

Ultraviolet, Infrared & Fluorescence Photography

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Reflected Ultraviolet Photography

Introduction

The electromagnetic spectrum is comprised of a series of waves arranged in order of wavelength. The various types of radiation forming this spectrum differ widely, and only a very minute part of this spectrum has any relevance to photography. Usually photography is confined to the visible part of the spectrum, those waves that the eyes see as "light". This part of the spectrum is comprised of wavelengths from approximately 400 - 700 nanometers (nm), which can be seen by the eye as a change of color. The shorter wavelengths are blue, the longer ones red. At either end of the visible spectrum lie two "invisible" spectra: the ultraviolet which extends from x-rays to the blue end of the visible spectrum, and the infrared which extends beyond the red and into heat (Figure 1). One important function of photography is to extend the range of spectral visualization of the human eye and record these "invisible" spectra. Infrared and ultraviolet photography therefore acts as investigative tools that are capable of discovering new facts about the subject. In some fields of investigation, extensive work has been reported on the use of invisible radiation photography. Other areas of application, however, remain unexplored and await the attention of the research-oriented photographer.

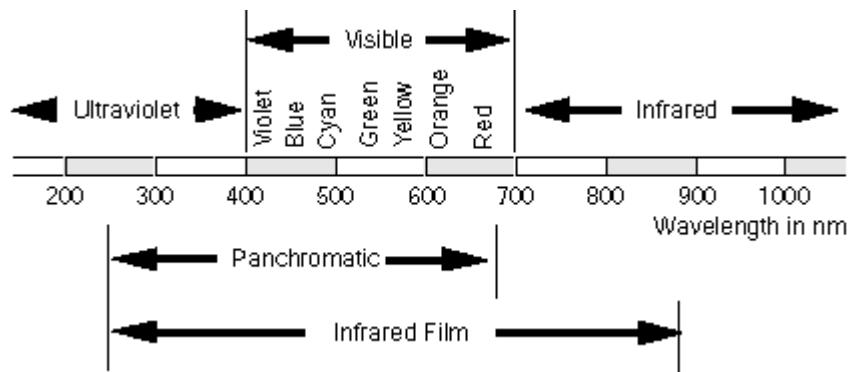


Figure 1 (above) - At either end of the visible spectrum lie two "invisible" spectra: the ultraviolet which extends from x-rays to the blue end of the visible spectrum, and the infrared which extends beyond the red and into heat.

Both ultraviolet and infrared photography offer a visible interpretation of an invisible state - no one has ever seen what the subject looks like under these radiations because the retina is insensitive to them. There is, therefore, no "correct" density to print to. It is also sometimes very difficult to interpret the infrared or ultraviolet record. It is for these

reasons that one should always include a control photograph taken with visible light to provide an exact comparison of the subject. It is also worth pointing out that clinicians and scientists will often have an incomplete understanding of the value of infrared and ultraviolet techniques. The competent photographer, however, will always be alert to the possible application of these techniques, and may indeed need to correct misunderstandings about their use.

There are two distinct techniques of ultraviolet photography: the reflected or direct method, and the ultraviolet fluorescence method. Reflected ultraviolet photography requires the subject to be lit with ultraviolet radiation, and filtration used so that only ultraviolet radiation is allowed to reach the film. The ultraviolet fluorescence technique requires that only ultraviolet radiation is allowed to fall on the subject, and the camera (if there is any fluorescence) records the emitted visible light.

Ultraviolet Radiation

The ultraviolet spectrum extends from approximately 10 to 400nm, overlapping x-rays at the shorter wavelengths and running into the violet end of the visible spectrum (Figure 2). The ultraviolet spectrum is further divided into near UV (320-380nm), middle UV (200-320nm) and vacuum UV (10-200nm) by physicists, or into UVA, UVB, UVC OR UVD, by biologists. The UVA extends from 320nm to 400nm and is known as the glass transmission region, the UVB extends from 280nm to 320nm and is known as the erythema or sunburn region, while the UVC extends from 185nm to 280nm and is known as the bacterial region. The UVB region is best known for the erythema effects - which stimulate melanin production as a means of protection - sun tanning. The suntan was once popular as a symptom of a healthy lifestyle (Figure 3) but the dangerous effect of ultraviolet in triggering malignant melanoma of the skin is now recognized. The photographer's interest lies in the near ultraviolet, or UVA, region although the researcher should understand the effects of the other regions of ultraviolet. For example, there are two significant biological effects of ultraviolet radiation: germicidal and erythema. Short wavelength ultraviolet is very effective as an antibacterial agent. Some caution needs to be exercised with "continuous" sources of ultraviolet, as there is a real risk of burning yourself and/or your patient, or of getting conjunctivitis. This is because the eye cannot "see" below 400nm, but the peak of erythema activity occurs at 297nm (Figure 4); also there is no heat emission from most sources of ultraviolet to warn the photographer of harmful exposure.

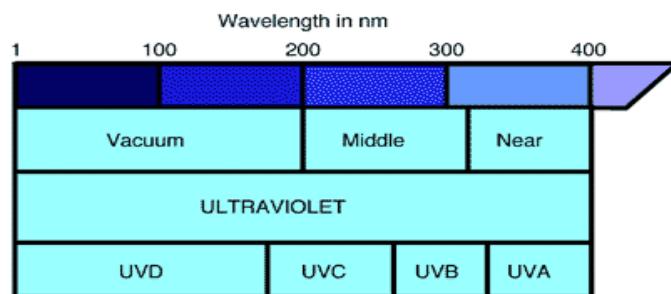


Figure 2 (previous page) - The ultraviolet spectrum is divided into near UV (320-380nm), middle UV (200-320nm) and vacuum UV (10-200nm) by physicists, or into UVA, UVB, UVC OR UVD, by biologists.



Figure 3 (left). Sun beds are efficient sources of UVB radiation designed to stimulate melanin production - a tan - the historic symbol of a healthy lifestyle.

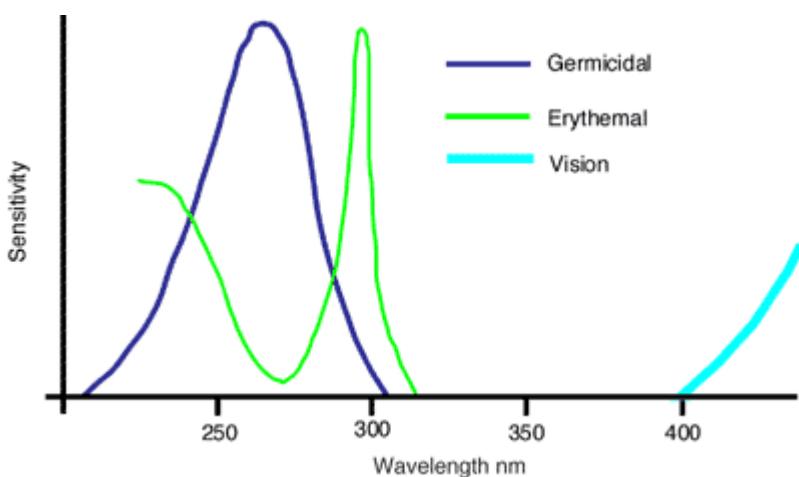


Figure 4 (above) - The eye cannot "see" below 400nm, but the peak of erythema activity occurs at 297nm so caution needs to be exercised with "continuous" sources of ultraviolet as there is a real risk of burning yourself and/or your patient, or of getting conjunctivitis.

REFLECTED ULTRAVIOLET PHOTOGRAPHY

Reflected or direct ultraviolet photography

The reflected ultraviolet photographic technique records only ultraviolet radiation, in the region 320nm to 390nm, reflected from the subject. All other radiation is prevented from reaching the film. A source of ultraviolet is directed at the subject which will then reflect this radiation back into the camera. In some instances the subject may be excited by this high-energy radiation and emit fluorescence in the visible spectrum. With the reflected technique, it is necessary to fit an ultraviolet transmission filter over the lens to prevent any visible radiation from impinging on the standard black-and-white film. Visible radiation, either in the room or reflected from the subject, can thus be ignored because it is absorbed by the filter over the camera lens. Figure 5 illustrates a general arrangement.

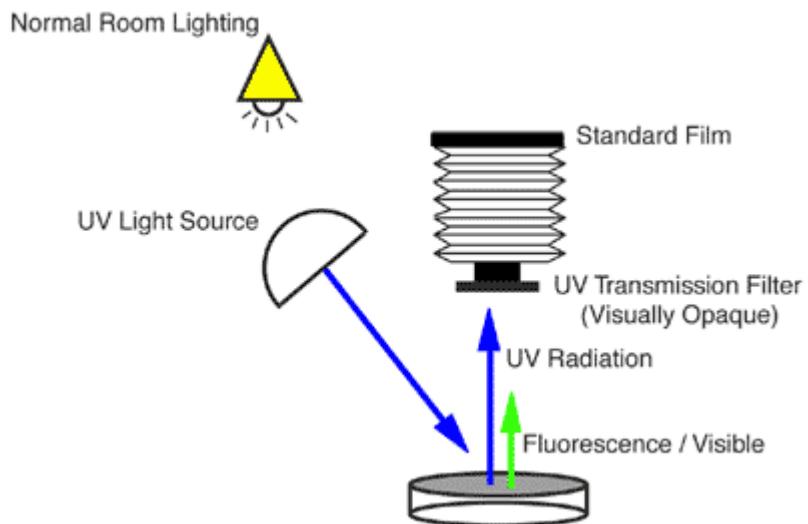


Figure 5 (above). A generalized arrangement for reflected ultraviolet photography.

For most photographic purposes ultraviolet is a problem - it is scattered easily by haze in the atmosphere which often ruins the appearance of landscape pictures, and causes very blue shadows in color photographs taken with daylight or with flash. Figure 6 demonstrates this effect; when the author took this color photograph of the Toronto waterfront the extent of low wavelength atmospheric haze was not visible to the eye but fairly effectively ruins the photograph. Photographic manufacturers have responded to these problems, and most films now have an ultraviolet absorbing overcoat and most electronic flashguns an ultraviolet absorbing filter over the flash tube. As professional photographers we are so accustomed to ultraviolet being a problem that we even advocate fitting a "skylight" or ultraviolet absorbing filter permanently over the lens (Figure 7). To turn the situation completely around and intentionally use this ultraviolet radiation to make the photograph, therefore presents quite a challenge.



Figure 6 (above) - The Toronto waterfront on a sunny summer's day - effectively ruined in this photograph by the ultraviolet dispersion in the atmospheric haze.



Figure 7 (left) - The 'UV Filter' or 'Skylight' filter routinely fitted to the front of camera lenses as physical protection is actually a UV blocking or barrier filter - useful for preventing the unwanted effects of haze in landscape photography and blue color casts in flash photography. It does not enable reflected ultraviolet photography but prevents it.

Many subjects have very unpredictable reflectance or absorption under ultraviolet. Figures 8 and 9 show examples of how different some subjects appear under reflected ultraviolet radiation.



Figure 8 (left) - Many subjects have a dramatically different appearance when viewed via reflected ultraviolet photography. This colorfully patterned blouse seen recorded with visible light onto panchromatic film in the top "control" photograph turns into a candy striped material when recorded with reflected ultraviolet radiation.



Figure 9 (left) - These photographs of an orchid also demonstrate the marked difference between the reflected ultraviolet record (top) and the visual appearance (below). Flowers have often been the subject of reflected ultraviolet photography in an attempt to identify markings or 'guides' for insect vector pollination.

Some materials that are black in visible light reflect ultraviolet so effectively that they record as white using the reflected ultraviolet technique, the fur of white seal pups, for example, records black against the white background of snow, and have been used in aerial surveys of arctic seal populations (Lavigne, 1976). Most biological subjects react less dramatically but the principle is the same. Tone and color differences so slight they are barely discernible to the eye often become very clear when imaged with the reflected ultraviolet method.

REFLECTED ULTRAVIOLET PHOTOGRAPHY

Sources Of Ultraviolet Radiation

There are many sources of ultraviolet radiation; indeed sunlight itself emits 10% of its energy in the ultraviolet region (Figure 10). Tungsten lamps are very poor sources of ultraviolet (Figure 11) and should be avoided. In practice, ultraviolet sources can be divided into two types - continuous and flash. Continuous sources are more suited to chromatography, immunoelectrophoretic studies, fluorescence and document examination, while flash is obviously more suited to patient photography. Gas discharge lamps, particularly the mercury vapor discharge lamp, are the most popular form of continuous ultraviolet source. The proportion of ultraviolet emitted by a mercury vapor lamp varies considerably with current density, but the operating pressure of the lamp mainly governs the spectral quality. Low-pressure mercury vapor lamps emit about 90% of their output as a line spectra at 254nm (Figure 12). High-pressure lamps, however, have a peak output at 365nm and secondary peaks at 334nm and 313nm (Figure 13). The high-pressure mercury vapor lamp fitted with a Wood's filter (Figure 14), is the standard instrument in dermatology for examining the skin under ultraviolet-this filter virtually restricts output of the lamp to a line at 365nm.

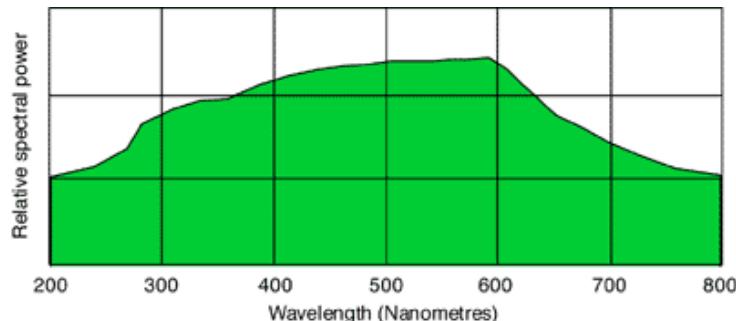


Figure 10 (above) - The spectral emission for averaged daylight shows a reasonable amount of ultraviolet content (Note this may vary enormously depending on the weather, time of day/year and the latitude).

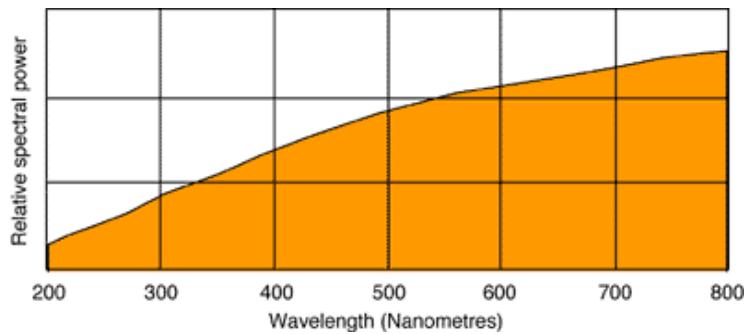


Figure 11 (above) - The spectral emission for Tungsten illumination demonstrates that whilst it is relatively rich in infrared it is a very poor source of ultraviolet radiation.

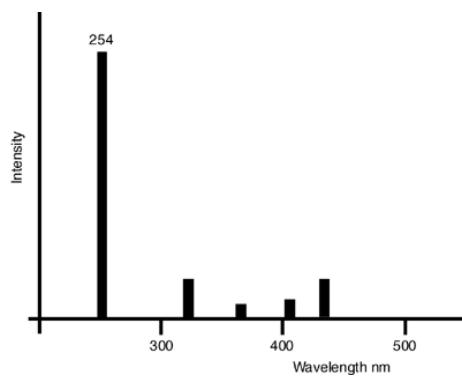


Figure 12 (above). The spectral emission of a low pressure mercury vapor lamp is a line spectra with about 90% of its output at 254nm.

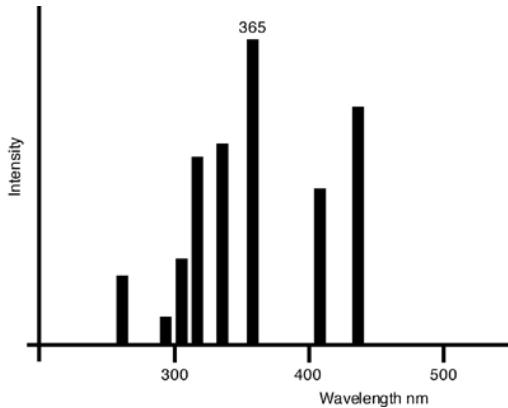


Figure 13 (above) – High pressure lamps, however, have a peak output at 365nm and secondary peaks at 334nm and 313nm



Figure 14 (left) - The 'classic' Wood's lamp found in many laboratories and clinics is a high pressure mercury vapor lamp fitted with a UV transmission filter - or Wood's filter - which effectively restricts the lamp's output to a single line spectrum at 365nm.

Mercury vapor lamps are supplied by several companies; in the USA these are:

- Edmund Scientific Co.
101 East Gloucester Pike
Barrington, NJ 08007-1380, USA
- Hanovia Lamp Division
Emglehardt Hanovia, Inc.
100 Chestnut Street
Newark, NJ 07105, USA
- Curtin Matheson Scientific
1850 Greenleaf Avenue
Elk Grove Village, IL 60007, USA
- Ultra-Violet Products, Inc.
5114 Walnut Grove Avenue
San Gabriel, CA 91778, USA

The domestic fluorescent tube is a very poor source of ultraviolet but special tubes are available with ultraviolet emitting phosphors - the so-called "black light" tubes. They are inexpensive, efficient sources of ultraviolet and do provide very even illumination that is useful for large subjects. They are, however, quite inefficient when compared with the output of either mercury vapor or xenon flash tubes. Some manufacturers incorporate small ultraviolet fluorescent tubes into battery driven hand lamps - these are very useful as examination lamps prior to fluorescence photography with a more efficient source (covered in more detail in [fluorescence photography](#)).

Open arcs provide substantial emission of ultraviolet and are still used as primary sources in some process work. The xenon arc lamp is a particularly good continuous source of ultraviolet. It has a fairly flat, but high spectral output from 300nm to 1100nm and is therefore suitable as a continuous source for both ultraviolet and infrared photography. Figure 15 shows the spectral emission curve for the xenon arc lamp.

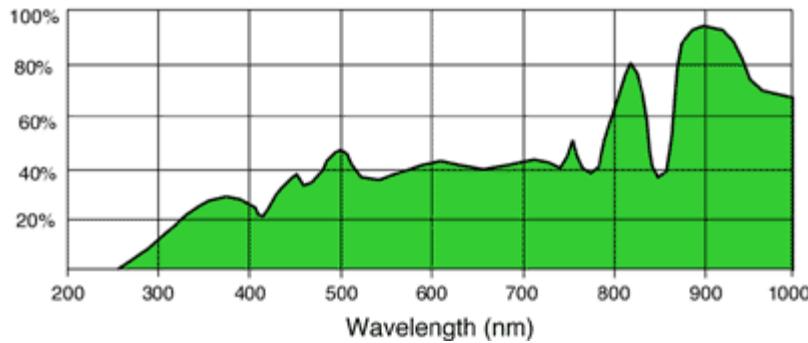


Figure 15 (above) The xenon arc lamp is a particularly good continuous source of ultraviolet. It has a fairly flat, but high spectral output from 300nm to 800nm with a peak of activity between 800nm and 1100nm and is therefore suitable as a continuous source for both ultraviolet and infrared photography.

Several manufacturers now supply xenon arc lamps especially made for invisible radiation work. Examples would be the Polilight, Lumilite or Omniprint. These all have a series of stepped interference filters, which are then tunable by tilting their angle to the beam to give a continuously variable output from 300 to 1100nm. An LED display shows the frequency of the output accurate to +/- 20nm. Visible and ultraviolet radiation are delivered to the point of use by an efficient liquid light guide with quartz and silica optics on the end and infrared via conventional fiber-optic light guide (Figure 16).



Figure 16 (left). The Polilight, a commercial example of a xenon arc lamp especially made for invisible radiation work.

The xenon flash discharge tube has a very high output between 300 and 400nm and is the most useful source of ultraviolet to the biomedical photographer. Figure 17 shows the spectral output of the standard xenon flash tube. Electronic flash manufacturers have been well aware of the high output of ultraviolet radiation and the deleterious effect this has on color photography (blue color casts in shadow areas). In many instances they have coated their flash tubes with a gold coating to absorb the ultraviolet or have fitted ultraviolet absorbing screens to the front of the flashgun (Figure 18). The effect of such filtration is quite variable; some coatings seem very efficient and markedly reduce ultraviolet output, while others have very little effect. Ultraviolet absorbing filters fade with exposure and thus become ineffective over time and this may explain why older or well-used flash tubes suffer less from the absorption problem. When new, however, such coatings do absorb ultraviolet efficiently, and so it is helpful to obtain uncoated or

unfiltered tubes. Several manufacturers supply them for studio flashes (Bowens, Courtney and Elinchrom). Nikon used to supply a portable flash with an uncoated tube - the SB-140 (Figure 19). The Nikon unit came complete with filters for both ultraviolet and infrared work and had a useful exposure guide - in many respects the ideal source for invisible radiation patient photography, especially on location. Figures 20 to 23 show the spectral emission curves for this source with its various filters. Unfortunately Nikon have now withdrawn this unit from their product range - like so many products suited to specialized imaging from different manufacturers. The authors are fortunate enough to own two of these SB-140s and can vouch for their usefulness for invisible radiation photography; so don't hesitate to acquire one if you happen to come across one second hand or 'left over' in a camera store.

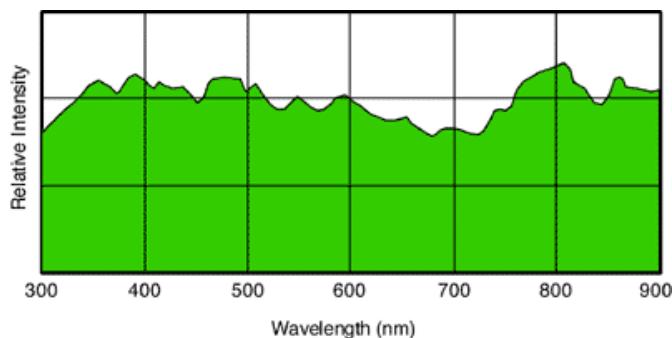


Figure 17 (above) - The spectral output of the standard xenon flash tube with a very high output between 300 and 400nm this is the most useful source of ultraviolet to the biomedical photographer.

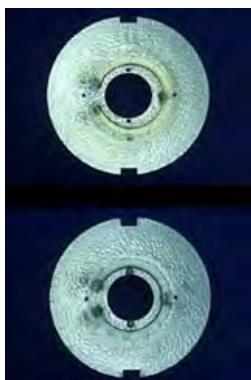


Figure 18 (left) - Many manufacturers of electronic flash units coat the flash tube with a thin metal layer - usually gold - to absorb the ultraviolet radiation which causes unwanted blue casts in color photography. The coated tube (above) looks pale yellow in comparison with the bare or uncoated tube (below).



Figure 19 (left) - The Nikon SB-140 flashgun especially manufactured for invisible radiation photography with uncoated xenon tube and filters for visible, reflected ultraviolet and reflected infrared photography.

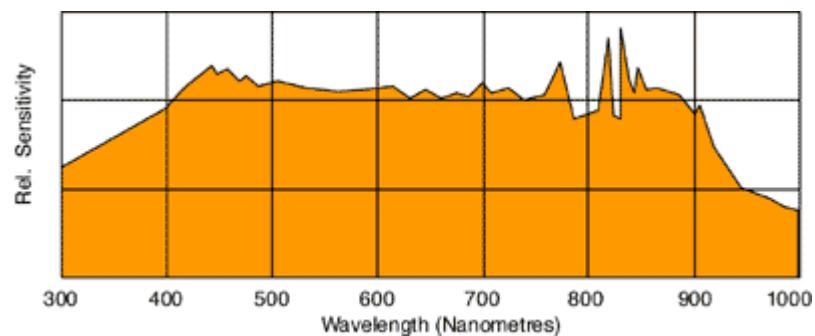


Figure 20 (above) - The spectral emission curve for the unfiltered Nikon SB-140 xenon flash tube.

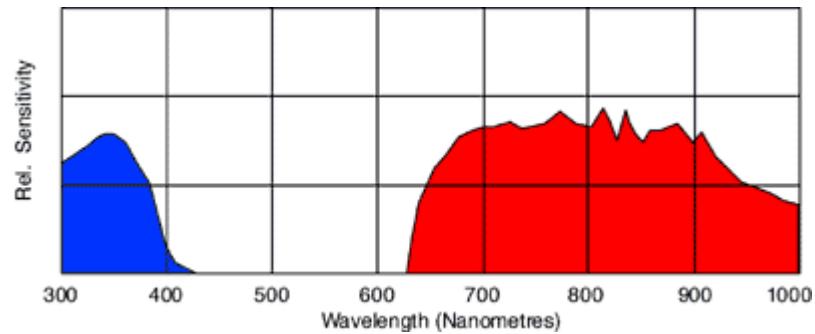


Figure 21 (above) - The spectral emission curve for the Nikon SB-140 xenon flash tube fitted with its UV transmission filter.

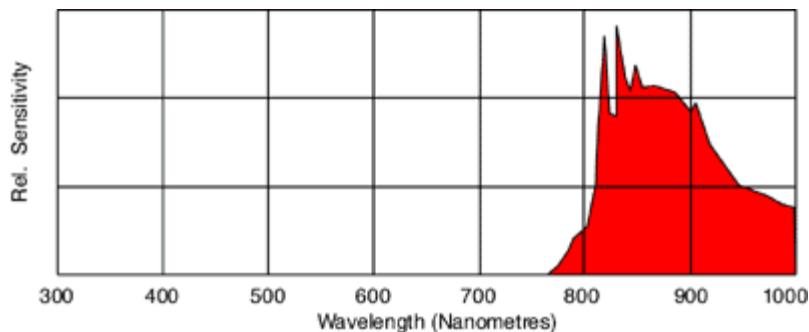


Figure 22 (above) - The spectral emission curve for the Nikon SB-140 xenon flash tube fitted with its infrared transmission filter.

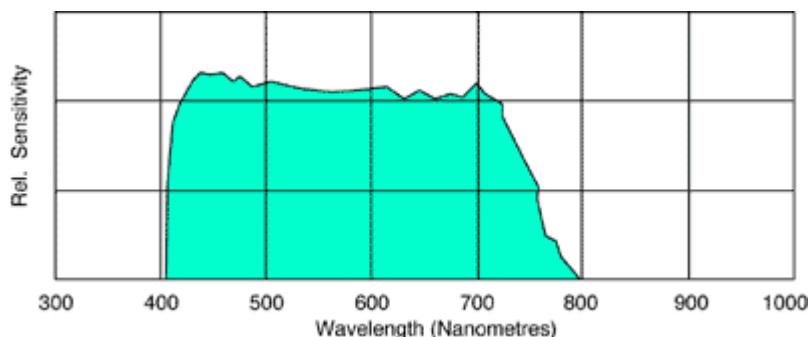


Figure 23 (above) - The spectral emission curve for the Nikon SB-140 xenon flash tube fitted with a filter designed for 'normal' visible light photography.

Great care needs to be taken when working with continuous ultraviolet sources or a severe burn to the patient, or a keratitis to the photographer, may occur. As can be seen from [Figure 4](#) the peak of erythema occurs at about 310nm. Conjunctivitis and skin erythema only appear 4 to 5 hours after exposure to ultraviolet radiation, and there is no heat involved to warn the photographer of an impending burn. In addition, the retina only starts "seeing" above 400nm, so there is a real potential danger to both photographer and patient. The low-pressure mercury vapor lamp has found renewed popularity in an unfiltered form for some electrophoretic investigations using radiation at 254nm. Special care needs to be taken with these and with the newer short-wave ultraviolet fluorescent tubes - goggles and skin protection must be worn. Electronic flash only emits a very brief burst of radiation and is completely safe - it is therefore a much more practical source for patient photography. The medical photographer however should be aware that patients suffering from xeroderma pigmentosum can be seriously affected by even moderate exposure to normal electronic flash (Menezes, 1996).

Filters

Like films and radiation sources, much has changed with the availability of filters for invisible radiation photography, and many have been withdrawn from the market. For reflected ultraviolet photography, for instance, Kodak now only manufactures the 18A.

The same is true of all Pilkington filters - the familiar Chance OX1, OX5 and OX7 much referenced in the literature are no longer manufactured.

The reflected ultraviolet technique requires a filter to be placed over the lens that will transmit only ultraviolet to the film called an ultraviolet transmission filter. All UV transmitting filters are made of glass, as gelatin absorbs ultraviolet. (Note - the skylight or UV filter commonly used over camera lenses as physical protection from damage and optical protection against UV haze effects - is an UV absorbing filter).

The Kodak Wratten 18A is still the standard filter with a transmission window from 300 to 400nm. (The generic term "Wood's filter" - named after Professor Robert Wood the 'Godfather' of invisible radiation study - applies to any filter with this range of transmission). It should be noted from Figure 25 that not only is there a window of transmission in the ultraviolet region of the 18A spectral curve, but that there is also a window in the 700 to 900nm region, which also makes it very effective as an infrared filter - provided of course that the recording medium is also sensitive to infrared. Normal photographic film is insensitive to infrared radiation (see [Infrared photography](#)) but Charged Couple Devices (CCD) found in digital cameras are sensitive to both (see [electronic recording](#)). Figure 26 shows the broader transmission curve for the Kodak Wratten 18B, which was very popular and is found widely in circulation in laboratories and studios. Curiously the Wratten 18A filter is now only available from Kodak as a very expensive 'spare part.'

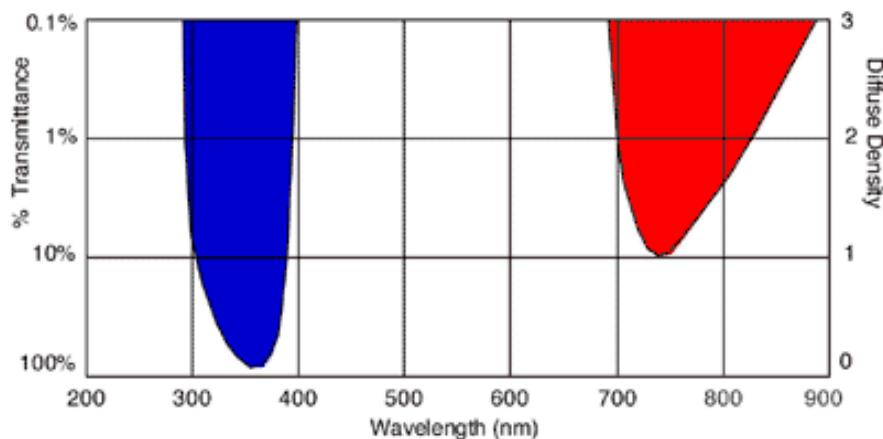


Figure 25 (above) - The spectral transmission curve for the Kodak Wratten 18A filter demonstrates not only the window of transmission in the ultraviolet region but also a window in the infrared region between 700nm and 800nm.

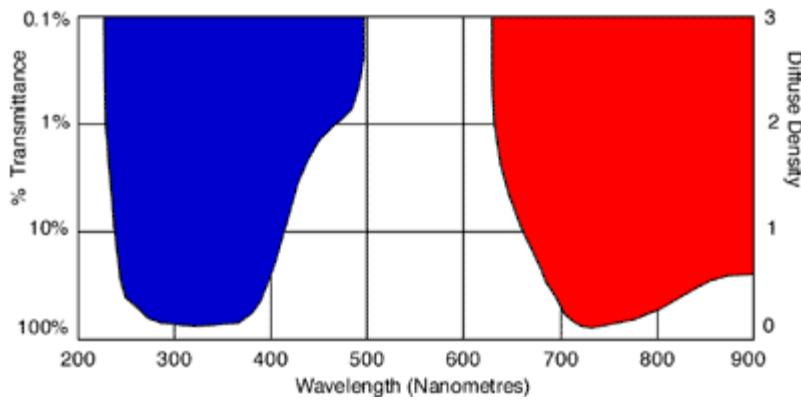


Figure 26 (above) - The spectral transmission curve for the Kodak Wratten 18B filter no longer sold commercially shows a wider transmission window in both the ultraviolet and infrared region making it a less 'pure' filter but often easier to get a result with.

B+W a German company (6550 Bad Kreuznach, Postfach 2463, Germany) - a division of the Schneider Optics empire, supplies an ultraviolet transmission filter (code number 403) with a very similar transmission curve to the Wratten 18A, at a much lower price (Figure 27). Precision Optical Ltd in England (425 Stratford Road, Shirley, Solihull, West Midlands, B90 4AE, UK), supply Schott, UGI, UG5 and UG11 filters (which are the equivalent of the old Chance Pilkington OX1, OX5 and OX7). The curves for these are shown in Figures 28, 29, and 30). Oriel Scientific in USA (250 Long Beach Blvd, PO Box 872, Stratford, CT 06497, USA), supply interference filters for ultraviolet in 10, 20, 50 and 100nm wavebands throughout the ultraviolet spectrum. (Dye absorption filters are only applicable down to 310nm; interference type filters made of quartz or silica must be used below this wavelength). Tiffen - the major supplier of photographic filters in the USA supply an equivalent to the Wratten 18A in a wide range of sizes to fit common lens filter threads. The Rolyn Optics Company (706 Arrowgrand Circle, Covina, California 91722, USA) supply UG1, UG5 and UG11 filters in various sized glass squares.

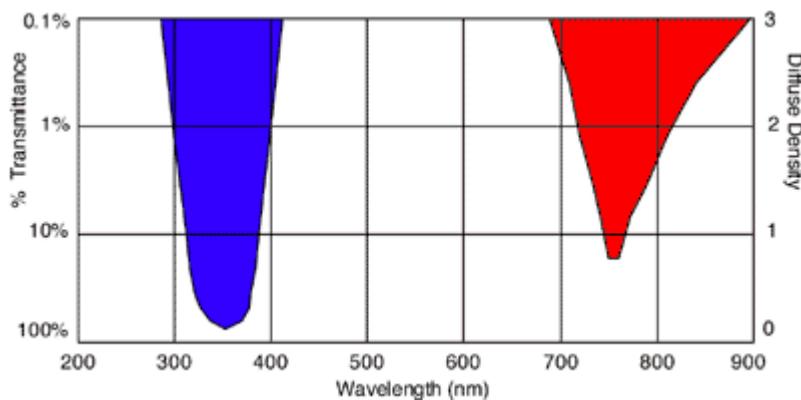


Figure 27 (above) - The spectral transmission curve for the B+W 403 UV transmission filter - a less expensive alternative than the Wratten 18A.

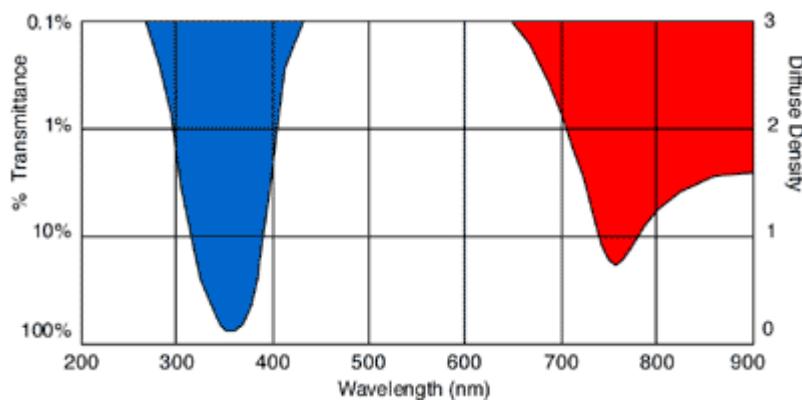


Figure 28 (above) - The spectral transmission curve for the Schott UG1 ultraviolet transmission curve.

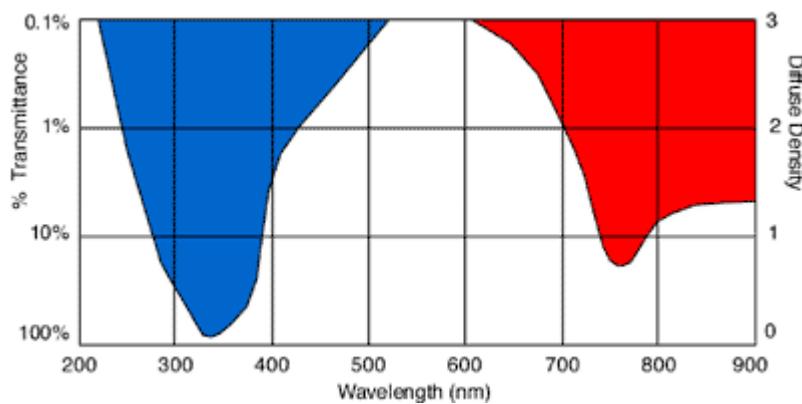


Figure 29 (above) - The spectral transmission curve for the Schott UG5 ultraviolet transmission curve.

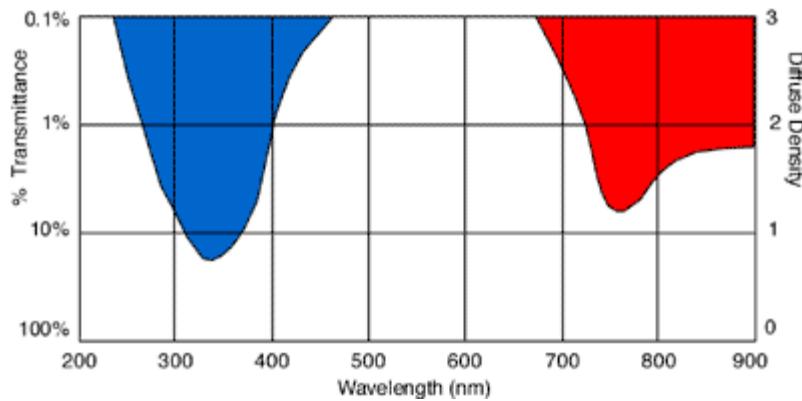


Figure 30 (above) - The spectral transmission curve for the Schott UG11 ultraviolet transmission curve.

As all ultraviolet transmission filters are visually opaque, a filter holder mechanism must be used which will allow the filter to be placed quickly over the lens after the visual focus point has been established. It is important that the holder provides a light-tight mount.

Examples of such holders are Kodak Pathe's Porte-filter Professional No.2 for large format work (Figure 31), and the Nikon AF1 holder for 35mm, designed with a light-tight mount that can be flipped up and locked when ready to take the ultraviolet exposure (Figure 32).



Figure 31 (left) - Kodak Pathe's Porte-filter Professional No.2 for large format work allows the visually opaque UV transmission filter to be dropped in after establishing the visual focus.



Figure 32 (left) - The Nikon AF1 filter holder swings up over the lens once the visual focus

Films & Processing

All photographic films - color negative and transparency, black-and-white, infrared, process, etc. - are sensitive to ultraviolet radiation (because silver halide crystals are sensitive to ultraviolet). There is no significant advantage to using color film for reflected ultraviolet work because only the blue layer of the tri-color pack will be exposed by the ultraviolet (the integral yellow filter effectively preventing exposure of the red and green layers). Some workers however have designed systems that use source/filter combinations and color film to give false color renditions; these are dealt with in reflected ultraviolet photography with color. For the pure recording of reflected ultraviolet radiation therefore black-and-white negative emulsions are invariably used.

The recording of ultraviolet radiation involves a number of problems even though silver halide has an inherent sensitivity to all radiation of shorter wavelength than the visible. Firstly, the emulsion grains themselves, and more importantly the gelatin support structure of the film, absorb ultraviolet significantly. This results in the ultraviolet image lying near the surface of the emulsion because the radiation is unable to penetrate very far. Modern films with flat, tabular-grained silver halide crystals near the surface of the emulsion have a natural advantage therefore in recording ultraviolet. Unfortunately, though, in order to remove the generally unwanted complication of ultraviolet sensitivity, most films now have an ultraviolet absorbing filter built into the over coating of the emulsion - this has the effect of reducing the relative sensitivity of these films to ultraviolet. Silver halide crystals are inherently sensitive to short wavelength radiation but the progressive absorption by the gelatin from 300nm downward results in an effective cut-off at 250 nm (90% transmission). The spectral sensitivity curve for a generalized panchromatic emulsion demonstrates that it has a relatively high sensitivity between 350nm and 400nm (Figure 42).

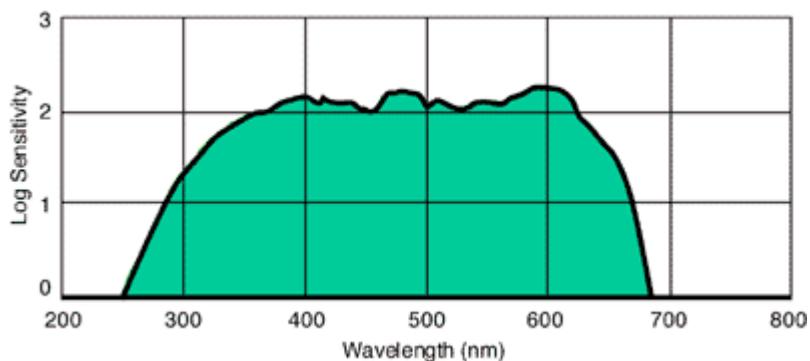


Figure 42 (above). The spectral sensitivity curve for a generalized panchromatic emulsion demonstrates that it has a relatively high sensitivity between 350nm and 400nm. Silver halide itself has an inherent sensitivity to all radiation of shorter wavelength than the visible but unfortunately the gelatin support of photographic film absorbs UV strongly from 300nm downwards resulting in an effective cut-off at 250 nm.

In order to determine the best film for reflected ultraviolet photography of patient's extensive tests were carried out by the authors. A "high speed" film was indicated, as five or six stops more exposure were typically required over the visible equivalent, and a relatively small aperture was required to achieve adequate depth-of-field in patient photography. A high sensitivity to ultraviolet was therefore required. ISO film speeds are not necessarily a good indicator of ultraviolet sensitivity; previous workers had reported that slow "non-color" sensitive films, such as Ilford's N531 (0.1 ISO), were just as sensitive to ultraviolet as panchromatic films of 400 ISO (Arnold et al., 1971).

Unfortunately, many of the special emulsions, such as Kodak's Spectroscopic Film Type 103-0, have either disappeared from the market, or are special bulk order only items. Also, many of the traditionally useful films now have the ultraviolet absorbing overcoats mentioned above. A range of commonly available films including the following: Kodak Tech Pan, Ilford Pan F, Ilford FP4, Kodak T-Max 100, Kodak T-Max 400, Kodak Tri-X,

Ilford HP5 Plus and Kodak T-Max 3200 were tested by recording a resolution chart, 18% gray card and step wedge (Figure 43). Each film was exposed to visible radiation (no filter) and ultraviolet radiation (18A filter) in a strictly controlled manner. The films were developed as recommended by the manufacturers in ID-11, T-Max developer, or HP5 Plus developer, to a gamma of 0.55 or 0.60 (as determined from the density step wedge). Accurate densitometric and resolution data were then obtained from the negatives using a transmission densitometer and a traveling microscope. The various films responded differently in the ultraviolet spectrum in terms of sensitivity-ISO speeds were not particularly indicative - and some relatively fast films performed less well than medium speed equivalents. These tests measured relative sensitivity to ultraviolet, and resolution, in a practical working situation.

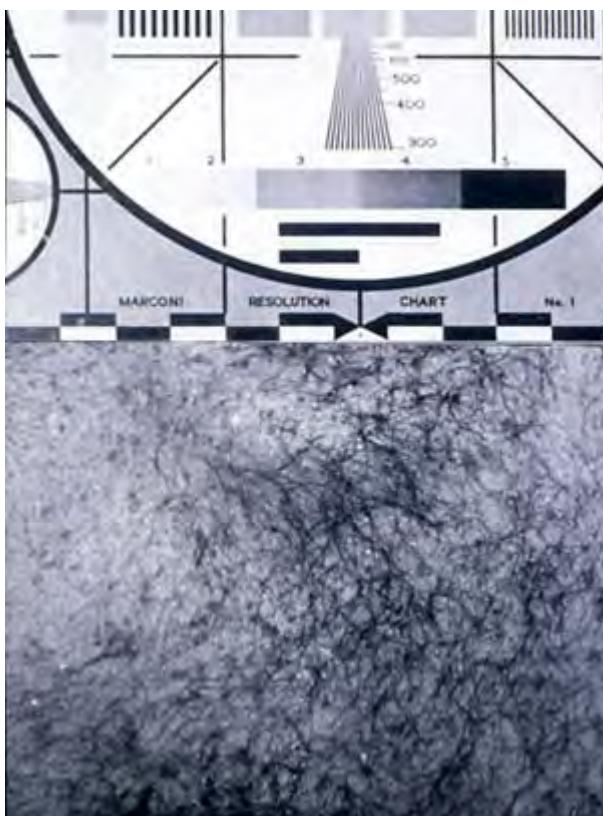


Figure 43 (left) - An example of a test result from the extensive film testing undertaken by the authors. Each standardized photograph of skin was recorded using reflected ultraviolet radiation and incorporated a resolution chart, 18% gray card and step wedge.

The results from these tests showed that typically fifty times more exposure was required in the ultraviolet than in the visible to achieve a correctly exposed negative. The Tri-X turned out to be about one and a half times the speed of T-Max 400 in the ultraviolet spectrum, although nominally they are both the same ISO rating. However, the Tri-X had poorer resolution and was lower in contrast than the T-Max. It was interesting to note that the Ilford film, HP5 Plus, again 400 ISO, was in fact over four times the speed of T-Max 400 in the ultraviolet region and that FP4 was approximately 50% faster than the T-Max 400 in the same region!

It was clear that the HP5 Plus was the fastest of all the films, i.e., more than three times faster than Tri-X, its next nearest rival, in relative sensitivity to ultraviolet. Initially, therefore, it was concluded that HP5 Plus was the best film due to its speed. Even though

the HP5 Plus appeared the film of choice from these initial tests, its relatively poor sensitivity meant that an aperture of only f/8 could be employed, clearly not sufficient for patient photography.

The real problem remained that of sensitivity to ultraviolet, and it was obvious that "push" processing was required to increase film speed still further. From publications of previous workers (Friar et al., 1989) it was known that T-Max films responded very well to "push" processing. Further tests, therefore, involved processing the two selected films with extended development to determine which performed the best; HP5 Plus to 1600 ISO, and T-Max 400 to 1600 ISO. Figure 44 shows the family of D Log E curves for T-Max with progressively increased development. The results were compared to T-Max 3200 processed normally. It was found that HP5 Plus performed poorly, with marked increase in granularity that reduced resolution considerably. Although the T-Max 3200 was found to be faster than the T-Max 400 rated at 1600 ISO, the resolution was not as good. T-Max 400 can be "pushed" quite satisfactorily to 3200 ISO and it was quite interesting to note that even "pushed" to this speed the image quality obtained was actually better than the T-Max 3200 film itself (Figure 45)! Figure 46 shows the film's spectral sensitivity curve.

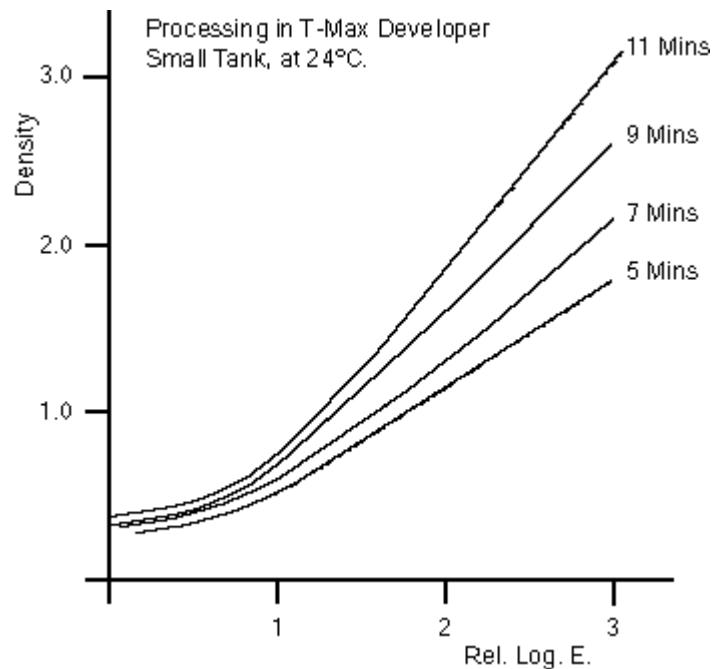


Figure 44 (above). The effects of increasing development with T-Max 400 film as shown by a family of DlogE curves.

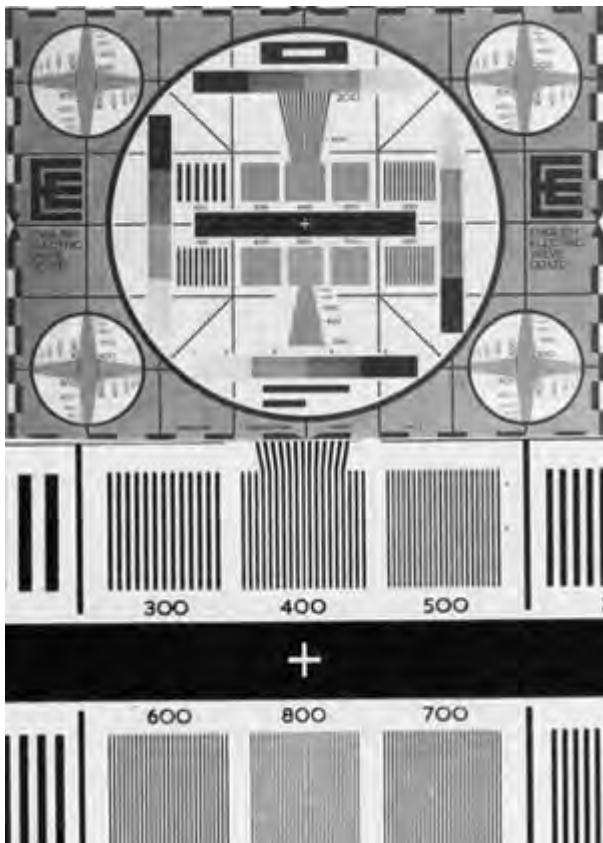


Figure 45 (left) - A reflected ultraviolet photograph of a resolution test chart taken with Kodak T-Max 400 rated and 'push' processed to ISO 3200; the whole image (top) and a much enlarged section from the center of the negative (below) demonstrates the remarkable speed/resolution of this combination.

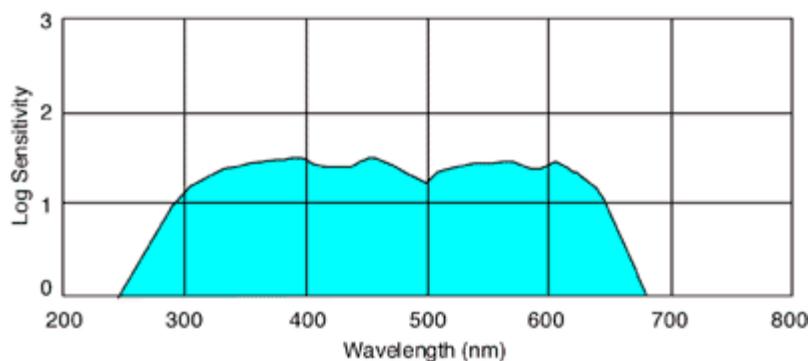


Figure 46 (above) - The spectral sensitivity curve for Kodak T-Max 400 film.

Reflected ultraviolet photography suffers from the gamma/lambda effect - which is a reduction in contrast with decrease in wavelength. Figure 47 shows the reduction in contrast between a photograph taken with visible radiation and that imaged with reflected ultraviolet. As the wavelength decreases through the blue region to the ultraviolet, the gamma, or contrast, of the negative gradually falls (Figure 48). This is well known in the graphic arts industry when making color separations; traditionally the blue separation has always been given more processing to raise its contrast, and similarly increased development is required in reflected ultraviolet photography. Processing must be

increased by 25-30% to achieve a normal contrast index. Where "push" processing is being used to increase film speed it will automatically raise the contrast of the finished negatives. In order to obtain the required speed index of 3200 ISO, a processing time of 9.5 minutes must be used. This fortuitously raises the contrast index to approximately 25% higher than normal.

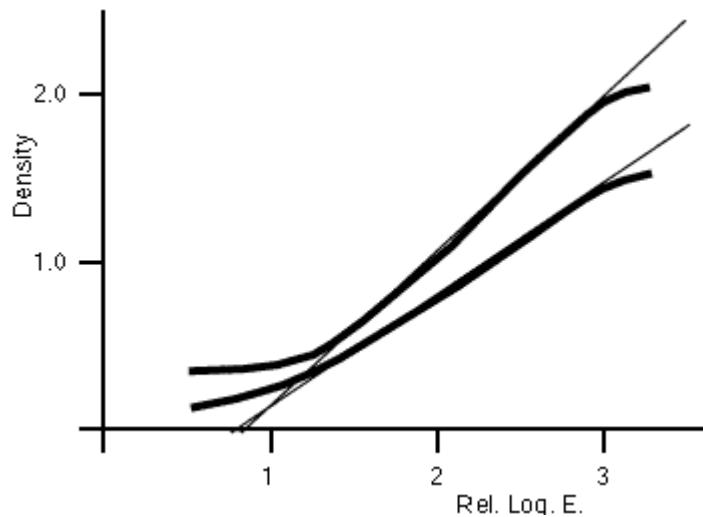


Figure 47 (above). DlogE curves for a test chart image recorded with visible frequencies (upper curve) and with reflected ultraviolet radiation (lower curve) show the reduction in contrast at the shorter wavelengths.

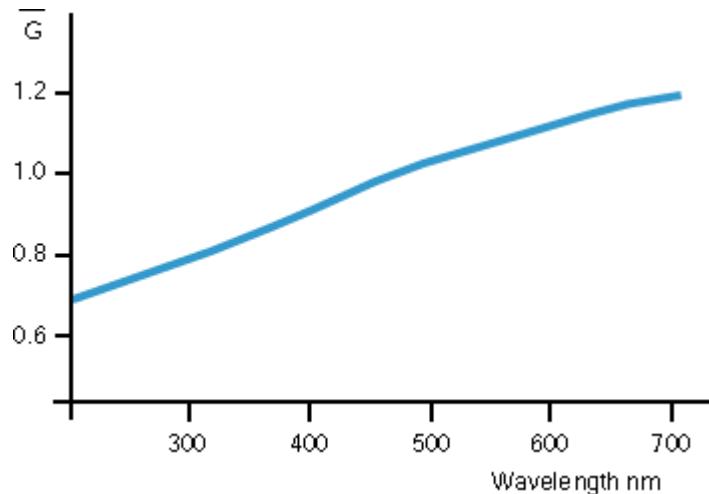


Figure 48 (above). A graph to show the effect of reducing contrast (Gamma) as the wavelength of the imaging source falls.

The film/processing combination to be recommended for reflected ultraviolet photography of patients is therefore T-Max 400 processed in T-Max developer, 1:4 for 9.5 minutes, at 24°C, to give a relative speed of 3200 ISO.

Fluorescence Photography

Ultraviolet induced fluorescence

In the case of the ultraviolet fluorescence technique, a source of ultraviolet radiation filtered with an ultraviolet transmission filter - or excitation filter - is aimed at the subject in a completely darkened room. The subject reflects the ultraviolet and may also emit a visible fluorescence. The ultraviolet is then prevented from entering the lens by an ultraviolet absorbing filter (or barrier filter) and fast black-and-white or color film records any visible fluorescence emitted in the region 400 -700nm. Figure 4 shows the basic technique used. Whether one is examining a primary autofluorescence or a secondary fluorochrome fluorescence, the technique is essentially the same. It must be emphasized that this technique requires a completely darkened environment, as any daylight will wash the fluorescence. This requirement can be quite a challenge, particularly when trying to work on location. Ingenious solutions to this problem include the use of light-tight tents, or box enclosures, as for example in Callender (1977), who devised an enclosure with a bite block and retractors at one end and the recording camera at the other for photographing fluorescence of the teeth on location. Myers (1981) found that he could work in subdued room lighting when he used electronic flash synchronized to the between-the-lens shutter of a Hasselblad set to the fastest shutter speed. It should be possible to use the latest generation of focal plane shutters that synchronize flash at 1/125th sec. in the same way.

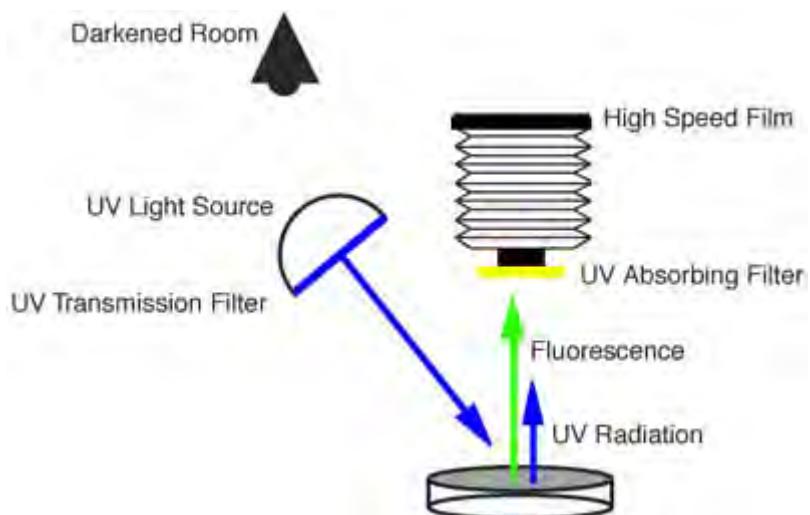


Figure 4 (above) - The basic technique of ultraviolet induced fluorescence. The subject is photographed in a darkened room, illuminated by a source of ultraviolet radiation and then visible fluorescence recorded onto high-speed film (all the ultraviolet having been blocked at the lens by the use of an ultraviolet absorbing filter).

Sources Of Ultraviolet Radiation

The sources of ultraviolet radiation for inducing fluorescence are the same as those for the reflected ultraviolet technique, and the reader is referred to the '[Sources of ultraviolet radiation](#)' section of the reflected ultraviolet article for details. Dermatologists use continuous high-pressure mercury vapor lamps fitted with Wood's filters for inspection, but electronic flash is always used for photography of patients. The relatively low emission of the hand-held Wood's lamp necessitates exposures that are too long for the living subject; alternatively one is tempted to place the lamp too close to patients with the attendant risk of burning them. It is however, very helpful for the photographer to have a continuous source of ultraviolet available in order to locate the area that is fluorescing, prior to recording with electronic flash. Some manufacturers build small hand lamps with ultraviolet emitting fluorescent tubes driven by batteries. These are most useful for locating areas of fluorescence in the clinical studio when working on location. Figure 5 shows an example of such a lamp. Continuous sources of ultraviolet such as mercury vapor discharge lamps are useful for the photography of fluorescence from static objects such as documents, minerals, gels and chromatograms. It is worth re-emphasizing that care should be taken with these lamps, especially the low-pressure variety, in order to avoid damage to skin and eyes. It is imperative to use effective barrier spectacles when viewing with a continuous source, not only because of the danger of conjunctivitis, but also because the crystalline lens within the eye itself fluoresces, making it very difficult to see clearly.



Figure 5 (left) - A battery operated, portable hand lamp is invaluable for identifying where (and if) fluorescence is occurring prior to full photographic recording

Films

Since the radiation emitted as a result of ultraviolet stimulation is always in the visible region of the spectrum, films with conventional spectral sensitivity, either black-and-white or color, are suitable. Color is, however, most often used to record the characteristic colors of many types of fluorescence. Fast film is essential - the luminous intensity of most fluorescence is very low indeed. The choice of black-and -white versus color will depend on whether it is important to record the color of the fluorescence or simply to capture a record of its presence. If the latter is the case, Kodak T-Max 400 either rated normally, or if the fluorescence is very weak "push" processed up to 3200 ISO, is excellent. For color work the authors recommend Kodak Ektachrome P800/1600 "pushed" if necessary to 3200 ISO. ("Push processing" is the term used to indicate a longer than normal time in the developer, or in the case of color reversal film the first developer, which results in a higher than normal effective ISO film speed.) The enhanced contrast obtained by push processing the films also adds to the clarity of the fluorescent record. Both the T-Max and the Ektachrome P800 films have a built-in ultraviolet absorption filter in the overcoat of the emulsion that helps eliminate any of the reflected ultraviolet radiation.

Filters

The radiation source must be fitted with an excitation filter so that only ultraviolet radiation is allowed to reach the subject. The classic Wood's filter, or Wratten 18A, is usually selected but any of the alternatives such as the Schott UG1 are acceptable (see [Filters for reflected ultraviolet](#)). All ultraviolet transmission filters are glass since gelatin and plastics absorb ultraviolet.

A light tight filter holder mechanism is required to hold the filter in front of the flash. Mecablitz makes an accessory filter holder for their professional flashguns, and the Nikon SB-140 is supplied with the filter holder as an integral part of the design.

All ultraviolet radiation reflected from the subject must then be absorbed by the barrier filter fitted over the lens.

The Wratten 2 series filters (Figure 6) are technically suited to the task with cut-offs at between 400nm and 450nm, but in practice it is often preferable to use a yellow filter, such as the Wratten 12 (Figure 7), to eliminate the blue 'leakage' common with many Wood's lamps and ultraviolet transmission filters. Sometimes a pale cyan filter (10-20CC) is also used as part of the barrier combination to absorb the slight red leakage of the Wratten 18A.

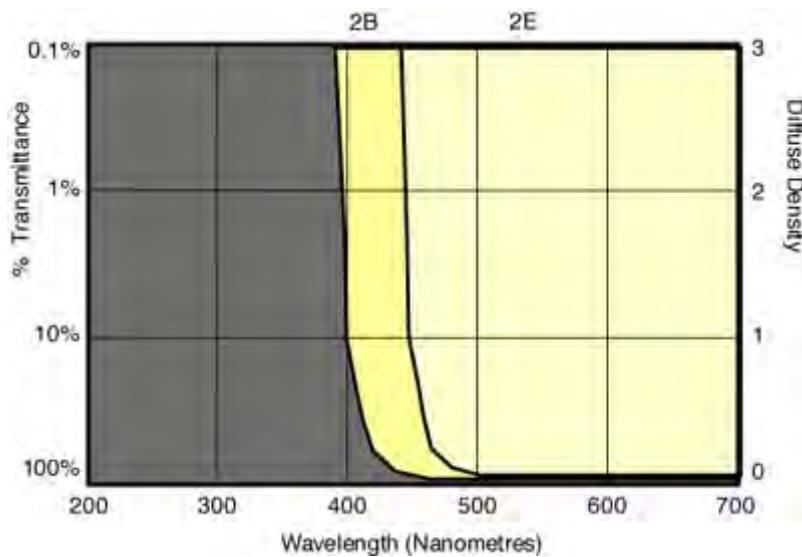


Figure 6 (above) - The Wratten 2 series filters are technically suited as barrier filters for the ultraviolet induced fluorescence technique with cut-offs at between 400nm and 450nm.

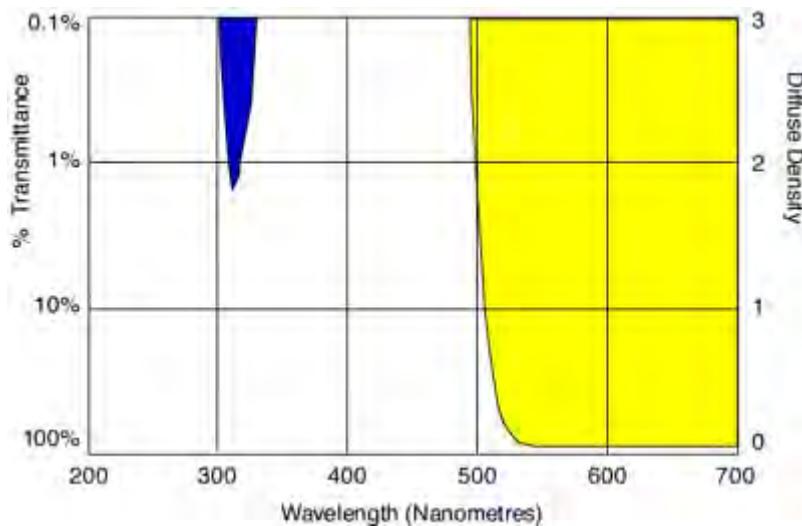


Figure 7 (above) - The transmission curve for the Wratten 12 yellow filter, classically used in ultraviolet induced fluorescence imaging.

Ultraviolet absorbing filters, especially gelatin ones, fade with exposure to ultraviolet, so should be replaced regularly (Figure 8). Also, some gelatin filters may themselves fluoresce when excited by ultraviolet radiation. All of the Wratten ultraviolet absorbers - 1A, 2A, 2B, 2E, 12 and 15 - fluoresce slightly when illuminated by short-wave ultraviolet radiation. Figure 9 shows the Wratten 2E filter fluorescing when stimulated by short wave ultraviolet. The remedy for this is to fit the filter to the rear of the lens so that the

glass of the lens absorbs the short wavelengths causing the fluorescence before they reach the filter.

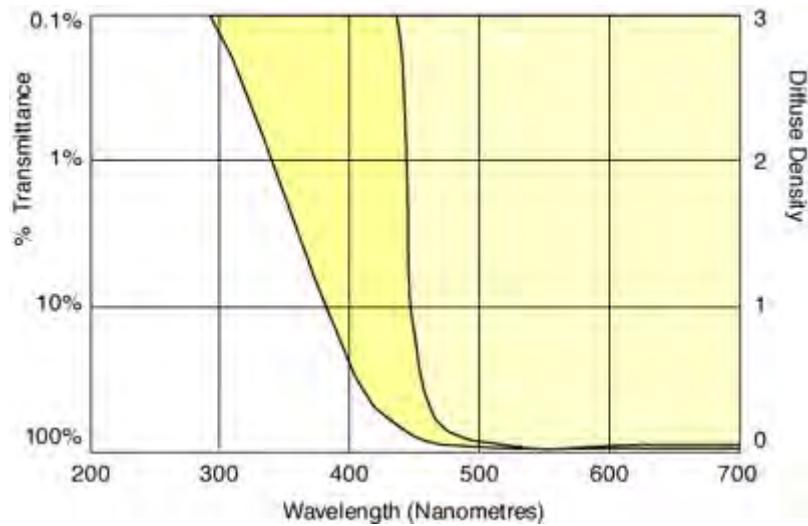


Figure 8 (above) - Transmission curves for a new (right) and well used (left) Wratten 2E filter demonstrate that these ultraviolet absorbing filters gradually lose their effectiveness and should be replaced regularly.



Figure 9 (above) - This fluorescence photograph of a Wratten 2E filter was taken with short wavelength radiation and a Wratten 15 barrier filter, and demonstrates that the Wratten 2E actually itself fluoresces. For critical work the barrier filter is therefore more effective if it is placed behind the lens: which then absorbs the shorter wavelengths of ultraviolet.

The "efficiency" of any excitation/ barrier filter combination can be tested by photographing a metallic object such as a ball bearing - as metals do not exhibit autofluorescence (Hansell, 1968). Ideally, the specular reflection from the source off the

metal should be entirely absorbed by the barrier filter on the camera lens. If however, the combination of excitation and barrier filter is perfect, there may be difficulty in orienting some subjects. This is because only the fluorescence records on the film since there is no background illumination. Some workers (e.g. LeCover, 1972) have advocated providing a low level of overall illumination to orient the subject, but this must be carefully balanced so as to avoid swamping the fluorescent areas. A better technique is to mismatch the excitation and barrier filters to allow some "background" illumination. It can also be helpful to include some known fluorescent test object within the field of view, eg. text written with a fluorescent "highlighter" pen, in order to 'prove' that the filter combination is working. Figure 10 shows the use of both test objects - fluorescent test marker and steel ball - in a single exposure.

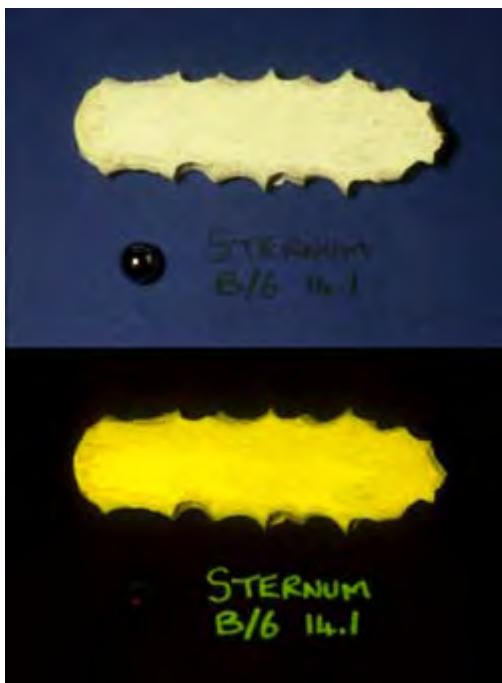


Figure 10 (left) - A specimen of bone is photographed normally (above) and with the ultraviolet induced fluorescence method (below). Included within the scene are a polished metal ball-bearing to determine the effectiveness of the filter combination and fluorescent writing to 'prove' the stimulation.

Applications of the ultraviolet technique:

Forensic

Application	Notes	Reference
Blood stains	Described the practice of using fluorescent dyes to lock to the compound luminol so that blood stains could be recorded.	Zweidinger et al. 1973

Metal traces	Showed examples of how the presence of minute amounts of trace metals left on the skin of victims from knives etc., could be detected by fluorescence photography.	West, Friar & Seal 1989
Metal traces	Demonstrated fluorescence of metal traces on the abdomen of a rape and homicide victim which were in the shape of a characteristic belt buckle. Led to successful conviction.	Friar & West 1989
'Old' trauma	Discovered 'old' wounds fluorescing at autopsy with narrow bandwidth (15nm) ultraviolet induced fluorescence at 450nm.	Barsley, West & Friar 1990
Skin trauma, semen & saliva	Confirmed the detection of skin trauma, semen and saliva at autopsy by fluorescence photography.	Lynnerup et al. 1995

Infrared Photography

Reflected Infrared Photography

Infrared radiation was discovered by William Herschel (Figure 1) in 1800. His description of the time read "It now being evident that there was a refraction of rays coming from the sun, which though not fit for vision, were yet highly invested with a power of occasioning heat, I proceeded to examine it as follows..." Herschel dubbed this 'new' radiation as the "thermometric spectrum." Herschel used a slit, prism and a series of thermometers to demonstrate the existence of radiation beyond red in the spectrum (Figure 3). Today the infrared spectrum is recognized as extending from about 700nm up to wavelengths of about 1mm where it overlaps with radio waves. Photography is normally confined to the near infrared - 700 to 900 nm. A great deal of confusion continues to arise concerning infrared photography and the measurement of infrared energy in the form of heat. This confusion often leads to futile attempts to detect thermal patterns through the use of infrared photography in cases where the technique does not apply. Contrary to what many people believe, the infrared record in a photograph is not a measure of ambient temperature variation - it is a record of the amount of near infrared radiation reflected or transmitted by the subject. Thermal photography cannot be done with infrared sensitive film. Far infrared (approximately 2 -15μm) is usually regarded as "heat" and can only be recorded by converting the radiation into a visible form using an image converter tube, and this is the province of thermography. Hot objects, naturally enough, are usually emitting a good degree of near infrared - leading to the ability to capture images of hot irons, etc., on infrared film and also contributing to the confusion!

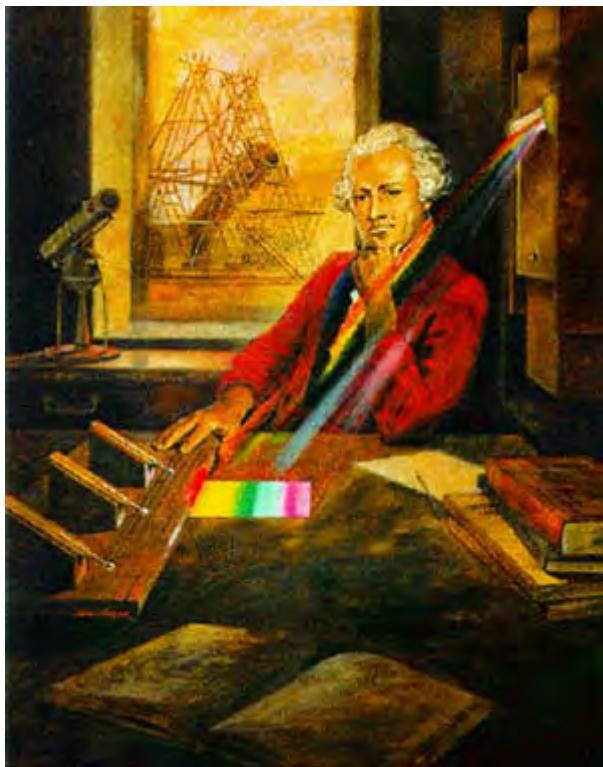


Figure 1 (left) - Infrared radiation was discovered by William Herschel.

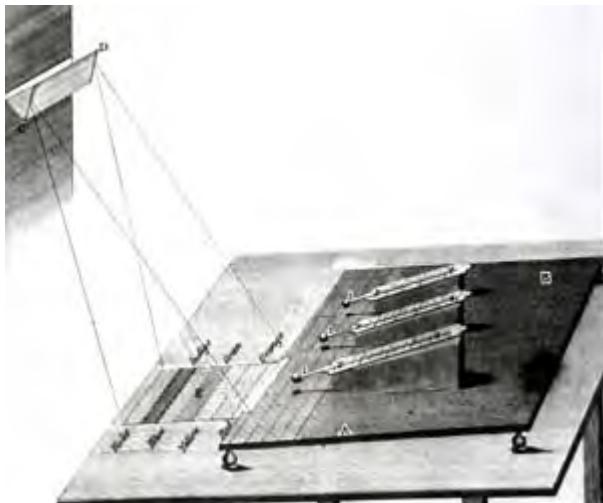


Figure 2 (left) - Herschel used a slit, prism and a series of thermometers to demonstrate the existence of radiation beyond red in the spectrum.

The term 'photographic infrared' is used loosely to describe the region 700 -1350nm, the range over which silver halide emulsions can be sensitized; but most infrared emulsions are only sensitive up to about 900nm, which then becomes the practical upper limit. Infrared sensitive emulsions have been available since the 1930's, so reflected infrared photography is certainly not a new area of study. Indeed there has been a great deal of work done in the field. Gibson's standard work *Photography by Infrared* last published in 1978 contained over 1,800 references to applications of infrared photography and thermography. While it would be foolish to duplicate Gibson's efforts - and the reader is referred to his excellent text for this extensive bibliography - much has changed in the

practical field. New films, filters and light sources are now used and this article attempts to bring this topic up to date and to present practical working methods.

Some of the earliest uses of the reflected technique continue to the present day. One of the first applications was in the field of document examination for criminal forgery; art museums also made early use of the technique to examine paintings, thereby revealing their authenticity and development. Medical investigators were quick to appreciate the value of the technique and even with CT, ultrasound, Doppler, NMR and PET scanning; there is still no other non-invasive method that can reveal the same information. The selective reflection of infrared by healthy and diseased plants coupled with its ability to penetrate haze held to early applications in the fields of agriculture and forestry - applications which continue to be in use today in the form of remote sensing from satellites. There are few photographic techniques that enjoy such widespread use in science, medicine and engineering. The ethereal nature of black-and-white infrared images, or the strange false color representations of color infrared, have excited pictorial photographers for years and amateur photographers continue the fascination. A recent web search by the authors on infrared photography led to over 72,000 citations!

In its simplest form the technique only requires sunlight, an infrared transmission filter over the camera lens and some infrared sensitive film in the camera to produce quite dramatic results. Chlorophyll reflects infrared almost totally so foliage reproduces nearly white and infrared is scattered less so blue skies appear nearly black (Figure 3); add to this the inherently high granularity of the infrared film and pictorialists have a wonderful time. The human eye and indeed that of many animals, is insensitive to infrared radiation which has led to the widespread use of infrared imaging for surveillance at night. In this circumstance the radiation source must be covered with the infrared transmission filter, not the camera's.



Figure 3 (above) - An example of a reflected infrared photograph taken in daylight. Note that foliage appears nearly white and the sky nearly black.

The reflected infrared technique works by using a source of infrared radiation to light the subject, and then filtering out all visible light by fitting an infrared transmission filter over the lens. A specially sensitized film then records the infrared reflected from the subject. Figure 4 is a diagrammatic representation of the basic technique for use in scientific and medical applications. Each component of the infrared imaging chain is considered on the following pages.

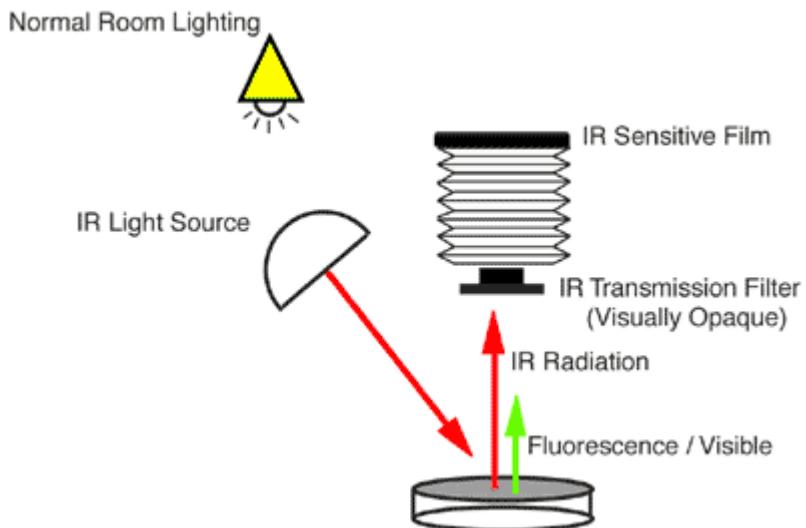


Figure 4 (above) - Diagram of the basic reflected infrared technique.

Sources Of Infrared Radiation

Many common sources of radiation emit infrared - sunlight, tungsten (Figure 5) and halogen lamps, xenon arcs (Figure 6) and lasers - but the most practical source for the biomedical or scientific photographer is electronic flash. Daylight is a very unpredictable source of infrared with the actinic values altered by both weather and atmospheric haze (as can be seen in Figure 8). The tungsten and tungsten halogen lamps do produce high outputs of infrared, but unfortunately this is accompanied by large amounts of heat - usually a problem for biomedical subjects.

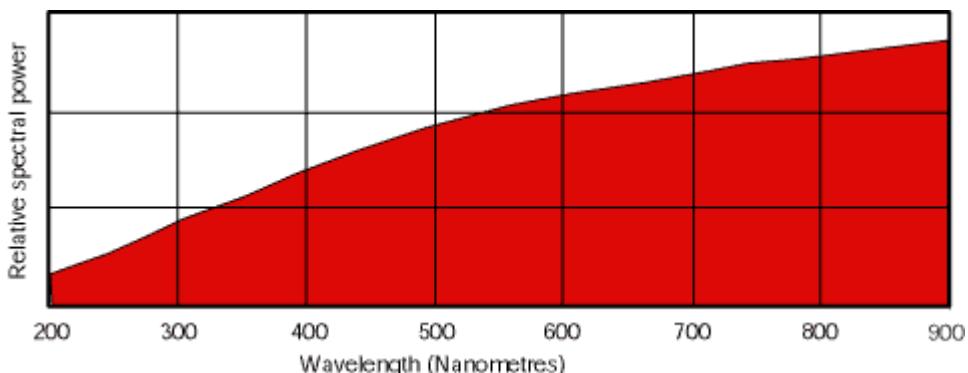


Figure 5 (above) - The spectral output for tungsten lamps.

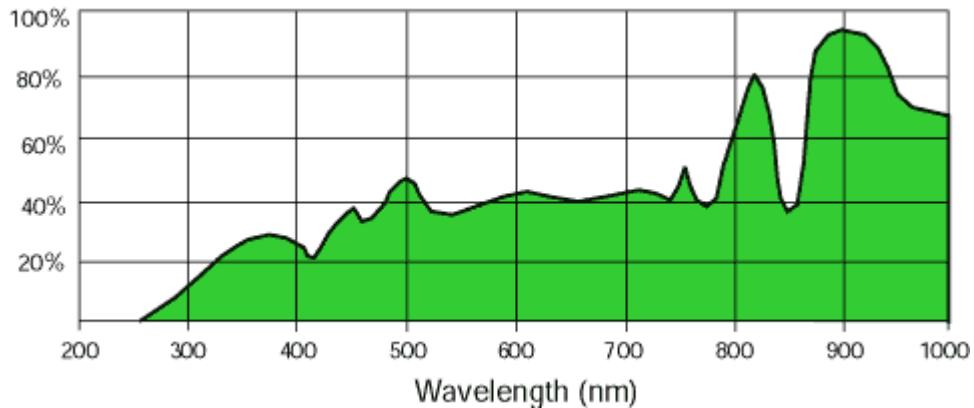


Figure 6 (above) - The spectral output for Xenon arc lamps.

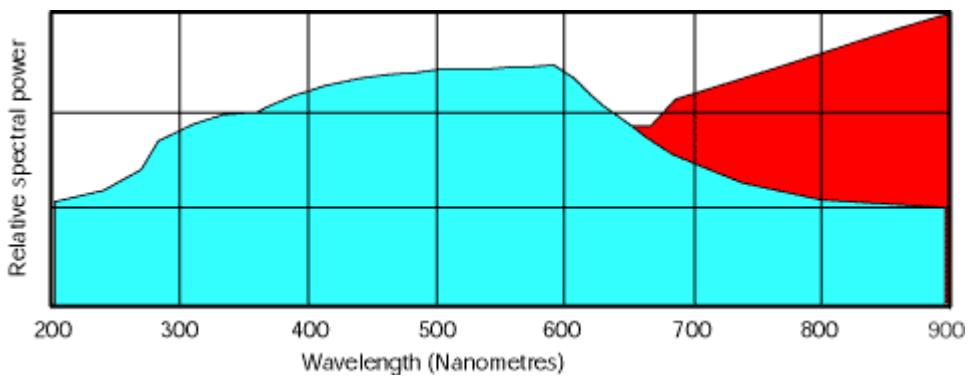


Figure 7 (above) - Daylight is a very rich but unpredictable source of infrared radiation which changes its spectral qualities with changes in the time of day and atmospheric conditions. The blue curve shows the spectral distribution at noon, the red curve demonstrates the shift to red and infrared towards dusk.

The xenon arc in combination with a fiber-optic light guide is a useful source of infrared especially for forensic applications where the subject is unlikely to move.

Several manufacturers now supply xenon arc lamps especially made for invisible radiation work. Examples would be the Polilight, Lumilite or Omniprint. These all have a series of stepped interference filters, which are then tunable by tilting their angle to the beam to give a continuously variable output from 300 to 1100nm.

An LED display shows the frequency of the output accurate to +/- 20nm. The illuminating radiation is delivered to the point of use by an efficient liquid light guide with quartz and silica optics. Figure 8 shows the Polilight.



Figure 8 (left) - The Polilight has a series of stepped interference filters, which are then tunable by tilting their angle to the beam to give a continuously variable output from 300 to 1100nm.

The xenon flash tube has a high output in the 800-900nm region of the spectrum (Figure 10), and has the usual advantages of electronic flash - short duration and illumination without heat. Since the problem with over coating that we find in ultraviolet photography does not exist, nearly any electronic flash is suitable. Many electronic flashguns are particularly rich in infrared. Figure 11 shows, for example, the spectral output of the Mecablitz CT45 portable unit. Nikon used to supply a portable flash with an uncoated tube - the SB-140 (Figure 12). The Nikon unit came complete with filters for both infrared and ultraviolet work and had a useful exposure guide - in many respects the ideal source for invisible radiation patient photography, especially on location. The filters fit over the front of the flash (Figure 13); the spectral transmission curve for the IR transmitting filter is shown in Figure 14. This is especially useful for photography of nocturnal animals, etc but is not terribly useful for studio photography since one would need to work in a darkened room. It is preferable to use an infrared transmitting filter over the lens and work in normal room lighting with an unfiltered flash. Unfortunately Nikon have now withdrawn this unit from their product range - like so many products suited to specialized imaging from different manufacturers. The authors are fortunate enough to own two of these SB-140s and can vouch for their usefulness for invisible radiation photography; so don't hesitate to acquire one if you happen to come across one second hand or 'left over' in a camera store.

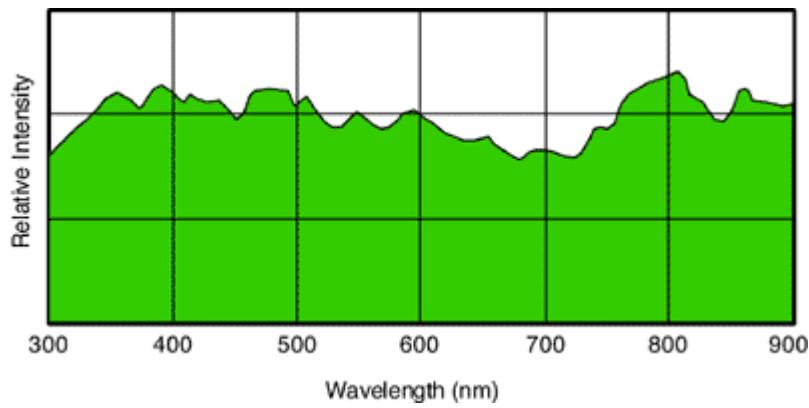


Figure 10. The spectral output of the 'raw' xenon flash tube is very rich in infrared.

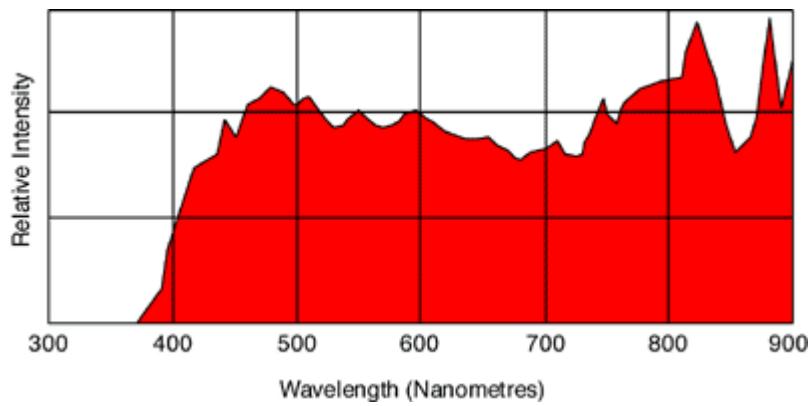


Figure 11. The spectral output of the Mecablitz CT 45 electronic flashgun has a typically useful peak of infrared emission at 750nm - 850nm.

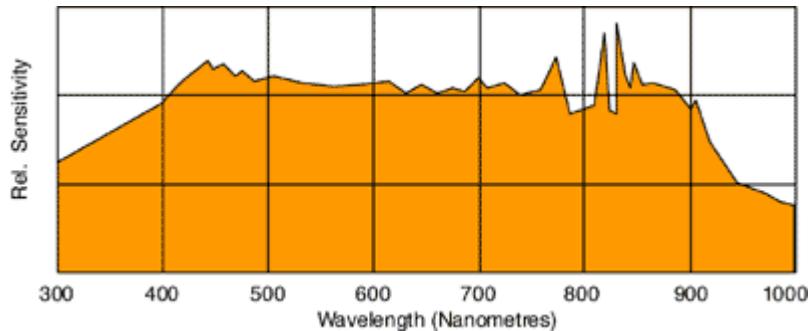


Figure 12. The spectral output of the Nikon SB140 flash tube shows a high actinic output continuously from 400 to 900nm.



Figure 13. The Nikon SB-140 has a completely unfiltered tube with the facility to attach separate filters over the flash-head in light tight mounts: here we see it with the IR transmission filter in place.

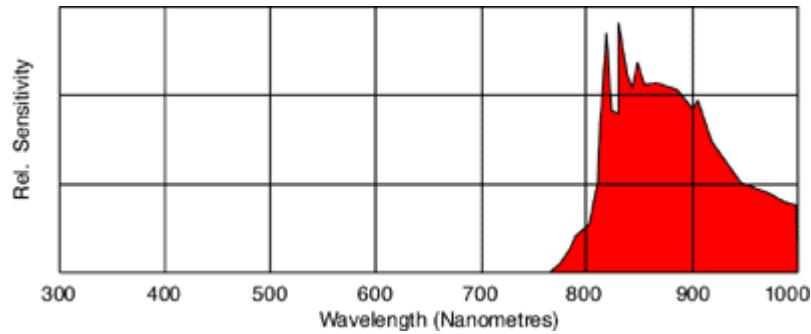


Figure 14. The spectral output of the SB-140 with IR filter fitted over the flashhead.

Reflected infrared photography: Lighting

Lighting technique is particularly important in reflected infrared work. Infrared photographs reveal density differences due to variations in the absorption characteristics of tissues, and any shadows cast by the lighting will cause confusion in interpretation.

We know from the laws relating to illumination that the light intensity on an inclined surface varies with the cosine of the angle of incident light, and that the illumination of any surface by a single light source varies across that surface by a factor equivalent to the Cosine³ of the angle of illumination. This accounts for the edges of curved surfaces, such as those of the torso or face, recording relatively dark when lit from the front. This problem is further exacerbated in infrared where the incident radiation is absorbed heavily into the skin. Therefore, illumination drops very quickly with increasing angle in infrared work. All of this leads to the requirement for the subject to be evenly illuminated, often using several sources of radiation.

Soft lighting produces a dramatically improved infrared record, not only because it eliminates the shadowing problems mentioned above, but also because the contrast of the resulting image can then be raised, thereby enhancing the detail of the blood vessels or

other important subject matter (Figure 15). At the very least, therefore, two lights should be placed one on either side of the subject. But ideally some kind of "wrap-around" lighting should be used. Some workers go so far as to recommend the use of a white room or "tent" to obtain diffuse enough lighting (Gibson 1965, Gilder et al. 1970, Gilson et al. 1981). The diagram for Gibson's original infrared 'tent' can be seen in Figure 16. A modern version of the tent utilizes large diffusion panels such as those manufactured by Lightform for professional studio photography. The P22 panels are approximately 6'x3', and one placed either side of the patient at 45 degree angles and lit by two lights, provides very even illumination and good exposure levels (Figure 17). If a tent or is employed the diffusion material must be checked to ascertain whether or not it transmits infrared freely; otherwise there may be a significant loss of light.

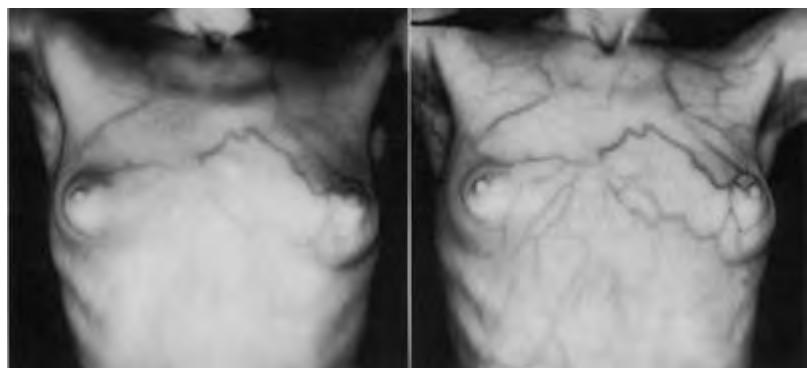


Figure 15. The infrared image on the left is lit conventionally with main and fill lights whereas that on the right has been recorded with wrap-around soft lighting using a tent. The softer lighting has then enabled the photographer to reproduce the image at a much higher contrast, revealing much more detail in the vessels. Images © Gibson.

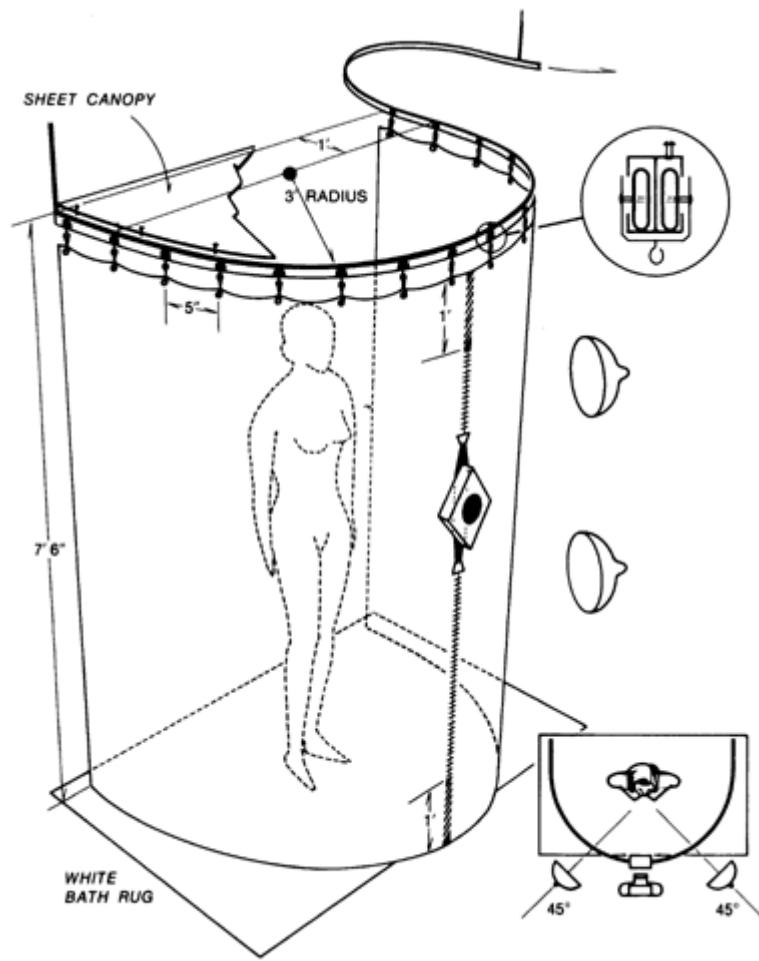


Figure 16. Gibson's original diagram for an infrared 'tent'.

Figure 17. Lightform P22 panels in use to provide diffuse illumination for studio based infrared photography.



As with ultraviolet techniques, one must remember that different background materials, papers, and paints reflect infrared radiation more or less successfully, and may produce very unpredictable tones. Many photographers prefer to work with an unlit black background for infrared work. Once again, the recommendation is to test any background photographically.

References:

- Gibson, H., Buckley, W. & Whitmore, K., 1965. "New vistas in infrared photography for biological surveys," *J. Biol. Photogr. Ass* 33(1):1-33.
- Gilder, R. & Rutherford, A., 1970. "Diffuse lighting for infrared photography in medicine, *Med. Biol. Illustr.* 20:227-230.
- Gilson, C. & Parbhoo, S., 1981. "Standardized serial photography in the assessment of advanced breast cancer," *J.Audiovis. Media Med.* 4:5-10.

Reflected infrared photography:

Filters

An infrared transmission filter must either be used over the camera lens in a light-tight mount for the normal technique, or over the light source in total darkness for the night surveillance technique. These infrared transmission filters are visually opaque, or depending on the type, may reveal some deep red transmission when viewing a bright light source. A number of manufacturers supply glass filters in screw in mounts, as

optical resin squares for use in "Cokin" type holders, or as thin gelatin or polyester filters for use in a gelatin filter holder such as the Nikon AF1, or for fixing over light sources.

Kodak makes a whole series of gelatin-based infrared transmission filters (Figure 18) from the Wratten 89B, which transmits the far red through the 88A, 87, 87C, 87B to the 87A, in increasingly narrower-cut versions. The Wratten 87 is often selected as the standard infrared filter as it has a sharp cut-off at 750nm, and transmits freely throughout the infrared region. The 88A has a slightly wider window with an effective cut-off at 700nm and is preferred by some workers. The spectral transmission curves for the Wratten series of infrared transmission filters are shown in Figure 19. Charles Wratten incidentally was a British optical manufacturer famous for making filters to very exacting tolerances; Kodak bought the Wratten company in the 1920s and ever since the Wratten specifications have been the benchmarks by which all others are measured. Most amateur and pictorial applications of the reflected "infrared" technique use a Wratten 25, tri-color red which actually transmits all the red and infrared radiation. The filter used will have to be carefully matched to the film's sensitivity: there is no point, for example, using a narrow cut 87A with the Konica, Ilford or Agfa films.

Figure 18. Kodak supply a range of infrared transmission filters as gelatin squares - part of the extensive, and famous, Wratten series of filters.
Image © Marco Pauck.

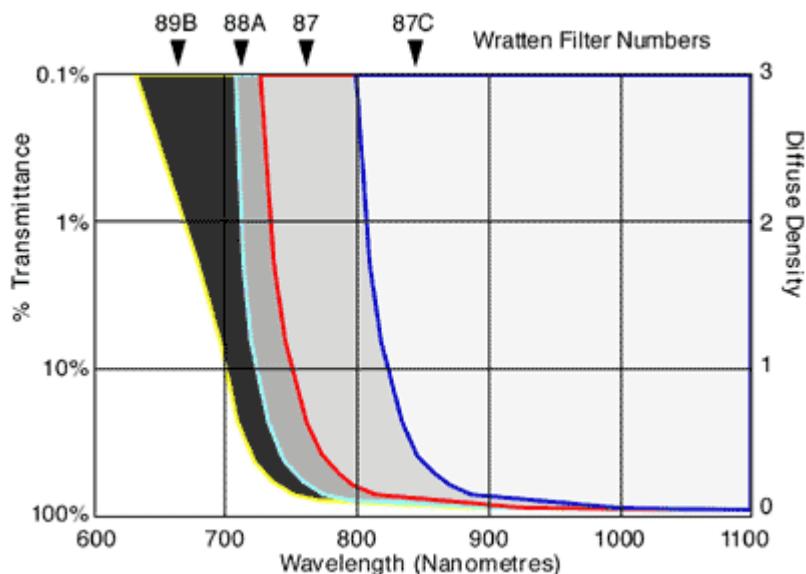


Figure 19. The spectral transmission curves for the Kodak Wratten series of infrared transmission filters.

Other manufacturers also supply very efficient and useful infrared filters. B+W, for example, supplies the 092, which has a wide window of transmission from 690nm to 3000nm - equivalent to the Wratten 89B - and is suitable for black -and -white infrared work (Figure 20). They also supply the 093 - equivalent to the Wratten 87C and a 094 with cut off at 880nm - equivalent to the Wratten 87A. Their equivalent of the Wratten 25 deep red is the B+W 090.

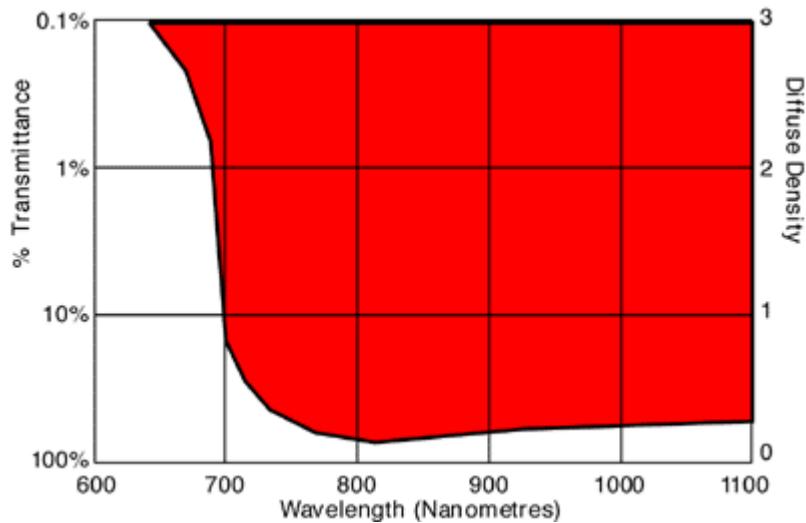


Figure 20. The spectral transmission curve for the B+W 092 IR filter.

Schott now supplies filters which match all of the old Chance Pilkington numbers; so the UG2 and UG5, for example, are the equivalents of the OX2 and OX5. As can be seen from Figure 21 the UG5 also transmits ultraviolet radiation, so a deep yellow (ultraviolet absorbing) filter should be used in combination with this filter.

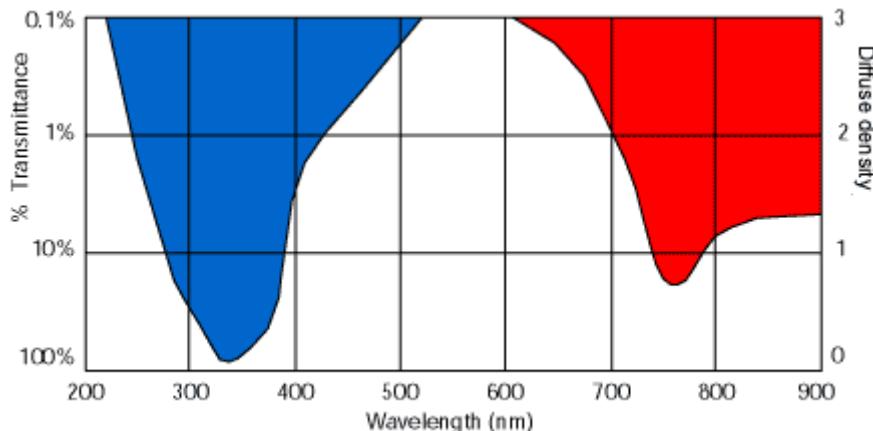


Figure 21. The spectral transmission curve of the Schott UG5 filter.

Hoya have a wide range with the peak sensitivity indicated by the name: the R70 with a transmission wavelength at 700nm, the R72 at 720nm, the R76 at 760nm, the R80 at 800nm, the R83 at 830nm, the R85 at 850nm, the RM86 at 860nm, the RM90 at 900nm and the RM100 at 1000nm. The spectral transmission curves of the Hoya range are shown in Figure 22. Hoya's 25A is the Wratten 25 equivalent, the R72 being the 89B equivalent and the RM90 being the 87A equivalent. (Note that the equivalent Wratten numbers that Hoya states for their filters are not accurate - Figure 23).

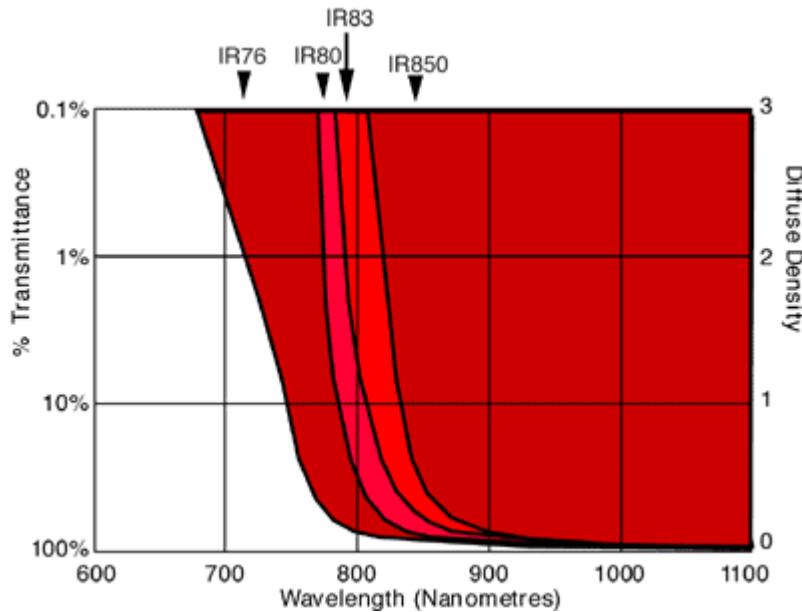


Figure 22. The spectral transmission curve of the Hoya series of IR filters.



Figure 23. Hoya infrared transmission filters - Note that the equivalent Wratten numbers that Hoya states for their filters are not accurate. Image © Marco Pauck.

Heliopan have an extensive range: the 5715 equating to the 88A, the 5780 equating to the 87, the 5830 equating to the 87C, the 5850 equating to the 87B and finally the 5100 equating to the 87A. They also have a 1025 deep red filter.

Tiffen supplies the T187 which approximates to the Wratten 87 filter in a reasonable range of screw in sizes, whilst Brenner supplies the 8872 infrared filter - which spectrally sits somewhere between the Wratten 25 and the Wratten 89B - in 8x8cm gelatin squares (Figure 24).



Figure 24 Brenner filter from Germany - despite being titled an "infrared filter" it is actually a deep red. Image © Marco Pauck.

Oriel Scientific supplies narrow pass band interference filters for use in the infrared region from 750nm to 1300nm in equal increments of 50nm. Although very expensive, these are particularly useful for separating out frequencies into narrow wavebands in document examination, for example.

A number of manufacturers supply cheaper polyester filters, eg. Lee Lighting #87 that is not optical quality but can be used over light sources.

As a curiosity it is also possible to "manufacture" an infrared transmission filter by combining any two of the Wratten tri-color filters (47 blue, 25 red, and 58 green). As combinations, any of these pairs will transmit freely approximately 700nm upwards, although the 58 and 25 combined have a tiny (5%) transmission at 590nm.

It is perhaps worth noting that all the standard ultraviolet transmission filters pass infrared, so in combination with an effective ultraviolet absorber (such as a Wratten 12 or 15) they become useful infrared filters. (In ultraviolet work the infrared transmission is not ordinarily a problem, as the films used are not sensitive to infrared.) Rutherford (1977) actually recorded both ultraviolet and infrared with a single exposure through a Wratten 87 filter onto high speed infrared film: a technique which has been re-invented by users of modern digital cameras which happen to be sensitive to both UV and IR radiation.

Whichever filter is selected, some kind of holder that allows rapid placement of the filter after obtaining visual focus is essential. The Nikon AF1 holder is ideal for this purpose as it attaches to the filter thread of the camera lens; the front portion containing the actual filter can then be swung up and down as required (Figure 25). An alternative is the Kodak Pathe Porte-filter Professional shown in Figure 26, which allows one to drop square filters into a light-tight chamber after focusing. If one is prepared to devote a whole camera back to the infrared emulsion - which professional imaging scientists almost

certainly are - a neat solution is to fix an infrared absorbing filter between the guide rails of the camera back in the imaging plane. The disadvantage to this technique is that any dust specs, lint, etc will image with clarity on the film. The advantages are that one can use the viewfinder conventionally to frame the image - most useful for 'action' photography of live events and subjects and that one filter works for all the lenses that can be fitted to that camera. Unless one is using apochromatic or mirror lenses a focus shift still needs to be applied so the method is not entirely ideal for action photography. It is nonetheless a most useful technique.



Figure 25. The Nikon AF-1 filter holder for the 105mm Micro Nikkor which swings into place once the visual focus has been established.



Figure 26. The Kodak Pathé filter holder designed so that the visually opaque filters can be quickly dropped into place.

The infrared Ektachrome color film requires special filtration of its own. The three emulsion layers of this film are all sensitive to blue, so a deep yellow filter is required over the camera lens to remove this sensitivity, eg. a Wratten 12 (Figure 27). In addition, however, it may be necessary to use other color compensating filters to avoid incorrect color bias. It is advisable to test all batches of film individually. Gibson et al. (1965)

showed that the usual guidelines for removing color casts in the subtractive process could not be used with this false color film. The following table shows Gibson's recommendations:

Color Cast	CC Filter to use
Green (Needs more magenta)	Cyan Series 1
Yellow (Needs more blue)	Cyan Series 2
Cyan (Needs more red)	Blue
Blue (Needs more yellow)	Magenta

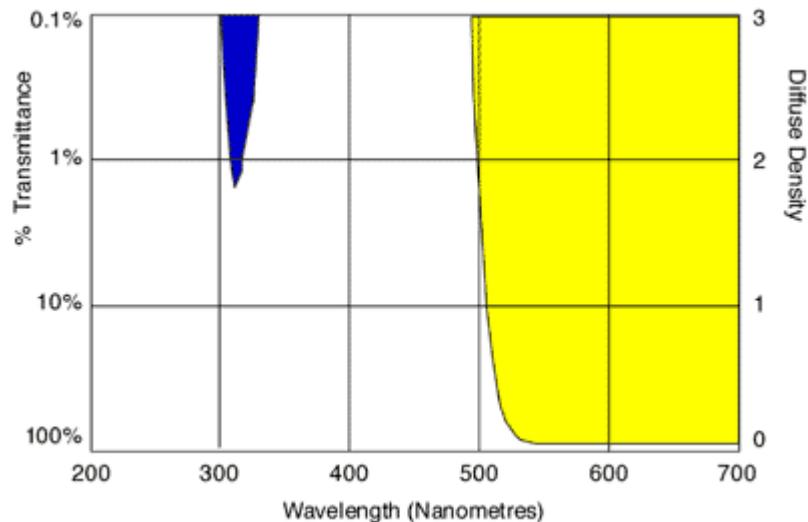


Figure 27. The spectral transmission curve of the Wratten 12 filter used with Kodak infrared Ektachrome to stop all three layers of the emulsions tri-pack being exposed by blue light.

Michel Wurtz has web authored an [excellent article](#) on color balance and Kodak infrared Ektachrome.

References:

- Gibson, H., Buckley, W. & Whitmore, K., 1965. "New vistas in infrared photography for biological surveys," *J. Biol. Photogr. Ass* 33(1):1-33.
- <http://www.cocam.co.uk/CoCamWS/Infrared/EIR/eir.htm>
Article by Michel Wurtz on color balance and Kodak infrared Ektachrome.
- <http://www.pauck.de/marco/photo/infrared/filter/filter.html>
Infrared Filters and Spectral Sensitivity by Marco Pauck.

Reflected infrared photography: Optical considerations

Specialty infrared lenses were once available for infrared photography, such as the Zeiss Sonnar Superachromatic for the Hasselblad or the Leitz Telyt-R Apochromat for the Leica, but these have long since been withdrawn from the market. One is obliged therefore to use a lens which has been manufactured for use with visible light and make some correction to the focus for the infrared image. In a normal lens, wavelengths longer than 700nm, are brought to focus away from the optimized point of visual focus. The difference in distance between the visible focus and the infrared focus is known as the "focus shift" and unless some correction is applied, unsharp photographs will result. Pictorial photographers working in the far red region often use wide angle lenses and depth-of-field to compensate for focus. Some authors have advocated the simple expedient of focusing through a red filter in the case of infrared photography (Gibson 1978). Manufacturers' data sheets for their infrared films make general recommendations for an increase in the lens to image distance at various magnifications but also suggest the use of the infrared focus mark. Many lenses are engraved with these infrared focusing marks (Figure 28) as an aid to obtaining correct focus. The idea is to focus visually through the camera, read off the distance to the subject and then move that same distance to the infrared focusing mark by rotating the lens barrel. Unfortunately these infrared marks are only an indication of the focus shift necessary when working at infinite distances, in other words for landscape photography. For scientific and biomedical photography, where one is ordinarily working much closer to the subject, some focus shift must be applied. In order to understand the problem of focus shift one needs to examine the process of achromatization.



Figure 28. The infrared focusing marks often found on modern lenses. Two marks are actually engraved on this lens to represent the range of focal lengths of the zoom.

Focal length is, strictly speaking, specific to a given wavelength; even different glasses will focus the same wavelengths at different focus points. Chromatic aberration in normal photography has the effect of producing concentric colored "circles of confusion." Lens manufacturers expend much effort in trying to design combinations of glasses that will effectively eliminate the so-called "chromatic aberration." Crown and flint glasses perform differently with varying wavelengths (see Figure 29), and in practice the lens manufacturer uses these two glasses in such a manner that equal and opposite amounts of chromatic aberration are induced - this process of bringing two or more spectral lines together is called achromatization. Normal lenses are chromatically corrected to cope with a range of wavelengths from 400nm to 700nm. Achromatic lenses have been

designed to bring two wavelengths (normally red and blue) into precise coincident focus. Achromatic lenses have been designed to do the same for three wavelengths (Ray 1988). In the achromatic lens, the red and blue come to focus at the same plane with the curve resembling a parabola. The apochromat lens focuses three colors on the same plane with the curve resembling a sine wave (Figure 30). The shape of these curves is very important to invisible radiation photography because they show where other wavelengths are likely to fall in relation to the visible focus. Thus, an inspection of the curves shows that with a modern multi-element achromatic lens, the infrared radiation may focus at approximately the same plane of focus as the ultraviolet (Figure 31). In general, it can be seen that the focal length of an achromat increases for infrared, necessitating some correction of focus from the visual point. Depending on its design, the modern apochromat may not need correction for infrared photography.

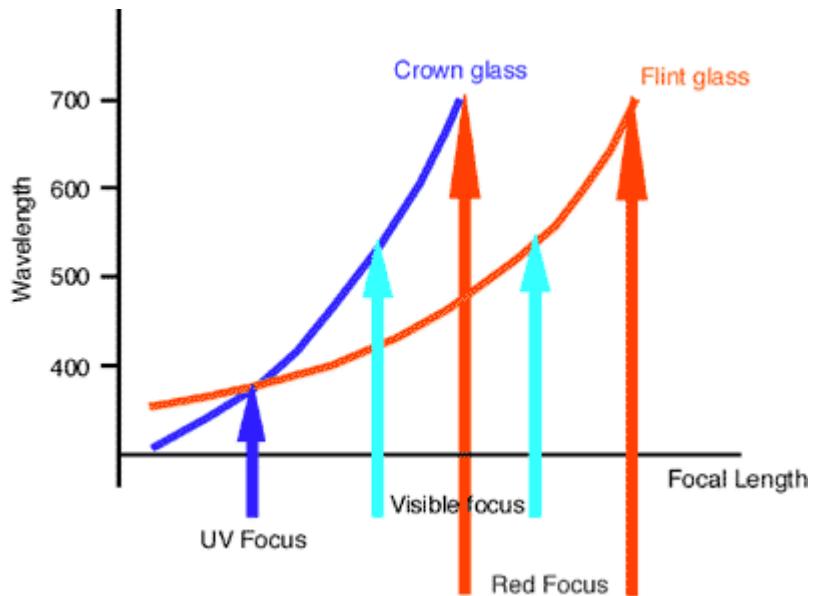


Figure 29. These curves for crown and flint glass demonstrate that each glass focusses radiation of the same wavelength at different focal points, and that visible light is focused at a different point from ultraviolet or infrared.

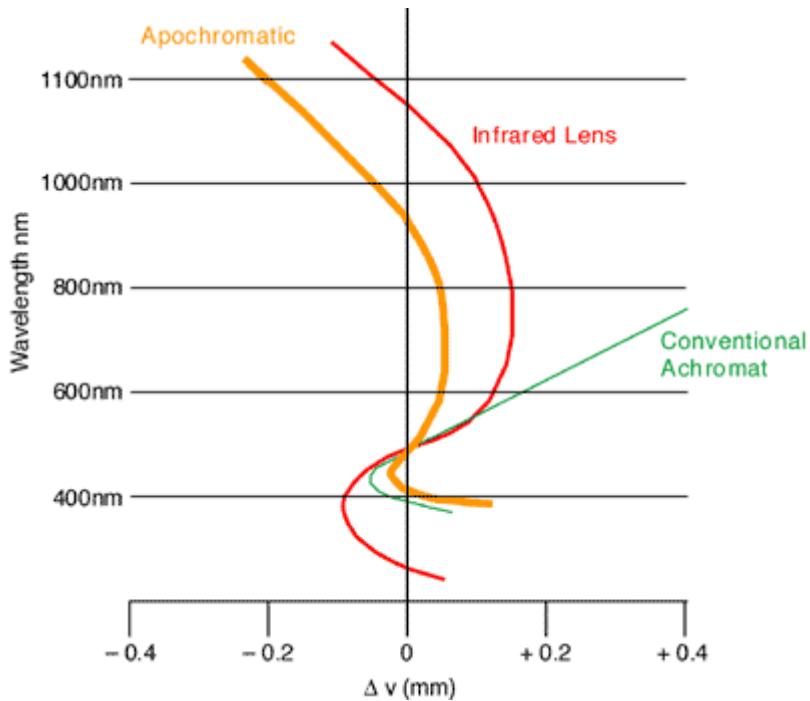


Figure 30. Variation in focal length for different wavelengths, with three types of lenses.

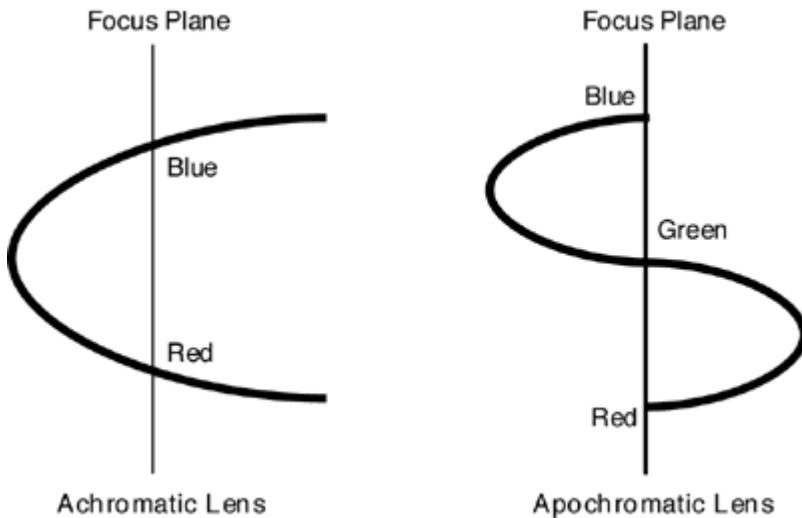


Figure 31. Focus plane curves for a generalized achromat lens and a generalized apochromat lens demonstrate that the infrared image will always focus in a different plane than the visible. Note that it will depend on lens type whether the focus shift for infrared and ultraviolet are in different directions or the same direction.

For critical work, especially at higher magnifications one really cannot rely on the manufacturer's description of the lens and focus tests will be required. This means that some focus shift must be applied after the subject has been sharply focused by eye in order to obtain sharp results with infrared radiation. The exact amount of shift required will need to be established by testing specific lenses, at specific magnifications. Some

workers have tested specific lenses; Clark (1939a) was the first to identify the focus shift caused by chromatic aberration in the infrared and quoted infrared shifts for the then available Kodak lenses, and Freytag (1969) quoted infrared correction values for the Hasselblad lens as varying between 0.9 and 0.3%. In an attempt to provide some definitive guidelines for the medical photographer, an extensive series of tests were conducted (Nieuwenhuis, 1991). A test block made of one hundred pieces of 1mm thick card was constructed. Each piece of cardboard was numbered from -50 mm to +50 mm with 0 being in the middle. This block thus provided a test target with a total depth of 100mm in measured 1mm steps. Figure 32 shows a schematic of the test set-up and Figure 33 an actual photograph of such a 'focusing block'. In each case the camera was focused visually on the zero point in the middle of the block with the expectation that some other step in the block would be recorded sharply, thereby giving a quantification of the focus shift. The aim was to test a practical range of magnifications with various common formats in medical photography. Three formats were selected for testing: 35mm, 120 roll film, and 4 x 5 sheet film. The lenses selected were of the short telephoto variety commonly used for clinical photography. The table below shows the recommended shifts to be applied for black-and-white infrared photography:

35mm with 105mm lens	6x7cm with 135mm lens	4x5inch with 370mm lens
1:10 - 53mm	1:10 - 56mm	1:10 - 0mm
1:8 - 32mm	1:10 - 44mm	1:10 - 0mm
1:4 - 8mm	1:4 - 24mm	1:4 - 2mm
1:2 - 5mm	1:2 - 6mm	1:2 - 3mm
1:1 - 2mm	N/A	1:1 - 4mm

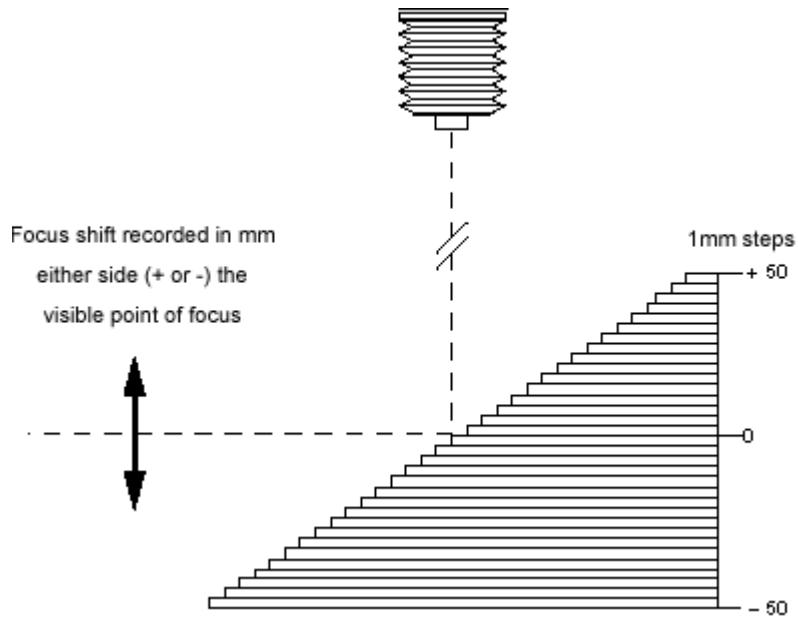


Figure 32. A schematic diagram of the focusing block constructed for testing actual focus shifts with different optical configurations.

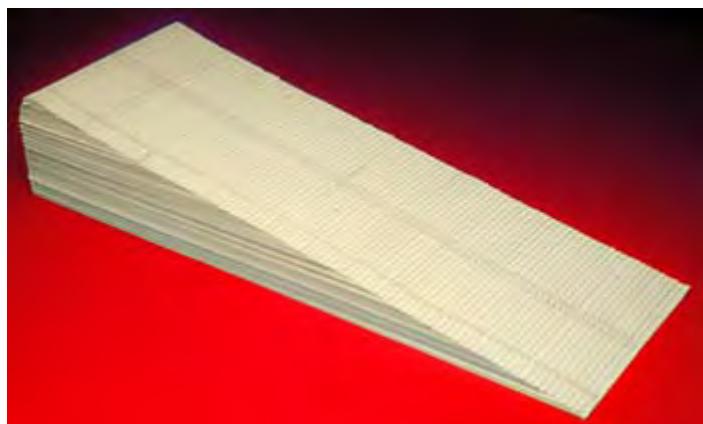


Figure 33. A photograph of the actual focusing block used by the authors.

The application of focus correction can be applied in two ways: either by changing the image distance--moving lens or film plane--or by keeping the camera set at a known magnification ratio and moving the whole camera in relationship to the subject. With large format photography where one has full control of lens and film plane movements, it is easier to apply focus shift to the film plane (Figure 34). For 35mm and roll film formats it is more convenient to move the whole camera. This is best accomplished by using a focusing slide of the kind manufactured for macro photography (Figure 35).



Figure 34. With large format photography it is easy to apply focus shift to the film plane using the calibrated guides.

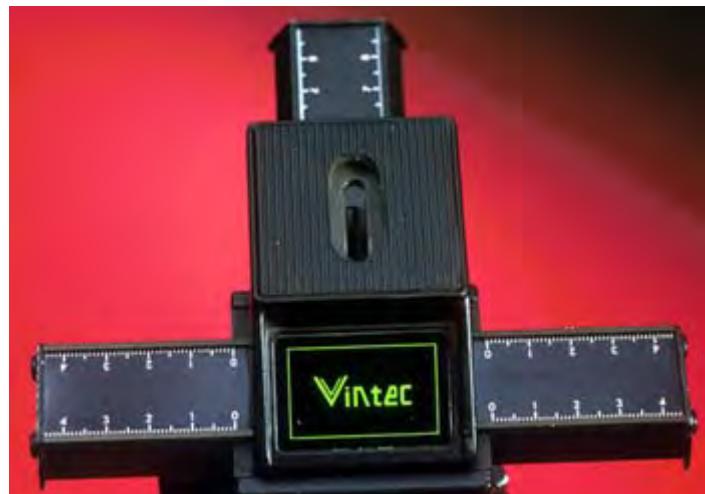


Figure 35. For 35mm a focusing rack calibrated in millimeters is most helpful for applying the focus shift in a practical working situation.

Many lenses that have been corrected for wavelengths in the visible spectrum give an image of poorer quality when used in the infrared range - this occurs even when the optimum infrared focus has been obtained. Diffraction is twice as bad with long infrared wavelengths as it is with short (blue) wavelengths and various diffraction effects have been observed in lenses used for infrared photography. This problem is often made worse by photographers trying to mitigate the effects of focus shift and stopping down in order to get better depth-of-field. Nieuwenhuis, 1990, reported diffraction when using the new style 105mm Micro Nikkor at apertures smaller than f/16. All lenses likely to be used for infrared work should be tested at small apertures for this effect by photographing an evenly lit grey card.

Correct focus with the Ektachrome color infrared film is virtually impossible to achieve, as one is trying to get infrared, green and red all parfocal. In practice one can only focus normally and rely on depth-of-field for the infrared layer of the image. Alternatively a true Apochromatic lens or a mirror lens (which is free of achromatic aberration) could be used. Sharper results are actually obtained by making the three negative images separately - green, red and infrared, applying the correct focus shift to the infrared image, and then combining them together in Photoshop (see [electronic recording of the infrared image](#)).

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- Freytag, H., 1969. *The Hasselblad Way*. Chapman & Hall, Limited, London.
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Reflected infrared photography:

Films page 1

Emulsions have to be specially sensitized to radiation beyond the red region. Infrared sensitizing dyes were discovered early this century, but infrared materials were not widely available until the 1930's. Indeed panchromatic film was not widely used until the 1940s (See Kodak advertisement comparing the reproduction of orthochromatic and panchromatic films, Figure 36). Through successive discoveries, the sensitivity given by sensitizing dyes has been extended in stages to the limit of 1350nm. Only specialized spectroscopic plates extend this far up the spectrum, conventional infrared films available today only being sensitive to about 900nm.

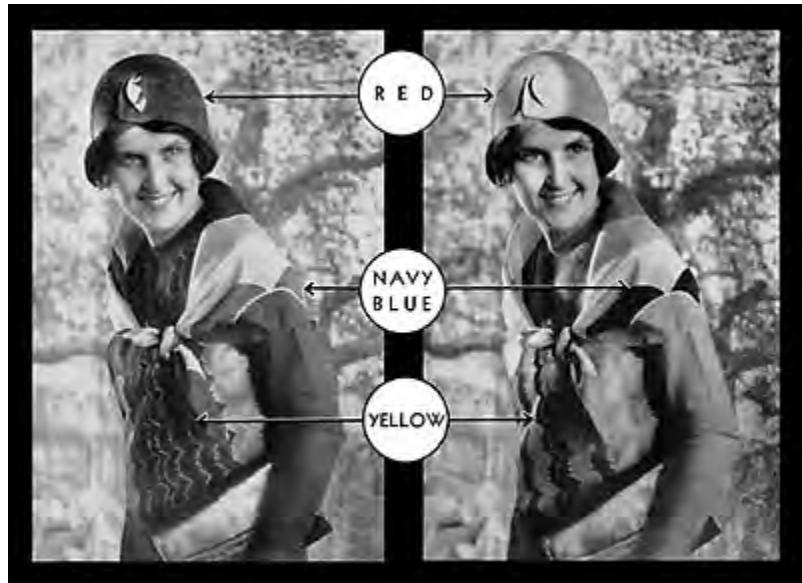


Figure 36 (above). A Kodak advertisement from the 1930's extolling the virtues of the new panchromatic film over the existing orthochromatic film. It must be remembered that for the first hundred years of photography's history film was insensitive to red, or indeed infrared.

In 1958 Engel surveyed the range of films for infrared, and found that eight manufacturers collectively supplied over twenty different emulsions. By the early 1990s the range had declined to just two manufacturers (Figure 37) but thanks to the interest in infrared photography by mass market amateur consumers there have been several new introductions in recent years.



Figure 37 (above). By the 1990s the range of IR films had declined to two manufacturers.

Kodak supplies probably the most widely used and universally available high speed black-and-white infrared film known by the HIE or HIS codes (depending on country). This film is available in the 35mm format (HIE-135); as cassettes, or as 150 foot rolls. In

it's aerial configuration (HIE 2443) it is also available as 70mm 150ft rolls or 9.5 inch wide 125, 200 or 400 foot rolls coated onto an Estar base. The 4x5 sheet film (HIE 4143) was recently withdrawn from the market by Kodak due to declining demand. The emulsion has a moderately high contrast and an infrared sensitivity peaking between 750 and 950nm - the furthest into the infrared spectrum of any commonly available film (Figure 38). It is inherently grainy. This film has no anti-halation layer and therefore exhibits two associated effects: 'light piping' and halated highlights. The 'light piping' means that infrared radiation entering the film structure, at say the leader, is able to internally reflect within the film base along into the bulk of the film within the cassette. This problem is exacerbated by the felt light trap on the cassette being less effective in infrared than in visible light. This means therefore that the film is very susceptible to fogging and must be loaded/unloaded into the camera in total darkness. The lack of anti-halation layer is also the reason why bright point sources of light in the scene record on this film as having 'halos' around them. The infrared passes through the silver halide and reflects from the back of the film or camera pressure plate to create secondary halo images. There are numerous reports of this causing problems with different camera pressure plates. This film is also famous for exhibiting processing artifacts such as uneven density and pinholes - more of this in processing. Kodak also warn that this film is susceptible to static 'flash' fogging in very dry conditions and suggest that it may even be necessary to ground the camera to avoid a build-up of static (although the authors have used this film extensively in the Australian outback - very low humidity and temperatures in excess of 40° Centigrade - with no obvious static marking). The film base is actually grey and so printing times are extended. Despite all these difficulties HIE remains the most widely used infrared film for scientific purposes.

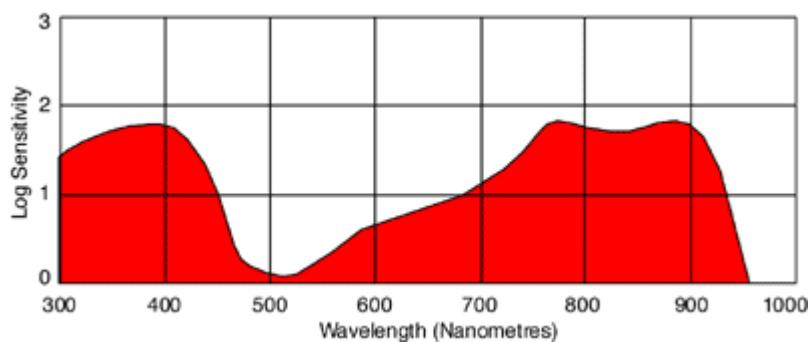


Figure 38 (above). Spectral sensitivity curve for Kodak HIE 135 black-and-white film; the most universally used true infrared film on the market.



Konica have introduced a black-and-white infrared emulsion in 120 roll film and 35mm, 24 exposure, formats - Konica 750. As its name implies, this film has a peak spectral sensitivity at 750nm and, as can be seen from the spectral response curve show in Figure 39, only has sensitivity extending to 800nm. Strictly speaking,

therefore, this film is an extended red film not an infrared film. The film has a single, thin, infrared sensitive emulsion layer coated onto a colored anti-halation tri-acetate base. It has fine granularity, high contrast and excellent resolving power. It is slower than the Kodak products but much less grainy. The presence of an anti-halation backing removes



the halo and light piping effects common with the Kodak films. This film is extremely popular with pictorial photographers who use it with a Wratten 25 (red) filter. The limited infrared sensitivity means that care in the selection of a filter for use with this film is therefore imperative; the narrow-cut Wratten 87A, B, or C, for example, would lead to virtually no result. Some workers have reported availability problems with this emulsion, which is apparently produced only once a year in February and in common with all infrared film has a short shelf life.

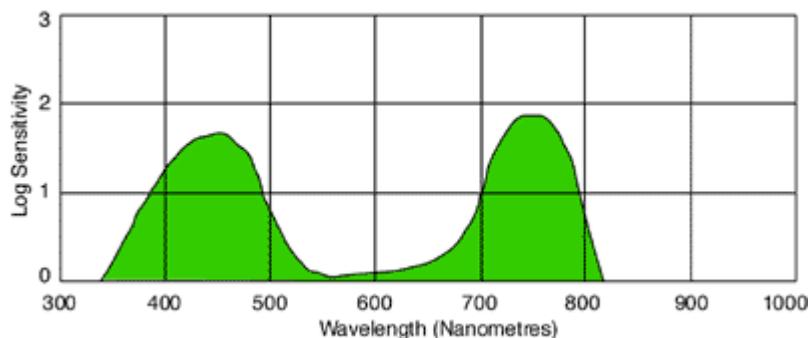


Figure 39 (above). Spectral sensitivity curve of the Konica 750 IR film widely used by pictorial photographers. Whilst clearly lacking the full range infrared extension of the Kodak it has much finer grain structure.



Ilford now supply SFX 200 in 35mm, 36 exposure cassettes and as 120 roll film (it was previously only available as SP816T - a special purpose traffic surveillance film). Ilford themselves describe this film as "a black-and-white camera film with extended red

sensitivity for creative photography." The spectral response peaks at about 720 nm and falls rapidly to zero at 780nm. It is coated onto an acetate base with an anti-halation backing. It is a medium speed film with wide exposure latitude, is compatible with all common developers, and exhibits fine grain and wide tonal range. Like the Konica product its ease of use has made it very popular with pictorial photographers but the same caveat about spectral sensitivity exists: the use of true infrared filters (Wratten 87 series) would result in no image. The lack of true infrared sensitivity, combined with severe reciprocity effects, limit this films application to science and medicine.

Agfa Agfapan APX 200S and 400s are sometimes quoted as being useful for "infrared photography effects." These are again medium speed black-and-white films with extended red sensitivity that started life as a traffic surveillance films and have been re-packaged for the pictorial/creative photographer. The 200ISO version is available in 35mm cassettes or 17 meter 35mm rolls, whereas the 400ISO version is only available as 17, 30.5 or 48.8 meter rolls and they are all coated onto a thin polyester base with anti-halation backing. The film exhibits reasonable sensitivity between 600 and 670nm and is therefore only a mildly extended red film. It is a medium speed film with wide exposure latitude and exhibits fine grain and wide tonal range. It can only be used with a red filter - true infrared is not possible with this film



Maco are a new player in the infrared film market; they are a division of Hans O. Mahn & Co in Hamburg, Germany. At Photokina 2000 they released details of a prototype infrared film Maco IR 820c which then went into experimental production in 2001 and final product release late in that year. It is now widely available in 35mm, DX coded, 36 exposure cassettes, 120 roll

film and 4x5 sheet films. It is a cubic crystal emulsion with spectral sensitivity extending to 820nm (Figure 40), coated onto a clear polyester base with antihalation backing. It is a fine grain, high resolution emulsion designed for scientific and technical applications (although it is also likely to be well received by pictorial photographers - which may help keep its viability in the marketplace). The anti-halation layer prevents the common problems associated with the Kodak HIE film and is removed prior to development by using a water bath. Like HIE this film must be handled in complete darkness.

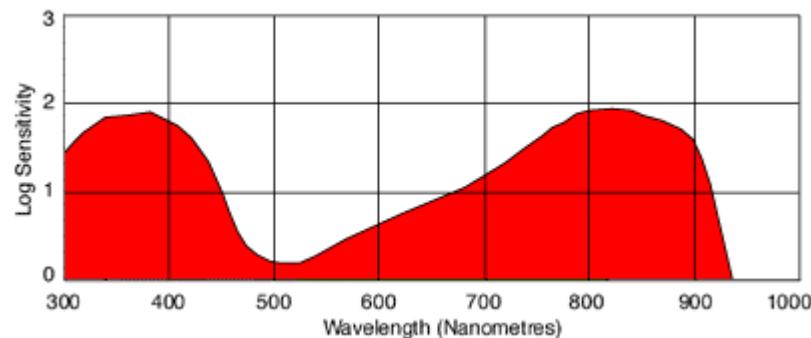


Figure 40 (above). Spectral sensitivity curve of the Maco 820c IR film - a true infrared film newly introduced onto the market from a German manufacturer.

References:

- Engel, C., 1958. "Present-day materials for infrared photography," *Med. Biol. Illustr.* 8:89-91.

Reflected infrared photography:
Films page 2

Infrared 'false' color film

Eastman Kodak has a long history and commitment to the manufacture and supply of a false color infrared sensitive color transparency film. Originally developed during the Second World War for camouflage detection the idea has survived over sixty years through various configurations and changes to Ektachrome processing (although periodically going out of production or being withdrawn). Walter Clark of the Eastman Kodak Company and one of the founders of infrared photography described the history thus: "Also in these days (1940s) we researched the aerial photography and the potential of camouflage recognition. We considered the possibility of combining IR-characteristics with color contrasts. I believe that the first thoughts about a two-color separation camera

working according to the Technicolor principles originated from D.A. Spencer and A. Marriage at Kodak in London. This idea was then transferred to Kodak Research Laboratories in the US, the persons involved were Mannes, Jelly, Wilder, Copstaff and me. We then considered the use of the multiple layer color film, in which one layer should be infrared-sensitive. Many combinations were tested, in particular a two-layer/two-color system and two three-layer/three-color films. One of these three-layer films was then selected, and released to the US Air Forces as Kodacolor Aero-Reversal-Film for camouflage recognition." The modern version of this is the Ektachrome Professional Infrared EIR film.

Some workers believe that color infrared film is more useful than black-and-white, since color contrast is easier detected than grey-scale contrast and many publications testify to the usefulness of this film (see References and Biomedical applications). Others find the false color representation difficult to interpret - infrared yields red image, green records as blue, and red as green. Chlorophyll in living plants reflects both green and infrared, and therefore appears magenta on this film. Many other subjects appear with characteristic colors such as melanin that records red-brown, arterial blood that reproduces green, cholesterol and collagen that reproduce blue and so on (Figure 41).



Figure 41 (left). The characteristic appearance of Kodak's false color infrared film, with chlorophyll appearing magenta and blood green.

Normal color films have three light sensitive layers sensitized to record blue, green and red; during processing each layer produces a dye of complementary color - yellow, magenta and cyan. When white light is passed through the three layers of the processed transparency the viewer sees a close visual reproduction of the colors of the original scene. In the case of infrared Ektachrome the three layers are sensitized to green, red and infrared (all three layers are inherently sensitive to blue and ultraviolet and therefore a deep yellow barrier filter must always be used with this film. Infrared reproduces as red, green as blue and red as green. Numerous other colors are formed of course depending on

the proportions of green, red and infrared reflected by the subject. Figure 42 illustrates diagrammatically how this film works.

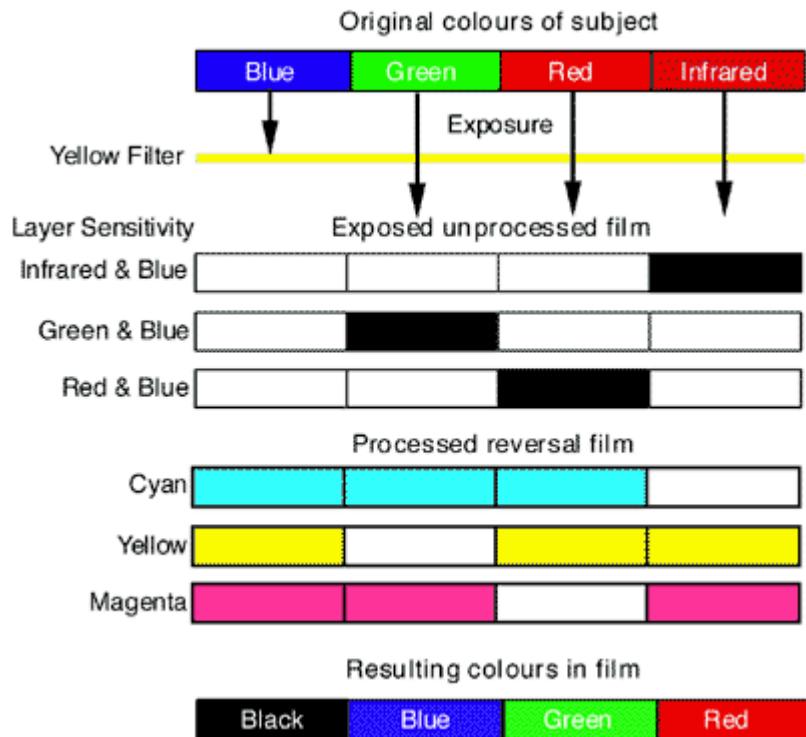


Figure 42 (above). A demonstration of how the layers in the infrared Ektachrome 'False-color' film respond to different frequencies of light. The three layers are sensitized to green, red and infrared (all three layers are inherently sensitive to blue and ultraviolet and therefore a deep yellow barrier filter must always be used with this film. Infrared reproduces as red, green as blue and red as green. Numerous other colors are formed of course depending on the proportions of green, red and infrared reflected by the subject.

Kodak EIR is a true infrared film with a peak spectral sensitivity at 730nm and good sensitivity extending to 900nm (Figure 43). Like its black-and-white counterparts - Kodak HIE and Maco 820c - it must therefore be handled in total darkness, including loading and unloading the camera. It is coated onto a 4mil (0.101mm) Estar base with anti-halation backing. It is relatively fast - 200 ISO in daylight with the Wratten 12 filter - has fine grain and medium resolution characteristics. Storage conditions for this film are exacting - Kodak recommends storage in original packaging at -18° C to -23° C , and the film must be processed as soon as is practical after exposure. Unexposed film will not tolerate more than one week at room temperature. Exposed film must not be kept longer than two days at room temperature - it should be returned to refrigeration. Adverse storage conditions affect the three layers of this film differently, and cause a significant change in color balance. A loss of sensitivity and a color shift towards cyan typically indicate poor storage conditions.

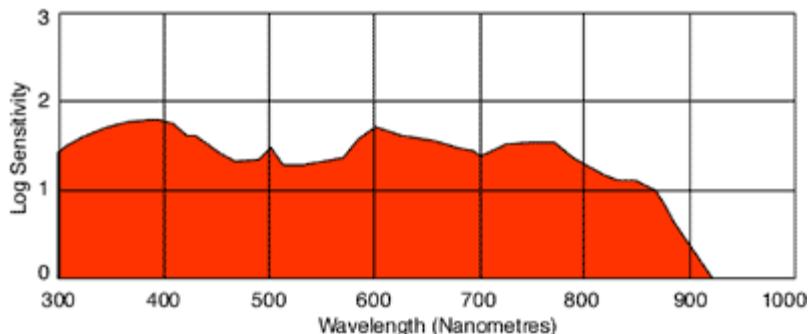


Figure 43. The spectral sensitivity curve for Kodak EIR infrared Ektachrome false color reversal film.

At exposure times of between 1/100th and 1/1000th of a second no filter or exposure correction is required for reciprocity effects but outside of this range the film starts to require considerable correction for reciprocity failure. The three layers of the film all behave differently. As a guide at 1/10th of a second the exposure needs to be increased by one stop and CC20B added to the Wratten 12 yellow filtration.

The choice of film will therefore depend on the application and the need for extended spectral response. Where the furthest penetration into the infrared spectrum is required (850 - 950nm) Kodak HIE is the only choice. Where the spectral range can be limited to less than 850nm the improved granularity and handling of the Maco 820c makes it the film of preference. In the far red range (700 - 800nm) the Konica product comes into its own, whilst in the extended red region 700-750nm (which is actually where most amateur photographers operate), one has the additional choice of the Ilford and Agfa products. For false color imaging there is only one option - the Kodak EIR (although there are electronic ways of achieving the same effect - see electronic recording of the infrared image).

Storage of infrared films is critical; their relative speed and contrast will deteriorate rapidly if they are not kept properly. Unexposed film, in the original sealed containers, must be kept in a refrigerator at 13° C or colder. Ideally they should be bulk stored in a freezer, removing them to a refrigerator a day or so before use and then to cool room temperatures for 6 hours before use. Exposed film should be kept cool and dry and processed as soon as possible. If exposed film must be kept for some time before processing it should be returned to the refrigerator and stored at a temperature lower than four degrees Centigrade. Even when refrigerated, the shelf life of infrared emulsions is limited, so care must be taken to ensure that only fresh stock is used.

Reflected infrared photography: Exposure

Precise film speeds cannot be quoted for infrared emulsions, and since exposure meters are not sensitive to infrared there is little point in using them. Some workers calibrate their exposure meters by placing a deep red filter over the sensor and then conducting

tests to establish the "effective" film speed using this system (this involves calculating the relative speeds of the red versus the infrared). Care must be taken with this approach as the relationship between the actinic value of visible light and the infrared content varies considerably with different times of the day in daylight.

Infrared films are now remarkably sensitive. When used in daylight with the Wratten 88A filter one can expect exposures of the order of 1/125th sec. at f/8 for most of the black-and-white films, or with a moderately powered electronic flash unit, exposures of f/32 of f/22 are common-place for close-up biomedical work. Infrared Ektachrome is also very fast with an effective speed rating of ISO 400 when used with the Wratten 12 filter and processed in E6 chemistry. This falls to 200 ISO when processing in the AR-5 chemistry. (Kodak state that the effective film speed in E6 is only 200 ISO but in practice the authors have found that in both daylight and under studio flash conditions it is one stop faster).

The following table gives some idea of the relative sensitivity of the commonly used black-and-white-film and filter combinations:

Filter	Kodak HIE	Maco 820c	Konica 750
No filter	200 ISO	100 ISO	80 ISO
Wratten 25	50 ISO	12 ISO	12 ISO
Wratten 89B	25 ISO	6 ISO	8 ISO
Wratten 88A	25 ISO	4 ISO	N/A
Wratten 87	25 ISO	N/A	N/A
Wratten 87B	12 ISO	N/A	N/A

The real advice is bracket, bracket, bracket - two stops either way in half stops is usually necessary. The half stops are important and will often save the image.

Reflected infrared photography:

Other considerations

It should be noted that many materials transmit infrared freely, examples being some of the plastics used in the manufacture of sheet film dark slides, developing tanks, cameras and camera bellows (Figure 47 shows an example). Care must also be exercised when using "changing bags" with the true infrared films - Kodak HIE and the Maco 820c - as the black cloth material may transmit infrared.). It is imperative, therefore, that all equipment to be used for infrared photography is tested prior to use in order to avoid fogging the film. Incidentally the ability of infrared to pass through some dark materials has led to sensational reports in the press about the "See through clothes ...x-ray" images obtainable from digital cameras (Figure 48) - no doubt providing a healthy boost to sales!



Figure 47 (left). Many materials transmit infrared freely despite their appearance in visible light this includes some plastics used for the manufacture of dark slides and camera bellows.



Figure 48 (above). The black material that this bag is made of is quite black in normal light (left) but almost transparent to infrared (right) - notice how clearly the writing can be read through the bag. This has been described, quite erroneously, as an 'x-ray effect.' Images © MaxMax.

Not all cameras are suited for infrared use - even if their construction is infrared opaque. Some modern cameras, for example, use infrared devices for film loading and frame counting. These cameras will fog infrared film or at the very least the rebates of the film. The Canon EOS Elan/100, A2 E/5 and Hasselblad Xpan are all reported as causing this effect. Other cameras have dimpled pressure plates to reduce frictional drag which then cause problems with the Kodak HIE film and halation (reflection from the pressure plates causing halos around bright light sources in the image). The Pentax LX and K1000 are both reported as problematic in this area. Minolta cameras like the 9xi and 700si, which had a pressure plate with a circular hole built to accommodate a data back are also reported as causing the same problem. Infrared LED data backs, common on compact 35mm cameras, fog infrared film and so must be turned off. Others have reported problems with infrared leakage around take-up spools and re-wind handles (the Horizon 202, for example), or through plastic film identification windows. The only reliable approach is test everything first.

Some workers have advocated the use of the twin lens reflex camera for infrared work as this enables the photographer to maintain visual framing while the imaging lens is fitted with the visually opaque infrared transmission filter. Whilst certainly convenient this method still requires a focus adjustment and may further be subject to parallax error between the two lenses.

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