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Color Comparison in Questioned Document Examination Using Microspectrophotometry

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ABSTRACT: The work of the document examiner is often aided through the use of specialized analytical instruments. One such instrument, in use at the Immigration & Naturalization Service Forensic Document Laboratory (INSFDL), is the Nanometrics 10S Microspectrophotometer, manufactured by Nanometrics, Inc., of Sunnyvale, CA. This pseudo-dual-beam spectrophotometer performs nondestructive color analysis of objects down to 2 μm in size. First, an object to be examined (such as an ink line) is viewed through a microscope and the light reflected from it is measured over the visible spectrum. The reflected energy is then compared with a standard stored in the system's microprocessor, and a spectral curve is provided which is characteristic of the color of the object examined. At INSFDL, the Nanospec 10S® has been successfully used to differentiate similarly colored printing inks, stamp pad inks, and fibers found on various travel and identity documents. Examples from recent cases will be demonstrated.

KEYWORDS: questioned documents, spectroscopic analysis, colors (materials)

The Nanospec 10S® microspectrophotometer (manufactured by Nanometrics, Inc. of Sunnyvale, CA), is an instrument used for color measurement, allowing the nondestructive analysis of colored objects down to 2 μm in size. Its effectiveness has already been reported in such applications as the scientific examination of paints [*1-3*], fibers,[2] and inks [*4,5*]. A recent paper even explored the possibility that the Nanometrics DOCUSPEC® (an updated version of the 10S) might be used to determine the sequence of line crossings in document examination problems [*6*].

This paper addresses the use of the Nanospec 10S in the examination of inks and dyes on documents as performed at the Forensic Document Laboratory (FDL) of the U.S. Immigration & Naturalization Service, in Washington, DC.

Part of the work of the FDL involves the examination of passports, visas, alien registration receipt cards ("green cards"), and other travel and identity documents used by aliens to gain entry to the United States, or to obtain certain benefits once in the country. Most of these documents are produced by some printing process, and all of them contain stamped, handwritten, or typewritten entries. These entries are often erased or altered for fraudulent pur-

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[2]P. Lachambre, "Microspectrophotometric Observations of Disperse Dyes on Synthetic Fibers," unpublished manuscript.

poses, and the underlying documents themselves may be counterfeit, either wholly or in part. Microscopic methods are useful in attempting to differentiate between suspect and genuine articles, and the documents can also be nondestructively examined with various instruments and filters to detect differences in the way the paper and inks react to ultraviolet, infrared, and colored lights. But occasionally some questions remain: Is the article genuine?; or, if counterfeit, did two or more documents come from a common source? The inks involved can be chemically analyzed, using simple and inexpensive methods such as thin-layer chromatography, but not without some damage to the document. Other chemical methods can be expensive, time-consuming, and equally as destructive. What is desired is a method of comparison that can quickly, reliably, and nondestructively characterize and differentiate inks and dyes. For this purpose, the Nanospec 10S has proven itself useful in a number of areas.

Basic Theory of Operation

Objects are visible to our eyes because of the manner in which they reflect, absorb, or transmit visible light. They exhibit "color" because they react in a certain way to specific wavelengths of light. Sir Isaac Newton demonstrated with a prism that white visible light was not actually "white," but made up of various colors which, in combination, appear white [7]. The range of colors extends from violet at a wavelength of about 400 nm, through the various colors of the rainbow to red, at about 700 nm. When illuminated with white light, a red object appears red because it tends to reflect the red portion of the incident light and absorb other wavelengths. A white object reflects all colors to roughly the same extent and appears white, while a black object absorbs or scatters most wavelengths to the same extent, and appears black.

The human eye is a fairly good color comparator, but the perception of color is still fairly subjective. It varies from one observer to another and it even varies in the same observer, depending upon the light source used. A spectrophotometer measures color, however, by illuminating an object with light of a variety of wavelengths and measuring the amount of light transmitted or reflected at each of those wavelengths. It provides an absolute measurement [1] because it compares the light transmitted or reflected at each wavelength with the intensity of light incident on the object, making the result independent of the type of illumination used. The result of the comparison is a spectral curve or "spectrum"—a pictorial representation of the way a certain colored object reacts to the various wavelengths of light used. The curve has a distinctive shape, made up of peaks, shoulders, and troughs. Since the color of an object is due to the particular dyes, pigments, and other colorants in it, the overall shape of the curve should be distinctive, and unique to that particular dye combination.[3] Therefore, the spectrum of one object can be compared with the spectrum of another to determine similarity or dissimilarity between the samples. This makes a spectrophotometer particularly useful for discriminating between objects with "metameric" colors—colors that are actually different, but whose visual appearance, under a certain set of conditions, is similar or identical to the eye.

Parts of the System

The Nanospec 10S system at the FDL is comprised of the following parts:

Leitz Orthoplan trinocular microscope
with brightfield/darkfield vertical illuminator,
×16, ×32 objectives,
12-V 100-W tungsten halogen lamp for operations in 380 to 900-nm range (usually run at 11.5 V), and

[3]J. S. Christie, Jr., R. Harold, and R. P. Mason, personal communications, Hunter Associates Laboratory, Inc., Reston, VA, Feb. 1982.

100-W mercury arc lamp for ultraviolet (UV) fluorescent operations down to 220 nm;
Hewlett Packard 6286A power source for visible light operation, stabilized to 0.1%;
Leitz 1230 power source for UV operation;
Nanospec 10S microspectrophotometer head for ultraviolet, visible and near-infrared operations (220 to 900 nm) which mounts on camera port of microscope, grating monochromator with 2-nm resolution, gallium arsenide photomultiplier tube, monocular for viewing/focusing sample in adjustable mirrors, and variable entrance slit, adjustable to provide sample size from approximately 0.125 mm in diameter (with ×16 objective) down to 2 μm;
Nanometrics SDP-2000 Spectral Data Processor that:
controls wavelength drive,
stores one reference spectrum,
converts analog intensity data to digital bits,
reads out in intensity, ratio (transmittance, reflectance, absorbance or -log absorbance) or difference, and
calculates chromaticity coordinates and tristimulus values;
Hewlett Packard 7015 B *x-y* recorder for recording spectra; and
Axiom EX-801 Microprinter
prints intensity values every 10 nm of scan.

Operation

The basic system is designed to operate in the visible and near-infrared range from 380 to 900 nm. The NanoColor option allows the calculation of chromaticity coordinates and tristimulus values when the system is operated between 370 to 740 nm, as well as printing out the transmission values every 10 nm. (Special optics and a mercury arc light source are also installed which enable the system to be used for viewing ultraviolet and visible fluorescence starting at 220 nm, although this feature has not yet been tested at the FDL.)

In making a spectral analysis, a document is first placed on the microscope stage, and an object of interest (for example, an ink line on paper) is focused on a set of moving mirrors, as seen through the monocular in the photometer head. The exact area analyzed depends on the dimensions of the entrance slit as controlled by the mirrors. (Using the ×16 objective, the maximum slit size is a square approximately 0.125 mm per side which is an appropriate size for examining single written or printed ink lines which are normally around 0.2 to 0.5 mm in width. However, in practice, the slit is normally adjusted to a narrow rectangle whose axis is oriented in a N-S direction, because of the orientation of the monochromator.[2])

Moving the image to an uninked, uncolored portion of the document, a percent reflectance scan of the background paper is taken from 400 to 700 nm and the gain is set to nearly 100% at the wavelength where the maximum reflectance has occurred. Another scan is then made of the same area and the spectrum stored in memory. (This background reading approximates a measurement of the light incident on the sample.) Next, the ink line of interest is scanned and ratioed with the stored background, producing a spectrum representing the color of the ink line. (The spectrum can be plotted in one of three modes: % transmittance (% reflectance for our purposes), absorbance, or -log absorbance. Scan time is variable, and usually times of 1 to 1-1/2 min per scan are used to cover either a half sheet or a full sheet of graph paper.)

Since ink deposits vary greatly in density and coverage, at least three to five spectra need to be made to determine the overall variation between spectra. The same is true for the back-

ground paper sample, for irregularities in reflectance of the paper could cause interference in the readings.[3]

Next, the object to be compared (for example, a similarly colored ink line on paper) is placed on the stage, and the background of this sample scanned and stored in memory, if the ink to be analyzed is not on the same paper as before. The ink line itself is then scanned, and the spectra compared. Spectra of inks of identical composition should be similar in peak and trough positions and in relative peak heights, although the height of the curves on the "y" or ordinate scale may differ depending on the color's densities.

Experimental Procedure

As a practical test of the system, three samples of printing were obtained from another government agency. The samples were made on the same type of paper using red ink of the same formula, but the printing parameters were varied slightly, so three different shades of red were produced in the final products. Spectra were run on these samples, and are shown in Fig. 1.

Note that although the inks used were identical, the spectral curves were not. They varied slightly in shape and relative peak heights. This reinforces the observation that multiple scans must be made of the same object to determine the overall variation among spectra. Although researchers using instruments built to examine "macro" samples (approximately 1/4 to 1 in. (0.6 to 2.5 cm) in diameter) have found that successive spectra of the same sample

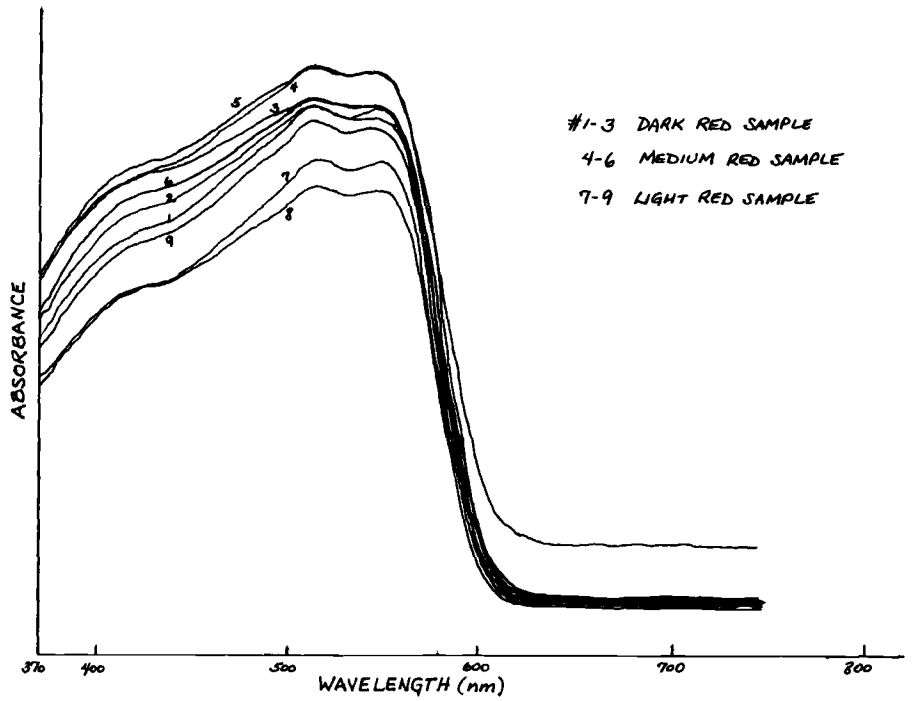

FIG. 1—*Printing samples made with the same red ink.*

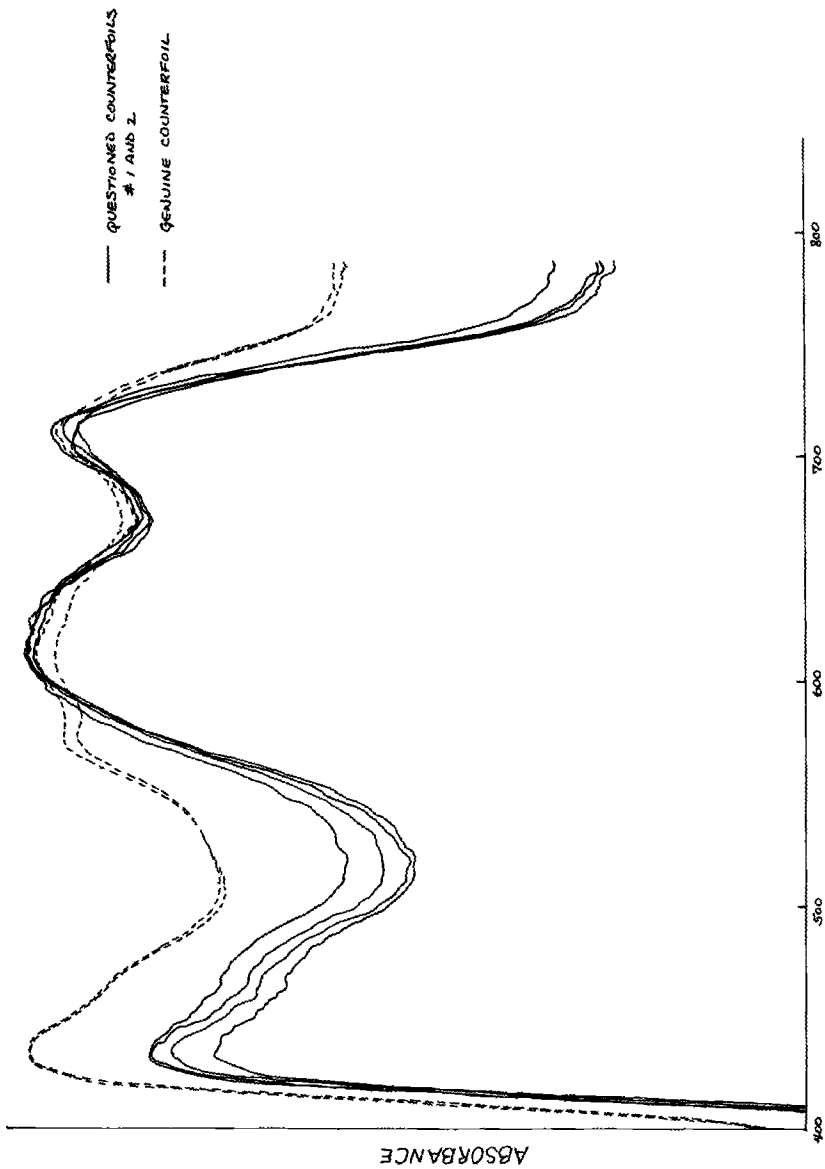

FIG. 2—*Green printing inks.*

are relatively parallel and overlapping, it appears that in the examination of micro samples, a number of variables come into play which can cause the spectra to differ (that is, the opacity or transparency of the ink, the extent to which it is absorbed by the paper, the consistency of the reflective quality of the paper, and the possibility of contamination of the ink by minute quantities of foreign material).[3]

Case Studies

Work at the INSFDL using the Nanospec 10S has primarily involved the examination of three things: printing inks on paper, stamping and ribbon inks on paper, and fibers embedded within paper. The following cases are a few examples demonstrating the usefulness of the system.

Case 1—Printing Inks

Two sets of counterfeit U.S. counterfoils were received at the lab at different times. (A counterfoil, which looks like a large intricate postage stamp, is issued by the State Department in addition to a nonimmigrant visa as an additional security feature in certain high fraud areas.) It was obvious on close examination that the counterfoils were counterfeit, but

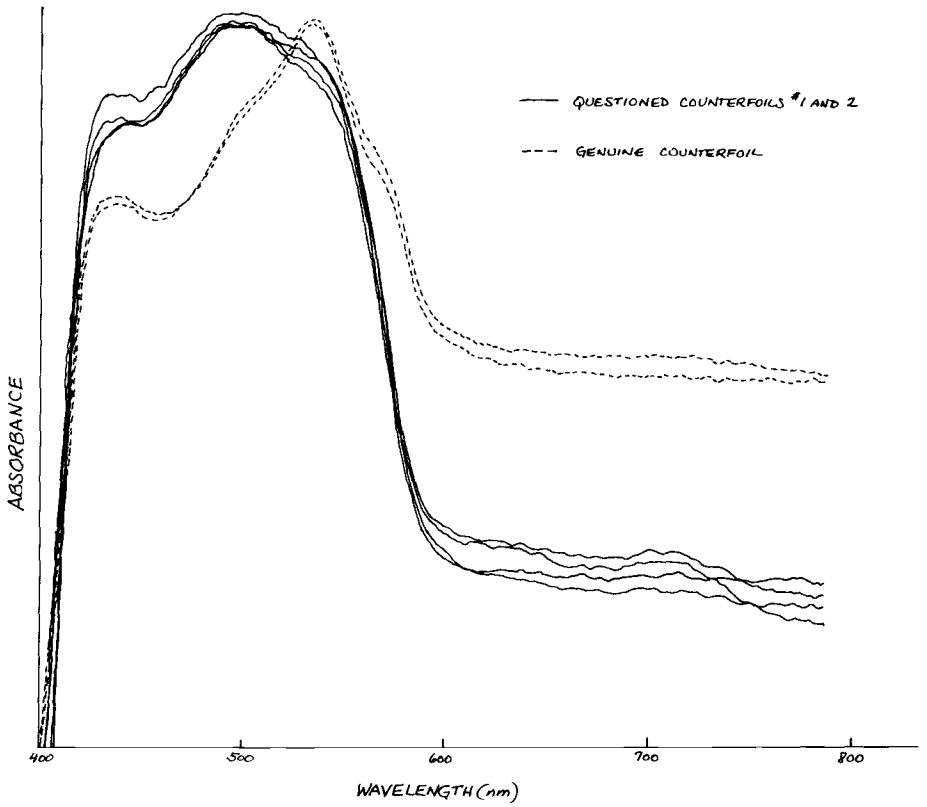

FIG. 3—*Red printing inks.*

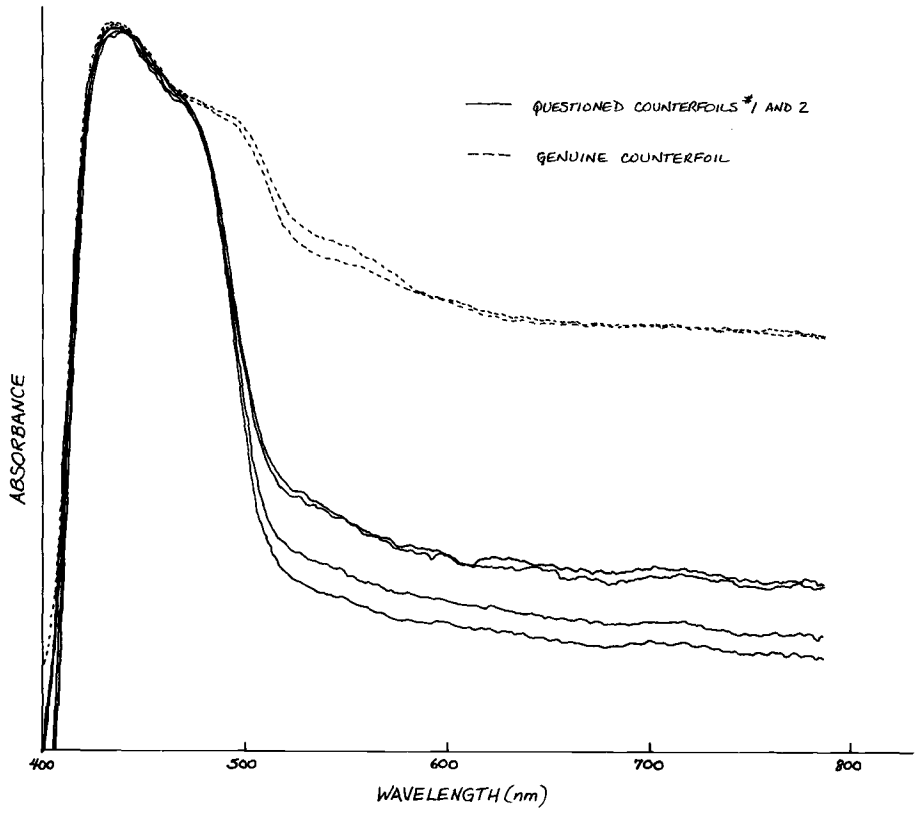

FIG. 4—*Yellow printing inks.*

we wanted to determine if they could have been made at the same plant. The green, red, and yellow inks used on the counterfoils were examined in various locations, and the resulting spectra compared (Figs. 2, 3, and 4). The close similarity of the spectral contours revealed the counterfeit inks to be of a virtually identical color, suggesting the same formulation of ink was used. Also noted was a substantial difference in color between the genuine and counterfeit inks. (It was later learned that all the counterfoils had been confiscated at the same counterfeiting operation.)

Case 2—Stamping Inks

Three passports were submitted to the lab for examination. Each had rubber stamp impressions supposedly documenting the person's arrival at a port of entry and processing for status as a resident alien. All of the cachets were suspected of being counterfeit even though they fluoresced in a similar manner to those made with the ink normally used. When the questioned impressions were compared with genuine ink impressions in visible light the ink

colors appeared different, but this may have been due to the fact that the genuine samples were on white paper, while the questioned ink was backed by brightly colored passport pages. Under ultraviolet light, the fluorescence of the inks *was* very similar.

Examination with the Nanospec 10S did demonstrate a substantial difference in color between the genuine and suspect inks (Figs. 5, 6, and 7). It also revealed that the ink on the suspect stamps appeared to be of a similar composition.

Case 3—Security Fibers

Many documents (especially currencies) contain colored fibers introduced into the paper during the pulp stage, which act as a visible security feature to make counterfeiting more difficult. A passport received at the lab gave indications that it was not genuine, or had been altered. The paper used contained colored threads, which were discovered to be actually caught among the paper fibers and not printed on, nor merely stuck to the surface of the

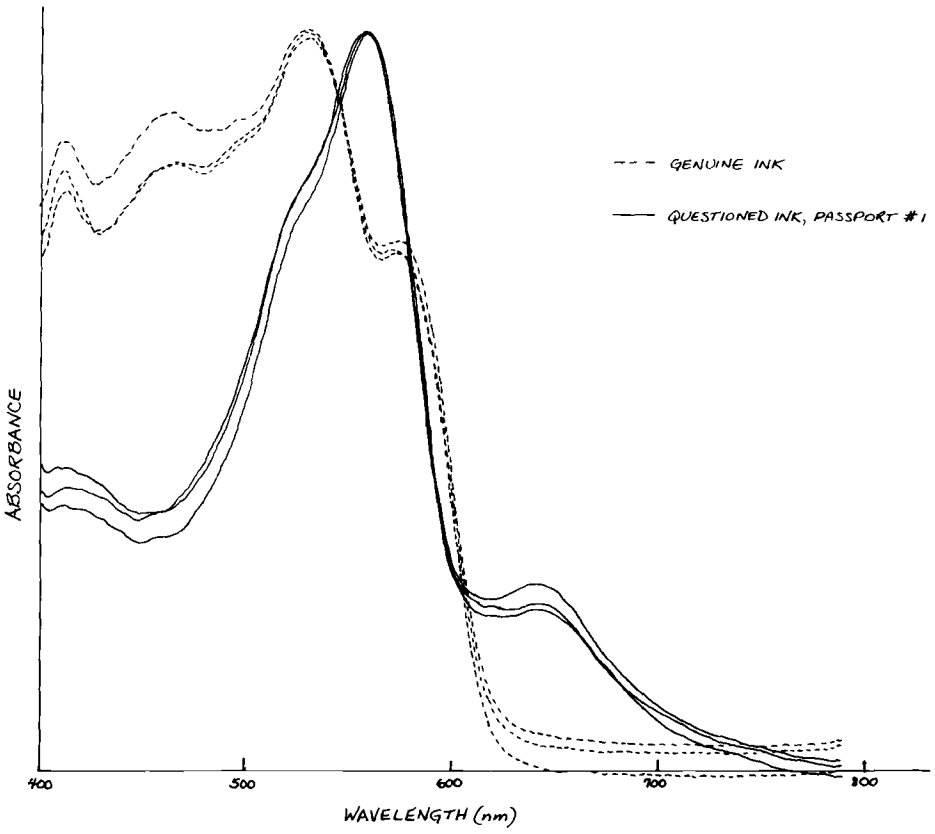

FIG. 5—*Red stamp pad inks.*

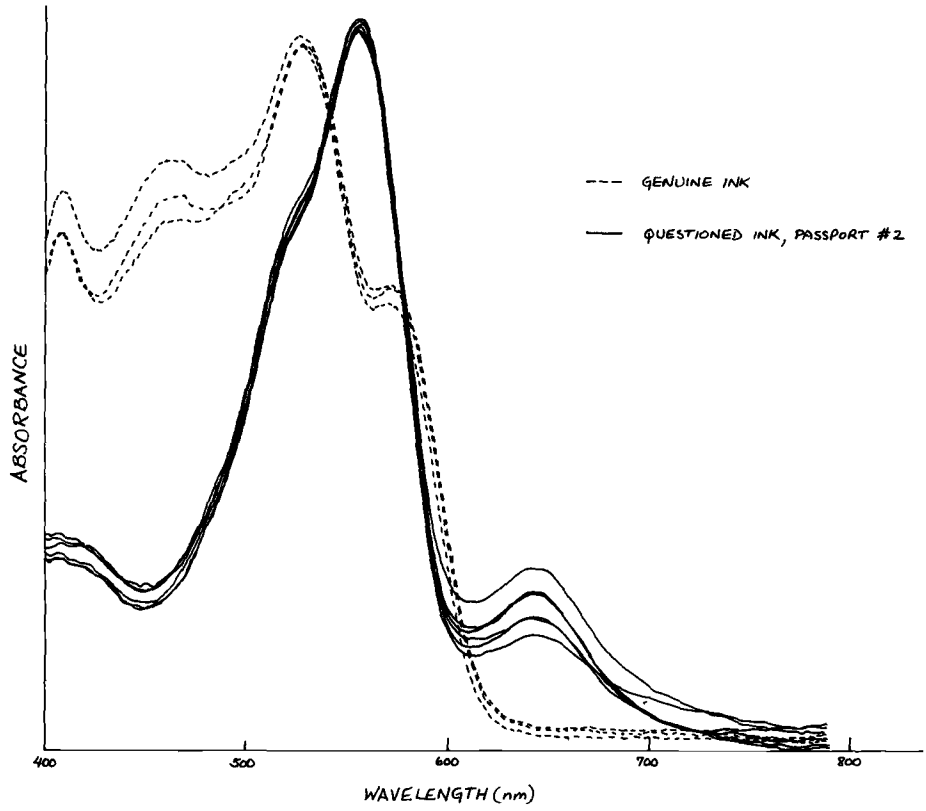

FIG. 6—*Red stamp pad inks.*

paper, as are found in some counterfeits. A check of these fibers against those in a genuine passport showed that the fiber color was virtually the same (Fig. 8), so the passport could not be ruled out as being genuine without further analysis.

Summary

Additional research still needs to be done in the area of refining spectra for better discrimination. At this point it is easy to distinguish inks having different dye components but not to identify conclusively inks with the same components. The Nanospec 10S will not replace qualitative chemical methods such as thin-layer chromatography or gas chromatography to identify inks and ink components; however, it will provide a quick, nondestructive screening of inks and other colored objects on documents to assist the document examiner.

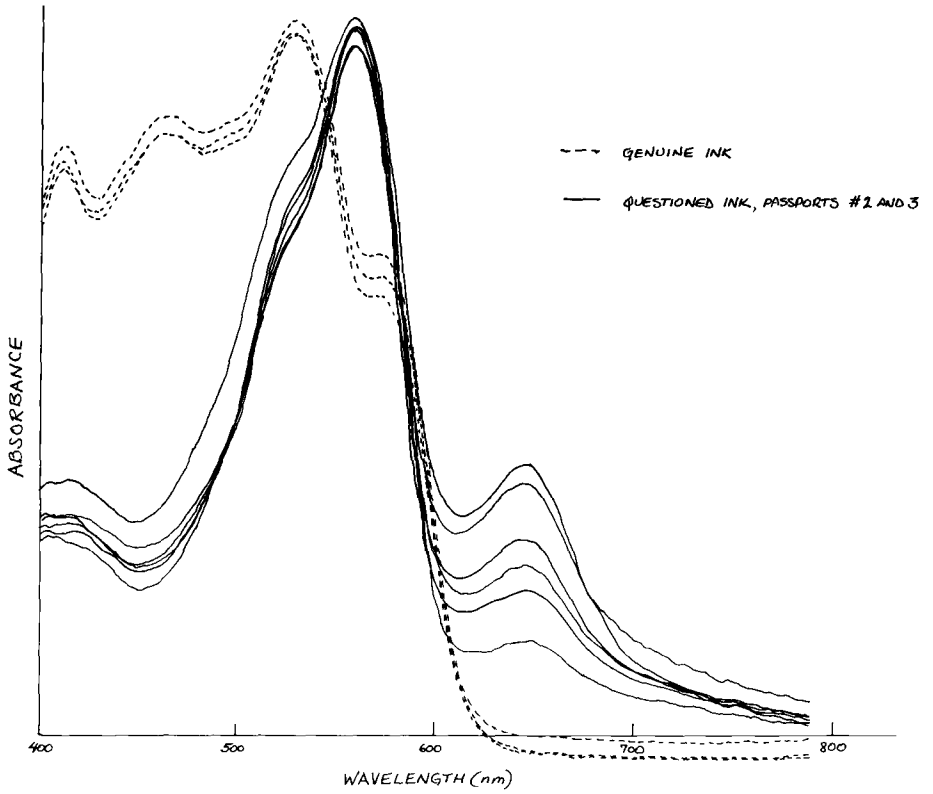

FIG. 7—*Red stamp pad inks.*

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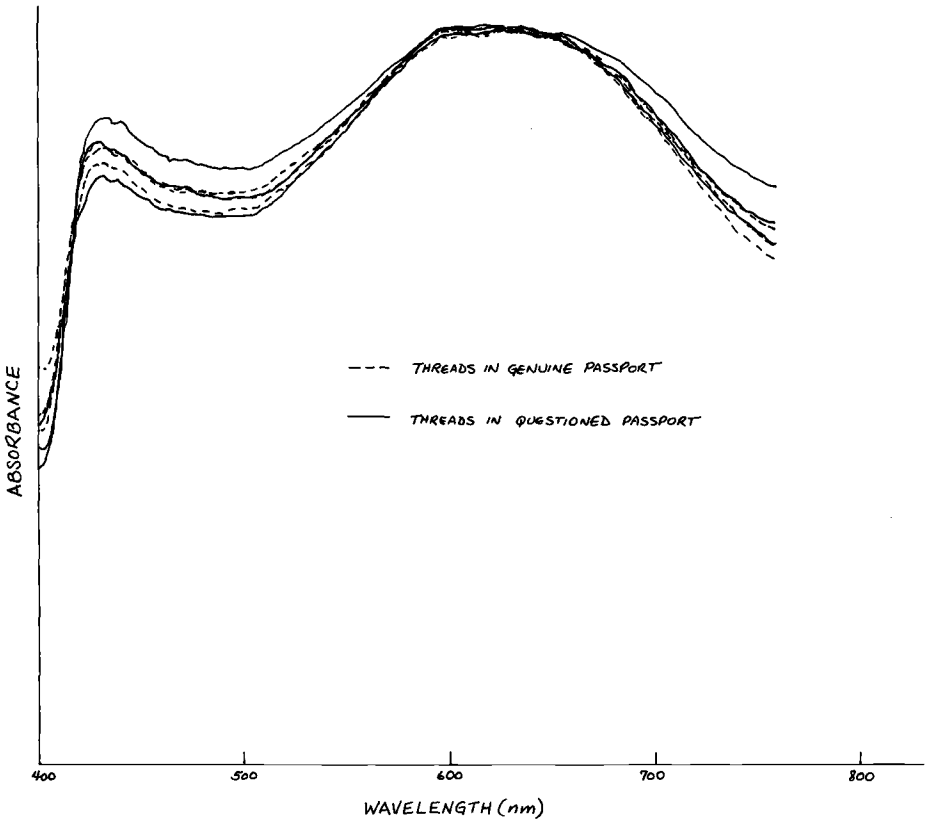

FIG. 8—*Blue security threads.*

[6] Rile, H., "Application of the Docuspec® to the Sequence of Strokes Problem," presented at the Meeting of the American Society of Questioned Document Examiners, Nashville, TN, 1984.
[7] *Using Filters*, Kodak Publication KW-13, Editors of Eastman Kodak Company, Rochester, NY, 1981.

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