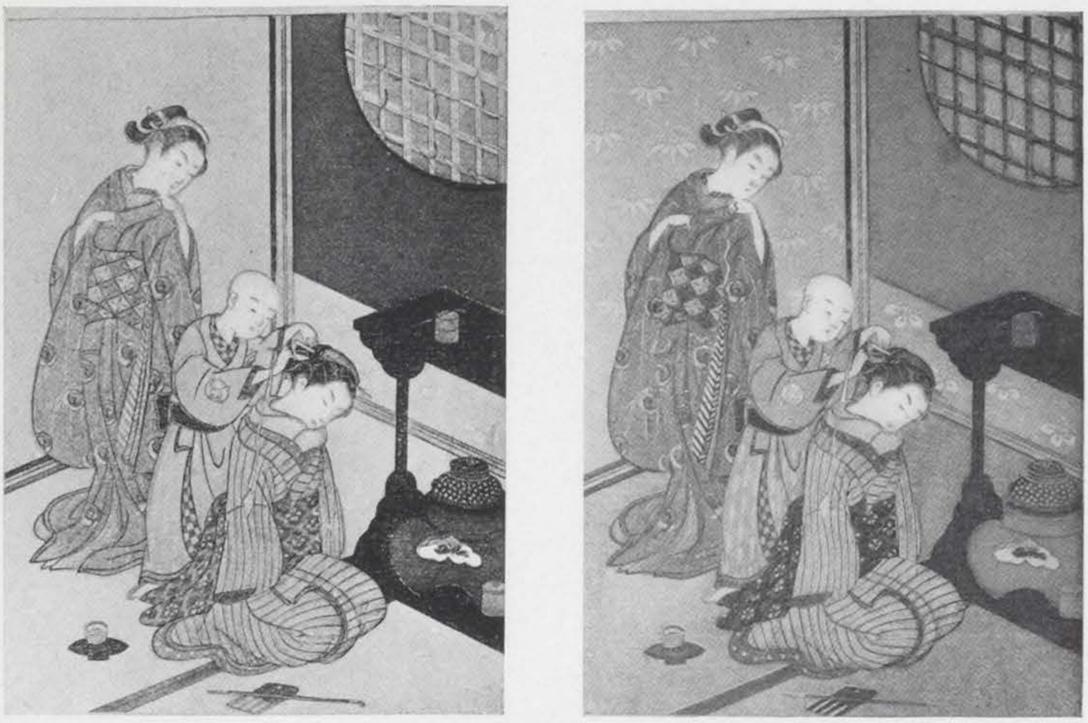
B

FIG. 39. PAGE OF THE PIERPONT MORGAN LIBRARY "MANUEL MOSCHOPOULUS" PALIMPSEST

A. In incandescent light

B. In ultra-violet light. The earlier writing, which has been erased, is brought out by the rays

(see page 41)

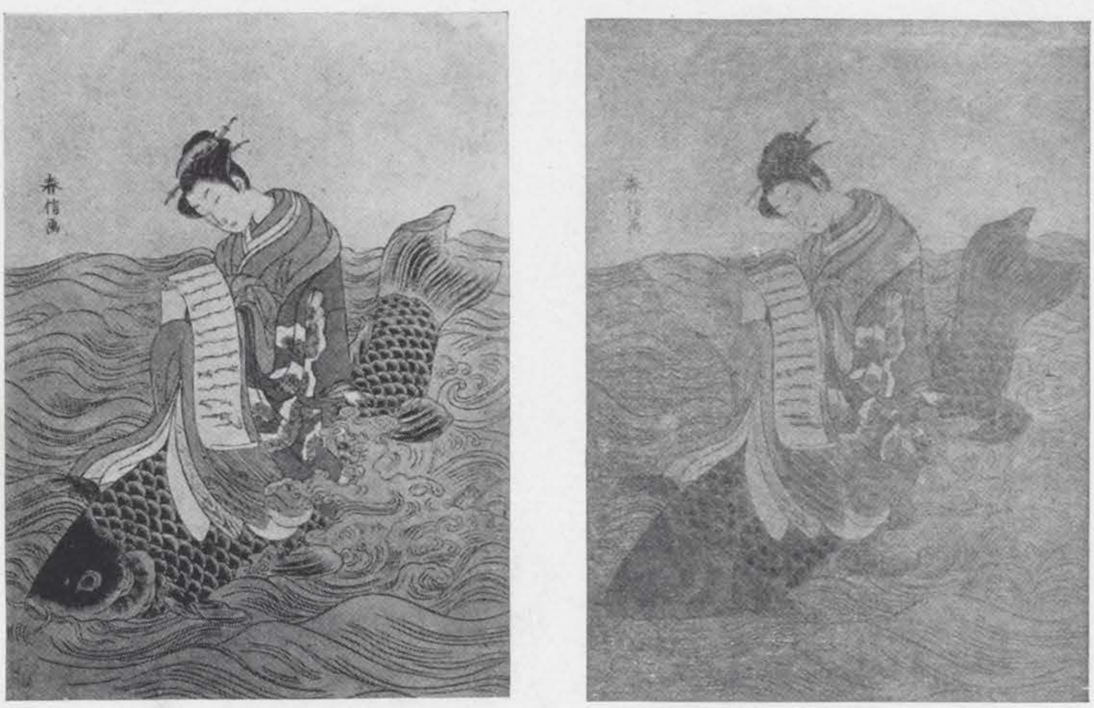


A B

FIG. 40. JAPANESE PRINT BY HARUNOBU

A. In incandescent light
B. In ultra-violet light

(see pages 41 and 42)



A B

FIG. 41. JAPANESE PRINT IN THE STYLE OF HARUNOBU

A. In incandescent light
B. In ultra-violet light. The print has been tampered with

(see pages 41 and 42)

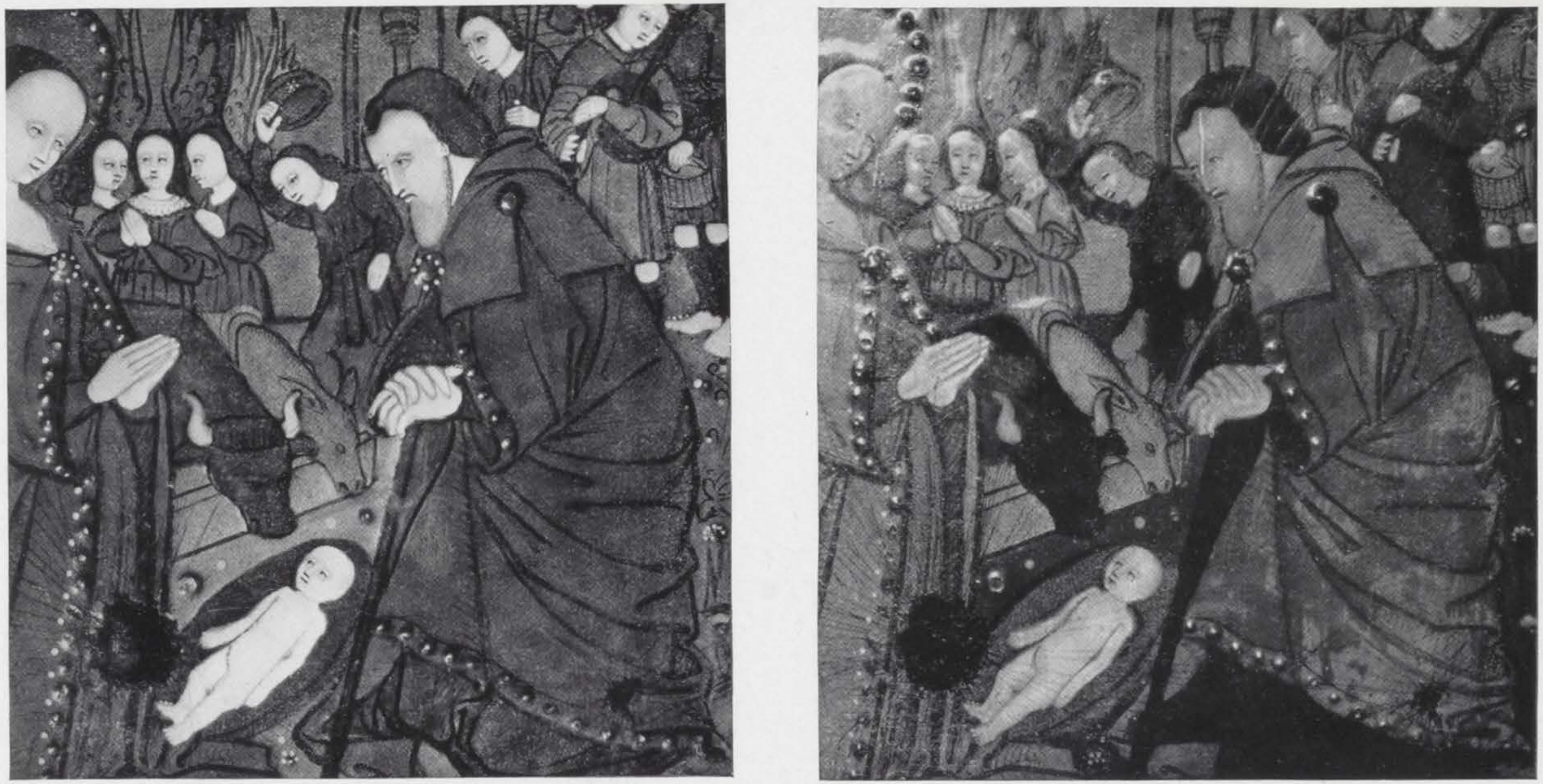
A

B

FIG. 42. MISCELLANEOUS ENAMELED GLASS SAID TO BE XIV CENTURY SYRIAN

A. In incandescent light
B. In ultra-violet light. The bottle on the right is a forgery

(see pages 43 and 44)

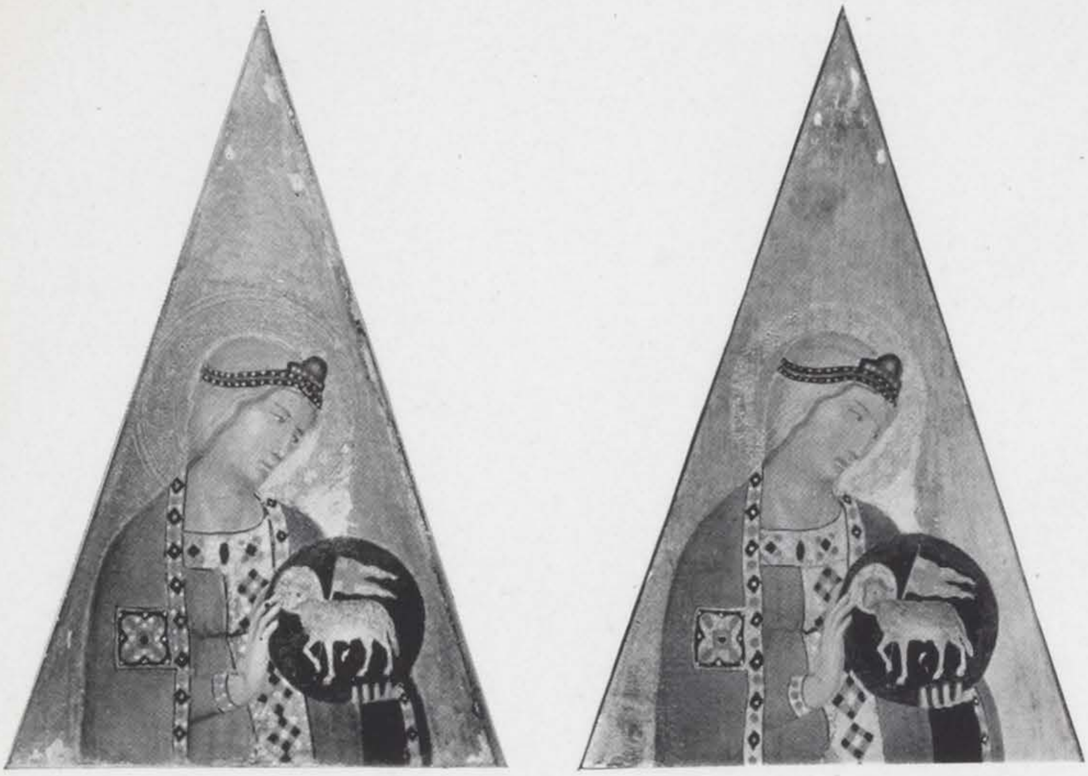


A B

FIG. 43. DETAIL OF XVI CENTURY LIMOGES ENAMEL

A. In incandescent light
B. In ultra-violet light. Cracks, changes in surface condition, and restorations are to be noted; the light part in the upper left corner is the result of reflection

(see pages 44 and 45)



A

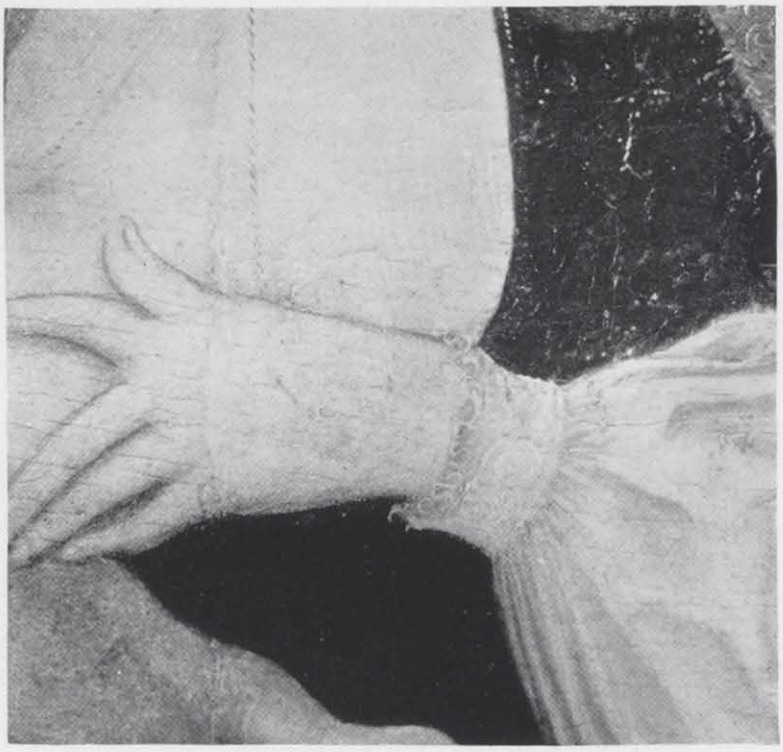
B

FIG. 44. XIV CENTURY ITALIAN PANEL (LEFT) BY AMBROGIO LORENZETTI AND MODERN COPY (RIGHT). COLLECTION OF EDWARD W. FORBES

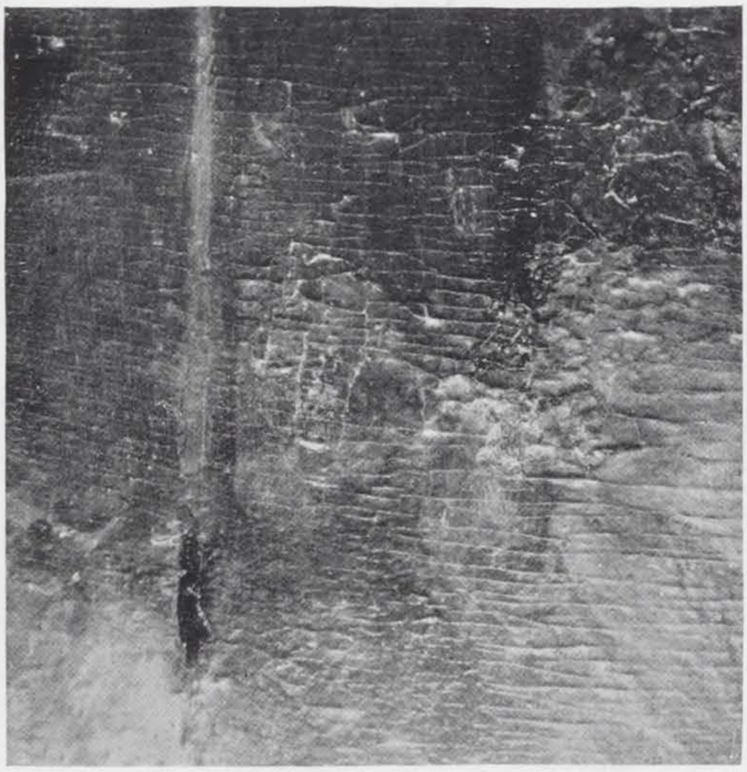
A. In incandescent light

B. In ultra-violet light. The reactions of varying pigments to the rays, as well as the manner of working, are revealed

(see page 48)



A



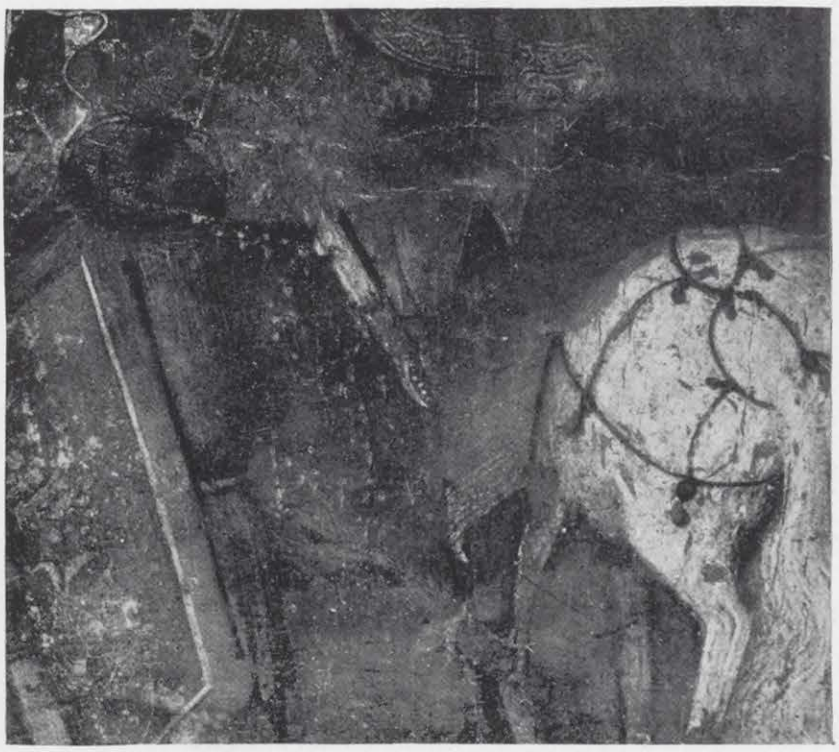
B

FIG. 45. DETAIL OF OIL PAINTING ATTRIBUTED TO LUCAS CRANACH

A. In incandescent light
B. In ultra-violet light. Repairs and surface condition are shown

(see page 48)

A



B

FIG. 46. DETAIL OF HEAVILY VARNISHED TEMPERA PAINTING BY BARTOLO DI FREDI

A. In incandescent light
B. In ultra-violet light. Under the rays the fluorescences of the repairs are as visible everywhere as are the restorations of the horse in this illustration

(see pages 48 and 49)

A B

FIG. 47. DETAIL OF XVII CENTURY OIL PAINTING

A. In incandescent light
B. In ultra-violet light. The light spots are restorations

(see page 49)

OF THIS BOOK

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