

Overview of Infrared and Ultraviolet Photography

Theory, Techniques and Practice

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The following pages are the textual reproduction of a traditional slide presentation with the associated annotations for each image as if the material was presented “live”.

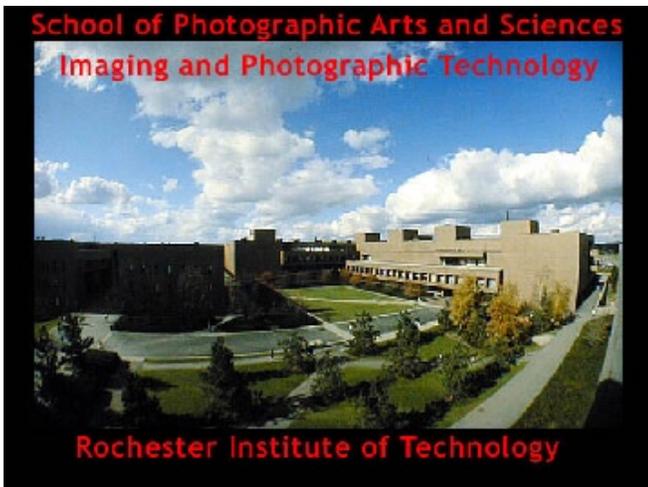
Along with a general introduction to the theory and practice of photography by invisible radiation among these slides you will also find references to practical applications of the various techniques available to the industrial, technical, forensic or creative photographer.

The material also can be used as a tutorial on the subject of infrared and ultraviolet photography and associated techniques. Hopefully you will find this material interesting and informative.

INFRARED and ULTRAVIOLET PHOTOGRAPHY

...photographs of the invisible

Andrew Davidhazy



Before getting started with the rest of the material I'd like to mention that this presentation will not cover certain topics that are related in general terms to the main topic that we are concerned with. Photography is primarily concerned with an accurate representation of subject colors. However, variations in color reproduction can be achieved by constructing emulsions that assign other than proper dye layers to the various colors present in a scene. These would be called "false color" reproductions.



This is exemplified by the image seen here. It was made with color infrared film. This kind of film or emulsion is sensitive to red, green and blue and also infrared. The sensitivity to blue is essentially eliminated by photographing through a yellow filter and thus the three emulsion layers are now sensitive to green, red and infrared and these control the cyan, magenta and yellow dyes formed in the film as a result of exposure.

Sometimes this is referred to as a “false color” emulsion but in fact it is an emulsion that simply interprets reality differently (but predictably) than normal color films designed to reproduce red, green and blue in a scene correctly.



This is a comparison of the images made on normal color film on the left with reproductions of the same scene made on color infrared film taken through a Wratten #12 (yellow) filter (to eliminate blue to which all three layers of the film are sensitive) and through an Infrared filter that eliminates green and red (and blue) from the scene. The latter image is made up of only tones of red because exposure to infrared controls the cyan layer while the other two layers produce magenta and yellow dyes. Since these two layers are unexposed they produce the maximum amount of each dye they are capable of producing. The cyan layer is denser or less dense depending on amount of infrared falling on the film. Where there is a lot of IR exposure the cyan layer is not very dense and thus that area is seen as red in the final record. Where there is not much infrared present the cyan layer is very dense and thus a black area is reproduced in that location. This means that one can identify areas where there is a lot of infrared by noting the color of the image. If it is very red that stands for lots of infrared.

In the middle photograph the red plastic flower reproduces very closely as the red living flowers do but the green plastic leaf next to the flower reproduces quite differently than the living green leaves at the bottom of the picture. This is because the plastic leaf has very low IR reflection characteristics while the living leaves exhibit significant IR reflectance. The red flowers turn Yellow because they not only reflect copious amounts of IR but also red. Thus the cyan layer is “overexposed” as is the magenta layer which is controlled by exposure to red light.



All that remains therefore is yellow dye (controlled by exposure to green) and so the red flowers (plastic or living) are reproduced as yellow.

In any case, this presentation will not discuss color infrared materials any further than this.

Often infrared photography is also associated with the recording of heat or thermal energy emitted, reflected or transmitted by a particular subject. While strictly speaking this is correct, in general, infrared “photography” refers to making photographs with relatively unsophisticated equipment including film cameras and emulsions as well as digital cameras.

The recording of thermal radiation as exemplified by this photograph is accomplished with quite specialized imaging equipment that contains sensors which are sensitive in a region of the electromagnetic spectrum significantly outside the range of conventional cameras. It is assumed by many that one can make such images with regular film or digital cameras. It is possible to deduce quite easily this would be impossible by simply thinking about how one would load a camera containing film that was sensitive to thermal radiation.

The mere act of holding the film cassette or camera in one’s hands would expose or fog the film or cause a digital camera’s sensor to acquire an overall fogging exposure as well.

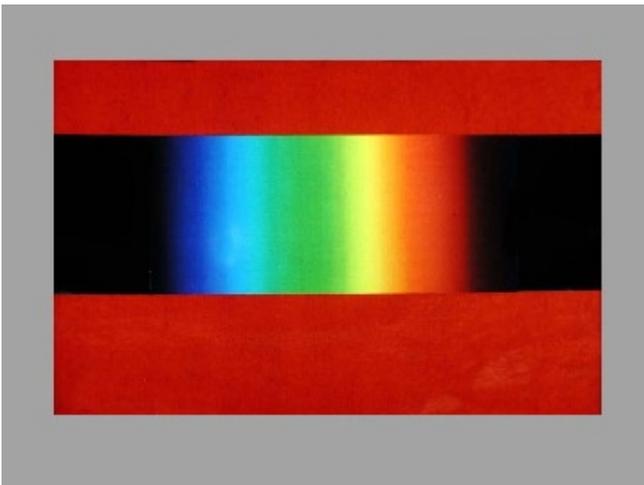


Thermograms, or thermographs, are images made with cameras that are sensitive to thermal radiation. These can also produce what might be called false color images but in this case colors can be assigned temperatures and so they are useful as tools for quantitative study of the temperature of objects within a scene.



Cameras that are sensitive to thermal radiation are often used to quantitatively map and study thermal or heat loss in buildings, electrical equipment, insulators, etc. In this case a thermal camera was driven along a street periodically capturing a single line in space and the speed of the vehicle moving the camera was adjusted so that the aspect ratio of the subjects would be maintained in the reproduction as seen in this photograph. White represents areas that are hot and thus losing heat while areas colored blue are cool and close to ambient temperature.

This is the extent to which this presentation covers thermography, a subject that deserves its own presentation.



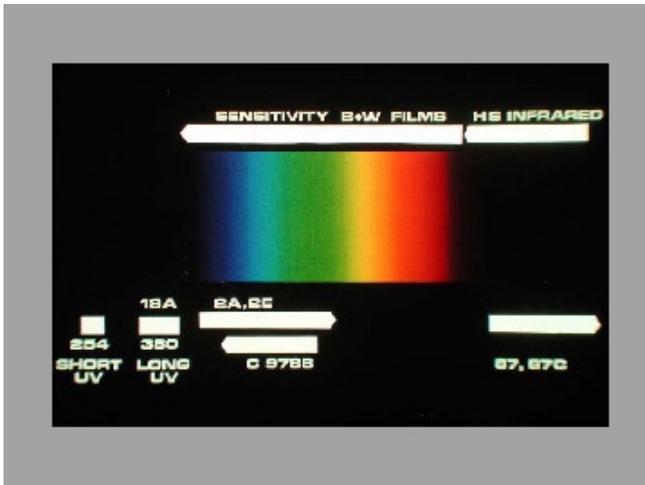
So, now we progress to the subject at hand.

Any discussion of photographing with infrared and ultraviolet radiation typically starts out with a brief introduction to the fact that there is such a thing as the electromagnetic spectrum and that “light” is only a small part of it. The spectrum is characterized by its wave nature and referred to by wavelength. It includes a large number of “zones” from the very short wavelengths where one finds X-rays, Gamma-rays, etc. to the very long ones where one finds radio waves and thermal infrared wavelengths.

In between, occupying a very small portion of the EM spectrum, we find those wavelengths that comprise what we call “light”. The major components of these wavelengths are blue, green and red wavelengths. In between blue and green we find cyan wavelengths and between green and red the yellow ones.

Interestingly there are no magenta wavelengths in the spectrum. Magenta is a color made by the mixing of red and blue light and in the spectrum itself no “mixing” per se takes place. Each wavelength stands for a particular color.

At either end of the part of the spectrum we call “light” (because we can see it) are other wavelengths that we can not see. At the short end of the spectrum and immediately adjacent to the blue/violet colors there are rays or wavelengths that are called ultraviolet. At the other end of the light spectrum we find the near-infrared wavelengths. Also invisible to us. But both of these areas can be used to “see” or record the appearance of subjects that emit, reflect or absorb such wavelengths.



Now let's summarize the tools that as photographers are available to us for exploring the “invisible” spectrum of ultraviolet and infrared photography.

Photographic emulsions are inherently sensitive to ultraviolet and can be sensitized to extend their response into the near infrared. Most emulsions can respond to all visible wavelengths into the deep red.

A few emulsions may be available that extend their “reach” or sensitivity into the infrared area. In brief, as shown in this illustration, most B&W films can “see” into the red area while one emulsion, High Speed Infrared, can detect wavelengths beyond the red ones.

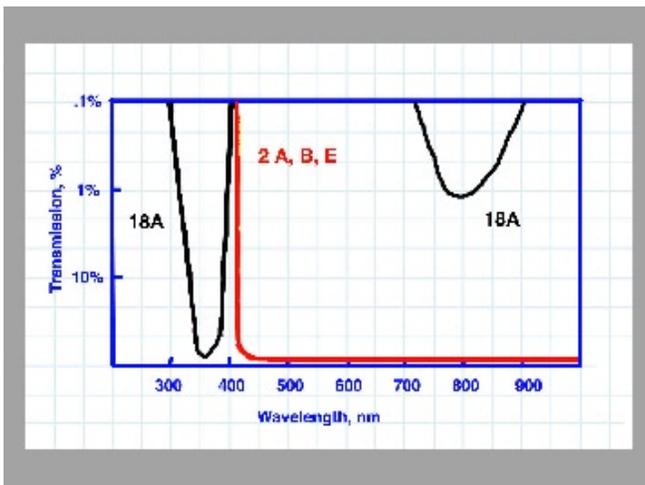
On the other end, most B&W emulsions respond to visible wavelengths as well as ultraviolet ones without any problem. Color emulsions, on the other hand, will only respond to UV on their top layer because below the top layer there is incorporated a yellow filter which eliminates UV from the bottom two layers.

We control the wavelengths that will fall on the camera's film or sensor by appropriate choice of filters to modify the light incident on a camera's lens or emitted by a “light” source.

To photograph in an area of the spectrum known as “short wave UV” special precautions or steps need to be taken. This area is the one that is responsible for suntans and is known as an actinic wavelength. These wavelengths can damage skin and eyes and appropriate eye (in particular) protection should be worn when such wavelengths irradiate a scene. Nearest to the visible range are the “near ultraviolet” wavelengths and these are the most popular ones for most photographic activities. Associated with this region is the Wratten 18A filter.

Associated with the 18A and with ultraviolet photography are the UV absorbing filters. These are pale yellow in color and are such filters as the Wratten 2A, 2C, 2E, etc.

On the other end of the spectrum we find those filters that only allow infrared rays to pass. These are such filters as the Wratten 70, 87, 87B, 87C, etc. Coupled to these filters are filters that do not transmit infrared at all but which allow light wavelengths to pass more or less freely are cyanish/greenish looking filters and a common one is the Corning 9788 filter. There are many variations on this filter and some are called “hot mirrors” by the way in which they eliminate IR from passing through them.

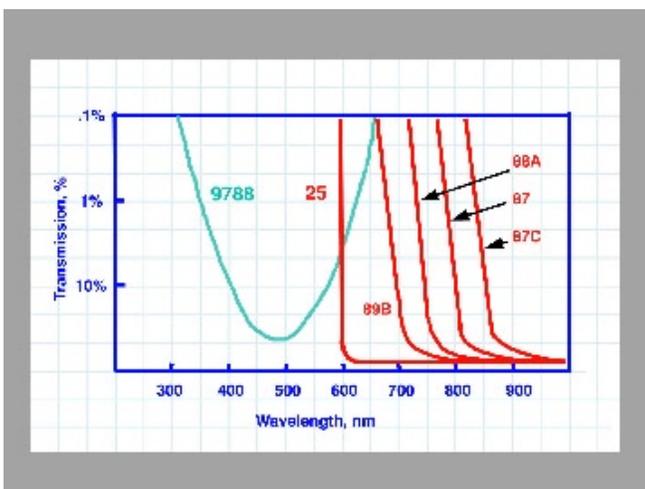


Now we will take a look in greater detail at the spectral transmission characteristics of the filters presented earlier. These are the transmission curves for the filters commonly used for ultraviolet photography.

The 18A as you can see transmits a fairly narrow range of wavelengths just beyond the visible range. From about 320 to about 400 nanometers with a peak transmission around 360 nm. Note that this filter also has a “notch” or window in the infrared region. For some applications this needs to be considered and accounted for. The Wratten 18A designation is sort of a “generic” name based on the designation given to it by the Wratten division of Eastman Kodak many years ago. There are several filters with similar transmission characteristics available from various manufacturers. The 18A is a glass filter unlike the yellowish filters described below that can be made from cast gelatin or glass.

The “companion” or complementary filters to the 18A are a set of filters that start to transmit at around 400 nm and allow anything longer than that to pass freely but which effectively block ultraviolet. These are the 2A, 2B, 2E series. Each of these cuts more and more into the blue region and appears a deeper yellow in the process.

NOTE that both of these filters are called ULTRAVIOLET filters. One must be careful in technical applications to discriminate between ultraviolet transmitting (18A) and ultraviolet _blocking_ filters such as the 2E. The latter are used to eliminate UV from reaching the film in film cameras loaded with color film and prevent an unwanted blue cast to the images when photographing in situations where there is an abundance of UV present such as snowscapes, beach scenes, etc. UV blocking filters may not be as needed with digital cameras as the sensors are inherently low in sensitivity to UV rays.

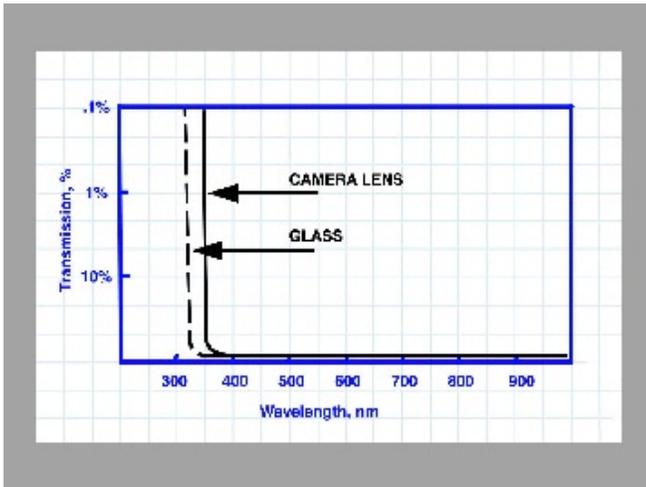


On the infrared side of the spectrum there is a similar “complementary” set of filters that are in common use for applications related to photography of infrared radiation.

Common filters used by photographers are the Wratten 25 or 29 filters. These are deep red filters which transmit red and infrared freely. Photographers use this filter over their SLR camera lenses because at least they can see something through them even if it is only a reddish image. In the strictest sense of the word one then records red and infrared simultaneously when using a 25 or 29 filter.

For solely infrared recording the filters generally used are the Wratten 89B, 88A, 87 and 87C (and others of similar characteristics) which vary in their infrared cutoff wavelengths with the 89B allowing the most infrared wavelengths to pass while the 87C is close to the least. All of these filters are visually opaque with the 87B allowing a very small amount of red to pass and some people are able to detect this especially if the subject is a very bright one.

To go along with the infrared filters mentioned above, the complementary filter is the Corning 9788 (or others with similar transmission characteristics). This filter only allows visible wavelengths to pass. Visually it has a cyanish/greenish hue. The important thing to remember about this filter is that it does not pass infrared rays in particular. It is a rigid, glass, filter.



Before going further it is appropriate to mention that when one engages in photography by invisible radiation (in fact, any photography for that matter but in UV and IR imaging it is probably more apropos to think about this) one needs to be aware of the spectral characteristics of every item included in the imaging “chain”. From the spectral emittance of the source of illumination, to the spectral transmission of the medium through which the reflected or transmitted rays travel, the spectral transmission of lenses and any filters used as well as the spectral sensitivity of the photosensitive material or capture device.

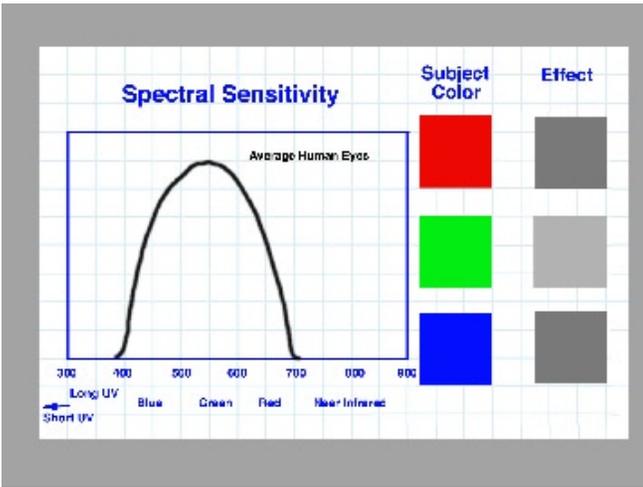
In this context then note that lenses, which are made of a variety of glasses, don’t transmit all wavelengths of the spectrum even though they generally transmit all visible wavelengths quite well. As shown in this illustration camera lenses tend to stop all wavelengths below something like 350 nm and plain float or window glass stops anything below 300 nm or so. This simply means that simply because one can see through something is no assurance that one can effectively make photographs with other than visible wavelengths. When in doubt get a spectral transmission curve for the refractive (lens) elements!

BETTER WAVELENGTH TRANSMISSION

QUARTZ LENSES
PINHOLES

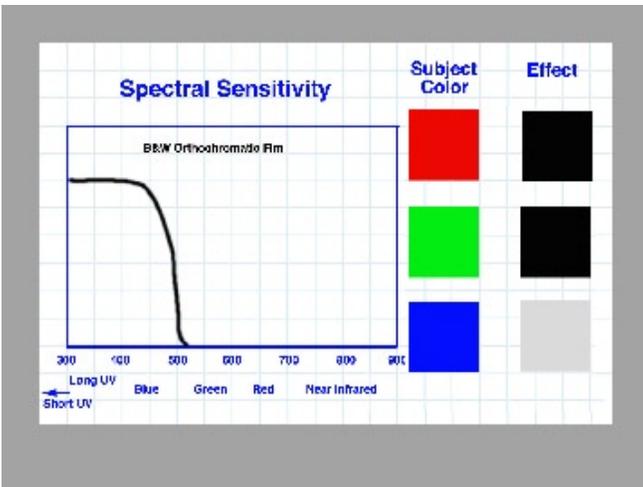
If one desires better or broader wavelengths transmission than that afforded by conventional camera lenses one might consider lenses made with quartz elements. This is the expensive, high-tech, solution. There are not many such lenses made but Nikon and Pentax and a few other german and japanese companies have manufactured the. They are typically destined to the law enforcement, forensic or document examination markets.

At the inexpensive side of things one might consider pinholes as image forming devices that transmit a very broad range of wavelengths. In fact, as broad the the transmission medium (eg. air or water) allows. It is worth noting that some cameras used in the nuclear and explosives research industry are simple pinhole cameras. Capture a broad range of wavelengths and they are inexpensive and “disposable” while still providing useful data.

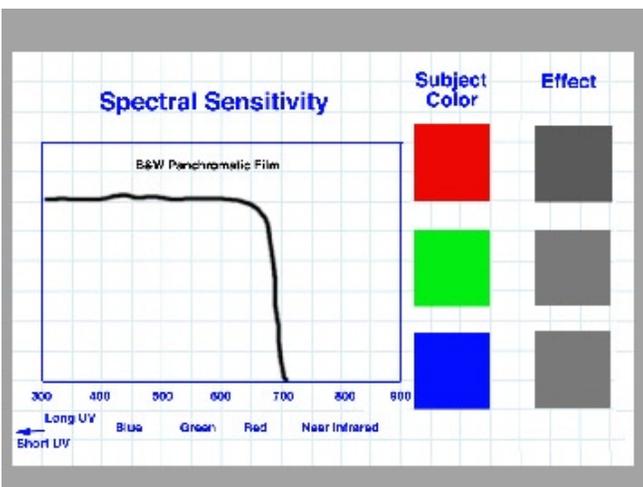


Now we will progress onto a discussion of the spectral sensitivity of the photosensitive materials used for image capture. To start with let's take a look at the spectral response of the human eye. This generalized curve simply states that human eyes can detect and respond to wavelengths from about 400 nm to about 700 nm. Eyes are most sensitive in the green region and specifically at about 550 nm where sensitivity peaks. This falls off on either side until we reach the deep blue at the shorter end of the wavelengths and to the deep reds at the longer wavelength end.

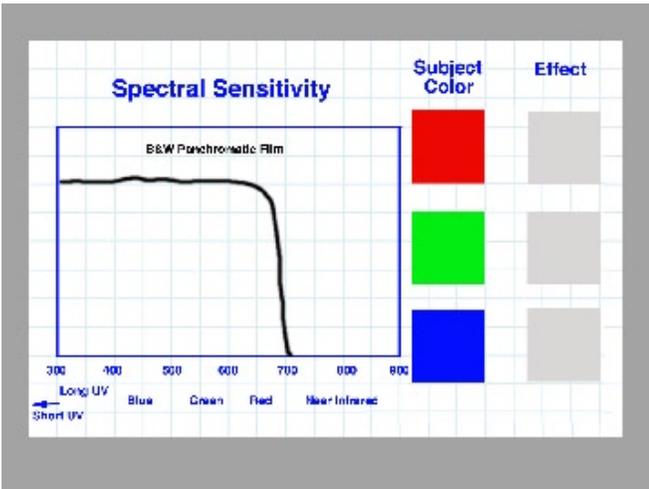
If we were to visually describe the grey level sensation that would result in our eyes when looking at three patches of different colors, Red, Green and Blue in this case, with each reflecting equal energy to our eyes we would tend to perceive the green patch as being slightly lighter in tone than the blue and red one simply because our eyes respond, are more sensitive to, green than to the other colors.



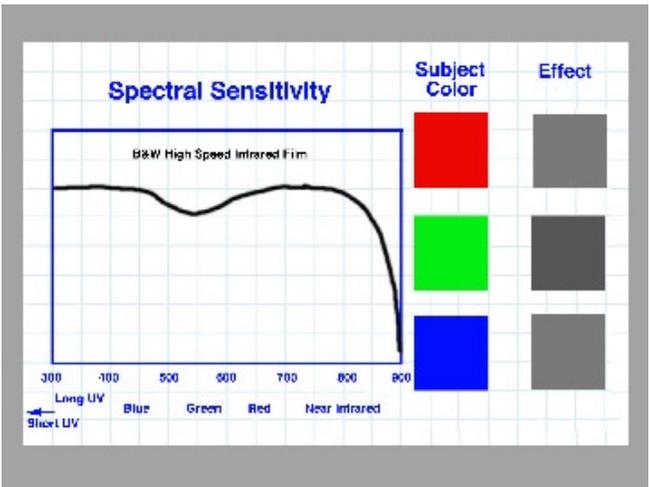
Now when a B&W photographic emulsion that has only blue sensitivity is used to photograph the same three patches the tonal reproduction will be different than that perceived by our eyes. Since this film (generally described as orthochromatic although some orthochromatic emulsions also respond to green to some extent) is not sensitive to green or red those patches appear clear on the negative and black when printed as positive prints. The film's spectral sensitivity curve shows that it has blue sensitivity however. Therefore the blue patch will produce density on the film and when printed that results in a light toned or white patch on the print.



If we increase the spectral sensitivity of the emulsion so that it extends into the red area of the spectrum we have what is called a panchromatic (all colors) emulsion. These are sensitized so that they essentially have a flat response across all wavelengths. Therefore the red, green and blue patches are reproduced as grey tones of pretty much equal value.

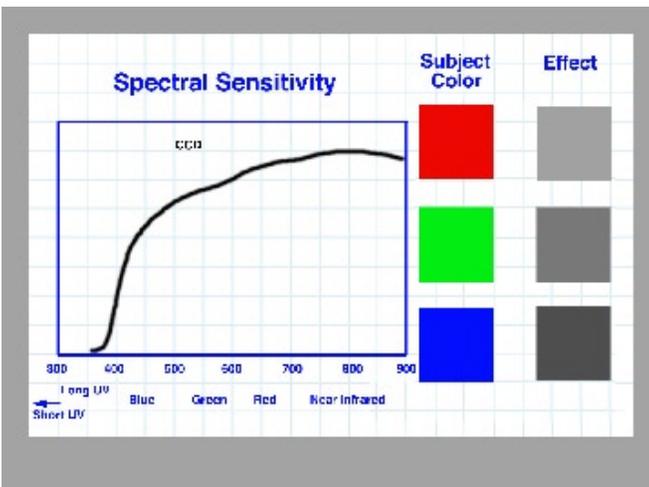


Changing the exposure received by the film as might be expected changes the tonal value for all colors at the same time. Greater exposure causes all patches on the negative to achieve greater density and when printed the tones appear lighter than when the exposure given was less.



The spectral sensitivity of Kodak High Speed infrared film extends across the visible spectrum and into the infrared up to about 900 nm. To accomplish this film designers had to compromise a bit and they gained the reach into the infrared by a giving up some sensitivity in the green area and that is shown by a slight dip in the curve in the green region.

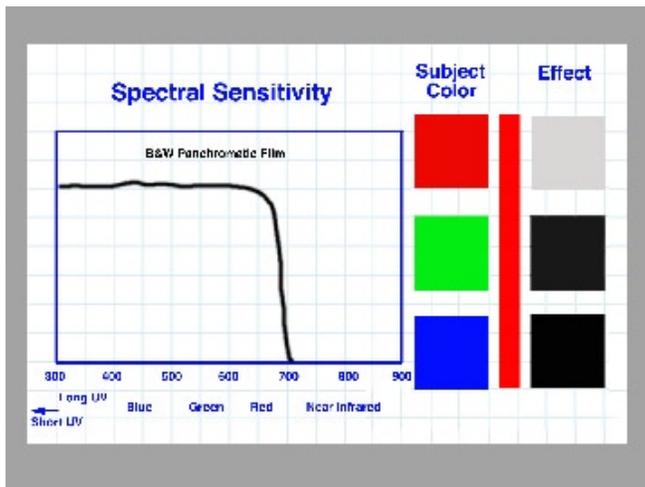
When analyzing the tonal reproduction of this film when reproducing the three colored patches this reflects a slight increase in density for the green patch and equal densities for the blue and red patch. Since we don't know about the characteristics of these patches in reference to infrared (or ultraviolet for that matter) we must assume that they are essentially monochromatic and thus the grey level reproductions are not influenced by the additional infrared sensitivity of the emulsion. We will explore this further later on.



When a digital camera equipped with a CCD sensor we might consider its typical spectral sensitivity. It is shown in this illustration and it indicates that the sensitivity increases across the visible spectrum and, indeed, into the infrared. The sensor has low blue sensitivity and high red sensitivity. When this sensor (uncorrected by the manufacturer to give a more "flat" response") is used to capture the same three R,G,B patches the grey level tonal reproduction shows that the blue patch is reproduced as the darkest and the red on e as the lightest.

Manufacturers might flatten out the response by installing a cyanish filter above the sensor. This would drop the amount of red reaching the sensor and even out the tonal reproduction but this is at the expense of overall light sensitivity so this is a matter of compromise at the design and manufacturing stage of a camera.

Other types of solid state sensors have similar or different response and it is not the point of this presentation to go into each one in detail but to point out that differences in tonal reproduction can be due by spectral sensitivity characteristics of the sensors used.



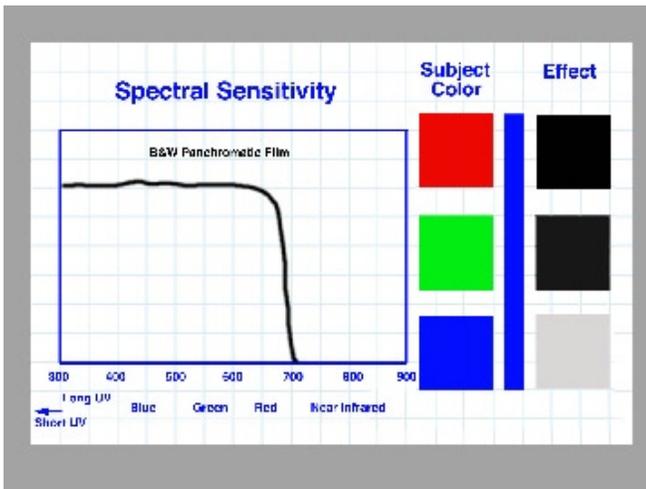
Now we take a further step in the process and we will install a filter between the subject (the three colored patches) and the photosensitive material. In this case a red filter is interposed between the subjects and the film or solid state sensor. Typically by installing a filter in front of the camera lens. In this case a red filter.

Now we will analyze the situation.

Any filter, by convention, (just be careful with the common ultraviolet filter - it "breaks the convention rule") is called by the color that it transmits. Therefore a red filter is known as such by the fact it allows red wavelengths to pass freely and it absorbs all other wavelengths (if it is a good, sharp "cutting" filter).

Since we are photographing with an emulsion that is sensitive to all wavelengths and the ones that the red filter allows to pass are the red ones this area on the film darkens on exposure and when a positive print is made the area achieves a light tone. Since green and blue are blocked from passing through the filter those patches do not record at all on the film and reproduce as clear areas. When these are printed they reproduce as black patches.

Now let us continue ...



This time we interpose a blue filter between the subject patches and the panchromatic film. The blue filter allows blue to pass and this reproduces as a dark patch on the film and eventually a white patch on the print. The blue filter blocks green and red and so those areas reproduce as dark patches on the final print.

So far we really have covered the basics of tone control when using black and white photographic materials (or solid state sensors used in B&W mode) much as if one were to try to emphasize white clouds against a blue (cyan) sky. Both the sky and white clouds have very similar exposure effects on the film and the contrast between them is low. By using a yellow (or red) filter to block the blue (cyan) in the sky the sky can be reproduced as being very dark and by contrast the white clouds will stand out clearly.

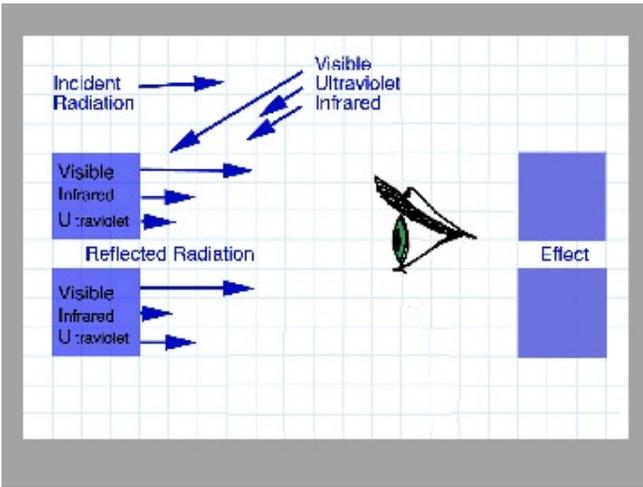
RESOLUTION
VS
WAVELENGTH

Before going further we might ask ourselves why would we want to photograph by anything than visible wavelengths?

One reason is that one can obtain sharper, more detailed, reproductions of subjects by using shorter wavelengths than longer ones. For many practical applications this is no great consequence but there are applications in microscopy, for instance, when one desires to capture the finest detail possible. This can be done more effectively with ultraviolet wavelengths than with visible ones. So, there are specialized ultraviolet microscopes available. Some of these use quartz optics and others use reflective (mirror) optics.

GAMMA
VS
WAVELENGTH

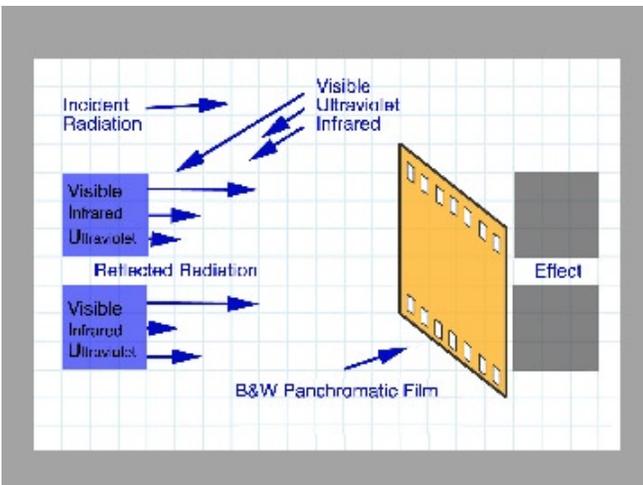
Although higher resolution is possible at shorter wavelengths this does not come without a price. The price is that the contrast of the images is less than if longer wavelengths were used. Further, photographic emulsions also produce images that have a lower contrast or gamma when exposed to short wavelengths rather than longer ones. This can be corrected by using a more vigorous development regimen or procedure when processing films exposed to short wavelengths. The amount of compensation necessary varies from emulsion to emulsion.



Now we will examine another reason for imaging with other than light wavelengths. This is to detect differences between subjects that appear identical to the human eye but which are, in fact, different.

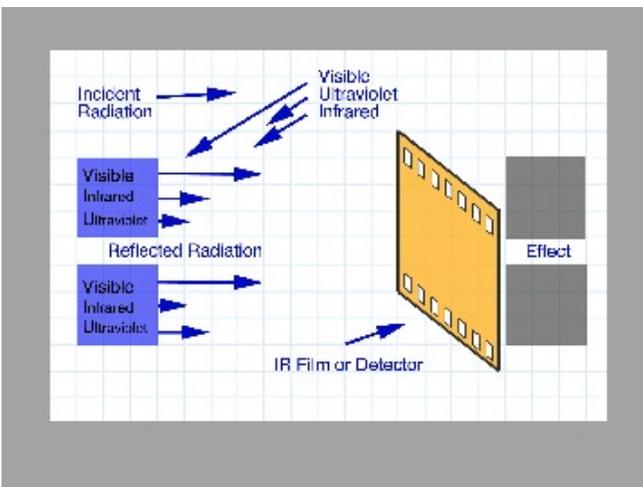
The “set-up” is as follows. Two visually identical patches are presented to human eyes and they are illuminated by a “broad band” source. This means the source emits visible wavelengths as well as ultraviolet and also infrared. The subjects reflect visible, infrared and ultraviolet energy to different degrees.

The impression in the eyes is made only by the visible wavelengths and since these are equal for the two patches this is interpreted by our brains as the fact that we are looking at, and perceiving, these two patches as being identical.



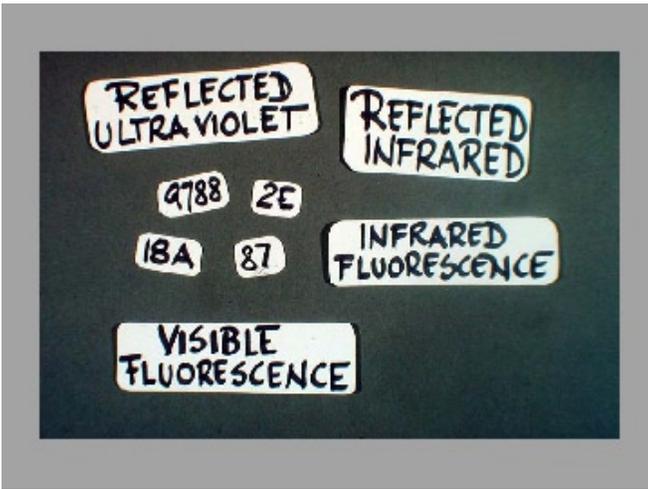
Now we will change things just a bit...

Instead of trying to use our eyes as detectors we will record the two patches with a camera loaded with B&W panchromatic film. It turns out that the two patches will still appear to be very similar because even though one sample may be reflecting a bit more UV than the other the effect of exposure to visible light is generally many orders of magnitude greater than the small amount of UV that is reflected.



Now we will record the two patches with infrared sensitive film. The situation is often pretty much the same as in the ultraviolet region of the spectrum. The detector (film or electronic) is swamped by the amount of light present and this will determine primarily what the two subjects will look like. So the two patches for all practical purposes will look alike.

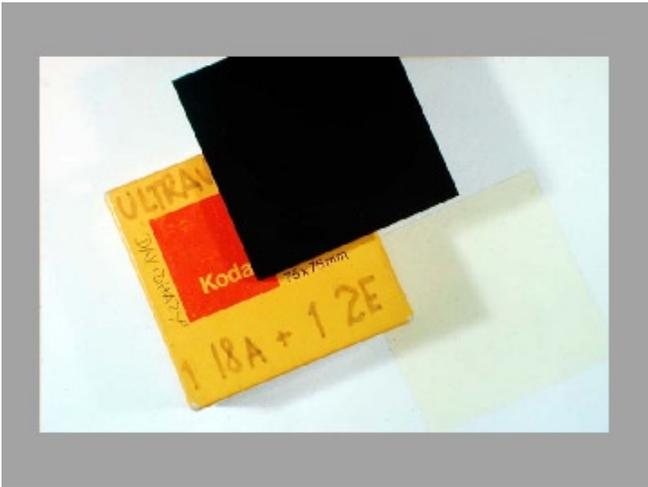
Somehow we have to emphasize the differences. These differences are in the UV and IR reflectance so we need to discriminate somehow between the light wavelengths and the other ones.



To do this we now are going to embark on describing and characterizing the methods and techniques associated with reflected UV, reflected IR, infrared fluorescence (sometimes called luminescence) and visible fluorescence. Note that three of these techniques are somewhat grouped together at the top of the illustration. The reason for this is that all of those techniques result in making records of invisible radiation. On the other hand, visible fluorescence or fluorescence in the visible, is an effect that can be perceived by our eyes.

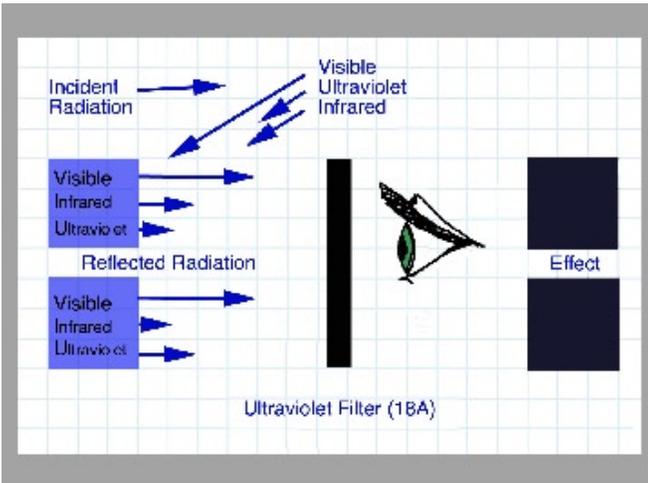
By extension it can also be stated that for the top three techniques one would appropriately use monochromatic film or make monochromatic digital records. This is appropriate because ultraviolet and infrared are not “colors” but simply energy. They can be assigned a color arbitrarily, as in false color infrared applications, but inherently infrared and ultraviolet are merely “energy” beyond the visible, or “light” wavelengths within the spectrum.

For recording visible fluorescence it would be quite appropriate to use color film as conventional fluorescence manifests itself as visible wavelengths and thus colors.



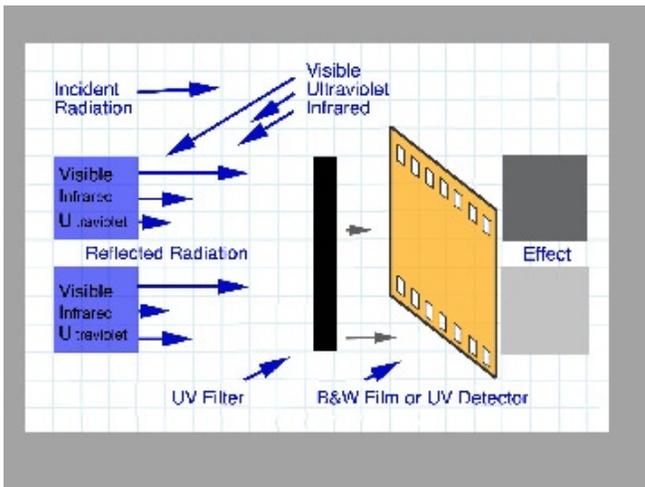
Now let us proceed to actual set-ups.

First we will treat ultraviolet techniques. To engage with these we will need filters to control light emitted by a source or reflected from the subject. The filters we are concerned with are the Wratten 18A (glass) filter shown at the top of this illustration as a black, opaque, object. It is indeed opaque to the eye and to conventional detectors because it essentially only allows UV to pass. Below the #18A is a very pale yellowish filter made of gelatin. It is the Wratten 2A. In spite of the fact it looks almost clear it very effectively blocks those wavelengths in the UV that the 18A filter passes.



Now we will take another look at the set-up described earlier. That of the two patches of blue presented to the eye. But this time we place the Wratten 18A filter between the eye and the subject. What is the effect produced in our eyes?

Well, since the 18A only passes ultraviolet to which our eyes are not sensitive we will perceive the scene as totally black. Including the two patches. In fact, everything in front of us will appear dark and black if we try to look through the 18A filter held close to our eye.



Now we change the recording medium from being human eyes to being a B&W film or a solid state sensor with ultraviolet sensitivity. In this case the Wratten 18A does not pass any visible but it does pass the small amounts of ultraviolet reflected from each patch to different degrees. The patch (bottom one) that reflects more ultraviolet than the other therefore will look somewhat lighter in tone in the record than the one that reflects less.

Thus we surmise that the two patches are not exactly the same kind of material even though they look identical to our eyes.



What we just covered is the manner in which reflected ultraviolet photography is accomplished. As you can see it consists of nothing more than placing an ultraviolet transmitting filter over the camera lens and having an emulsion or detector that is sensitive to ultraviolet.

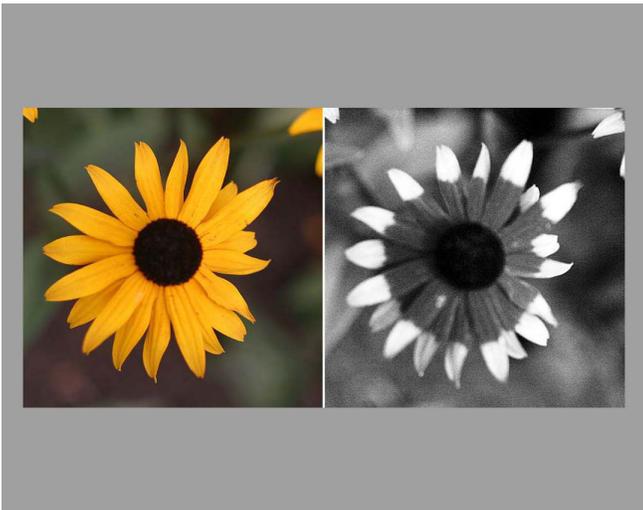
We need to have a source that emits a certain amount of ultraviolet. If it emits other wavelengths as well that is not a problem. Now we need a subject that reflects ultraviolet (otherwise we end up with no record at all) and then the camera is fitted with an ultraviolet transmitting filter which only lets the ultraviolet rays reflected from the subject through and onto the photosensitive detector (film or electronic).

Again, since we will be making a record of ultraviolet energy we should appropriately use a black and white photographic emulsion or if using an electronic sensor this should also be a monochromatic one if possible and if not then the digital data should be reduced to a monochromatic reproduction. Remember, ultraviolet has no color!



These are two photographs made of the same subject, from the same location and with the same lighting (a "fair" comparison) of some stamps. It can be seen that when a particular subject or location within a subject matches in tone in the two photographs the tones of other subject may not match exactly. This is due to differential ultraviolet reflectance of the subjects.

The rocks at the top indicated by the arrows are obviously different in terms of tone than the same rocks in the photograph made by visible energy. The tonal relationships within the stamps also are not identical in the two photographs.



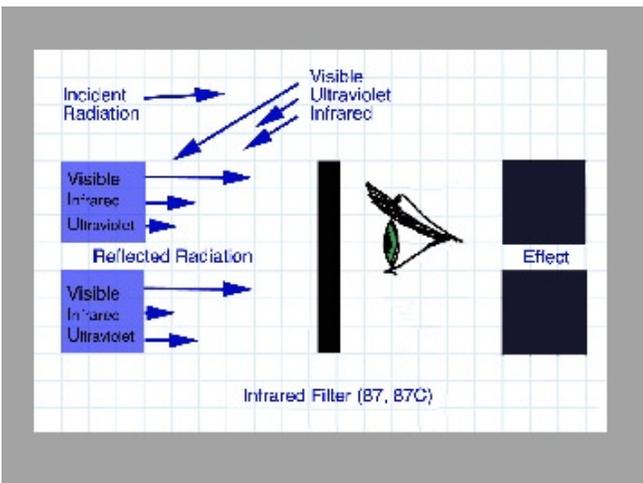
The situation or effect here is dramatically different. This is the same flower as seen on the left by visible energy and photographed on color film and on the right is the same flower photographed on B&W film but recorded through a Wratten 18A filter. The flower obviously appears different in the ultraviolet than the visible (besides the lack of color in the UV record). This may have something to do with the fact that some insects apparently are able to perceive ultraviolet and the plant may be using this “signal” to the insects as to where they should be going in order to pollinate the flowers.

This is merely a theory as nobody yet has been able to communicate with insects.



Now we will set-up for reflected infrared photography. The set-up is the same as for reflected ultraviolet photography except that an infrared transmitting (and visible energy blocking) filter is used. Such as a Wratten 87 filter.

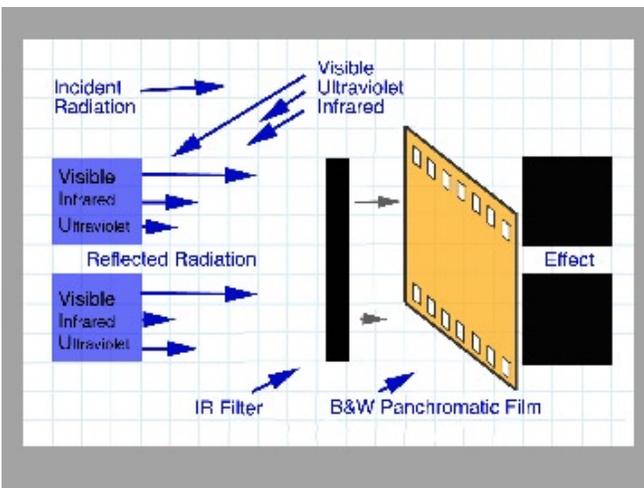
Again, the source of illumination must contain infrared. The subject must reflect some of this and then the infrared transmitting filter passes the infrared wavelengths reflected from the subject on to the film or solid state detector in the camera. Since infrared is not a color, again, a B&W record is what is most appropriate.



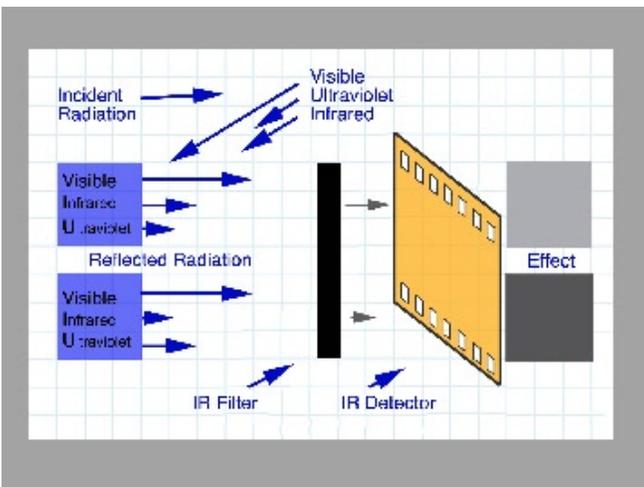
So now what about infrared reproduction or capture. For this let's start with placing an infrared transmitting filter in front of our eyes. Since we are not sensitive to infrared the visual effect is that the two patches, again, look totally black.



For infrared recording the filters look as in this illustration. The Wratten 87 series of filters appear to be totally black and opaque. They can be obtained in gelatin form or as glass filters. The infrared blocking, light passing filter can be something like the Corning 9788 and it is also a glass filter. There are other filters that perform the same function as the 9788 and some of them are known as “hot Mirrors” by the way in which they block the passage of infrared rays through them. Under certain conditions heat absorbing filters used in projectors can also be used but they tend to pass some infrared as well as all visible energy.



When our eyes are replaced by B&W panchromatic film the effect is still pretty much the same as if human eyes were recording the patches. This is so because the film has no IR sensitivity so the infrared reflected by the patches does not cause any photographic effect and the film remains unexposed. When printed the print therefore is dark or black because the negative was clear due to non-exposure.



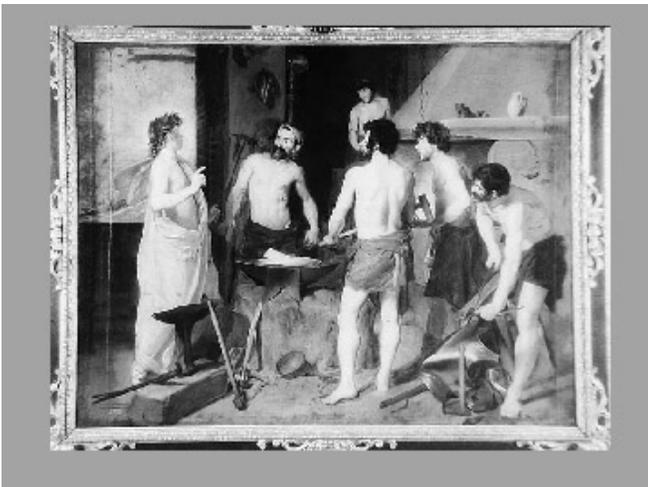
On the other hand, when infrared sensitive film or an infrared solid state detector is used in a camera whose lens is covered by an infrared transmitting filter then slight differences in infrared reflectance of the subject can be detected. In this case the top patch reflect more infrared than the bottom one and thus appears to be of a lighter tone than the bottom one.

In an investigation this would lead the investigator to conclude that the two patches, although visually identical, are probably made of different materials. This may or may not be important to an investigation.

Both the reflected ultraviolet technique and the reflected infrared technique are particularly applicable for document analyses where there might be alterations to the text by careless (from a forger's perspective) use of inks that do not match in their ultraviolet or infrared reflectance.



In this example an important painting by Velázquez called *The Forge of Vulcan* was examined by the reflected infrared technique to look for possible alterations to the original. This is the visual appearance of the painting hanging in the Prado Museum in Madrid.



This is the reflected infrared record of the same painting. Careful analysis reveals several sections where there are major discrepancies between the two versions of the painting. Very obvious are the dark bands towards the left side of the painting. One is a visual evidence of the fact (known) that Velázquez added some canvas to the original on the left side ostensibly to give the subject a bit more space on that side. At the top left there is a horizontal line as well as several small spots. These are associated with repair work done after the painting was damaged sometime in the past.

Most interesting, however, are the corrections, or “pentimenti”, that Velázquez made to the painting over time. He was known for repainting works that he felt could use fixing as he became more sophisticated or when he wanted to improve on a painting that he might have painted at some earlier time or one that was possibly started by an apprentice.

Vulcan’s head and right arm in particular are of great interest.



As seen here the whole torso and arms of Vulcan probably were repositioned and repainted. The final position of the head and body are much different than what the original stance depicted. Also the arm, which once held the hammer resting on the anvil has been raised and the hammer is off the anvil in a much more dynamic pose than the earlier, static, one. But these are topics that art historians dwell upon. As a photographer generally one is simply asked to provide the clients with the evidence and leave the interpretation to them!



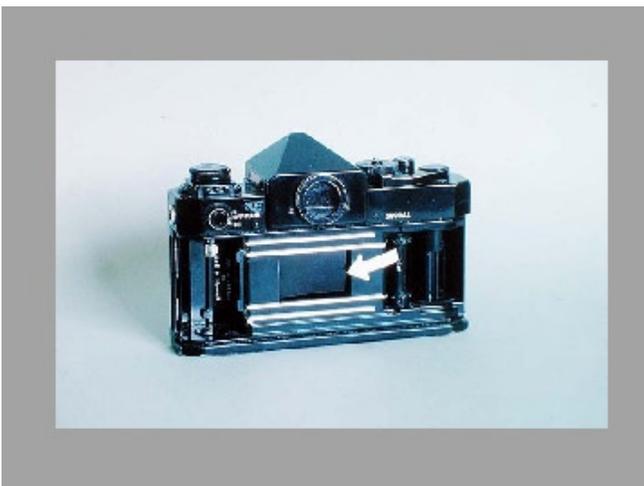
As mentioned above, to set up for reflected infrared photography all one really needs to do is to place an infrared filter over a camera's lens as shown in this illustration. But doing this with a single lens reflex camera essentially "blinds" the photographer as the viewfinder becomes obscured when this is done.

The filter can be successfully used to cover the lens of a camera equipped with a separate optical viewfinder such as installed in many point-and-shoot cameras or even sophisticated rangefinder equipped cameras. Also, twin lens reflex cameras can accommodate a visually opaque infrared filter over taking lens below without obstructing the viewing lens on top. Some SLR cameras have the capability of accepting a separate optical finder on a shoe mount located on the pentaprism or elsewhere.

But if one desires to cover the lens of an SLR with an infrared filter then viewfinding and composing on the groundglass screen is no longer possible. Since SLR cameras are so popular this may be a reason that real "action infrared photographs" are not seen often. But there is a solution to this problem.



This is to locate the infrared filter behind the moving mirror and either just in front of the shutter curtains by making the filter slightly larger than the shutter frame opening in the camera and installing it there holding it in place with small pieces of adhesive tape. Turning the camera around you can see the filter installed in front of the image aperture gate in the shutter assembly.



This is shown here while the shutter curtains have been locked in the open position. Placement of the infrared filter in this location does call for some precaution since it is easy to forget that the infrared filter has been installed in the camera and if by chance one happens to load the camera with regular B&W or color film no exposure of the film will result as a consequence of making photographs.



An alternative location for the filter is to install it almost at the focal plane. It should be fitted so it spans the width of the image gate (about 24mm) and is a bit longer than the gate. This allows the thin piece of gelatin filter material to be held in place with thin adhesive tape on each side. Since the filter is so light very small pieces of tape can be used and since it is so thin it fits in this location without causing any scratches or damage to the passing film. This is called installation of the filter BTFFPR or "between the focal plane rails". The filter should not extend over the film plane rails as that will prevent the film from moving through the camera due to high levels of friction. If you attempt this improvisation make sure not to force the film to pass through the camera. If it resists advancing the filter has been installed incorrectly.



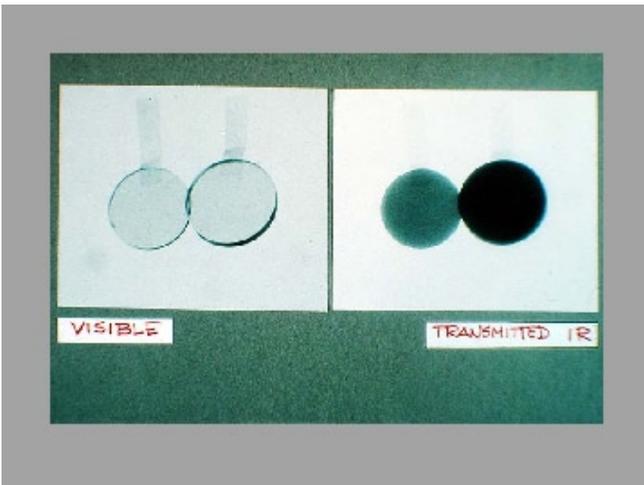
These are "fair" comparison photographs of a scene including some distant buildings. They demonstrate that infrared rays have greater haze penetration capability than visible wavelengths and for this reason infrared is sometimes used for aerial photography and long distance surveillance and other military applications.

In addition the photographs illustrate the tonal rendition of living plants. Dark foliage reproduces as light toned due to reflectance of infrared by subsurface layers of living vegetation. Sometimes diseased vegetation can be identified from healthy plants by the difference in infrared reflectance of the plants. If a field of identical vegetation is photographed by infrared the presence of pockets of dark areas may be an indication that the plants in those areas are starting to exhibit signs of disease even before any signs become visible to human observation.

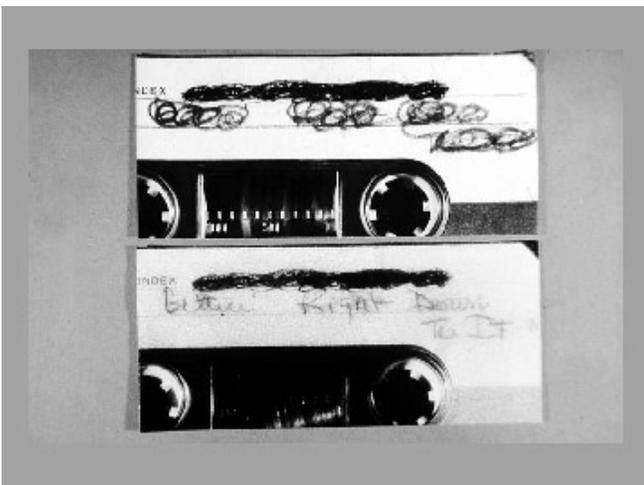
Finally these photographs also demonstrate that the sky appears dark in infrared photographs. The reason is that since red and infrared are not scattered by air and we see the sky by the light reflected or scattered by it we perceive it as blue or cyan. Therefore, since infrared is absent in the sky it leads to underexposure of the sky and a high density in a print made from it. Therefore to reproduce the sky in as dramatic a fashion as possible the use of infrared sensitive film with an infrared filter covering the camera lens will certainly achieve this effect.



photograph demonstrates that two pieces of glass that look visually quite similar ...



Are actually quite different in terms of infrared transmission. One of these pieces is a very effective blocker of infrared radiation while the other one is not quite as efficient. These are heat absorbing filters removed from slide projectors. Obviously the darker one would do a much better job of removing infrared (and heat) from the projection beam than the lighter one.



This is a forensic application of reflected infrared photography. In this case the “penetrating” power of infrared is exploited. Infrared rays sometimes are able to penetrate thin layers of material covering subsurface details. In this case a felt tip pen or marker was used to attempt to obliterate or cover up the writing on one part of this cassette tape. Infrared was able to penetrate the ink that the pen put down and the writing below became easily visible.

One needs to realize that this result would not have been obtained if the ink below the top layer also was infrared transparent like the top layer was. Further, it is obvious that infrared was not able to penetrate the material that was used to cover up the writing on the top line. That material was a black, waxy, substance instead of a black dye delivered from the felt tip marker.

Sometimes investigators simply get lucky!



This photograph is included here to remind me to mention that although infrared can be used for surveillance applications in dark environments by the mere expedient of covering an electronic flash with the infrared filter. Typically one would not use a filter over the lens as the idea is that one would photograph suspicious activity in near total darkness. While the infrared filter will make the flash quite unobtrusive unless one is looking directly at the flash when it fires, if the camera does not have a silent shutter the operator will give their position away by the loud sound of a shutter going off and that could endanger the operator or the mission.

The reason not to put a filter over the lens is that one wants to capture as much infrared energy as possible and even a filter that transmits infrared freely is not perfectly transmissive and a small amount of infrared is absorbed by the filter. This results in a slight loss in effective “speed” of the film.

It should also be remembered that when a flash is covered up in this fashion the heat generated by the flash firing does need to get dissipated somehow. This results in the filter eventually warping or if the flash is operated several times in quick succession it could even endanger the flash unit itself due to heat build-up in the flash head.



Here we again have a “fair” comparison of the reproduction of a scene illuminated by the energy released from an electronic flash as seen in the previous slide. The flash is covered with the 87 visually opaque infrared filter. The camera was loaded with black and white Tri-X film for the photograph on the left and with High Speed Infrared film on the right.

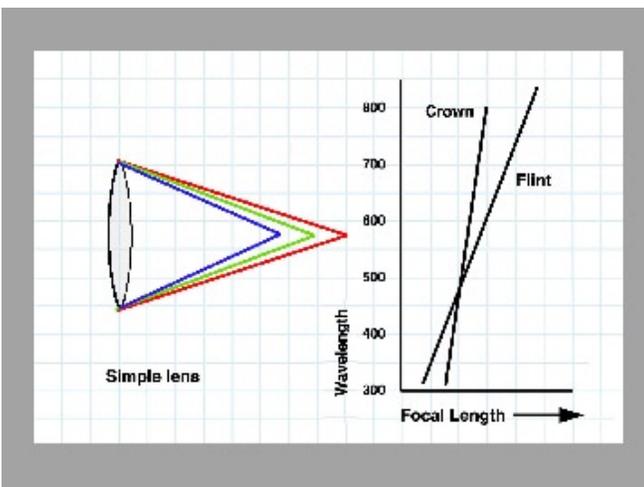
The scene is that of several students watching a projection in a darkened room. Obviously the flash of infrared failed to make any record on the Tri-X film since it has no infrared sensitivity. On the other hand, the infrared film captured the reflected infrared from the subjects and a perfectly acceptable record of their appearance was secured. Although not possible to infer from simply looking at this record the color of the jacket the student on the left was wearing was black. The black dye of his jacket, however, was a good reflector of infrared and so it ends up as a light tone on this reproduction.



This leads us to consider the adjustment that is needed to compensate for the fact that most lenses do not bring all wavelengths to a common focus. Often camera manufacturers will provide a “focus compensation” guide of some sort. In this case it is the red dot seen on the lens barrel. The function of that dot is to suggest to the photographer that when photographing by infrared the lens be first focused visually on the groundglass and then that distance be moved over to the red dot for infrared photography.

When photographing by infrared invariably the lens needs to be “racked out” or moved further away from the film or sensor plane to achieve sharp reproductions. The extension varies from lens to lens but it may be somewhere in the range of 1/200 of the lens focal length but an exact figure can’t be given as it depends on the chromatic correction of the lens and the actual infrared wavelengths by which photography will take place. This can be determined from chromatic correction charts produced by the lens manufacturer but the fact is these are often very difficult to obtain.

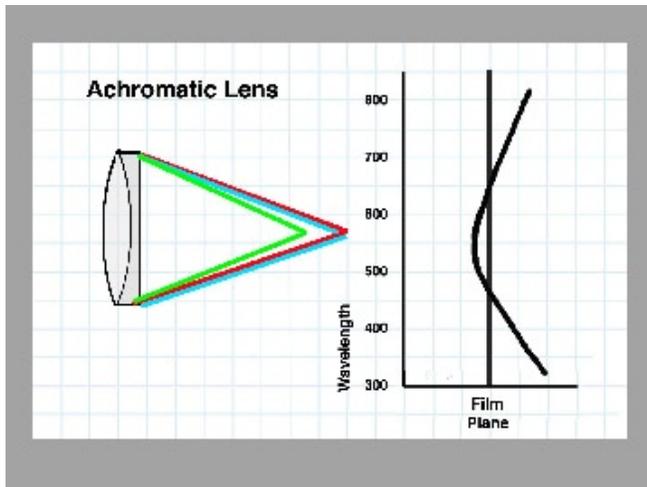
We will look at “idealized” chromatic correction charts in the next few illustrations.



First we will take a look at a simple lens. The refractive power of any material, like glass, is greater for shorter wavelengths than longer ones. Given a particular subject distance with lenses this manifests itself by the lens bringing to a focus blue rays or wavelengths emanating from the subject to a distance from the lens that is less than that to which the red wavelengths are brought to a focus. Some glass materials have a narrower range of distance over which the color are brought to a focus.

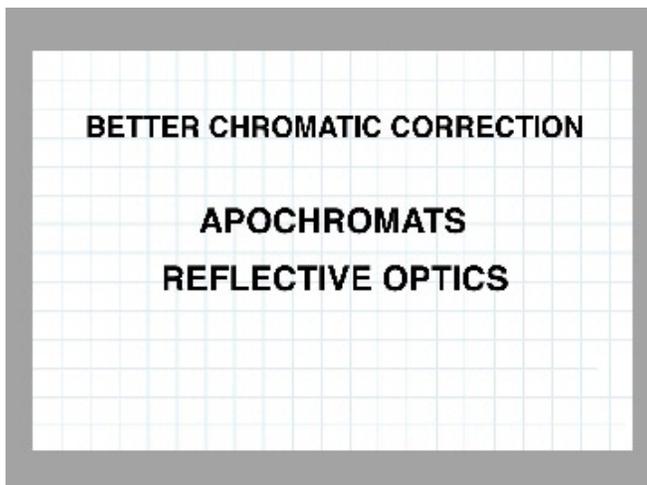
While visually on the left we can see that different colors are brought to a focus at different distances, the chart on the right tells us the same thing but easily provides quantitative information about the actual spread from 300 to 800 nm for both crown and flint glass. You will not that when photographing greenish wavelengths in the 475 - 500 nm area both glasses bring those wavelengths to a focus at the same distance behind the lens. Crown glass brings red and infrared wavelengths to a closer focus than the flint glass and the opposite is true at the blue and ultraviolet range of wavelengths.

This difference in refractive power of these two types of glass makes it possible to somewhat correct for chromatic aberration by combining a positive and a negative lens each made of a different material. Essentially the error introduced by one is offset by an opposite error introduced by the other one. This is known as an achromatic lens.



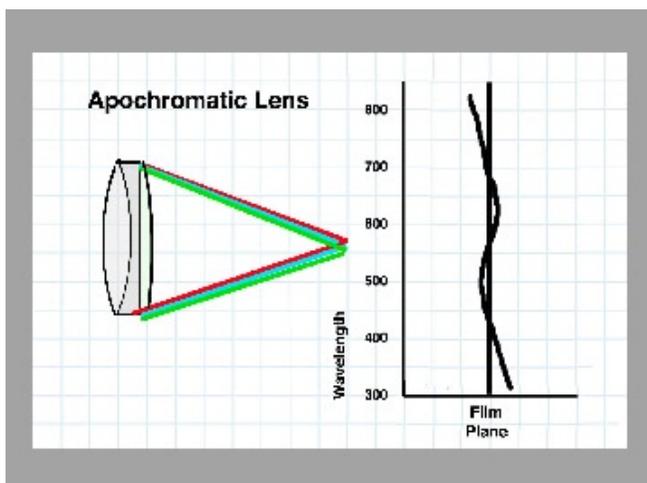
Here you can see the basic layout for an achromat. In such a lens the field of sharp focus ends up bent as shown in this illustration since it is very hard to compensate exactly at each wavelength. This shows that wavelengths of 450 nm and 650 nm are brought to a focus at the same distance behind the lens. However, green light in the 550 nm range is brought to a focus closer to the lens than the 450 and 550 wavelengths. Further the infrared ... and the ultraviolet! ... are brought to a focus farther from the lens.

Since most camera lenses are high quality achromats (they are obviously not simple lenses and probably of not higher order of correction because that is hard to do and manufacturers would state so and charge accordingly) they are generally bound by the simplified chart shown here.

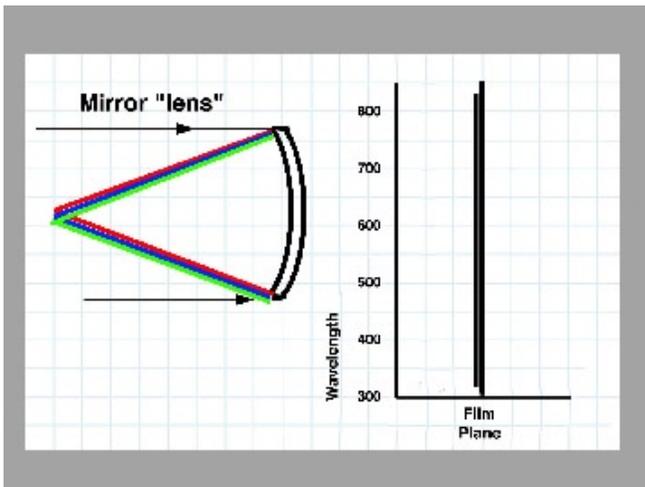


It is possible to increase the correction level by using more than two glass types.

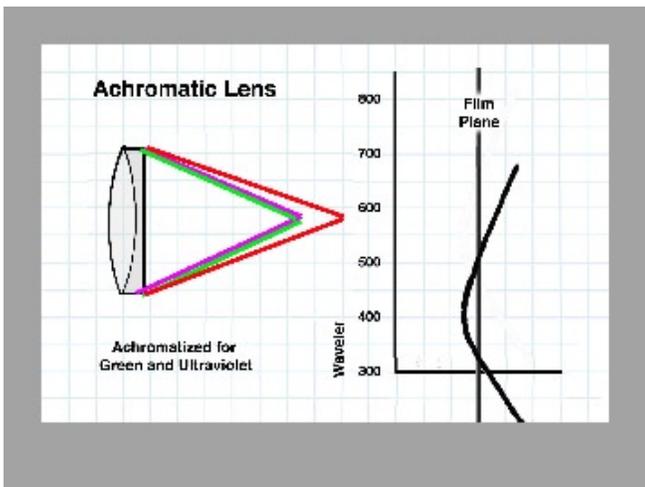
Apochromatic lenses achieve higher orders of correction by incorporating several type of glass and reflective optics exhibit no chromatic aberration at all.



In the case of an apochromat three types of glasses are used in the lens and the ultimate effect is that the focal plane is bent twice and achieves a shape as shown above in simplified fashion. Note that unlike a simple lens, in this case the lens brings infrared rays to a focus closer to the lens and ultraviolet farther from the lens while bringing red, green and blue wavelengths to a common focus. The plane of chromatic sharp focus could have been reversed from that shown here. This depends on the lens design. These lenses typically offer the highest degree of chromatic correction of any common refractive lens types.



When a mirror lens (as in many imaging devices used in astronomy, eg: reflective telescopes) is used to form images all wavelengths obey the rule that the angle of incidence is equal to the angle of reflection regardless of wavelength and therefore mirror optics are totally free of (longitudinal) chromatic aberration for both ultraviolet, visible and infrared wavelengths. Mirror optics are also to be recommended when one needs fast and low cost optics. Often reflective optics, however, are simply not possible for certain applications plus they have drawbacks of their own.



The possibility of achieving chromatic focus for two different wavelengths using the principle on which achromatic lenses are based gives the opportunity to design a lens that produces a sharp image in the green region of the spectrum and another sharp image in the ultraviolet. Such a design is sometimes used in microscopes because it allows for visual focusing of the image by illuminating the subject with green light knowing that simultaneously the image formed by ultraviolet is also in focus. Without the green filter in place the visual image will most likely appear blurry or subject edges will show color fringing. By limiting the view to only green a sharp image can be perceived as the microscope is focused. For photography one replaces the green filter in front of the light source with an ultraviolet transmitting one.



One of the major problems that photographers face is determining proper exposure. Light meters are used to provide data to the photographer as to the appropriate combinations of aperture and exposure time that will result in a proper exposure for a given level of illumination, sensor or film speed and subject matter.

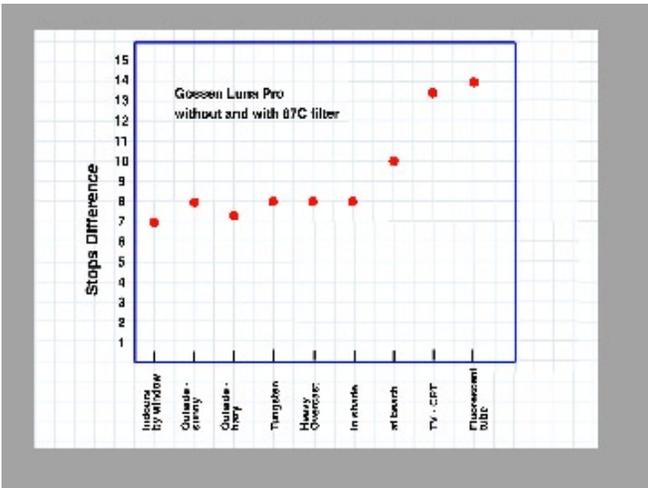
But light meters are designed to measure light which by definition does not include infrared or ultraviolet. The meters, in fact, are filtered so as to almost totally eliminate their response to these wavelengths.

It turns out, however, that meter movements are so sensitive these days that one can make use of their residual sensitivity to infrared and, in fact, make a rudimentary infrared meter.



This can be accomplished by the simple expedient of installing an infrared transmitting, light blocking, filter in front of a meter's sensor. With such a filter in place and no infrared present in a scene the meter would read nothing or zero. However, when a tungsten lamp or other source of infrared is illuminating a scene the meter may detect the presence of infrared with a slight movement of the indicator needle or digital display.

This deflection will be greater the greater the amount of infrared that arrives at the sensor. The deflection, in turn, can be calibrated against aperture/shutter speed combinations that will yield adequately exposed photographic records. For greater sensitivity one can often remove the infrared blocking filter from the meter assembly but this makes the meter very inconvenient to use for measuring light as one would have to consistently reinstall or cover the meter cell with an infrared blocking filter for light measurements.



In order to be able to use the filtered light meter to provide a useful exposure to infrared one needs to find out if there is a correlation between light readings and reading by infrared. If the amount of infrared is always proportional in some manner to the readings taken of scenes lit by visible wavelengths then a simple test can be devised to determine this and apply an exposure "factor" to the reading made by light to achieve correctly exposed images by infrared.

This can be done by first measuring meter response levels with and without the infrared filter in place. This chart of differences in readings shows that for the six situations on the left there was indeed a pretty good correlation between light reading and infrared readings. Meaning that an exposure factor could be applied. The three situations on the right, however, are not "standard" (if the other 6 are considered standard) and the use of an exposure factor would lead to 2 to 6 stops underexposure. This is severe enough to be of concern.

To arrive at the correction factor compared to some standard film that would need to be introduced when one wishes to arrive at the proper setting for infrared film one would first make an exposure reading by light and then compensate several stops to arrive at the suggested readings for infrared.

To get an idea of what the correction factor needs to be one needs to simply generate a good infrared negative and keep track of the aperture/shutter speed combination that delivered this negative. Then one makes a reading of the light illuminating the scene without the infrared filter in place and generates a set of negatives exposed with some standard film and the exposure determined without a filter over the meter cell.

TEST EXPOSURES
ALL AT f/16

	Plus-X				HS Infrared w/87C	
	↓				↓	
1/8	1/4	1/2	1	2	4	8
250	125	64	32	16	4	8
Exposure Index						

When a test was conducted by photographing the same scene at the same aperture with Plus-X and High Speed Infrared the best exposure with Plus-X was 1/4 second and with the HS Infrared it was 4 seconds. This would indicate that one could set the light meter to a speed of 125, then meter light and add 4 stops of exposure OR simply dial in a speed 4 stops slower than the Plus-X and under most conditions (as shown in the previous chart) one could expect proper exposure.

This is the suggestions on which the data sheets included with the film are based. Set a speed index of 4 and meter light OR leave meter set to a speed index of 125 and overexpose 4 stops over that required for a light reading.

However, if one wanted to use this particular meter to meter infrared and meter situations where the spread between a light reading and the IR one were larger or smaller than a constant number of stops (in this case and with this meter 8 stops) then one would need to determine what speed index to dial into the meter so that it will provide accurate exposure settings under these conditions.

WHEN USING HS IR W/87C vs. PLUS-X
WITH TUNGSTEN ILLUMINATION

A GOOD NEGATIVE REQUIRES	+ 4 STOPS
W/87C EXPOSURE METER READS	- 8 STOPS
∴ W/87C RAISE EI OVER PLUS-X BY	+ 4 STOPS
AND SO EI HS IR = 2000	

The “logic” to answer the question is based on the fact that from the test performed earlier the infrared film required 4 stops more exposure than Plus-X. But placing the 87C filter over the meter’s cell drops the reading by 8 stops. Therefore, if one sets the speed dial of the meter to a speed 4 stops higher than Plus-X one could indeed measure through the 87C filter and use those aperture/shutter speed suggestions directly.

In this case one would set the speed to 4 stops faster than Plus-X and this is an exposure index of about 2000.

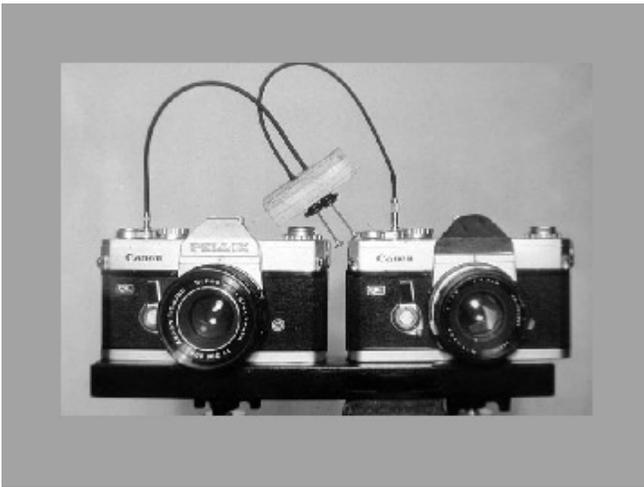
The reason someone would need to set the exposure index scale of the light meter to such a high value is that the meter cell is quite insensitive to infrared to begin with and for it to suggest appropriate exposure settings when metering through the 87C filter it needs to assume the film is much more sensitive than Plus-X. In fact it needs to be set to a speed that is 4 stops faster than Plus-X so that when it is metering a scene through the 87C filter it provides the 8 stop difference suggested by the first test mentioned a few slides ago.

Metering in this manner would also consistently produce negatives that contain some useful subject detail. The meter would invariably be used in the reflected light mode and be aimed directly at the subject. Metering in the incident mode might indicate there is a lot of infrared falling on a scene but if it falls on a subject that has very low infrared reflectance the record will essentially be useless as we will not have captured any subject detail. Making reflected meter readings ensures that the negatives will achieve a useful density no matter what the subject's infrared reflectance or emittance might be.

When the meter is used with the 87C filter in place this exposure index dialed into the exposure calculator dial of the light meter would indicate proper exposure setting when metering scenes with unknown infrared content. Scenes which may have a different "spread" from a white light reading than 8 stops. These scenes might be lit by sources having poor infrared emission such as fluorescent tubes. Or they may contain subjects with very high infrared reflectance and these would be overexposed if one simply used the exposure factor method to determine appropriate exposure.

When doing infrared photography one really does not care about "proper" tonal relationships in the result. What is desired is a record. If the subject happens to reflect little infrared it is really not useful to make a record showing a detail-less record. The point when photographing the invisible is to make a record and this can only be done if we design the metering system to produce "useable" negatives and this can only be done by taking reflected meter readings..

Essentially the Zone System is generally not applicable to infrared or ultraviolet photography.



To prove that such a scheme, namely the installation of an infrared filter over a meter's cell, can yield useful exposure data and that one need not guess widely about results, two matched cameras were used to photograph a variety of scenes. One camera was loaded with Kodak Plus-X film and the other with Kodak High Speed Infrared film. They were set-up side by side and their shutters released simultaneously with a double cable release assembly as shown in this illustration.

The cameras were used to photograph various subjects and the exposure on each was set according to the reading taken without and through an 87 infrared filter fitted in front of the meter's cell.



The second and fourth row are the records produced on regular black and white film. The top and third rows were made on High Speed Infrared film. Just about every infrared negative could be used to make a useable print from. Including the one of the fact of the CRT which has no infrared emittance at all. The interior photo of the fluorescent tubes shows that they emit lots of light and the light meter used in the reflected mode suggested an exposure that exposed properly for the lamps but underexposed the surrounding ceiling. On the other hand, the infrared record of the same scene shows the ceiling and the ceiling tiles all about the same level of density and exposure. This is because the room was illuminated by sunlight streaming in through a window. This was rich in infrared and it "lit up" the ceiling. The fluorescent tube, by contrast, emitted very little infrared and so they produced a density on the negative that was very similar to that which the ceiling tiles produced.

Note that the characteristic darkening of the sky and lightening of living vegetation seen in infrared photographs is also evident in these photographs. It is interesting to note that some color photographs on the lower right which are easily visible on the black and white record seem to be totally washed out in the infrared record. This is due to the fact that the dyes making up the color prints are transparent to infrared.

One might ponder as to why this might be so. The answer is simple. The color dyes making up color prints don't need to be infrared opaque because they are designed to be viewed by human eyes and human eyes can't "see" infrared. Obvious, no?



This is an “action infrared photograph” made with an infrared filter installed in the focal plane of the camera as described earlier. It is not meant to be a piece of art just a proof of concept. The exposure was determined by the reflected method using an 87C filter over the meter cell.

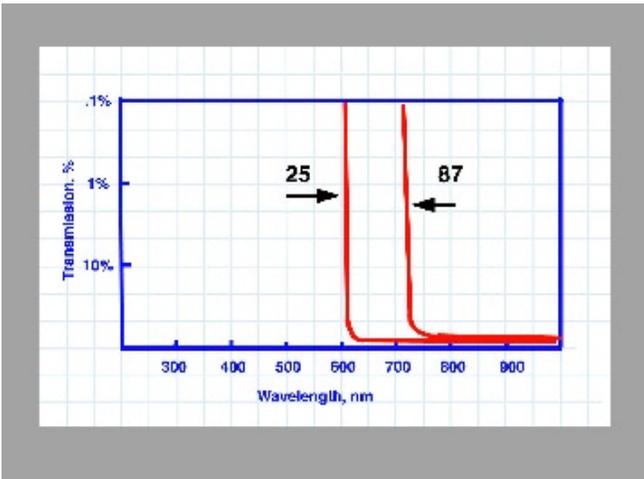


This is another action infrared photograph made with an SLR camera with an 87C filter installed in the focal plane.

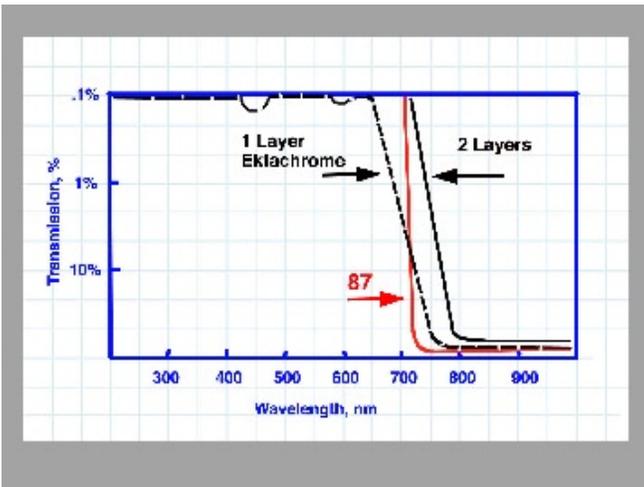


Going back a couple of slides you will recall that it was mentioned that color prints virtually disappeared or became white due to the fact that the dyes in the print were not infrared opaque. Well, it turns out that the dyes in color negatives or transparency films are not infrared opaque either. Here you can see two sheets of Ektachrome film that have been processed without having been exposed. The films therefore exhibit maximum density and are so opaque that one can hardly see through a single sheet and when two are superimposed the view is even more limited.

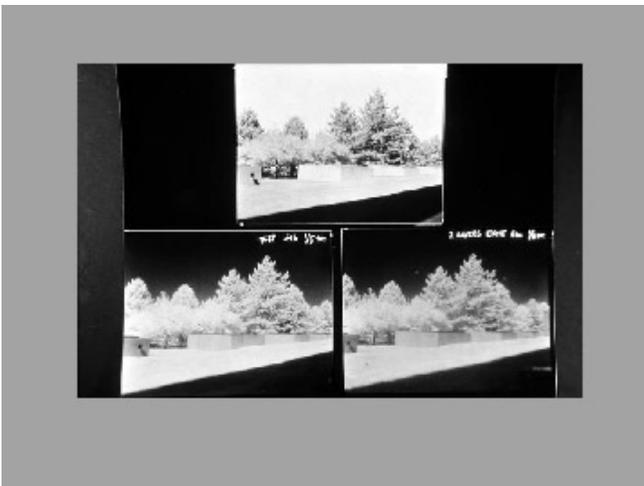
This affords the basis on which one might make an improvised infrared filter as shown next.



These are the spectral transmission curves of two common filters used for infrared photography. One is the Wratten #25, a deep red filter that allows for visual examination of the image on a groundglass and the second is the Wratten #87 filter which is visually opaque. Now we will compare these curves to those of Ektachrome film processed to maximum density.



As you can see a single layer of Ektachrome “leaks” a significant amount of red and even some green light. It’s color is a deep yellow/red/green color. However, when two of these are used the transmission curve starts to look very similar to that of the 87 filter. The curve indicates that the transmission characteristics of the 2 layers of Ektachrome show that the filters have a less sharp cutoff in the infrared than the #87 filter and that the filters are cutting out a bit more infrared than the #87 and finally that the minimum density of the combination is higher than that of the #87 filter. One can worry and be troubled by these “failures” to meet the standards of a true infrared filter or one can exploit the filter and do some true reflected infrared photography.



Here we can see the results obtained with Plus-X film at the top and with Kodak High Speed infrared on the bottom. The bottom left image was taken through a standard #87 filter while the one on the bottom right through two layers of Ektachrome film processed to maximum density as explained earlier. As you can see the results of the exposure made through the film are very similar to those achieved by making the photograph through a high grade infrared filter. The image is a bit softer to be sure since film is not designed to be as clear as a membrane of gelatin as used in the #87 filter but in a pinch it may serve a useful purpose especially if technical perfection is not an absolute necessity or if the filter is used over a light source (such as an electronic flash) instead of a camera’s lens.

If used over a flash one needs to make sure not to flash the tube repeatedly as this could generate and capture enough heat in the flash head as to cause flash failure.



Now we will move on to another technique associated with infrared and ultraviolet photography. The first one of these is called fluorescence photography. The technique depends on the fact that various substances interact with an incident beam of energy and while they may reflect a large amount of the energy falling on them they also emit new, generally longer, wavelengths than those impinging on the sample. This property of materials to alter the wavelength of incident energy to longer wavelengths is called fluorescence. The set up is as shown in this illustration.

One starts with a broadband source (one containing all wavelengths and then passes this energy through an ultraviolet transmitting, visible blocking, filter (known as an exciter filter in this set-up). Alternatively one could start off with a source that only contains ultraviolet radiation and in that case an exciter filter is not required. The ultraviolet energy passing through the filter or emitted by the ultraviolet source is allowed to fall on the subject. In this case some stamps.

The paper and the ink with which the stamps are printed interact with the ultraviolet falling on them. They reflect a great deal of the ultraviolet that falls on them but also create somewhat longer wavelength energy. This may be in the visible region of the spectrum and may appear as blue, green or red or something in between.

These two “beams” being reflected in one case and emitted in the second then travel towards the camera lens. If we simply look at the samples in a darkened environment we would see the emitted wavelengths as visible colors or colored areas. If we decide we want to photograph the newly formed wavelengths emanating from the sample we need to separate the copious amounts of reflected ultraviolet radiation from the less abundant but visible wavelengths. To do this a filter that transmits light but which block ultraviolet is placed over the camera’s lens. This is typically a pale yellow filter such as a Wratten #2E or similar. This filter, known as a “barrier filter” allows only the visible rays to pass and since these could be any number of colors it is most appropriate to use color film when making a record of fluorescence excited by ultraviolet energy.

Remember that when the subject is examined visually a barrier filter is not needed because our eyes are not sensitive to ultraviolet but failure to use the ultraviolet blocking or barrier filter over a camera lens will almost invariably lead to unacceptable results as films are inherently sensitive to ultraviolet.

Digital cameras may not need significant blocking of the ultraviolet rays as CCD and CMOS image sensors are inherently low in ultraviolet response but in my opinion one should use the barrier filter even with these cameras. It is good professional practice to do so. The use of such a filter assures that one will not be influenced by unwanted ultraviolet energy being reflected from the subject from contaminating the fluorescence record.

A discussion of these topics necessarily must include some reference as where one might find appropriate sources of ultraviolet or infrared energy. The sun is generally a good source of both but it is hardly a convenient source for use in a laboratory environment. Tungsten or incandescent sources are good emitters of infrared radiation. So are electronic flashes. However, one needs to pay attention to the kind of electronic flash that might be available.



These two are examples of typical electronic flash “heads”. While both of these are similar in spectral output at the start, the bottom flash has incorporated in front of the reflector a yellowish filter. The function of this filter is to remove the ultraviolet from the energy emitted by the flashtube. There is a good reason to do this and it has to do with the fact that if an unfiltered flash is used to photograph subjects that include brighteners or other substances that fluoresce in the blue region of the spectrum one would have a difficult time color balancing a scene that contained non-fluorescing subjects as well as fluorescing ones.

This situation is most often encountered in wedding photography where the wedding gown invariably includes brighteners. These fluoresce in the blue region of the spectrum so the white gown would reproduce as somewhat blue in a color record of a scene that also includes flesh tones that do not fluoresce. If one adjusts the color balance to remove the bluish cast from the gown the flesh tones are too red and if one adjusts for proper flesh tones the gown is too blue.

Obviously the solution to this problem is to eliminate the ultraviolet from the flash to begin with.



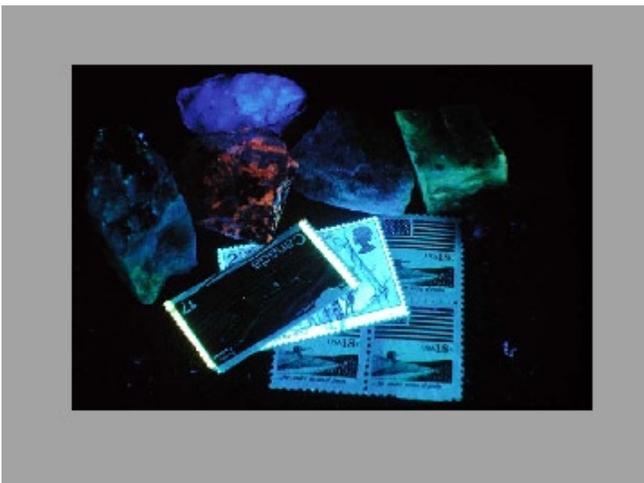
The flash on top would be a good source of ultraviolet while the one on the bottom would be a poor one. They both would provide ample amounts of infrared.

There are available many specialized sources for ultraviolet. Most are designed for use by mineralogists, geologists and forensic scientists or technicians. These contain fluorescent tubes that emit ultraviolet as well as visible and they are further filtered with filters that limit the output to areas of the spectrum described as long wave ultraviolet, peaking around 370 nm, and short wave ultraviolet, peaking around 250 nm.



Now we will take a look at a series of photographs of some minerals and some stamps as seen by light in every case but illuminated by a standard light source, then by a source of long wave ultraviolet and then by short wave ultraviolet. This is the normal, visual appearance of these subjects when illuminated by a tungsten lamp. We would say these are their natural colors. But what do they look like if we illuminate them with ultraviolet?

This is their appearance when illuminated by long wave ultraviolet. The white paper of the Canadian stamps appears very bright and white. Those areas fluoresce in the whole range of the visible spectrum and so they appear white. Several of the rock samples that normally appeared as grayish in color have acquired colored spots or have totally assumed a color other than gray. Those minerals are fluorescing, changing ultraviolet, into their respective visible colors. The American stamps lost all their color and are seen as shades of blue or cyan.

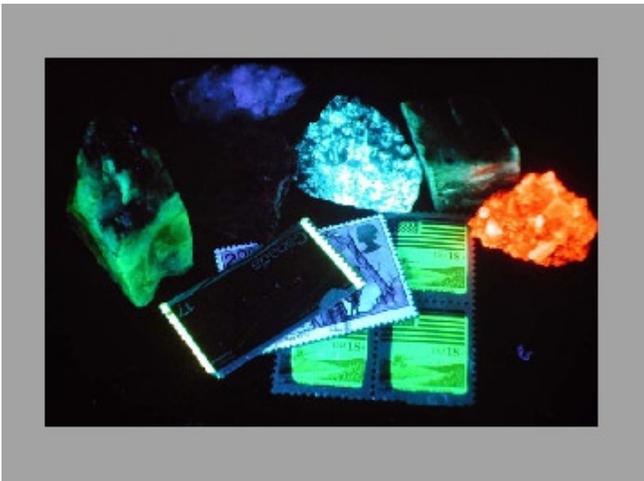


Although these records are properly exposed, they were secured using a lens set to a large aperture and exposing over an extended time because even though these items appear bright to the naked eye there really is very little energy reaching the camera lens. Our eyes looking at these fluorescing subjects in a dimly lit environment open the iris to the largest opening and the retina adjusts its sensitivity to the maximum.

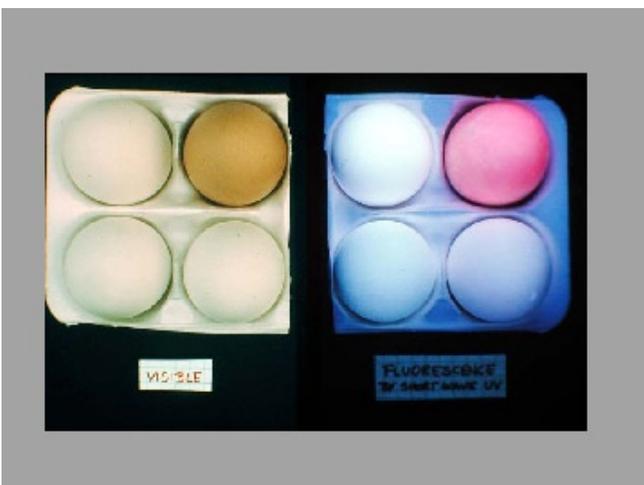
So we tend to see these fluorescing as very bright but for photography we need to rely on what normally would be considered extremes of exposure just to secure a useable image.

The “saving grace” of visible fluorescence is that ultra sensitive light meters can be used to determine appropriate exposure.

Next we will illuminate these same subjects with short wave ultraviolet.



Under short wave ultraviolet radiation the fluorescence of the various rocks has changed dramatically. The rock in the center that had reddish flecks in it by long wave ultraviolet seems to have no response to short wave ultraviolet. The rock on the far left has acquired a pronounced greenish color and the one on the right, that essentially was totally dark in the previous slide, is now glowing brilliantly in the orange region of the spectrum. The American stamps are exhibiting a pronounced greenish pattern while the paper substrate is quite dark. On these stamps this is a counterfeiting prevention measure or a means for the post office to quickly detect whether an envelope has a valid stamp affixed to it. This is of particular importance if machines are used to automatically sort mail based simply on the presence of the mark. If counterfeiters don't account for the fluorescent “tag” their nefarious work would be quickly detected.



Brown eggs exhibit fluorescence preferentially in the reddish area of the spectrum while white eggs exhibit a bluish/whitish fluorescence when illuminated by short wave ultraviolet.



In the illustration at left, made with a digital camera, it is possible to see that digital cameras can be used, like film cameras, to photograph subjects in the ultraviolet region of the spectrum. For this a standard digital camera can sometimes be used but generally with extended exposure times and large apertures under full sunlight or with copious amounts of ultraviolet present in the illuminating source.

In this case an “in between” reflected ultraviolet rendition of the sunflower is shown. The middle image is the color record output by the camera. It is a “false color” image since as we have discussed earlier ultraviolet has no color per se. The reason the camera displays such a color image is due to the fact that the red, green and blue filters transmit dissimilar amounts of ultraviolet and where the sensor should respond with a neutral reproduction it responds with varying digital values for each of these filters leading to a very colorful but technically incorrect image.

The correct monochromatic rendition of an ultraviolet record is seen in the image on the right.



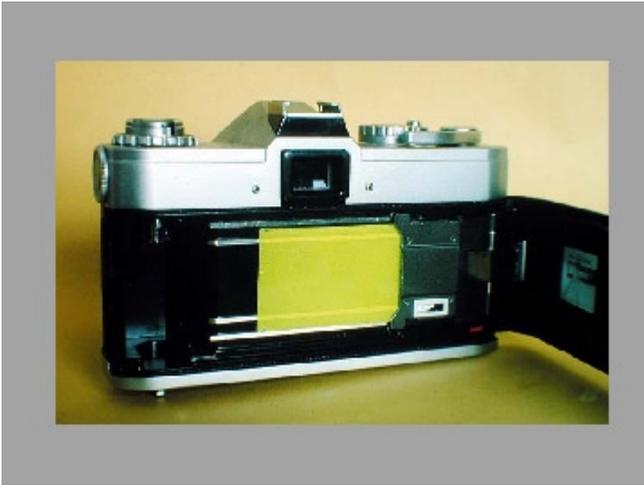
This photograph is sort of a summary of the two ultraviolet recording techniques, namely reflected ultraviolet (far right) and fluorescence (middle).

On the far left is the full-color image of the black eyed susan flower photographed with a regular Digital Single Lens Reflex camera.

In the middle is the ultraviolet excited visible fluorescence photograph made with an 18A filter over the camera lens and a 2E ultraviolet blocking filter over the lens.

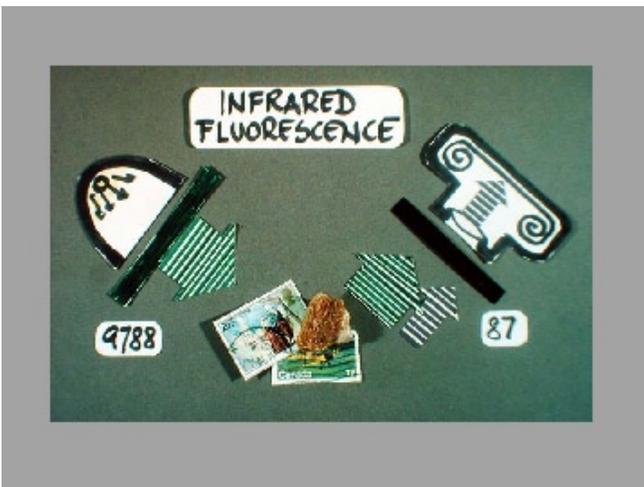
On the far right is a black and white reflected ultraviolet photograph made with just the Wratten 18A over the lens. The illustration is shown appropriately as a monochromatic image consisting of shades of gray.

It is interesting to note that where there is visible fluorescence in a sample there tends to be ultraviolet absorbance in the same region of the sample.



The fluorescent property of certain materials can also be used to visualize images at the focal plane of a camera whose lens has been covered with an 18A ultraviolet filter. This is illustrated here although only the “fluorescent groundglass” is shown in the back of the camera. The idea here is that while the 18A filter blocks all visible light from entering or passing through the lens it freely passes ultraviolet rays. These in turn fall on a coating of fluorescent paint that has been applied to a piece of clear glass. Wherever ultraviolet falls on the paint it glows and makes the image projected onto it by the lens visible.

In fact, this is an “image conversion” device. It changes ultraviolet into visible. With this arrangement one can accurately bring an ultraviolet image to a focus without having to resort to a special green/ultraviolet achromatized lens. One can even coat an interchangeable groundglass available for many Single Lens Reflex cameras with a thin layer of fluorescent paint and under certain conditions even photograph and track objects in motion.



The concept of fluorescence excited by ultraviolet can be carried a step further. Some materials change the wavelength of incident radiation to longer wavelengths than visible ones. That is, if they are flooded with light or visible wavelengths, they convert these wavelengths to invisible infrared ones. The concept is really exactly the same as that of fluorescence excited by ultraviolet except that the effect there is visible. In this case the effect is invisible so it is harder to judge whether fluorescence in the infrared (or luminescence as some scientists including H.Lou Gibson call it) is actually taking place. Only a trial exposure on High Speed Infrared film or a sensitive infrared image converter or camera can tell for sure.

The set-up in this case calls for a broad band light source that is filtered through a light passing, infrared absorbing, exciter filter. A light source devoid of infrared output can also be used without filtration. One simply needs to be sure that no infrared is present in the illuminating beam. This beam falls on the material or subject in question and it reflects a large amount of the incident light energy but it also may be converting some of those light wavelengths into infrared energy. These then travel towards the camera lens.

Since we are trying to pick up the small amount of infrared the reflected light rays need to be separated from the emitted infrared ones. This is done by placing an infrared transmitting, visually opaque, filter over the camera lens. This might be the Wratten #87 filter or similar. Since only the newly created infrared is able to pass the filter the camera, loaded with High Speed Infrared film records an image made up by these rays. If a digital camera were used its sensor would simply have to be one capable of efficiently detecting infrared energy.



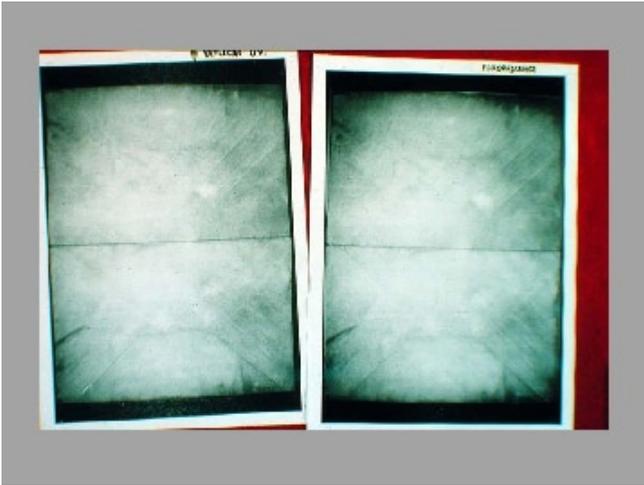
This is a typical set-up for conducting luminescence (or fluorescence in the infrared) photography. The electronic flash heads, good sources ultraviolet, light and infrared, have been covered with cyanish/bluish filters (Coning 9788) thus allowing only visible wavelengths through. The camera carries an infrared transmitting filter installed just in front of the film plane. The camera therefore can only record infrared coming from the subject. But the lighting has no infrared in it. The lens needs to be very fast as the amount of infrared generally emitted in this type of photography is very small.

This set-up was used to photograph a document that appeared to be totally unreadable to our eyes.

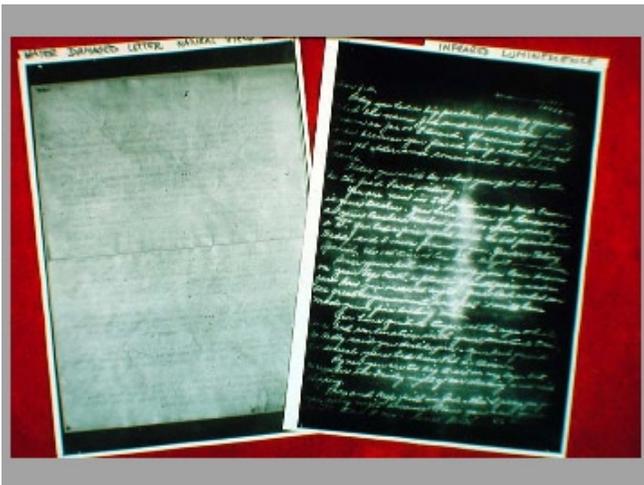


The document in question was one that had suffered water damage after being placed in a time capsule that leaked for a period of about 20 years. This piece of paper had a typewritten message on the opposite side that was easily readable but the side we are looking at had a message written with pen and ink and the ink had leached out of the paper and the paper looked as if there was no message written on it at all. The only reason it was known that there was something written on the paper was that the typewritten text on the reverse referred to this fact.

It was desired to determine if the message written on this side of the paper could be recovered and the message read. The assumption was made that possibly some residual ink was still embedded in the paper and various techniques were attempted.



Obviously the easiest were the reflected ultraviolet method and the visible fluorescence method. The reflected infrared method was also tried. None of these showed evidence of any message. However, when the document was examined by the luminance or fluorescence in the infrared method something quite surprising happened.



The minute amounts of ink residue that remained embedded in the fibers of the paper from the handwritten message essentially “glowed” in the infrared region of the spectrum. Since the ink emitted infrared and luckily the paper substrate did not the ink produced a dark record of itself on the film and when the print was made the ink, instead of appearing black on a white paper background, was reproduced as white against a black background.

The exposure required to secure an acceptable negative with the set-up shown a few slides ago was 16 flashes of the twin flash heads (each delivering 200 ws of power per flash or a total of 6400 ws) at a distance of 16 inches from the document and using an aperture of f/2 onto Kodak High Speed Infrared film. The filter in the camera was a Wratten #87C and the exciter filters were of Corning 9788 material.



This is an infrared image converter tube. It is powered by very high voltage (low amperage) electrical current supplied to it from a high voltage transformer. When the tube is powered up infrared and also light photons falling on the front photosensitive imaging surface cause electrons to be liberated into the tube and these are focused by an electromagnetic lens onto the fluorescing screen at the rear of the tube. When the electrons hit the fluorescing screen light is emitted in proportion to the number of electrons hitting the surface. Thus a reproduction of the invisible infrared image formed by a lens on the front surface is reproduced as a visible, glowing, image at the rear.



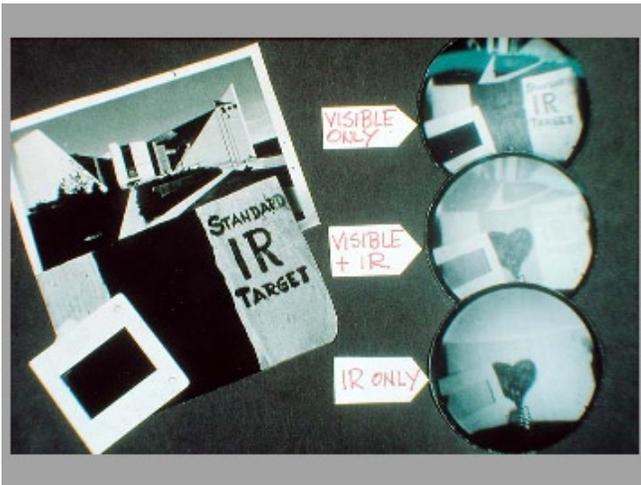
This is a home made infrared image converter device incorporating the tube mentioned in the previous slide. The lens sits in front of the image converter tube. It carries an infrared filter in front and so only infrared energy is able to pass to the image converter tube. The major part of the volume comprising this infrared image converter is the step-up transformer that takes the 9v battery power supply up to the 25,000 volts required for the operation of the tube.



This is a typical view of the fluorescing screen at the back of the image converter. It appears greenish because the material that is built into the rear screen of the tube happens to fluoresce in the green region of the spectrum when hit by the electrons directed to it by the electromagnetic lens of the tube.



Next we will take a look at these objects using the improvised image converter. Note that the subject contains a color print, a color slide and a piece of wood with "Standard IR Target" written on it as well as a dark patch covering about 1/2 of the wood sample. Note that when we view this subject in infrared we will no longer see it in color but only in shades of green.



On the left is the target while on the right are three possible views of the target as shown on the screen of the infrared image converter. The top circle shows a conventional black and white reproduction of this simple scene. The middle circle is a combination of infrared and visible made by simply leaving the infrared filter off the lens of the device. We are starting to detect detail that is invisible in the regular view. Most obvious is the heart shape on the wood and the disappearance of the "Standard Infrared Target" text.

In the bottom circle, made through a Wratten #87C filter the heart has become very visible and the black patch has completely disappeared. The reason for this is that the ink that was used for the patch was infrared transparent while the heart was drawn with infrared opaque material. Note that the slide frame appears to contain nothing within and the color photograph has also become quite white. In both of these cases one can surmise that the dyes making up color films and color prints are transparent to infrared.



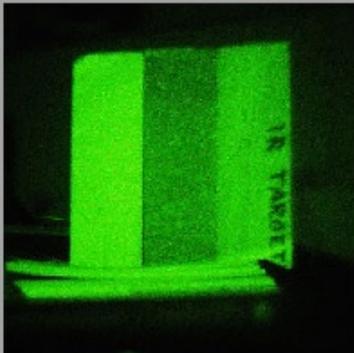
This is a commercial version of the infrared image converter. It is used in film and paper manufacturing operations as well as photographic laboratories to give the technicians a live view of processes that must be conducted in the dark. The facility where these are used must be fitted with a source of infrared radiation. Special safelight filters like these are made for these applications. Infrared image converters also have application in forensic surveillance and certain military applications.

A drawback of infrared image converters for "seeing in the dark" is that there must be a source of infrared provided. The IR converters detect infrared. If none is present they are just as "blind" as humans would be. If one lights-up an infrared source it is possible that the people being surveilled will detect the source and thus interfere with the covert surveillance operation. In a military situation if the enemy detects an infrared source it will simply destroy it if at all possible. Not good.

In such cases a "light amplification" imaging system is better than an infrared based one as those devices do not require an illumination source and they simply amplify whatever light (moonlight or starlight) happens to be available in a given situation. Of course if there is no light at all they do not work.



To reemphasize by example here is a target made up of three panels of differing densities. On the right hand panel one can clearly see the words “IR Target”.



This is the view by reflected infrared of the target. Several things have happened. Most obvious is that the writing is now on the right hand panel and that the middle panel is now the darkest of the three. This is an indication that the black panel was painted with a kind of black ink that was infrared transparent and the substrate was highly reflective in the infrared. The writing was written probably also in black ink over the visually black background but with infrared opaque ink.

To the perceptive eye there is yet another clue that the things are not quite the same as they were in the reproduction made by light. In a forensic case this might be important to note. This is that the top of the letters are closest to the edge of the target and so their orientation has been reversed from left to right while still retaining the order in a vertical sense.

**Many digital cameras with
CCD image sensors can be
successfully used for IR
photography**

**Cover lens with IR filter and use long
exposure times at large lens apertures
with camera on a tripod.**

As we are getting close to the end of this presentation it is appropriate to re-emphasize that many digital cameras exhibit residual infrared sensitivity in spite of the fact that manufacturers incorporate infrared absorbing “hot mirrors” in front of their camera’s CCD or CMOS sensors. Generally this will call for the camera to be used on a tripod with the lens set to a wide aperture and the use of long exposure times. Of course, an infrared filter would be used in front of the lens.

In certain cases these filters can be removed and the camera then becomes eminently suitable for infrared, and to some degree ultraviolet, sensitive.



One of the earliest amateur cameras that exhibited fairly good response to infrared even while not modified by the removal of its built-in infrared cutoff filter was the Nikon Coolpix 950. Later models of this camera had a much more efficient cut-off filter installed so it became much harder to use these for casual infrared work.



Some early cameras such as this Kodak DCS 315 had to be used with a “hot mirror” filter (shown at bottom of camera) in order for the camera to deliver accurate color reproductions of the “real” world. By not following directions and not installing the filter over the lens the camera could be used for infrared photography although the sensor was not very sensitive to begin with.

**Sony HandyCam Video Cameras
can “see” Infrared when used in
the NIGHTSHOT mode.**

**They even have an IR source built in so they
can “light up” a scene that is otherwise totally
in darkness - for example one can monitor
film development without risk of damage.**

Some readily available imaging devices allow for the “live” viewing of scenes illuminated by infrared radiation.



The Sony Handy-Cam line of camcorders has a setting they called Night Shot or Zero Lux recording mode. When used in this configuration the camcorder removes an infrared cutoff filter from in front of its CCD sensor and displays a greenish version of the infrared image formed by the lens (if lens is covered with infrared filter). Further, the camera has a built-in source of infrared to illuminate scenes where there is no or very little ambient light or infrared.

The camera was designed with this capability in mind as a monitor for babies in a nursery situation as it could send a live video feed to an external monitor of the goings on in a baby's crib even while the room was darkened. The camera obviously has many other potentially more useful applications in science and technology. For one, it acts as an image converter and when its lens is covered with an infrared filter it allows the pre-visualization of what the ultimate infrared record captured with a higher quality infrared imaging device might look like.



Finally, I would like to suggest a book for anyone interested in the general field of photography and its many and diverse applications. It is a book that is pre-digital but nevertheless it contains a wealth of knowledge and information especially useful to the photographic technologist. Its title is APPLIED PHOTOGRAPHY by Arnold, Rolls and Stewart. It was published by Focal Press and while no longer in print you might find one in a used bookstore or through online textbook outlets. It covers not only the topics covered in this presentation but also material such as photomicrography, high speed photography, photogrammetry, stereo photography, basic optics and sensitometry and many other topics. This book should be on every photo technologists reference bookshelf.

Thank you.

