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Understanding Color Infrared Photography

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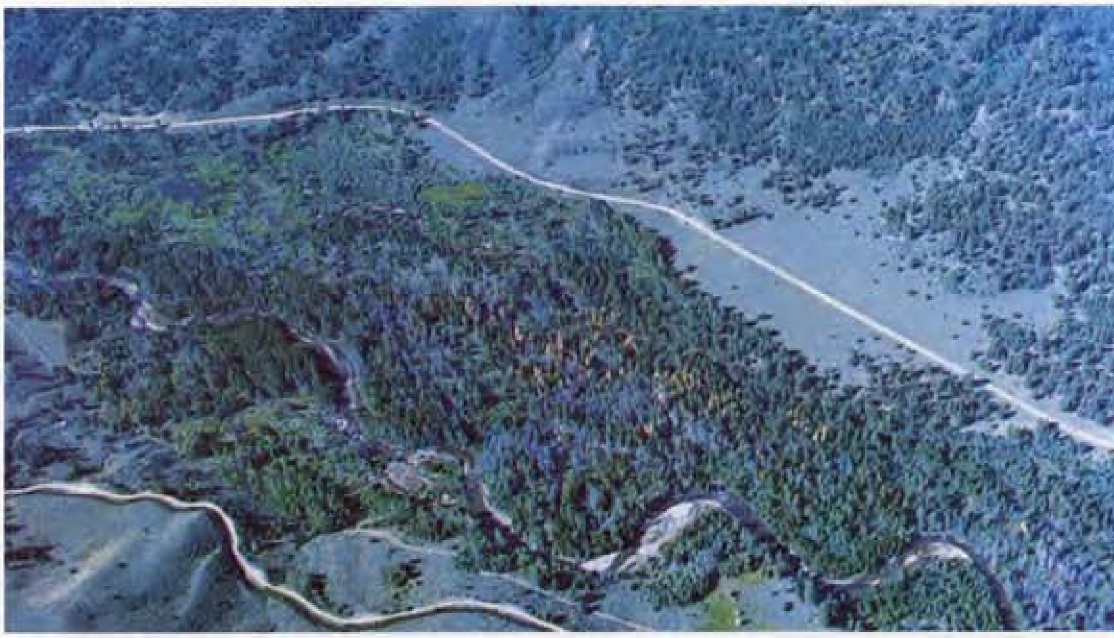

UNDERSTANDING COLOR INFRARED PHOTOGRAPHY

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ABSTRACT

Color infrared aerial photography has wide application in many aspects of forest management, but its potential may not be fully realized because many users do not understand the color process and consequently how to properly interpret it. This paper takes the reader through the entire photographic process, beginning with the principles of light and ending with the final positive transparency. The step-by-step sequence is supplemented with colored illustrations and color and color infrared paired photographs. Once the process is understood, the prospective photo interpreter will be able to independently deduce the acutal color of any image on color infrared film.

COVER STORY

These paired color and color infrared aerial photos were taken in July 1963 of a localized mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreak in ponderosa pine (*Pinus ponderosa* Laws) on the Ashley National Forest, Utah. The almost identical photos were taken with two parallel-mounted Nikon 35 mm cameras that were simultaneously actuated by a dual cable system. Note the differences in contrast between the different types of vegetation:

VEGETATION	COLOR PHOTO COLOR	COLOR INFRARED PHOTO COLOR
Live pine	dark green	magenta/purple
Dead pine with foliage	yellow/sorrell	white/yellow
Dead pine (snags)	grey	turquoise/cyan
Riparian (willows, grass)	green	pink
Aspen	green	pink

INTRODUCTION

Color and color infrared aerial photographs are widely used by natural resource managers, biologists, and other specialists for many forestry-related problems, including timber stand delineation, tree species identification, and insect and disease detection (Fritz 1967). In some applications, color infrared film is preferred over color film because of its haze-penetrating ability, and its greater tonal contrast between healthy and stressed vegetation, and between certain types of coniferous and deciduous plants (Heller 1970).

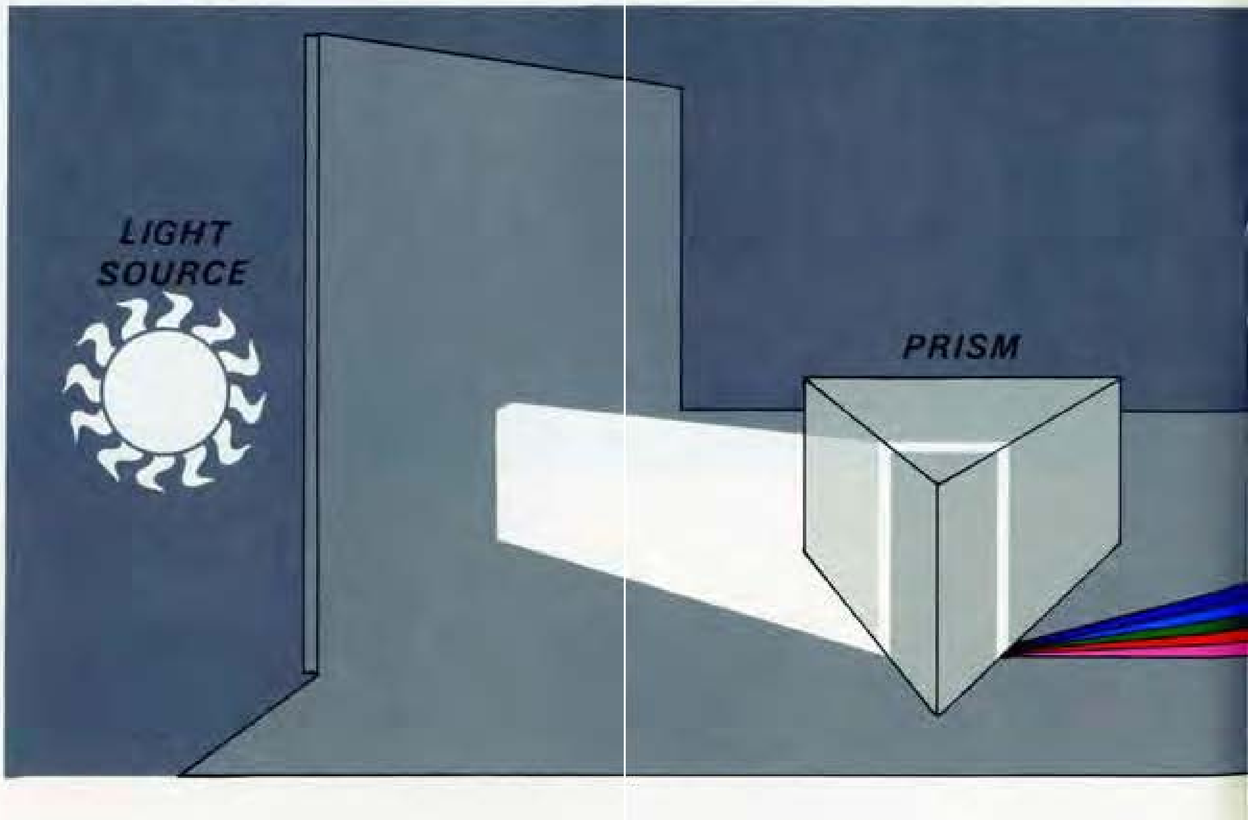
The single most significant shortcoming of color infrared film is that many of its users do not fully understand it, or know how to properly interpret it. To many, the recognition of colors is either by rote or by reference to a systematic key (Murtha 1972). A green tree should appear in various shades of magenta or red, green paint should be blue, water blue or black and dead vegetation yellow, yellow-orange, or white. Interpreters of color infrared photographs might like to deduce these relationships themselves, but lack the background to do so. In order to understand this process, one need have only cursory knowledge of the entire photographic process beginning with light and its additive and subtractive qualities; filters; film construction, sensitivity, and processing; and finally, the finished transparency. Information on a particular subject or process is available, but it is either fragmentary or over simplified, thus presenting the need for a comprehensive, easy-to-understand review of the color infrared process.

The purpose of this article is to provide the photo interpreter who is unfamiliar with the photographic process with a simple, non-technical, but comprehensive review of how color and color infrared work. To maintain certain basic principles, only saturated (pure) primary and complementary hues (colors) will be presented as examples. Once the principles are understood, most common color combinations can be determined.

LIGHT

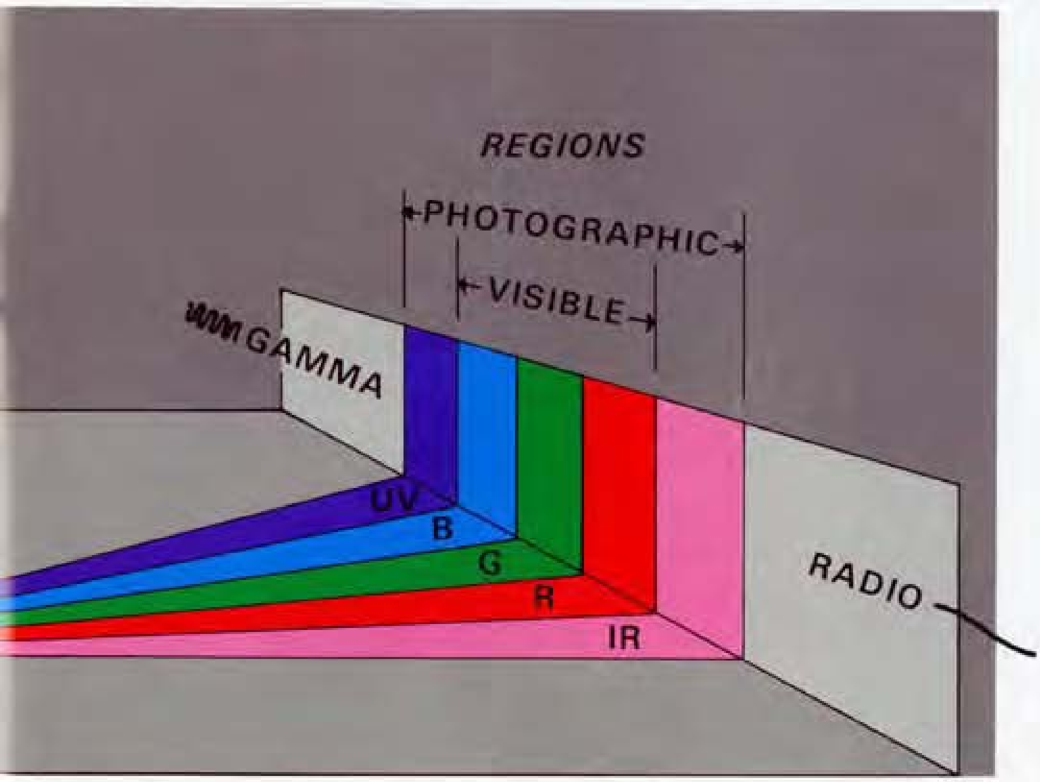
Energy received from the sun is electromagnetic energy which ranges from the shortest wavelengths, gamma rays, to the longest, broadcast waves. Within this very broad band of energy is the photographic and visible spectrum, or light (figure 1). The photographic spectrum ranges from the shortest wavelengths, ultraviolet (0.3 microns), to the longest, the near infrared (0.9 microns). The visible part of the spectrum, white light, ranges from 0.4 to 0.7 microns, and when passed through a prism, is refracted into its component wavelengths, the primary colors, blue, green, and red.

Figure 1. White light broken into its visible and photographic components.



THE ENERGY CYCLE

Energy in the form of light emitted from the sun is either scattered, absorbed, or reflected. Color as we perceive it is not innate to an object, but varies with the illumination of the object and with the ability of the object to absorb and reflect the light that strikes it. In the visible spectrum, tree foliage is green because it reflects green light and absorbs most of the blue and red light that strikes it. When fully illuminated, a cloud appears white because it absorbs almost no light but reflects in all wavelengths (blue + green + red = white). The full spectrum of colors can be produced by adding (figure 2) or subtracting (figure 4) the different wavelengths of light.



ADDING
+ LIGHT

Light is added when colored lights from different sources are blended together. A classic example of these additive properties can be shown with three standard slide projectors, each containing a colored slide of the three primary colors, blue, green, and red (figure 2).

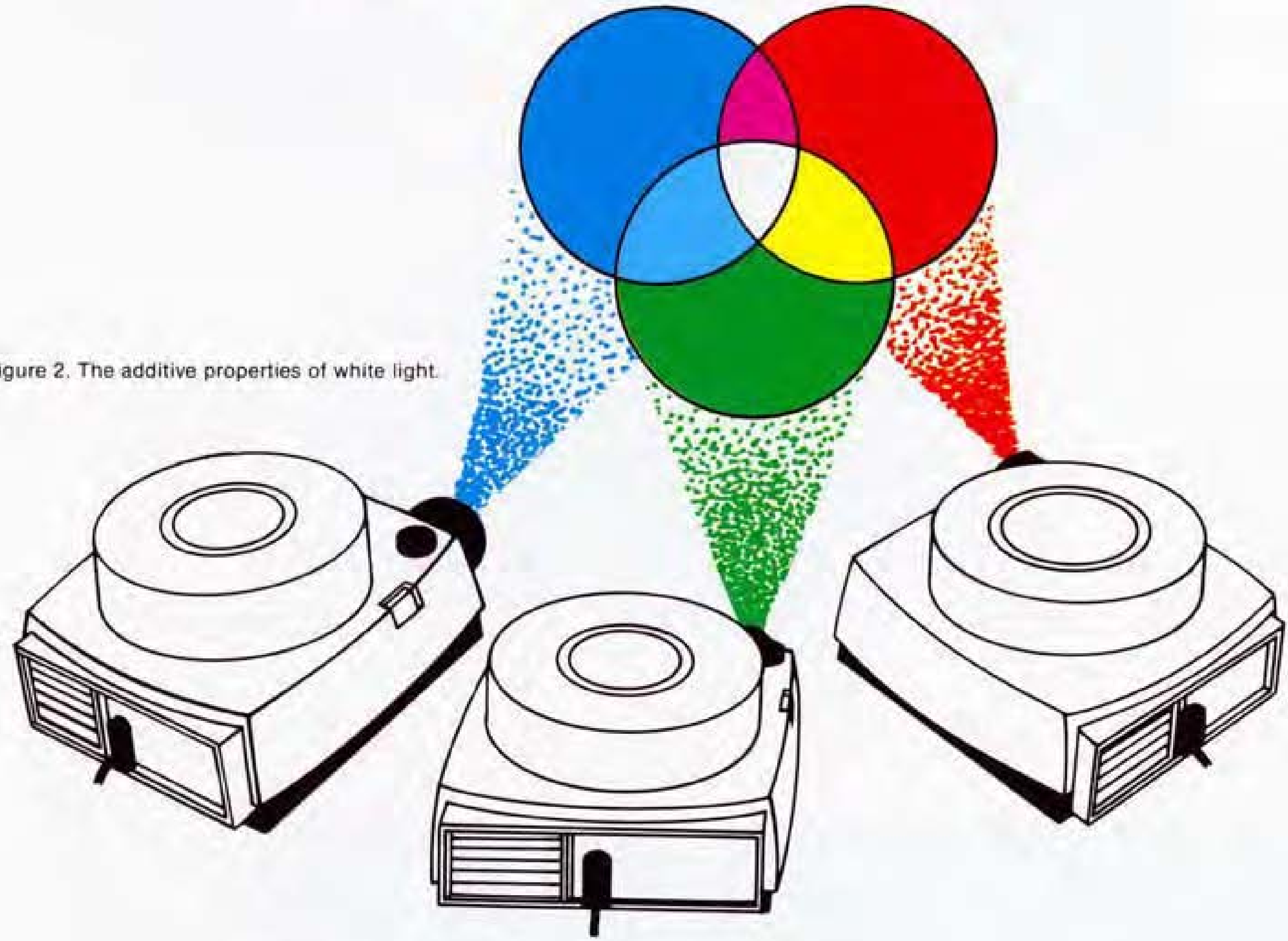


Figure 2. The additive properties of white light.

When blue light is added to green, the mix is cyan; when green blends with red, the result is yellow; and red added to blue becomes magenta. When all three colors are blended, the result is, again, white. The blend of any two primary colors is the *complement* of the remaining primary color (figure 3).

Figure 3. The primary and complementary colors.

SUBTRACTING

− LIGHT

Light is selectively subtracted when intercepted by a colored filter. *A filter transmits its own color and blocks or absorbs its complementary color* (figure 4).

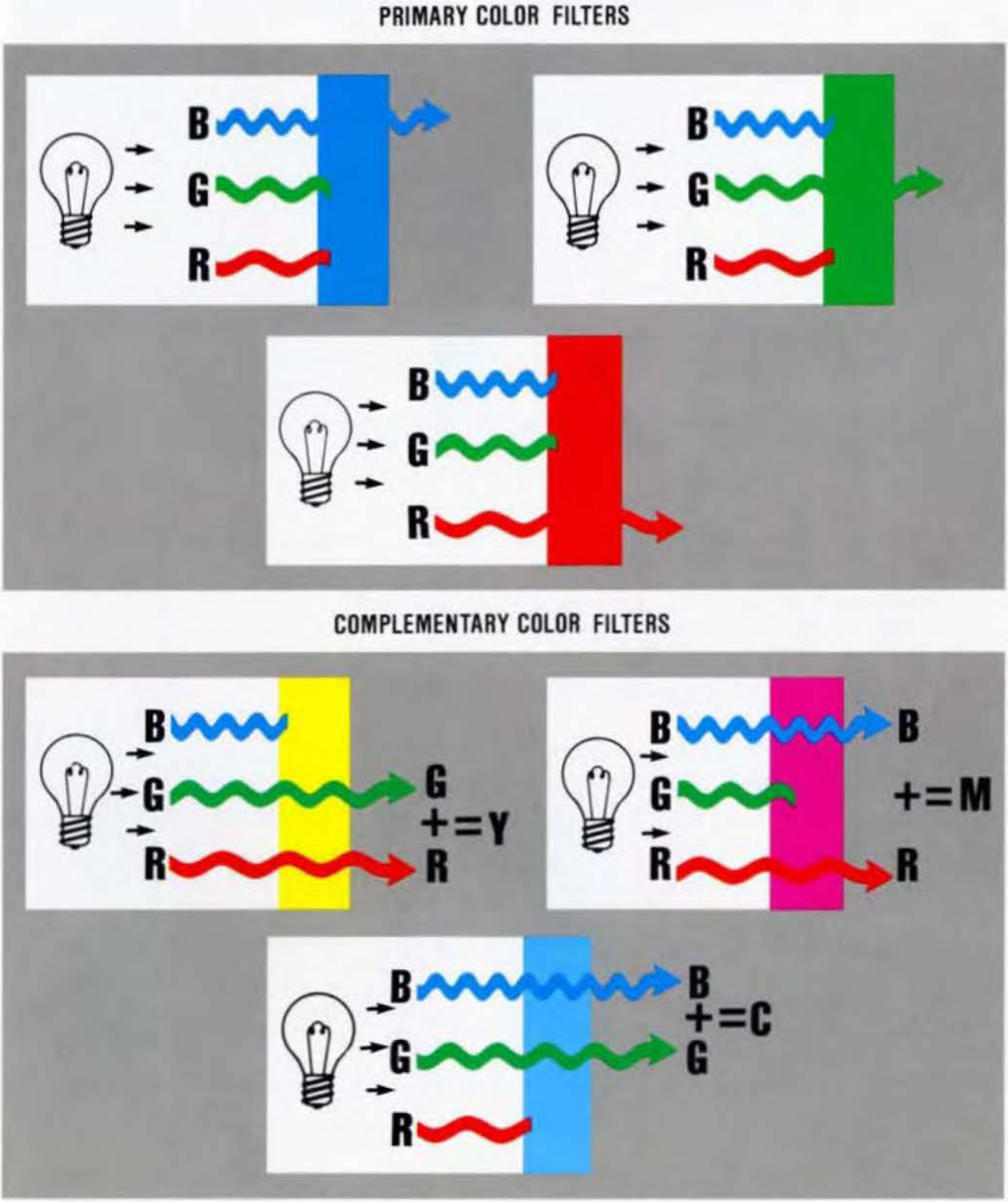


Figure 4. Color filters transmit their own colors and absorb their complementary colors.

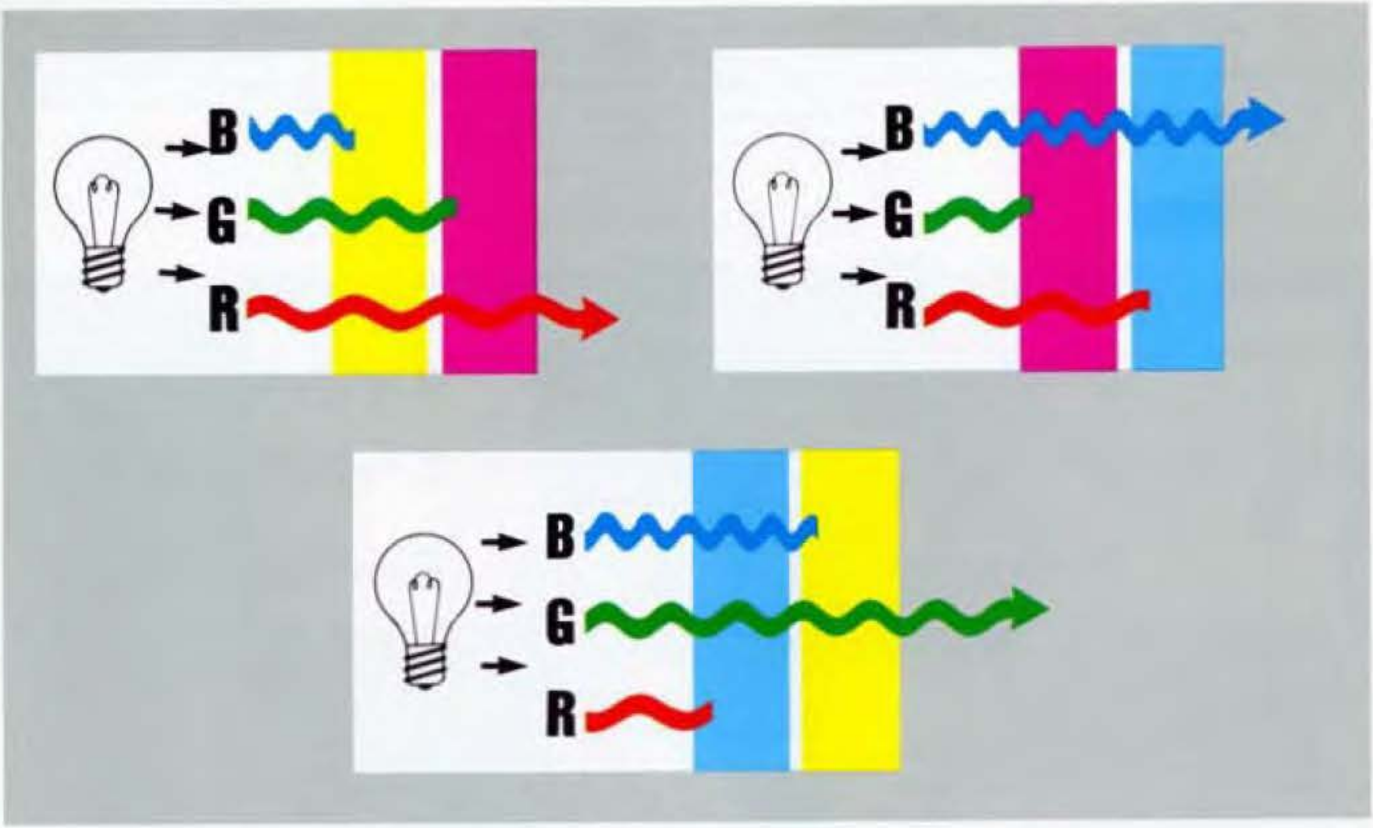


Figure 4.

A blue filter will transmit blue light and absorb its complement, yellow (green + red). A yellow filter will transmit yellow light and absorb blue. Light transmitted through 2 filters (stacking), say yellow and magenta, will transmit only red, since blue and green will be absorbed. No light will be transmitted through three complementary color filters (figure 5). In addition, no light would be transmitted through two primary color filters since each filter allows only its own color to be transmitted, i.e., the red filter illustrated in figure 5 would transmit only red light but the red light would then be absorbed by the blue filter since blue absorbs its complement yellow, which is a blend of red and green.

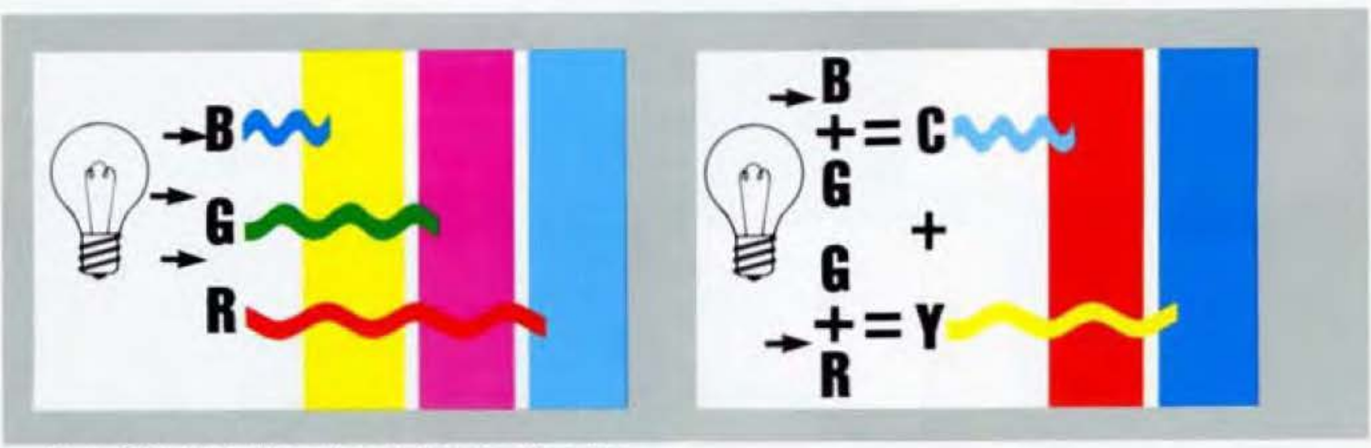


Figure 5. No light will pass through three complementary color filters or any two primary color filters.

In the previous example of adding light with the three projectors (figure 2), it is seen that in order for the three primary components of white light to be blended (added) on the screen, their complementary colors first had to be subtracted by the colored slides (filters) in the projectors. For example, the blue slide transmitted only the blue part of the spectrum but subtracted its complementary colors, green and red. The blue transmitted light is then added to red and green light which produced magenta and cyan, respectively. It is important to understand and differentiate between these two contrasting concepts of light addition and subtraction.

COLOR AND COLOR INFRARED FILM

Color and color infrared film is comprised of three emulsion layers, superimposed on each other, on a triacetate base. Each emulsion layer contains dye-forming silver halide compounds that are sensitive to certain portions of the photographic spectrum (figure 6).

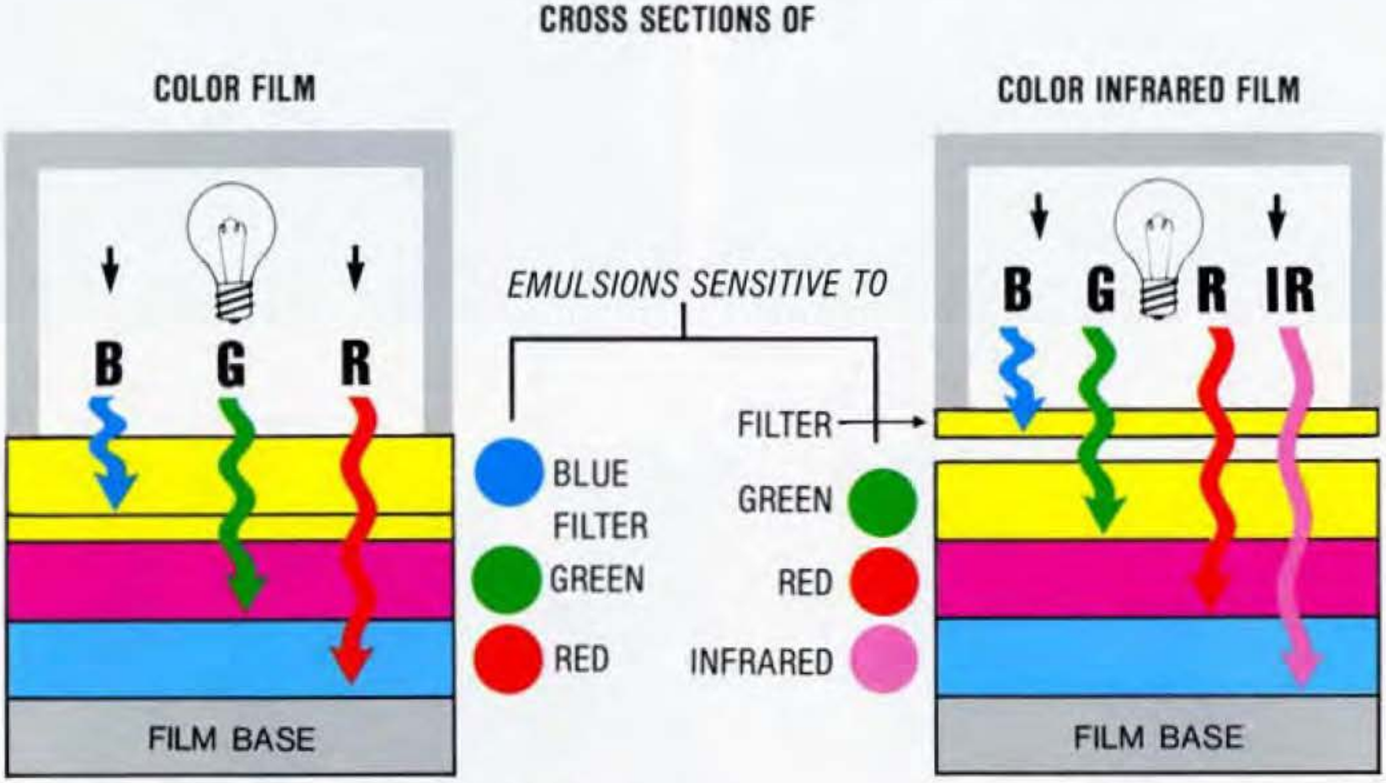


Figure 6. Cross sections of color and color infrared film.[2]

In both color and color infrared film these dye-forming layers become yellow, magenta and cyan. In color film these layers are sensitized by their complementary colors, blue, green and red, while in color infrared film these emulsion layers have been chemically "pushed" to the right, so that the same emulsion layers are sensitized by the green, red, and near-infrared components of the spectrum. Color film has an added built-in filter which prevents extraneous blue light from sensitizing the remaining emulsion layers. In color infrared film used for vegetation analysis, blue light is prevented from reaching the film by a yellow (minus-blue)[3] filter placed over the camera lens.

2 The actual sequence of emulsion layers in Ektachrome infrared film, from top to film base, is cyan, yellow and magenta (Fritz 1967). Although the emulsion layers have been rearranged for simplicity, the principles are the same.

3 Wratten 12 filter or equivalent.

FILM PROCESSING

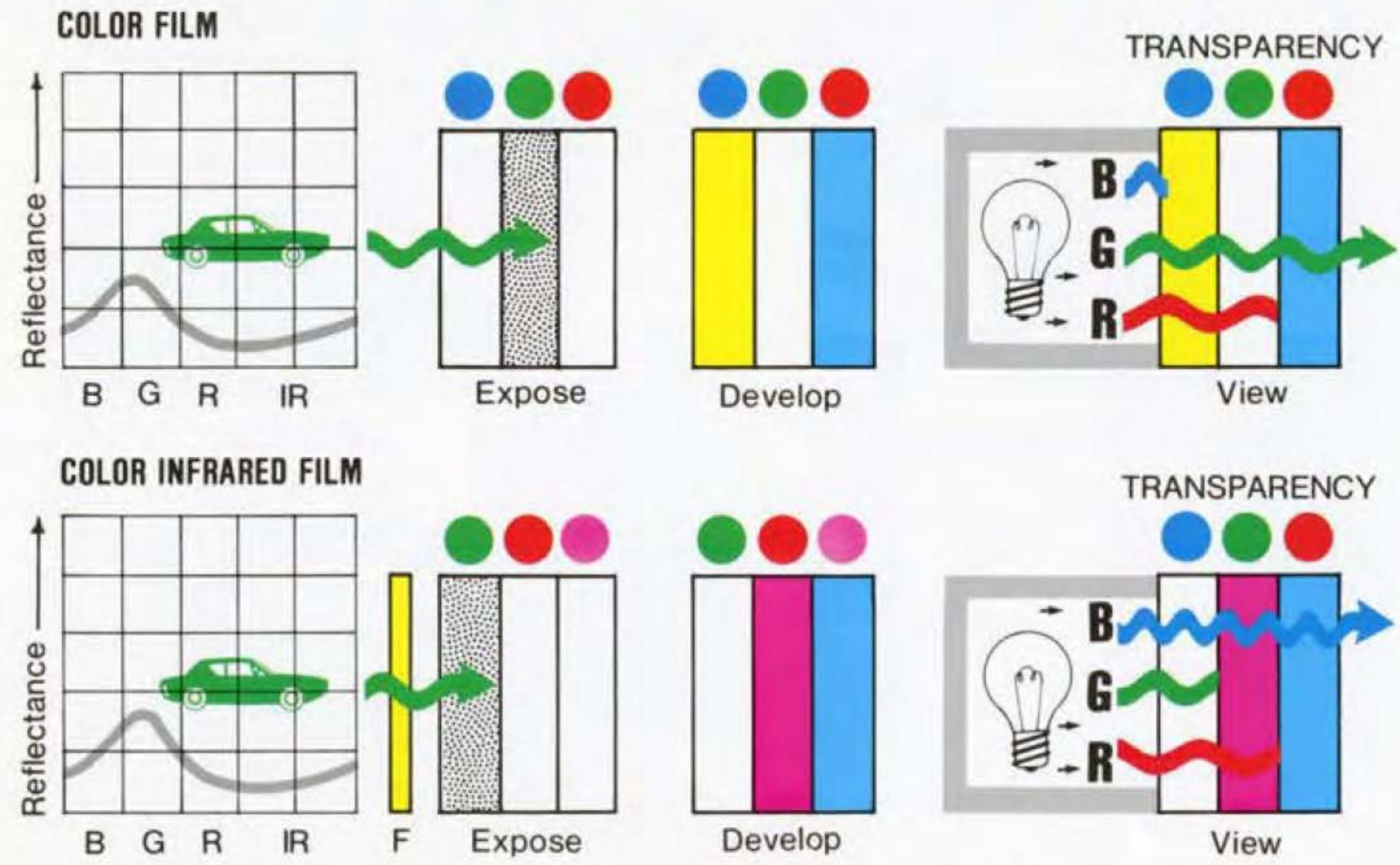


Figure 7. The reaction of color and color infrared film to a green image having no infrared reflectance. Curves from Hoffer 1976.

Color and color infrared films can be processed to a negative (complementary colors), a color print, or to a positive transparency. The positive transparency[3] is the most useful for detailed photointerpretation, and its development process, termed the "color reversal process", will be used in subsequent examples.

Briefly, in the color reversal development process, the exposed or sensitized emulsion layers are washed away and the unsensitized layers remain. Generally the densities of the processed emulsion layers are inversely proportional to the illumination and reflection intensity of the image being photographed. A non-sensitized emulsion layer retains its full color density after interacting with its dye coupler while a fully sensitized layer will be completely removed. Consider the example of the green automobile in the color and color infrared photographs (figure 7).

With color film the green sensitive magenta-forming emulsion layer is removed in the development sequence, while with color infrared film it is the green sensitive yellow-forming emulsion layer that is washed away. The film is then "fixed" and the tranparencies ready for viewing or projection.

When viewing the positive transparency, one should regard the transparency as comprised of three complementary color filters (yellow, magenta and cyan) stacked together (figures 4, 5 and 8).

Remember that light filtration is a subtractive process and that filters transmit their own color and absorb all others. In the preceding example with color film and the green automobile (figure 7), the magenta-forming layer has been removed, and when the transparency is held up to the light, only green light will be transmitted because blue and red light have been absorbed by the yellow and cyan layers respectively. With color infrared film, the green sensitized yellow-forming layer has been washed out, and when viewed or projected, only blue light will get through because the green and red parts of the spectrum have been blocked by the remaining magenta and cyan layers.

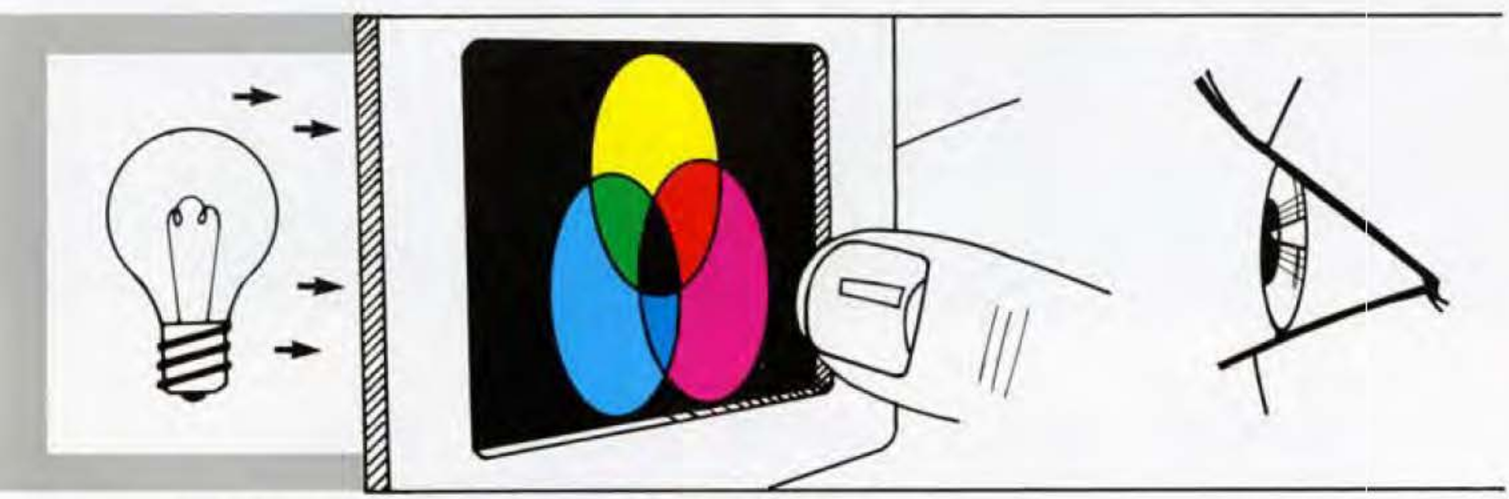
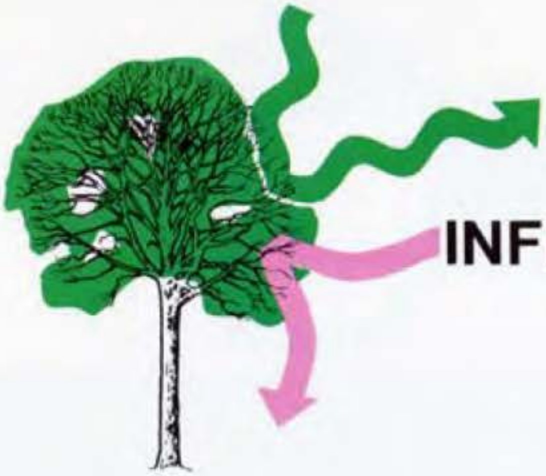


Figure 8. The subtractive properties of white light. A positive transparency can be regarded as three complementary filters of varying densities stacked together.

3 *Kodachrome slides are examples of a positive transparency.*



INFRARED REFLECTANCE

Color infrared photographs are particularly applicable to many forestry problems since vegetation is reflective in the infrared part of the spectrum. Generally, hardwoods have higher green and infrared reflectance than conifers, but there are exceptions. Pure water has almost no infrared reflection, but snow, clouds and some inorganic materials such as red paint reflect in the infrared. A good example is a red automobile that appears yellow on infrared film (figure 9).

One long held misconception was that only green vegetation containing chlorophyl exhibited

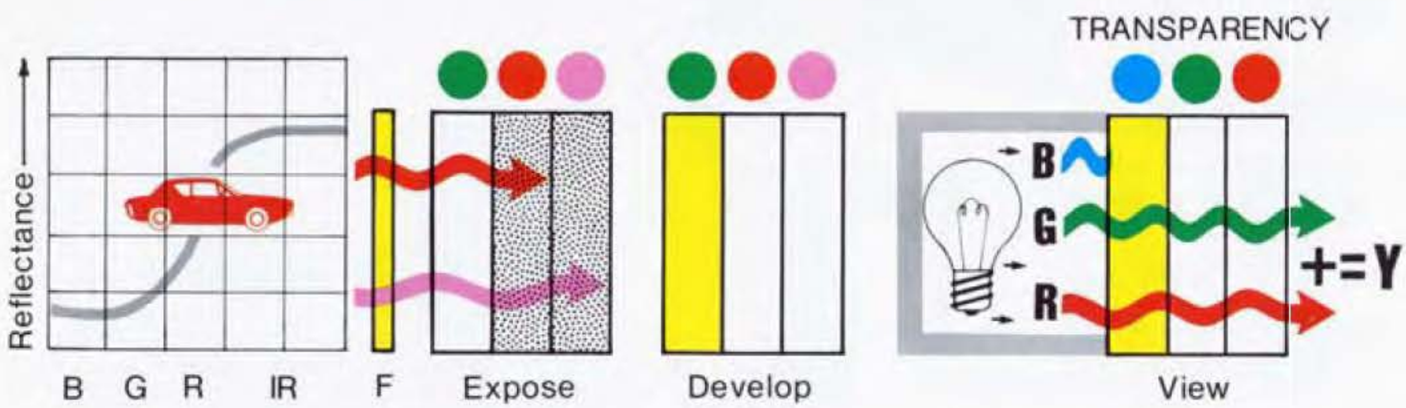
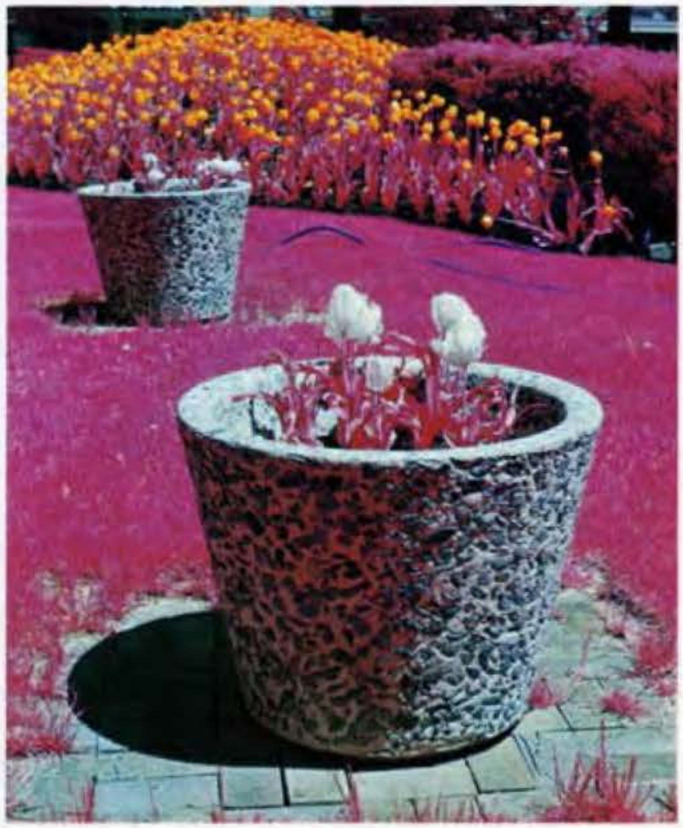


Figure 9. The reaction of color infrared film to a red image having infrared reflectance. Curve from Hoffer 1976.

infrared reflectance, but this has long since been disproved. An example is the yellow tulips that appear white on infrared film (figure 10).

Coniferous foliage, living or dead, is still infrared reflective. This can be shown in the following sequence with green and bark beetle-killed Jeffrey pine (figure 11). The green Jeffrey pines surrounding the dead tree and the incense cedars in the foreground appear in various shades of magenta on infrared film while the crown of the dead tree appears yellow-orange. Yellow is a mix of green and red, and orange is a blend of red and yellow. The spectral sequence would then be, from the shortest wavelengths to the longest, blue, green, yellow, orange, red and infrared. Red would dominate green since the spectrum is shifted closer to red.

During exposure the green sensitive yellow emulsion layer is only partially exposed, thereby leaving some yellow dye in the final transparency. The dead foliage still has sufficient infrared reflectance remaining to sensitize the cyan layer. With the magenta, cyan, and part of the yellow gone, the result is a pale yellow, almost white image. If the yellow emulsion layer were completely sensitized, the tree's crown would appear white, similar to the tulips in figure 10.



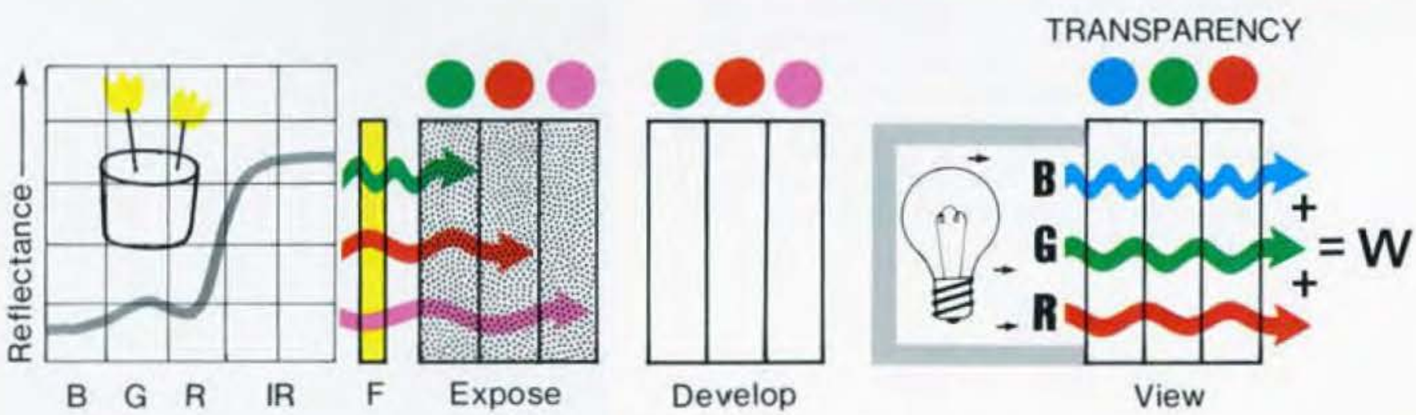


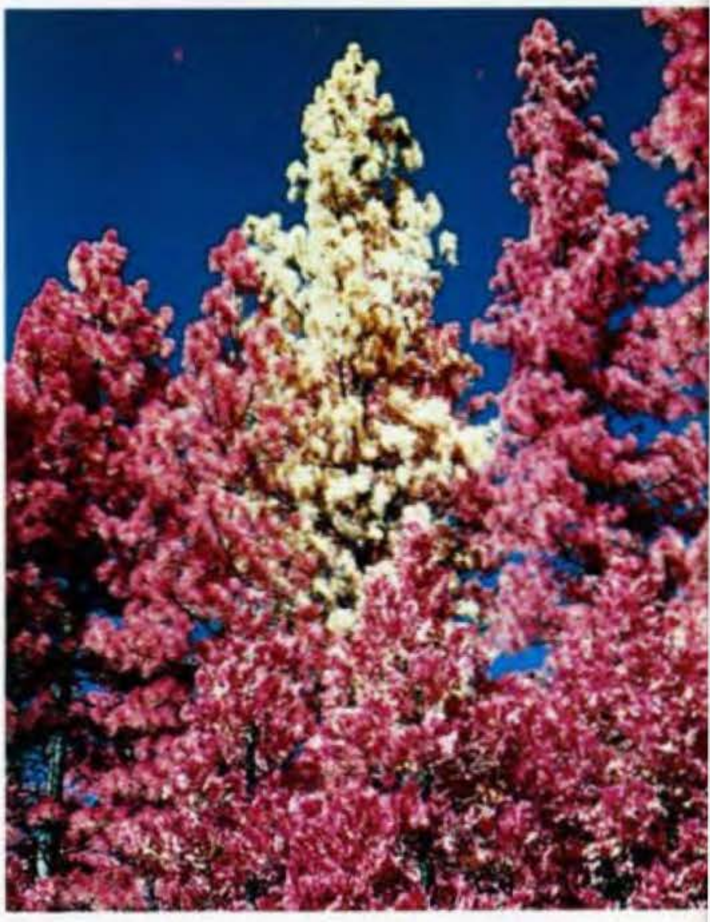
Figure 10. The reaction of color infrared film to vegetation lacking in chlorophyl but having infrared reflectance. Curve from Murtha 1978.

DETERMINING TRUE COLOR

By now it is hoped that these examples will dispel much of the mystery associated with color infrared film. By reversing this sequence of logic, an interpreter should now be able to determine the true color of almost any infrared image. As one example, consider the green nylon jacket worn by the young lady in figure 9. Viewing the color infrared transparency, the interpreters might first ask "Which emulsion layers have either been removed or remain to produce magenta?" They would first deduce that magenta is comprised of blue and red light, and in order for these two wavelengths to be transmitted, the yellow (green sensitive) and cyan (infrared-sensitive) dye-forming emulsions would have had to have been removed; consequently they had to be sensitized during the exposure process. The sensitizing wavelengths would then have to be green and infrared.

A second example would be the young lady's blue jeans which are also reflective in the infrared. Normally, blue would appear black since blue would be absorbed by the yellow filter and no emulsions would be exposed. It is evident that the dye used in the fabric contained green dye as well as blue, but the blue was blocked by the filter. One would then deduce that the jeans would have to be green or blue green (cyan) with infrared reflectance. Green without infrared reflectance would be blue (figure 7).

With this background, you should now be able to deduce almost any color or color combination by comparing similar objects in the paired figures in the text. Try, for example, to deduce the color of the parking surface in figures 7 and 9, and the concrete materials in figure 10. It is obvious that these materials have similar reflecting qualities. Do the materials have infrared reflectance?



ERRATA.

Klein, William H. 1982. Understanding color infrared aerial photography. Stephen F. Austin State University School of Forestry Center for Applied Studies. 16pp.

The hypothetical spectral reflectance curves in Figure 10 and top of Figure 11 have been inadvertently switched. The curve in Figure 10 belongs in Figure 11 and vice versa.

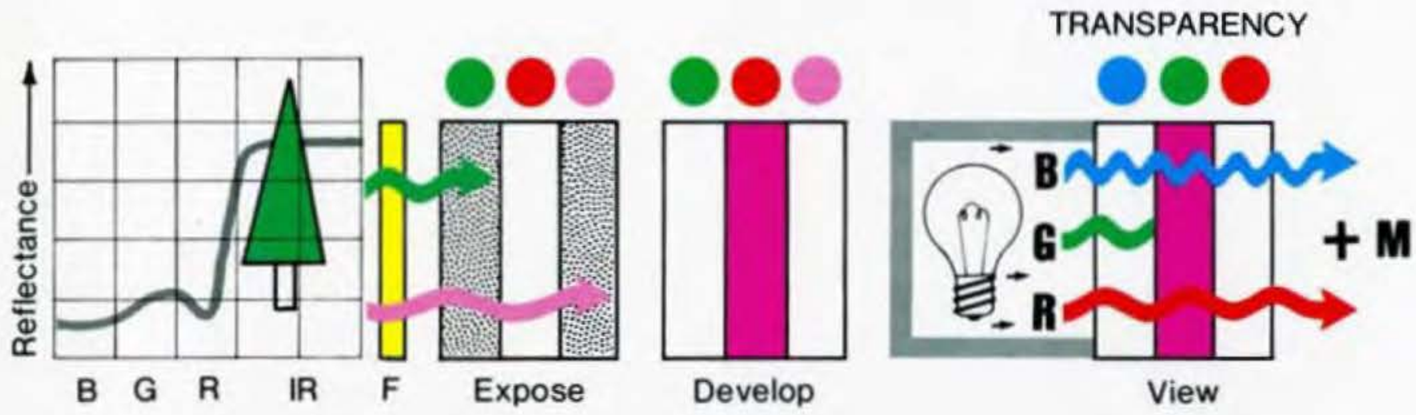
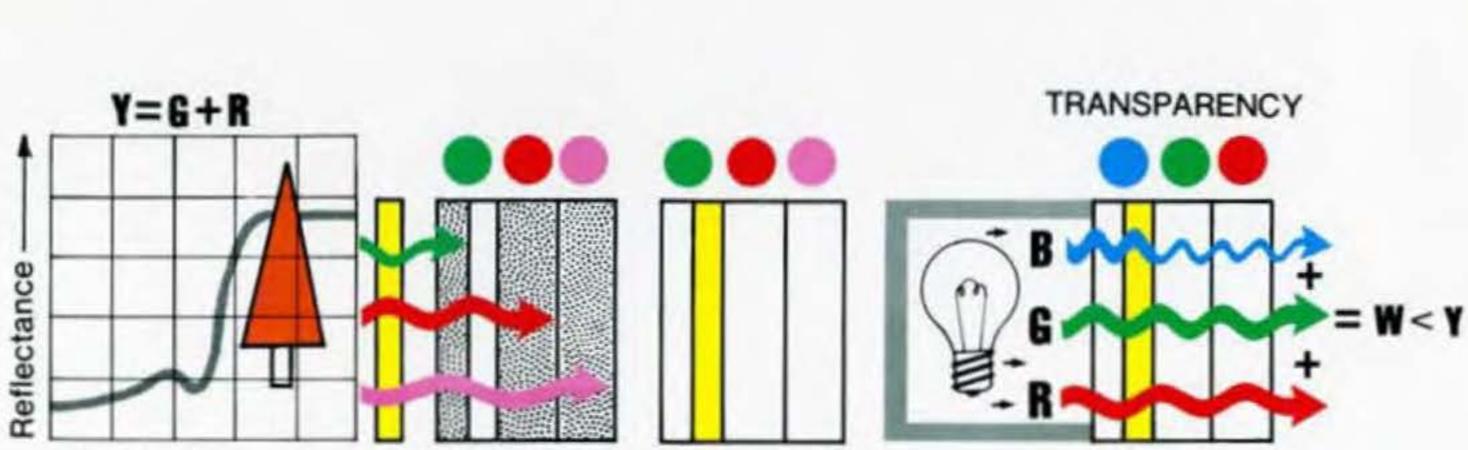


Figure 11. The reaction of color infrared film to living and dead Jeffrey pine having infrared reflectance. Curves from Murtha 1978.



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