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NEW NONDESTRUCTIVE DOCUMENT TESTING METHODS

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Anyone engaged in general questioned document examination has frequent need to try to dis-discriminate between visually similar but possibly different writing materials. The opportunities for detecting document fraud and discovering manipulation have a direct relationship to the number and the objectivity of discriminatory tests. The most useful of the various techniques for deciphering writings or differentiating writing materials are those labeled "nondestructive". The designation "nondestructive" simply means that after having applied such tests the materials remain unblemished and provide no visible evidence that any testing process took place. These nondestructive methods range from the simplest of visual inspections and comparisons to highly refined photographic recording and the use of electronic visual devices. They include employment of various colored light filters to enhance or subdue contrast and the reactions of invisible radiations with document materials, both with regard to its reflection and absorption and stimulation of photo-luminescent emissions.

The simpler inspection and comparison methods with or without magnification have been with us from the beginnings of the profession. The use of color filters began before the turn of the century. In the 20's and 30's these were augmented by ultraviolet and infrared photography, recording differences in the reflection of these radiations from the surface of the document, and the observance, as well as photographic recording, of fluorescence resulting from ultraviolet radiation. The last few years have seen the development of several further refinements and extensions of these basic techniques. Two of these newer developments will be the subject for brief discussions.

One development concerns a reaction which has come to be known as "infrared luminescence", which exploits variations in the emission of infrared energy of many common document material ingredients when excited by blue-green visible light. The resulting invisible emission is detected by sensitive photographic and electronic methods. It can be permanently recorded by photography. The other development deals with isolation of and visual use of the varying response of some document materials in reflecting far-red light. Far-red is a term applied to the part of the red spectrum within our visual appreciation but which lies for the most part beyond the red sensitivity of ordinary panchromatic photographic materials. In document examination this visual region can be most effectively employed by means of special dichroic (2-color) filters. At present, no satisfactory means of recording these far-red reflection qualities has been devised. Both developments have something in common, the use of blue-green light. One transforms a part of the absorbed blue-green energy into a feeble invisible emission in the infrared region. The other allows visual use of the reflection of some of the red light that remains after a blue-green absorption. Both are closely related to the established ultraviolet and infrared techniques we have long been familiar with. Much remains to be learned of their full usefulness in our work.

In addition, there are several other somewhat related promising techniques awaiting development as nondestructive tests in the questioned document field. There is every reason to predict that with an intelligent effort by those in document work, the next few years will witness the practical development of some of them as well as some further refinements or extensions of our present methods. We can look forward to an expansion of useful nondestructive tests for everyday use of the document examiner. For some time there has been a real need for an informed survey and comparative evaluation of nondestructive testing as applied to specific types of questioned document problems. Such a survey should place particular emphasis on a comparison of the various photo-luminescent methods.

INFRARED LUMINESCENCE

Inspired by the work of Barnes (1) disclosing methods used for exciting and visual detection of infrared luminescence in mineralogical research, the principle with its implications was proposed as a promising field for exploration for possible criminalistic applications (2). Just as many document materials emit a visible fluorescence when excited by ultraviolet light, it seemed possible that other spectral regions, including those of visible light, might give rise to similar undetected emissions in either other visible or infrared regions. With a practical method of isolating and detecting any such energy, document examiners might discover a new examination tool. On that premise, experiments were planned and undertaken that confirmed that some document materials do absorb a band of blue-green light converting a small fraction of it to an emission in the near infrared. Practical methods were developed for exciting the emission and detecting it, both visually, using electronic image conversion equipment, and recording it by means of infrared photography. These methods were disclosed to and confirmed by other examiners equipped with suitable types of equipment prior to a public report and discussions of the techniques at the technical sessions of the Questioned Document Section of the American Academy of Forensic Sciences in Chicago in February 1960 (3). In describing the effects observed the term "infrared luminescence", as used by Barnes, was retained because of experimental evidence of both fluorescent and phosphorescent properties.

Applications. The first work with actual document materials and practical types of problems emphasized the need to consider several things. First, to evaluate infrared luminescent reactions properly requires that they be compared and related to ordinary visual appearance and to the reactions to other nondestructive testing methods, especially ultraviolet induced fluorescence and reflected infrared radiation. This comparative approach led to the considered conclusion that infrared reactions are frequently significantly different from either visual appearance or behavior with older testing methods. Second, papers, forming the background material of most documents, were found to exhibit a wide variation in their luminescence. As the reactions of the marking materials necessarily are related to those of the background, being more, less or approximately indistinguishable from those of the paper, caution should be exercised in designating specific observed reactions as necessarily typical to the type of problem. Comment on practical applications should stress principles applicable to broad categories rather than detailed instructions for some specific application.

In general, the new-found infrared luminescence was determined to be a genuinely useful addition to practical nondestructive testing in three principal fields:

(1) As a possible differentiating test for many for many writing materials, principally papers and inks.

(2) The detection of some types of document alteration.

(3) In deciphering some erased, obliterated, obscure, or secret writing.

Differentiation Testing. Papers are highly variable in response possible because much infrared luminescence seems to be affected by minor constituents, trace elements or contaminants of materials. The luminescence observed seems to be independent of the presence of optical brighteners that frequently interfere with observing marking material fluorescence in contemporary better grade writing papers.

Marking materials, especially most fluid, ballpen, and stamping inks in which dyes are an appreciable ingredient, react with considerable variation within visual groupings. The major exceptions seem to be in the fluid blues and carbon based black inks.

Pencil marks were found non reactive with the exception of the indelible types and some colored pencils.

Typewriting impressions are unresponsive if fresh although occasionally a luminescent halo will be seen to surround the black deposit. This may be the result of migration of either the vehicle or a dye toner within the paper fiber structure.

Detection of Alteration. Where alteration has been attempted by addition of visually similar material the high variability in luminescence of many classes of inks sometimes contributes to spectacular demonstrations.

Deciphering. Perhaps the most useful possibility stems from the presence of small amounts of violet dyes in indelible pencils and many black typewriting impression inks. Where such writing has been on paper for some time under storage conditions of a favorable nature this dye appears to diffuse through the paper structure to some extent. Such writing erased abrasively can many times be deciphered by the luminescence of the dye traces remaining in areas adjacent to the original point of ink deposit. Other useful reactions occur with some types of obliterated or faded writing. There is some indication of possible application to restoration of some kinds of faded blueline (diazo) engineering drawings and hectograph duplicated material. Nothing has been observed that would suggest practical application in deciphering charred paper remains.

Miscellaneous Applications. Doubtless the technique will be found to have some merit in the comparison of chromatograms and electrophoretic separations on paper or other supports in much the same manner that ultraviolet fluorescence is so used.

Equipment. The basic conditions for exciting and detecting infrared luminescence are few and readily comprehended:

(1) The object of investigation is lighted by an intense light from which all red and infrared is removed by an optical filter, originally a copper sulfate solution.

(2) Any infrared luminescence thus excited can be detected by means of either appropriate photographic equipment and materials or electronic image conversion equipment fitted with optical filters passing only far-red or infrared energy.

(3) Provision must be made to eliminate and exclude stray far-red and infrared light from the object as its reflection will degrade or obscure the faint luminescent emission.

The fundamental requirements will be discussed in some detail with regard to their practical attainment.

Effective excitation of infrared luminescence involves two elements. One is the light source and the other the optical filter necessary to absorb the unwanted far-red and infrared energy. The most readily available intense light source is the incandescent lamp, a useful form of which is the reflector photoflood. The output of such lamps is unfortunately rich in unwanted infrared and heat, and no particularly productive of the blue-green energy required for luminescence stimulation. As photoluminescence is an inefficient process, photoflood lamps or other light sources should be placed close to and concentrated on the area under study. Hoover and MacDonell (4) report the successful use of magnesium wire flash lamps in an enclosed filter holder for photography. As such lamps are relatively small, a suitable holder for group arrangements of flash lamps gains efficiency, it being brought close to the object. Gibson (5), (6), (7) reports use of both xenon arc and xenon electronic flash lamps as well as more conventional light sources. Such specialized lamps are richer in the spectral region needed and can be obtained in special shapes appropriate to the small areas usually under study in document problems. The xenon flash particularly seems likely to find further application in some presently undeveloped nondestructive tests.

Source filters, as originally used by Barnes, Godown, and others were glass or plastic cells filled with a 5 to 10% $CuSO_4$ solution. Such liquid filters, while awkward to use, are superior in heat absorption and dissipation characteristics. Corning filter No. 9780 (4-76) is an effective glass substitute used by many workers. It must be protected from excessive heat effects, otherwise it will prove to be rather fragile. Hoover and MacDonell discuss glass source filter requirements, suggesting Corning Nos. 4784 and 4303 as the most useful. As source filters the glass filters can be of molded quality, but all require protection from the intense heat of incandescent sources when used for prolonged photographic exposures. The protection may take the form of a water cell, special heat absorbing glass, as Corning #CS 1-69, and/or Corning infrared reflecting glass between the lamp and the glass color filter. Provision should be made to avoid tight clamping of the glass, and if lamp and filters are confined in an enclosure, it is well to include forced air circulation. Several workers have taken advantage of the combination of these several desirable factors in modern slide projectors, most of which have efficient light condensing systems as well as the heat controlling measures and require only the addition of optical filtering to become an efficient luminescence excitement source.

Detection of infrared luminescence involves two elements: the sensitive device, camera or image converter, and the filter necessary to exclude all of the visible energy transmitted to the object by the exciting system yet freely pass the spectral region of the desired luminescence. Such filters are usually Wratten Nos. 87, 87C, or 88A, as used for infrared reflection photography. They may be of the simple gelatin type or glass-mounted. There is evidence that the band of useful luminescence is broad and extends into the visible red as well as the near infrared. The use of sharp cut-off red filters such as Wratten Nos. 29, 92, 70 and 89B or Corning Nos. 2-59, 7-56 or other similar filters will appreciably shorten photographic exposure times. Comparison of photographs made of the same subject using different cut-off regions may provide useful data. The effective use of cut-off filters may depend to some extent on the efficiency of precautions taken to eliminate stray radiation, a subject to be considered later.

Detection devices involve two alternatives. One is limited, for the most part, to visual inspection. It makes use of electronic image-conversion equipment. The other is a recording method using infrared sensitive photographic materials. There is merit in both, and neither completely duplicates all the useful qualities of the other. As many document problems require either a permanent record or demonstration to others, the photographic technique takes preference for these qualities as well as other advantages. Infrared luminescent photography has much in common with the more familiar reflected infrared photography. The main differences in dealing with photographic luminescence recording arise from the low efficiency of photoluminescence. With the best of exciting sources, luminescence is a faint phenomenon. It is helpful to resort to exposure shortening possibilities when exposures require several hundred times those adequate for reflected infrared work. Although usual infrared films and plates, excluding the slower emulsions, can be used, it is desirable to use one of the high speed type infrared materials. Of these, two forms are available; a wide roll used for aerial photography from which sizes suitable for loading cut-film holders of 5" x 7" or smaller can be cut in the darkroom, the other comes in conventional 35 mm. perforated bulk rolls which for a number of reasons seems well adapted to the needs of most document examiners. In much document work where infrared luminescence photography is of potential utility relatively small areas are involved which we frequently need to illustrate at near actual size. Because of the popularity of miniature 35 mm. cameras using short focal length lenses, relatively fast lenses are available for use with this size film. The 35 mm. format exposed with the image smaller than that ultimately desired, at f 2.8 or faster on high speed film does much to overcome the excessive exposure times formerly required for luminescent photography. The final size can then be obtained by projection printing without appreciable loss of significant detail. Slower optics and sensitive materials in conventional commercial cameras with large image sizes can be employed using long exposures if necessary. Another useful expedient that will help shorten exposure time is to use auxiliary lens equipment rather than lens extension to permit close approach of camera to copy to increase image size without affecting marked lens f ratios. In many instances the use of the auxiliary lens will not materially affect essential image detail.

On the *electronic image converters* only the more recent types with sensitive image tubes such as the #6032 are desirable. Most of the modern commercially available units can be used effectively and conversions of the few available surplus sniperscopes using 20 KV tubes have proved satisfactory. With these it is found that the exciting illumination must be reduced substantially from that used for photography. While it may be possible to record luminescence by photographing the visual image on the phosphor screen, such a procedure would seem to have limited utility except in some highly specialized application. Electronic equipment has its greatest utility in the preliminary scanning of documents and the screening of documents in volume. Visual technique does not achieve the contrast found in routine photographic treatment and provides no possibility for contrast enhancement or the cumulative action of faint emissions available to the informed photographic worker. Where preliminary electronic methods indicate luminescence effects, luminescent photography can proceed with certainty of results but where no useful luminescence is observed it cannot be safely assumed that luminescent photography will not yield significant evidence.

Stray infrared interference can be a source of serious difficulty but can be effectively eliminated by several methods. One is to confine all luminescent work to a darkroom and to so enclose the exciting source and its related filters that all the stray light in the room has been adequately filtered. Hoover and MacDonell worked in a darkened room with an open illumination system in which the light not passing through filters was directed to and absorbed by black material. An effective solution is to devise some type of enclosure that will exclude all but filtered light from the area under study. Enclosures of this type can make use of the liquid filter or may be designed to accommodate stock molded glass filter sizes. A practical example of the former had been made in the form of a double walled transparent plastic cylinder using concentric 6″ sections of large size stock tubing cemented to a black plastic base from which a central disc the inside diameter of the smaller, inner tube was removed. The 1″ hollow wall formed by the two cylinders is filled with $CuSO_4$ solution. In use the filter is centered over the area under study. Lights are arranged surrounding the filter and a vertical camera or image-converter employed. The gap between the top of the filter and the optics of the detector may be enclosed by black cloth to eliminate stray radiation from the system. A similar rectangular wooden device employing one or more glass filters in stock sizes is equally effective. Barnes, Gibson, and Russian workers in luminescence all used large elaborate cabinets, the walls of which provided various lighting and filtering facilities. Experience shows that a surprisingly small amount of residual stray light can degrade or completely mask the infrared luminescence of materials of even relatively high emission. Stray light suppression in some form is *essential.*

The Use of Dichroic Filters

A number of natural objects, notably the foliage of many common plants, have a peculiar and far from obvious quality. They are very efficient reflectors of the red part of the visible spectrum as well as green. The red remains undetected, overpowered by the green sensation, only to be revealed when the green fades in autumn. It is this secondary red (and infrared) reflection of chlorophyll that causes most foliage to record as light areas in scenic views photographed using a red filter and infrared film. The same quality is exploited in military camouflage detection by infrared photography. Long before such skill became part of our technology, a few keen observers had recorded that by using some particular combination of colored glasses as a viewing filter the dominant green color of foliage could be suppressed without affecting the red, thus permitting a direct view of the red light reflected by leaves. Trees appeared to have red foliage, seen through such a filter (8).

Curiosity led Packard (9) to look at some documents through one of these odd filters. Illuminated by strong incandescent light, some markings, notably the purplish, blue, and blue-black ball pen inks, appeared as various shades of red when seen through the filter. As the ball pen inks thus seen as red seemed to be those capable of emitting infrared luminescence, Packard inferred that the two reactions might be manifestations of the same condition. Because one of the elements of his viewing filter was no longer available, Packard made no attempt to publicize his discovery until an effective substitute could be devised.

The filter eventually developed by Packard (10) is a sandwich of three gelatin filters bound between standard slide glasses. The three elements of his modern combination are a special cyan filter (Wratten Experimental #9186), a stock Ilford #202 (orange) and a stock Wratten #85B. These combine to form a dense greenish appearing filter having a moderately broad, low intensity transmission in the green, coupled with a relatively high transmission in the red, dichroic in that it transmits two colors of light. Viewed through this filter combination, many commonly used writing materials, such as fluid and ball pen inks, appear as varied tones ranging from black to bright red in contrast to a surrounding greenish paper background.

Ink dyes and mixtures that show no appreciable difference in reflection of their fundamental color may differ substantially in their reflection of red light. This difference, difficult to detect or to demonstrate by usual methods, becomes prominent and vivid through the use of Packard's or other dichroic filters with intense incandescent lighting of high red content. These differences find application in the differentiation of some ball pen, fluid, and mechanical impression inks and in some problems of deciphering obliterated material involving some of these classes of inks.

Applications extend to enhancing the visibility of the elusive reddish, metallic surface reflection that is characteristic of some of the dyes used in blue and black fluid and ball pen inks. The filters enable the examiner to better judge similarities and differences with respect to this specular reflection quality.

It has been found that these reflected red and other closely related effects can be observed by several variations in technique, with filters applied either to the lighting of the object under investigation, or in its viewing, or both. Various relatively inexpensive suitable filters can be assembled from stock gelatin (11) and/or glass (12) filters which although they do not exactly duplicate Packard's combination will provide practical results. Of the several single stock filters of a dichroic nature, none used alone proved as useful as those formed by combinations of two or more elements. The governing principle of combination appears to be to select a filter of blue- blue-green or green transmission and high far-red transmission as well, i.e., W40, 44, 44A, 45, 45A, 50, 58. This is then combined, by trial and error, with the appropriate yellow-orange or purple filter to control or depress the non-red region to yield most effective results, i.e., W15, 16, 21, 22, 30–35, 97. Practical examples are: W45 + 16 (or 15), W44 + 22 (or 21), W44 + Ilford 202, W40 + 30 (or 34A), W55 + 30, W97 + 11 (or 44), W35 + 44 (or 45). The behavior of similar filter combinations of dichroic qualities is diagrammed by Evans (13). He illustrates the transmission characteristics, single as well as in combination, of Wratten Nos. 44 + 22 and 68 (obsolete) + 22.

Theatrical and stage lighting supply houses stock large 20″ x 24″ sheets of colored gelatin and plastic material for use as lighting filters. Two leading brands appear to be Gelatin Products Co. and ROSCO. While theatrical applications do not call for the same optical quality as the photographic industry, a number of useful 2-element *viewing* filters can be made of "ambers" and various blues.* Experiments have shown the following combinations to be effective:

G. P. C. gelatins #29 + #10, #630 + #10;
plastics #P31 + #P8, #P29 + #P8.
ROSCO gelatins #11 + #30, #13 + #131;
plastics #856 + #815.

An additional useful pair combines ROSCO #40 green with #113 "pink".

Variable density, red leak polarizing pairs can similarly be used to depress the non-red fraction and will produce a comparable effect when used with blue-green filters. Also a few colored glass filters can be used effectively, i.e., C—4-77 + W30 or cobalt blue of various thicknesses + W12 (or 15) (or 16).

The visual effects revealed by these dichroic filters seem to result from two circumstances. The absorption of all but red by the ink lines so that only red is reflected by the line. Reflection by the paper adjacent to the line of *both* red and non-red light, either as a neutral tone or as a color, contrasting with that of the red of the ink line. It is this *contrast* between line and background that presents these useful new red reactions. When a simple red transmitting filter such as W25 is substituted the effect disappears because the line and background both are red and provide no contrast.

In addition to permitting observation of red reflected light, some of the dichroic filter combinations produce a secondary effect of a dual reflection of both red and/or blue from ink lines. This effect provides a basis for an estimate of relative proportion of these colors as reflected by various ink lines under comparison.

The effects discussed here are in part associated with our visual color sensitivity in the particular spectral regions involved and to some extent visual sensitivity in the far-red not recorded by ordinary panchromatic films. As the color sensitivity and balance of color photographic materials are not intended to simulate visual color balance, it is not too surprising that the delicate contrast and far-red effects cannot be easily photographed in color. Nor can they be satisfactorily illustrated in black and white monochrome. It seems likely that the problems of photographic illustration of the effects in color can and will be overcome.

Elbridge W. Stein, eminent document examiner and a pioneer in the use of ultraviolet and infrared techniques in document work, wrote in 1932:

"A document examiner who wishes to keep abreast of modern inventions or blaze a new trail in the application of scientific principles or apparatus to the discovery and proof of facts in documents will do well to add such equipment for the use of special light waves as his finances will permit.

"It should be kept in mind that every piece of equipment is only a tool and that it is valuable only when put in the hands of an intelligent user. No amount of equipment, however complete, will take the place of applied experience, intensive study and well balanced common sense."

The two comments are just as appropriate to infrared luminescence and far-red techniques employing dichroic filters with their potential applications today.

* By special arrangement, viewing filters of this class material, bound in 2″ x 2″ or 3″ x 4¼″ slide cover glasses can be obtained in assorted appropriate combinations of established utility in document examination by applications from Visualizer Products, 121 West Wacker Drive, Chicago 1, Illinois.

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