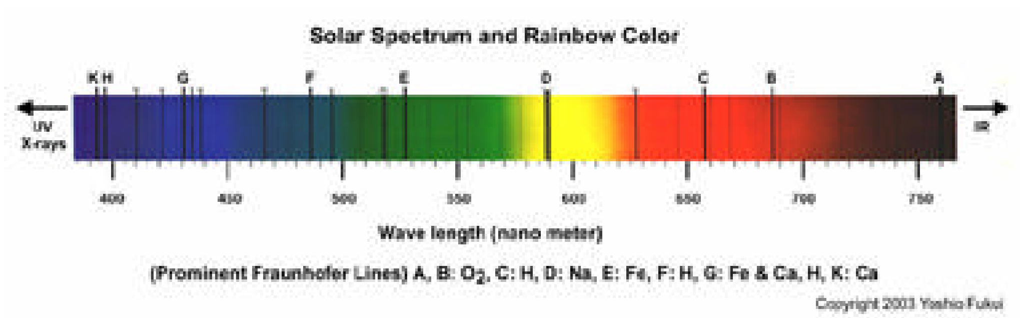
Seeing is Believing?

Human vision is a creation of brain. Signal for the vision comes as electro-magnetic wave of photons (light) and its sensor reside in the retina, where two types of cells, cone cells and rod cells, are present. Human vision can be distinguished as two types, “photopic” (color) and “scotopic” (monochromatic) recognitions, and the rod and cone cells are responsible for each. At least three pigments are known for photopic vision (red, green, and blue); whereas a single pigment called rhodopsin is responsible for the scotopic vision. For more detail, see “Human Eyes as an Image Sensor”.

As you know, electro-magnetic wave is a form of energy manifesting as various types such as X-rays, ultra-violet, visible light and infra-red. A chart below shows the solar spectrum illustrating the range of visible light. It is coded with color in similar way how a human recognizes. Human eye can sense the wavelength between 400 to 750 nm, by virtue of photo-chemical response of the known optical pigments.



Lesson-1: Color is a creation of our brain and it reflects only a limited range of the wavelength of electro-magnetic wave.

Now, how much is the sensitivity of our eye with respect to specific wavelength? As the graph bellow illustrates, human eye is most sensitive to the wavelength of 546 nm that correspond to “green” color in our vision. This is why we try to isolate monochromatic green light by installing an interference green filter (IGF) at the back of lamp housing of microscope. This means that significant part of the component of electro-magnetic wave is already lost when light enters into objective lens. This does not mean wrong *per se* because no existing device is capable of recognizing all wavelength anyway.

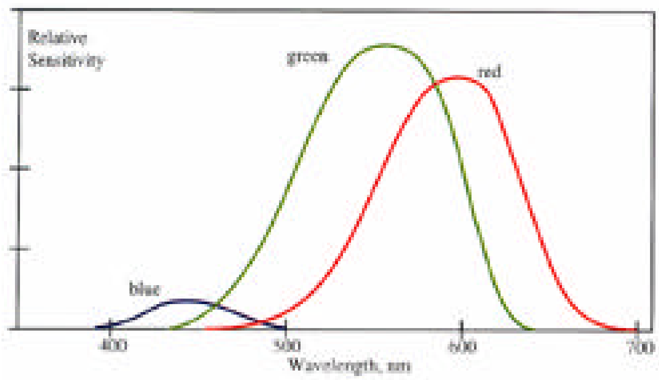
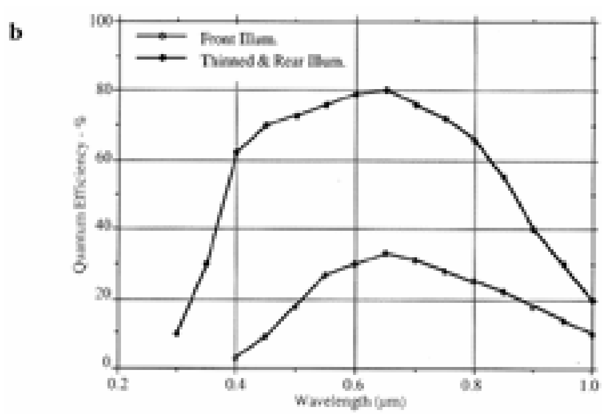


Figure 18. Spectral response:
a) *sensitivity of the cones in the human retina; while they are commonly identified as red-, green- and blue-sensitive, each actually responds to a wide range of wavelengths;*

Inoue and Spring "Video Microscopy" (1997)

Lesson-2: The light signal entering into an objective lens is a selective range of wavelength and may not contain all necessary information.

It is critical to understand that what our eye is seeing is not what an imaging device sees. For example, color films were made such that each wavelength can be translated into a respective color for human eye. In contrast, B/W films and most low-light CCD chips are made for recognition of differences of “contrast” ranging between black and white. What is important is the spectral sensitivity of those devices are unique; different each other and definitely different from that of human eye. For example, the graph below shows the spectral sensitivity of two types of solid state detectors. Each detector shows unique profile and both are different from human eye’s shown above.



b) *response of a solid state detector for the normal case of front illumination, and rear illumination after thinning the support, showing greater red and infrared sensitivity.*

Inoué and Spring "Video Microscopy" (1997)

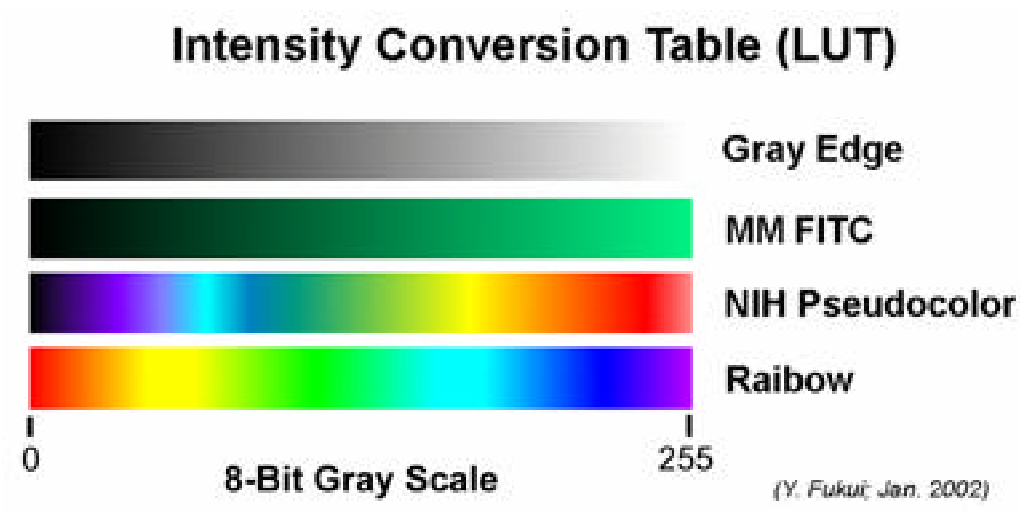
Lesson-3: The spectral profile stored in an imaging device is different from the profile made by human eye. Even if the signal is translated into numbers, they only represent the information reflecting the device’s spectral sensitivity. Note that “spatial” and “temporal” profiles are also unique to each imaging device and, theoretically, exact reproduction of bona fide structure is impossible.

Then, ***what is image***, by the way? Image is made of two components, color and gray scale. When an imaging device translates discrete wavelength into color, it produces a color image. In contrast, discrete steps of brightness is called the "contrast". The brightness can be expressed as gray value where black and white correspond to values 0 and 255 in 8-bit image sensor. When the device is capable of distinguishing more steps, it is more sensitive. Current low-light CCD is capable of 12-, or 16-bit gray scale recognition, meaning it can distinguish 2^{12} (4,096) or 2^{16} (65,536) steps of brightness. Human eye can only distinguish about 50 scales at best.

How about the spatial and temporal sensitivity? It is known that human eye needs to scan an object for at least 0.2 second for recognition and it can only isolate the two objects if their distance is larger than 4.6 µm. More than that, because human vision is produced by complicated pathway including lens, photo sensors, and visual cortex, its accuracy is affected by various factors. (For more detail, see "Human Eyes as an Image Sensor")

Lesson-4: The ability of human eye and image sensor can be assessed using same parameters such as spectral and contrast sensitivity, and spatial and temporal resolution. While human eye has limited ability, so are image sensors. Imaging system needs to be properly configured; otherwise it may create unnatural image profile such as "aliasing" or "moiré pattern", which can be considered an analogy to "hallucinations".

To help demonstrate the gray scale profile, the gray value can be translated into different colors. This is called "pseudocolor" or 'false color". Note that pseudocolor is completely different from the color spectral chart shown above. While the color spectral chart manifests human color vision corresponding to wavelength, pseudocolor uses arbitral translation of the gray scale into color. Below is some examples of the pseudocolor translation called LUT (look-up-table).



Note that if the original gray scale is converted into color, the color bar should be presented demonstrating what gray value is shown in what color. An example below illustrates how the original gray scale image can be presented as pseudocolor (NIH LUT).