Dave Morrow's Photo Editing System for Landscape Photography

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- **L2:** Photo Editing Fundamentals
- **L3:** Advanced Camera Technique / Sharp Focus Black Belt
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- Creating the Image - In the Field to Final Edit
- How to Print Your Photos Like a Pro
- Image Critiques
- Photo Editing - Start to Finish: All Episodes
- Plan Like a Pro: Weather & Location Scouting
- Hiking Equipment & Skills

Photo Editing System Cheat Sheet

SYSTEM 0: Photo Editing Setup & Organization

The "System 0" section in each photo editing course, teaches foundational skills such as software setup, organization, and workflow.

The following linked sections are to be used as "quick reference" after watching the courses, start to finish.

- **Photo Organization System & Workflow Setup (L2)**
  - Folder Setup & Lightroom Organization
  - Portfolio Import Preset for Lightroom
  - Web Sharpening Presets for Lightroom
  - How to Import Your Images into My Lightroom System
  - Hard Drive & Backup Solutions
  - Photo Organization Best Practices in Lightroom
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- **Photoshop & Camera RAW Optimization for Landscape Photography (L2)**
  - Camera RAW Setup & Settings
  - Photoshop Setup & Settings

- Brush Presets - How to Create
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- **Luminosity & RGB Histograms - Understanding Color & Light (L2)**
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  - Layer Masks & Smart Object Basics
  - Super RAW Files
  - Large Document Format for Saving Photoshop Files
- **An Introduction to Luminosity Masks & Channels (L4)**
- **How to Install Dave's Luminosity Mask Actions (L4)**

SYSTEM 1: RAW Photo Editing

The "System 1" section in each photo editing course, teaches my RAW Photo Editing System, including, Steps 1 - 5:

- STEP 1: Initial RAW File Adjustments
- STEP 2: Select a Color Harmony
- STEP 3: Balance the Light Across the Landscape
- STEP 4: Optimize the Color Mood
- STEP 5: Final Adjustments - Balance Color & Light

STEP 1: Initial RAW File Adjustments (L2 & L4)

GOAL: Obtain neutral white / color balance & test RAW file for color, light, and dynamic range.

- Start Here Presets for Color Balance
- RAW Processing Presets to experiment with image

STEP 2: Select a Color Harmony (L2 & L4)

GOAL: Select color harmony of visually appealing colors. My Composition, Color & Light Course + Composition Black Belt Course provide even more tips.

- If you don't have color harmony, it's not worth editing. REF: Black and White Course, if there is no harmony.
- Color Harmony Cheat Sheet is included below in this PDF.

STEP 3: Balance the Light Across the Landscape (L2 & L4)

GOAL: **Global adjustments** to match light & contrast **seen in the field.**

1. Scanning from bottom right to top left
2. Set White Point and Black Point (Basic Panel)
3. Contrast mid-tones, highlights, and shadows (Basic Panel)
4. Optimize final contrast with curves (Curve Panel)

STEP 4: Optimize the Color Mood (L2 & L4)

GOAL: **Global adjustments** to bring existing colors within color harmony & retain color seen in the field. **Remember selective areas** that need to be updated in Photoshop with smart objects, Step 5.

- Scanning from bottom right to top left
- Optimize existing colors to match selected color harmony using any of the following tools:
    - Calibration Panel for Saturation
    - Basic Panel: Saturation & Vibrance Sliders
- Use the Color Mixer Panel to Set Hue first, then saturation, then luminance.

STEP 5: Final Adjustments - Balance Color & Light (L2, L4, L4A, L7B)

GOAL: **Selective RAW file adjustments** that could not be made globally in steps 1-4. Final adjustments to retain color & light seen in the field.

- Scanning from bottom right to top left
- Determine selective adjustment areas and balance the color & light using smart objects.
  - Get in the habit of remembering these during Steps 1-4.
- Advanced Blending Techniques:
  - Exposure blending for "Super RAW" files. (L4 & L4A)
  - Luminosity Masks & Channels (L4)
  - Focus Stacking & Depth of Field (L4A)
  - Time / Motion Blending (L4A)
  - Long Exposures & Water (L7B)

SYSTEM 2: Photoshop Editing

The "System 2" section in each photo editing course, teaches my Photoshop Editing System, including, Steps 6-9:

- STEP 6: Light & Contrast Control
- STEP 7: Color Control
- STEP 8: Atmosphere, Glow, Depth & Texture
- STEP 9: Adding Scale & Perspective - Creative Control

STEP 6: Light & Contrast Control (L2, L4, L6)

GOAL: Selective editing. Draw eyes to interesting areas by lightening and hide boring areas by darkening.

- Scanning from bottom right to top left
- Dodge Midtones on New Layer to emphasize interesting areas. (L2)
    - Shortcut for New Layer
        - Windows: Shift+Ctrl+Alt+E
        - Mac: Shift+Command+Option+E
- Burn Midtones on the New Layer to hide boring areas (L2)
- Levels + luminosity masks (L4)
- Blend modes + luminosity masks (L6)

STEP 7: Color Control (L2, L4, L6)

GOAL: Selective editing. Draw eyes to interesting areas within color harmony with saturation, and hide boring areas outside of color harmony with desaturation.

- Sponge Saturate Color Harmony on New Layer (L2)
    - Shortcut for New Layer
        - Windows: Shift+Ctrl+Alt+E
        - Mac: Shift+Command+Option+E
- Sponge Desaturate Non-Color Harmony on New Layer (L2)
- Saturation & color balance + luminosity masks (L4)
- Saturation painting & channels + luminosity masks (L6)

STEP 8: Atmosphere, Glow, Depth & Texture (L6)

GOAL: Add depth and "interestingness" to photo using the techniques shown in the Level 6 Course.

STEP 9: Adding Scale & Perspective - Creative Control (L4 & L6)

GOAL: Return photo to scale & perspective **seen in the field**.

Steps for "stretching" or free transforming the photo:

- Add crop space to top part of image
- Create new layer:
  - Shortcut for New Layer
    - Windows: Shift+Ctrl+Alt+E
    - Mac: Shift+Command+Option+E
- Use marquee selection tool to select part of image to be transformed
- Use Free Transform to return image scale to what was seen in the field.
- Crop any remaining blank space off the top of the image

SYSTEM 3: Final Clean Up, Saving & Sharpening

The "System 3" section in each photo editing course, teaches my Final Clean Up, Saving & Sharpening System, including, Steps 10-13:

- STEP 10: Final Photo Adjustments & Cool Off Time
- STEP 11: Saving the Final Image
- STEP 12: Importing to Your Lightroom Portfolio
- STEP 13: Sharpening for Web & Print

STEP 10: Final Photo Adjustments & Cool Off Time (L2, L4, L6)

GOAL: Disconnect from the photo and editing process allowing you to make final adjustments with fresh eyes.

- Don't look at photo for a week
- Make any final adjustments
- Clean up with clone stamp tool on new blank layer
- Crop / Free Transform if required
- Move the photo to "Complete - Holding" Folder

STEP 11: Saving the Final Image (L2, L4, L6)

GOAL: Long break to ensure you have a "HECK YEAH" image. It's either heck yeah or no. If you don't love it, fix it so you do, or throw it out and start again.

- Don't look at photos for a month.
- Verify it's "Heck Yeah"
- Set the White Point
- Create a new layer
    - Shortcut for New Layer
        - Windows: Shift+Ctrl+Alt+E
        - Mac: Shift+Command+Option+E
- Select all layers
- Merge all layers > Shortcut for merge
    - Windows: Ctrl+E
    - Mac: Command+e
- Save as .Tiff

STEP 12: Importing to Your Lightroom Portfolio (L2)

GOAL: Import final image into lightroom as TIFF file & clean up photo editing system.

- Drag TIFF file(s) into Lightroom from "Tiff to Portfolio" folder in Bridge.
- Use Portfolio Import Preset in Lightroom
- Delete all files from photo editing system in Bridge, so you only have 2 files left on your computer for each image:
    - The final .TIFF file in Lightroom Portfolio
    - The original RAW file in Lightroom - RAW File Library.

STEP 13: Sharpening for Web & Print (L2)

GOAL: Sharpen photo for your online portfolio, or social media display. For printing, Reference: How to Print Your Photos Like a Pro Course.

- In Lightroom,
- Increase White Point for sRGB (it will look too bright)
- Increase Vibrance & Saturation for sRGB (it will look too saturated)
- Export Preset - Web Sharp JPEG in sRGB
- Reset the TIFF file in Lightroom to remove the white point, vibrance & saturation adjustment:
    - Mac Shortcut: Shift+Command+R
    - PC Shortcut: Shift+Control+R

Reference List - Advanced Editing Skills

This section pulls the advanced skills from across all of my courses into one location so you can easily access them.

This list links to specific skills after you have watched the entire course, from start to finish. Going directly to the specific videos before watching the whole course will not make sense.

L4A: Black Belt Blending | Focus Stacking, Dynamic Range & Movement

- **FOCUS STACKING for DEPTH OF FIELD**
  - Basics of Automated Focus Stack Technique
  - Manual Focus Stack Technique [Wide Angle Lens w/ Flowers]
  - Automated Focus Stack [Wide Angle Lens w/ Ferns]
  - Automated Focus Stack [Telephoto Lens in the Forest]
- **EXPOSURE BLENDING for HIGH DYNAMIC RANGE**
  - Test Your Camera - How Many Exposures Do You Need for Dynamic Range?
  - Exposure Blending Basics
  - 2 Exposure Blend [Low - Medium Dynamic Range Scenes]
  - 3 Exposure Blend [High Dynamic Range Scenes]
  - Super RAW Exposure Blend [Extreme Dynamic Range Scenes]
- **TIME BLENDING for DYNAMIC SCENES**
  - Basics
  - Light Blending
  - Cloud Blending
  - Clouds &Water Blending
  - Rain Spot Removal
  - Light Painting for Night Sky Photography
  - Rivers & Streams Movement
  - Waterfalls Movement
  - Star Trails Blending

Color Harmony Cheat Sheet

My Composition, Color & Light Course + Composition Black Belt Course provide even more tips.

Key Color

Key color is the main or most dominant color in the image.

- Without the key color, the image does not work.
- Don't worry too much about there being a "right" key color. Just pick a dominant color and go with it.

In the painting below, blue was used as the key color. The entire top of the painting includes different tints and shades of blue. All Paintings by Albert Bierstadt

Complementary Color Harmony

A complementary color harmony includes the key color and another color that lies directly opposite on the color wheel.

Complimentary colors produce a high contrast between colors known as color contrast.

Color contrast is produced when warm & cool colors are displayed side by side, of varying lightness values, high and low.

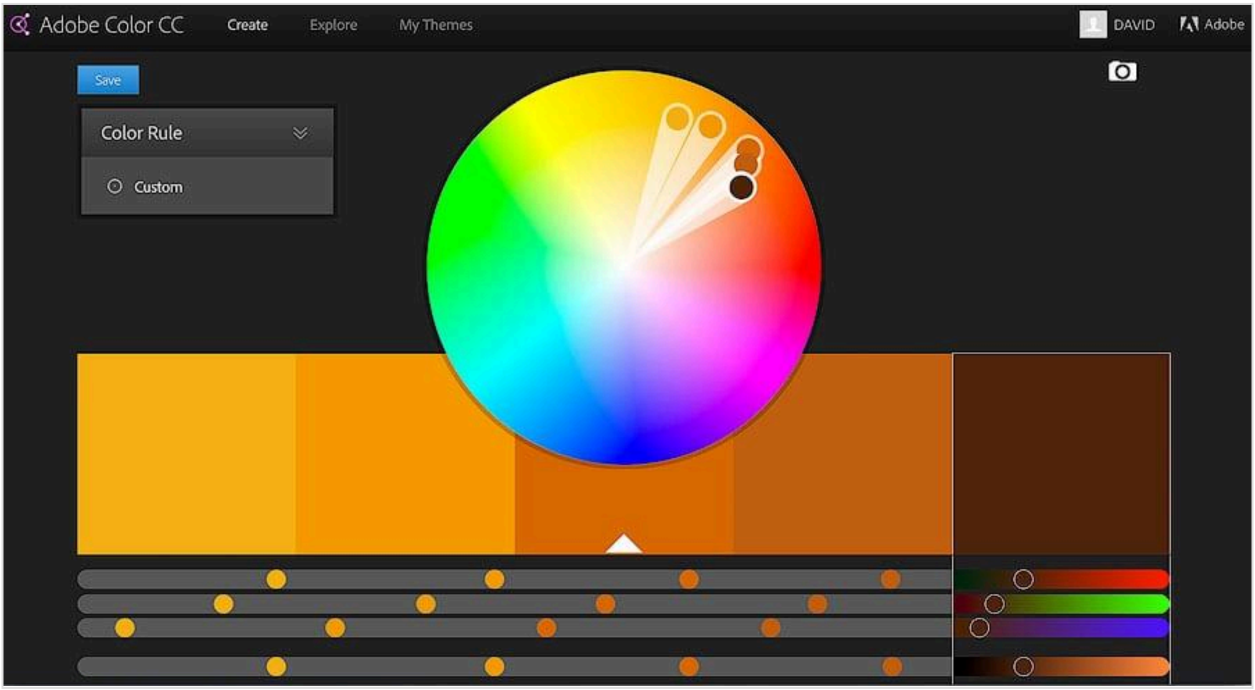
In the following image, the key color is blue and the complementary color is yellow. Different colors of blue and yellow are shown throughout the image, providing depth.

A dark shade (black added to a color) of green is present in the foreground but doesn't draw much attention.

Photographers can remove attention from unwanted objects by burning or darkening them in post-processing.

This causes the viewer to look at the brighter & more vivid colors first.

Analogous Color Harmony



Analogous colors lie directly next to each other on the color wheel.

Different tints (white added), shades (black added), and tones (gray added) of orange are used in the painting above.

The key color is clearly orange.

Analogous color harmonies are often found in nature and work very well for scenes with high tonal contrast.

Without large areas of dark to offset the warm colors the painting would be overwhelming.

Our eyes easily move around the painting due to the large numbers of different shades showing transitions from light to dark.

Triadic Color Harmony

The Triad or Triadic Color harmony uses 3 or more colors, spaced evenly, producing the points of a triangle.

Triadic color harmonies are often vibrant due to the spacing of the colors.

Usually, the Key Color is dominant while the other colors are more subdued.

In the painting above, high contrast is used in the foreground with shades (black added) of orange and green, while low contrast is used in the background with tints (white added) of blue, green, and orange.

Shading objects often makes them appear closer, and tinting objects often make them appear further away.

Tinting the background colors provides the feeling of diffuse, dense, and humid air catching the sunlight.

A transition from dark to light adds a sense of depth to the entire scene.

The cool colors of blue (sky) offset the warmer tints of orange (rocks), providing leading lines, moving your eyes from left to right through the painting.

On the right side of the large warm colored rocks, a green shade is used to provide depth & detail to the shadows.

Split-Complementary Color Harmony

The split-complementary color harmony is easy to use and often found in nature. Most sunsets and sunrises display this color harmony.

- After selecting the Key Color, find the complementary color that lies directly across from it.

- The split complementary colors are found on each side of the complementary color. They do not include the complementary color.

In the painting above blue is most likely the key color. It is found in the sky, waterfall, river, and shadows. Yellow and orange shades & tints are used as the split complementary colors.

Dark reds are used in the foreground producing an autumn scene, while saturated yellow is used for the center trees signifying a source of light.

Objects hit by direct sunlight often appear much more saturated than the same objects untouched by light.

Square Color Harmonies

By selecting a dominant key color and 3 subdued colors, spaced evenly around the color wheel, the square color harmony is formed.

This can change to a Rectangular Color Harmony by slightly moving each color. Test it out and see what works!

- The square color harmony is perfect for displaying the single most important object in a scene.
- All other subdued colors in the square are used to complement the key color and make the subject of the work stand.

Below, light yellow or blue is most likely the key color. Either will work in this case.

Without blue, the mountain is not dominant. Without yellow, the mountain also loses its power.

Both colors provide a stark color contrast of low and high lightness values.

All other colors, such as dark green, dark blue, and dark red complement and add more depth to the painting. The subject is clearly the peak, Mount Adams, which lies in the wilderness of my home state, Washington.

Fundamentals of Color & Light

Light is the single basic ingredient required to create photographs. Without light, pictures don't exist.

Digital photography is the process of transferring light energy, carried by photons, into digital information, which can be processed and displayed by computers and cameras in the form of digital images.

Light also contains the ability to produce color. Color is produced by specific energies or frequencies of light, known as visible light.

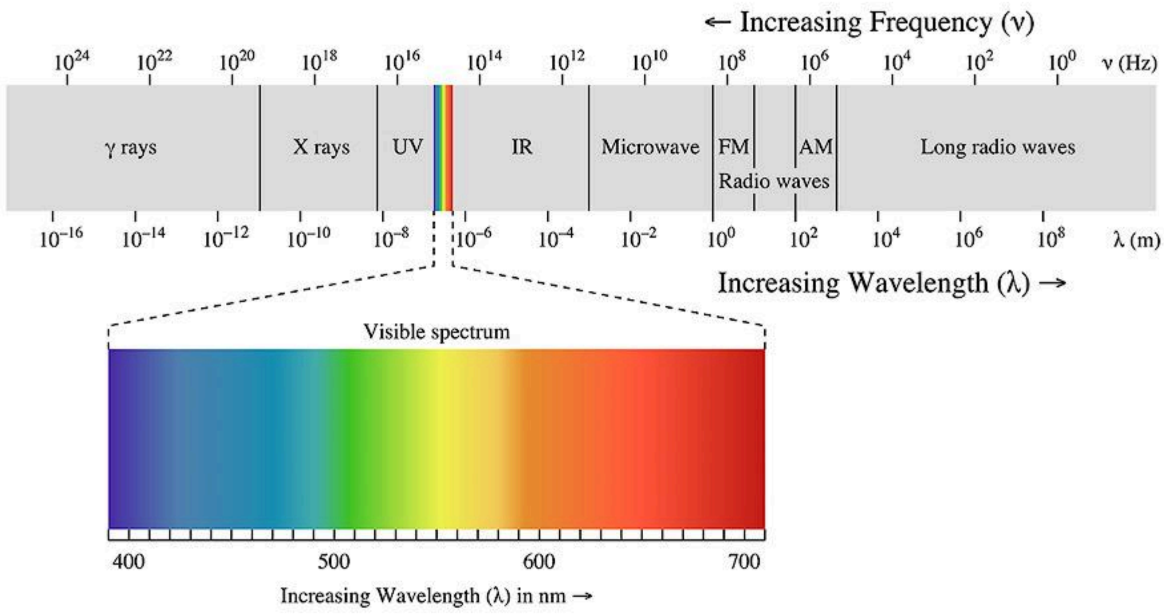
Understanding color theory and creating beautiful images requires a basic knowledge of color & light.

This basic understanding is essential for mastering all other aspects of photography, including shooting & photo editing.

Creating Color - Light Waves & Frequency

Light waves carry energy, determined by frequency, carried by small packets known as photons. This energy provides the basis for human vision, solar power and digital photography.

The human eye can see light that exhibits a certain range of energy. Energy contained in light photons interacts with the retina (rods & cones), releasing energy as electrons, creating electrical impulses, communicating with our brain to produce vision. Specific colors correspond to specific frequencies of light as shown in the graphic below.



Graphic Attribution - Philip Ronan

When light waves & photons interact with silicon image sensors free electrons are released from the collision.

The number of electrons released depends on the photon energy. The photon energy depends on the light frequency.

Pixels are small buckets for collecting & counting electrons. They are the basic building block of image sensors found in digital cameras.

Understanding Light Frequency

Compare light & light waves to ocean water hitting the beach as waves throughout the day.

Although the ocean is a single object, each of its waves carries different amounts of energy, acting as a separate entity.

Storm waves coming in very quickly, hitting the beach one after another, every second, contain a large amount of energy, often destroying buildings or boats.

Calm weather waves may only hit the beach every minute. The energy contained in calm weather waves is much less, allowing visitors to lay on the beach in the sun.

The energy carried by these waves can be defined by the frequency or number of waves coming in one after another.

The horizontal distance from the top of one wave to the top of the following wave is defined as 1 wavelength.

Waves coming in during a storm, very quickly, have a high frequency. High-frequency waves have small wavelengths with less distance from one wave top to the next.

During calm weather waves have a low frequency. Low-frequency waves have large wavelengths as the distance from the top of one wave to the next is much larger.

The characteristics of wavelength and frequency determine the energy carried by water and by light waves.

Photons - The Building Blocks of Light

Photons are the basic building blocks (particles) of light waves, which carry energy, determined by wave frequency. The number of photons is proportional to the amount of energy & light.

More Light = More Photons = More Energy

Less Light = Less Photons = Less Energy

Photons make up light waves yet have the ability to interact with their surroundings as singular particles.

Photons are waves and particles at the same time, thus photons maintain a "wave nature". This wave-particle nature or Wave-Particle Duality as taught in particle physics and quantum mechanics.

Light does not contain color and neither do photons.

Light & photons carry energy determined by frequency. When this energy interacts with another object, evolved or designed to "see" visible light, such as the human eye or an image sensor, color is perceived.

Different colors are the resultant of different light energy levels, determined by the the light wave's frequency, using the following simple equation:

$$E = h*f$$

E is the photon energy, h, is Planck's Constant & f is the lightwave's frequency.

Increased Frequency = Decreased Wavelength = Higher Photon Energy

Decreased Frequency = Increased Wavelength = Lower Photon Energy

Pixels - Buckets for Collecting Light

As light / photons collide with the image sensor free electrons are released from the sensor's surface.

Imagine a missile (photons) hitting a brick wall (sensor), pieces of brick (electrons) will fly everywhere.

Each free electron carries a small electronic charge.

Pixels, the smallest unit of the image sensor, are buckets for storing and counting electrons and their corresponding electronic charge.

This charge, collected by each pixel, produces a digital signal which communications the pixel color into digital space, using binary code (zeros & ones).

This massive amount of information is all carried by light, at the speed of 299,792,458 meters per second or 983,546,666 feet per second.

This entire section can be summed up by the following two equations:

More Light = More Photons = More Electrons = Larger Signal = More Photo Information

Less Light = Less Photons = Less Electrons = Smaller Signal = Less Photo Information

The Language of Color & Light

Prior to learning color theory, which contains the best practices for mixing, editing and displaying color in photographs, a basic understanding of the technical language is required.

This language is also used by camera software, and image editing programs such as Lightroom, Camera RAW, Capture One, and Photoshop.

RGB Color Wheel

The RGB Color Model, most often used in photography, is a language of color.

A color model is a system used to define & communicate color. RGB simply defines the primary colors for this model which are Red, Green, and Blue.

Color gamut is the entire range of possible colors which can be produced by mixing the three primary colors.

Combining primary colors, which lie adjacent to each other on the color wheel, produces secondary colors.

Red and blue produce magenta, blue and green produce cyan, green and red produce yellow. There is a nearly infinite number of different color combinations.

Photo editing programs such as Lightroom, Photoshop & Camera RAW use 3 basic technical terms to describe color & light, they are as follows:

Luminance - The Absolute Measurement of Light

Luminance measures the absolute intensity of light, that hits the eye, after reflecting off an object.

Luminance is measured in candela per square meter, written as cd/m^2.

Luminance is a measured value such as velocity or weight. It does not depend on the human eye or setting, only measured physical attributes.

Brightness - Our Perception of Luminance

Brightness is used to denote how the human eye perceives the luminance of an object.

For example, a computer screen at maximum luminance looks brighter in a dark room than it would outside in the sun.

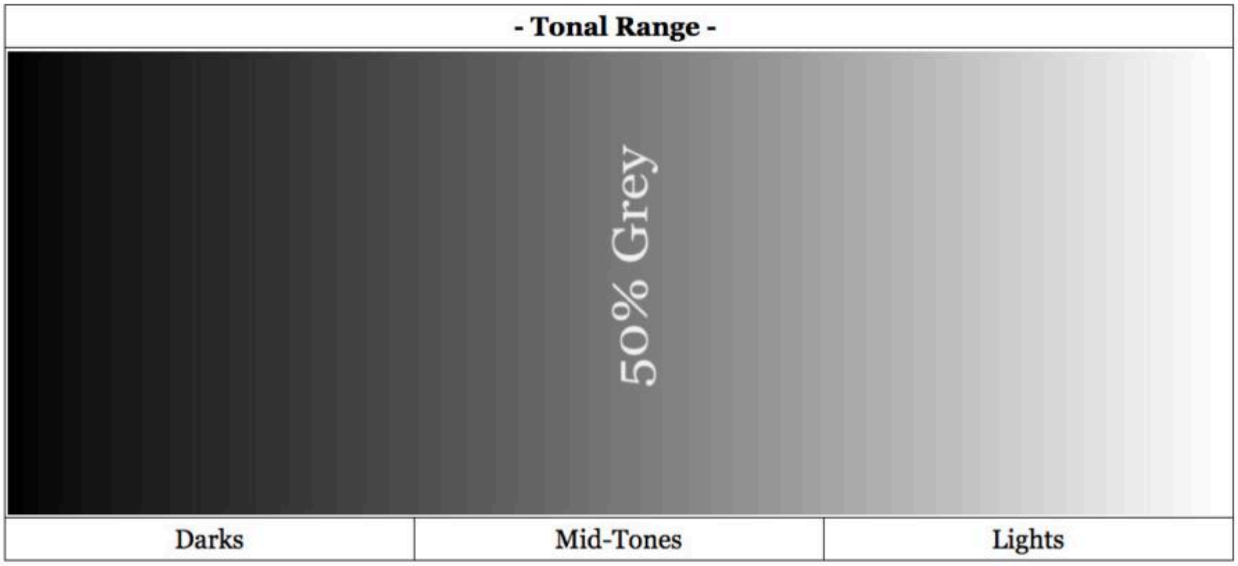
Although the luminance of the computer screen is the same our eyes perceive it's brightness differently, depending on the conditions for viewing.

Brightness can range from dim, at the low end, to brilliant at the high end. Brightness is perceived value. It is not measured. It changes dependent of surroundings.

Lightness (Luminosity) - Our Perception of Brightness

Lightness, also known as luminosity, is the perceived brightness of an object when compared to another 100% white object, both illuminated by the same light source.

Lightness is the perception of brightness, without color information, on a scale from



black to white.

The lightness or luminosity scale, ranging from black to white, is known as the tonal range or tonal scale.

Pure black is found on the far left and has a lightness of 0%. Pure white is found on the far right and has a lightness of 100%.

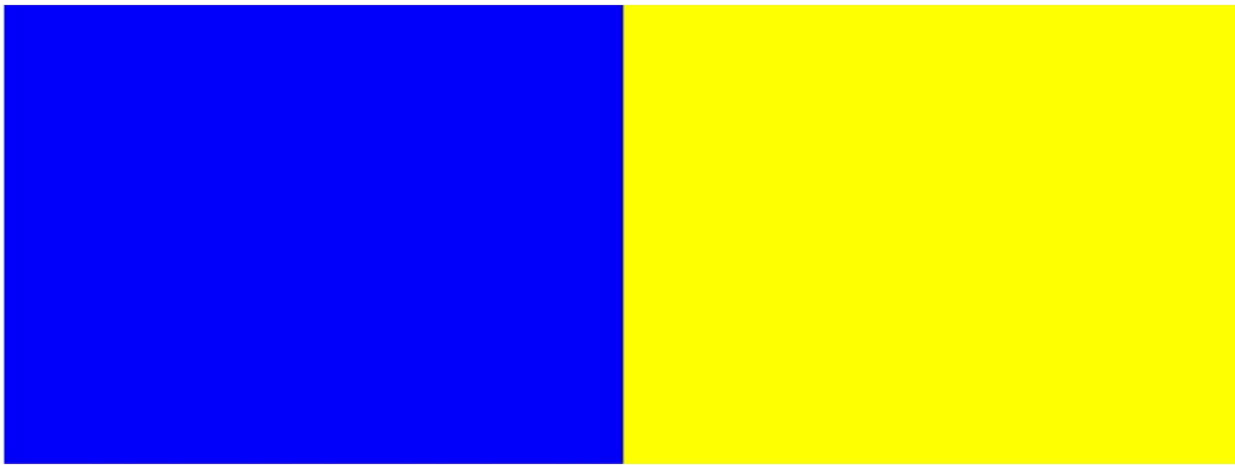
In the direct center of the tonal range lies 50% gray, which is a mixture of ½ black and ½ white. 50% gray also known as middle gray, has a lightness of 50%.

Many make the mistake and call this 18% gray. 50% gray has an 18% reflectance in visible light. It is not 18% gray.

Image histograms depend on luminosity, to display lightness information, for each pixel contained on the image sensor.

Understanding Luminosity - Brightness vs. Lightness

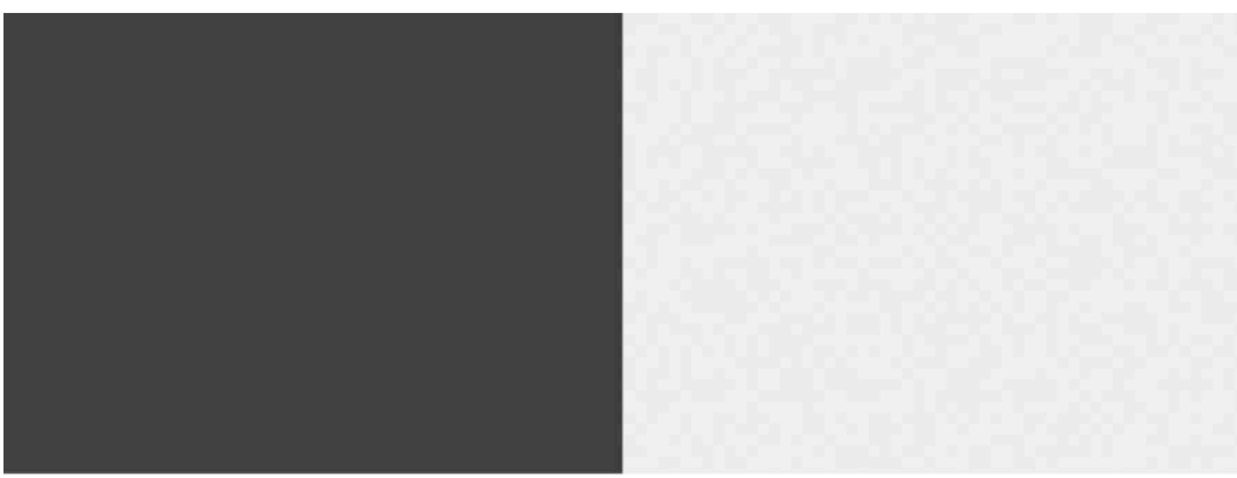
The following colors of yellow and blue have the same brightness, as viewed on the screen, but our eyes perceive this brightness differently.



- Compared to blue, our eyes perceive the brightness of yellow to be closer to white.
- Compared to yellow, our eyes perceive the brightness of blue to be closer to black.

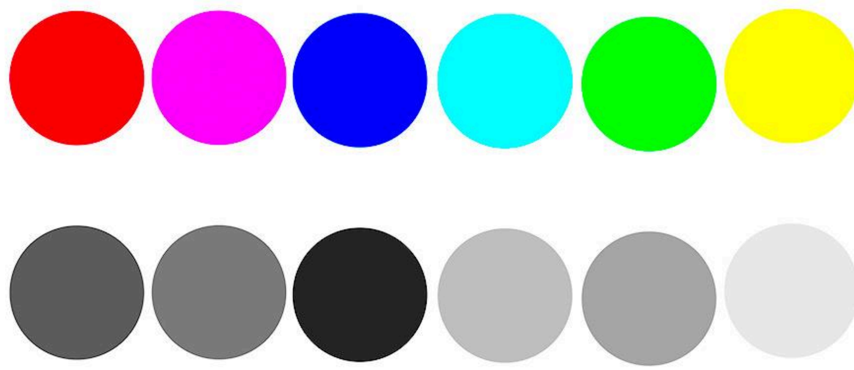
Yellow has a higher perceived brightness value, known as lightness, when compared to blue.

On the tonal scale, blue's lightness is provided on the left and yellow's lightness is provided on the right.



Just remember, lightness is the perception of brightness, without color information, on a scale from black to white.

In this last example, we look at 5 different fully saturated colors at 100% brightness, along with tonal values of how the human eye perceives their brightness, also known as lightness or luminosity.



The brightness of pure green and pure magenta are exactly the same in the color example above.

Our eyes perceive their brightness to be slightly different as seen in the tonal values provided below each color.

The perceived brightness, known as lightness, of green is greater than that of magenta.

These techniques are the basis for color contrast & color theory as taught in the following section. **Luminosity (Lightness) is one of the most important concepts in photography!**

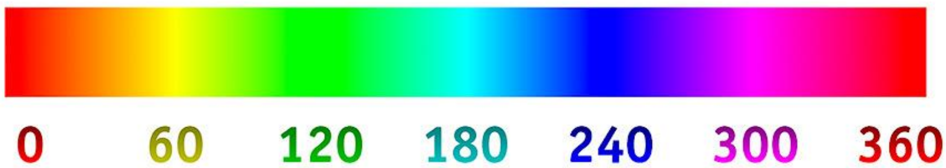
Now we will learn to control color using Hue, Saturation & Brightness.

What is Hue?

- A hue is a color without any black, white or gray added to it.
- A hue is known as a pure color.

Hues are shown in the graphic below. Usually, hues are labeled by degrees corresponding to their location on the color wheel circumference.

All hues are colors, not all colors are hues. To produce different colors, hues are tinted, shaded and toned.



What is Tint, Shade & Tone?

Adding white to a color is known as Tinting.

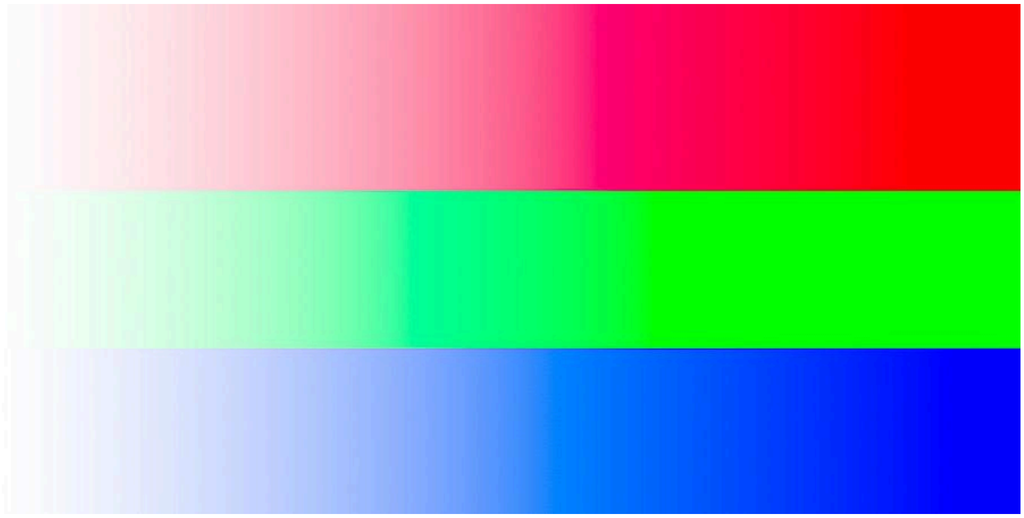
Adding white to a hue, such as green, which lies at 120 degrees, produces different tints of green, ranging from pure green hue to almost white color.

As colors are tinted their lightness (luminosity) value increases, on the scale of black to white, known as the tonal scale.

A luminosity histogram, as found in cameras and photo editing software provides lightness values for each pixel. As colors are tinted, the histogram shifts to the right, towards white.

The three primary colors in the RGB Color model are shown below. Pure hues are found on the right.

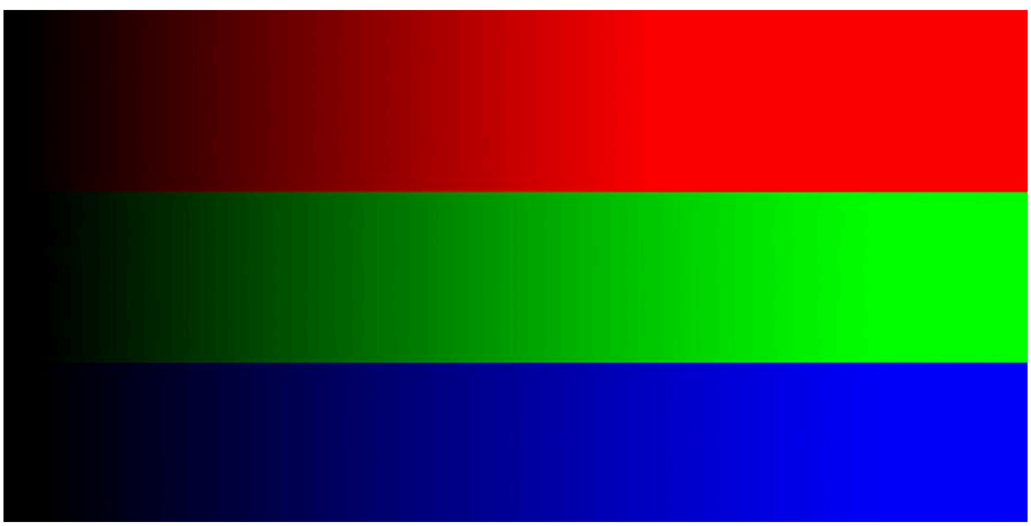
As white is added, the hues become tinted, and the lightness increases. Any color that's not pure white can be tinted.



Adding black to a color known as shading.

Shading decreases the lightness value of colors, decreasing their perceived brightness on the tonal scale. When a color is shaded, the histogram shifts to the left, towards black.

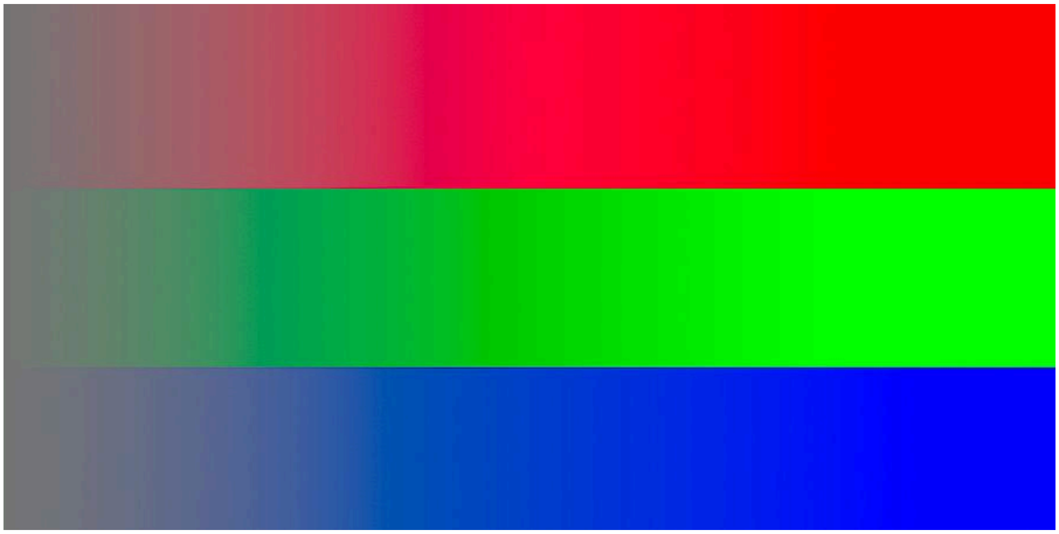
Hues are found on the far right, as black is added they become shaded and appear darker.



Adding gray to a color is known as toning.

The graphic below shows the addition of 50% gray (half black / half white) to red, green and blue.

Toning doesn't always have to consist of 50% gray, but can include all tonal values of gray.



What is Saturation in Photography?

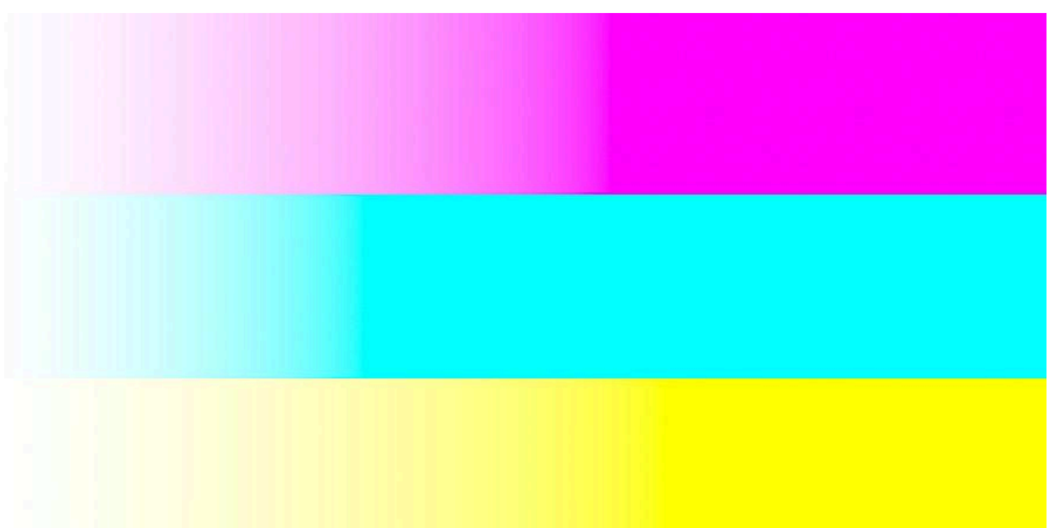
- Saturation is the purity of a color.
- Fully saturated colors are hues or pure colors.
- Non-saturated colors, known as tones, lie on the black to white tonal scale.

The more saturation a color has, the more vivid it looks to the human eye. The less saturation a color has the more washed out or faded it looks.

- Adding white to any color, known as tinting, desaturates it.
- Since toning adds white & black to a color it also desaturates the color.

Adding pure black, known as shading, does not desaturate a color, yet lowers it's lightness value, or perceived brightness, shifting the histogram to the left.

In the graphic below, fully saturated hues, magenta, cyan and yellow are found on the far right. As the colors are tinted, and white is added, the saturation lowers.



As a color becomes more tinted and desaturated, the luminosity or lightness of the color increases, as the perceived brightness becomes closer to pure white. This shifts the histogram to the right.

Photo Editing with The Color Wheel

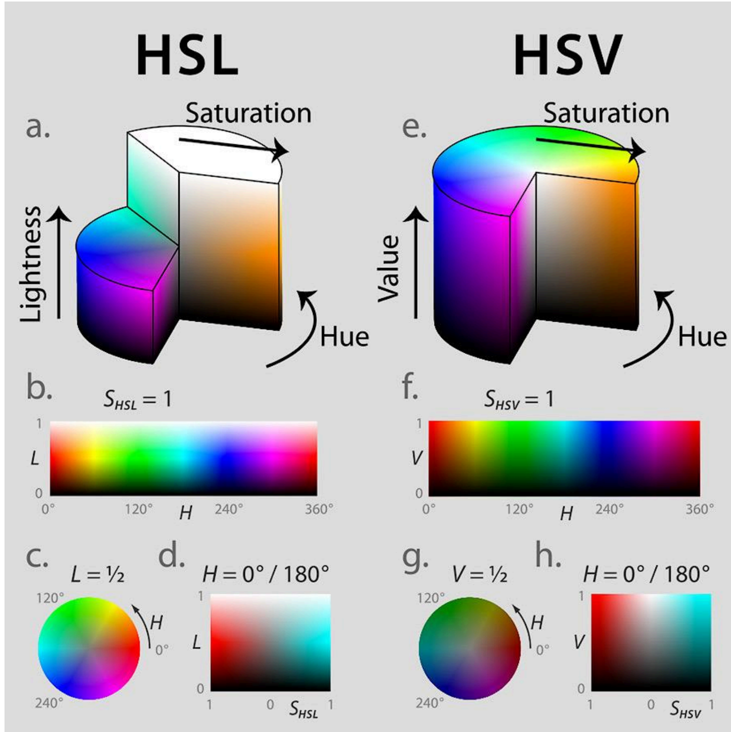
We use cameras, computers, and software to capture and manipulate digital images.

Therefore we need a way to communicate specific color properties with these electronic devices. Color Coordinate Systems allow us to do this.

The HSL Scale (Hue, Saturation, Lightness) is a cylindrical coordinate system used to represent all colors in the RGB Color Model.

The HSV Scale (Hue, Saturation, Value) is also a cylindrical coordinate system used to represent all colors in the RGB Color Model.

Sometimes HSV is referred to as HSB or Hue, Saturation, Brightness. They are one in the same. Brightness and Value, represent the same thing.



[Graphic Attribution: Jacob Rus]

Adobe Lightroom and Adobe Photoshop, as well as most other photo editing programs, use a combination of HSL and HSB Scales for the representation and adjustments of color and light.

Becoming proficient in digital photography requires the mastery of digital editing software, just as film required mastery of the darkroom.

Digital editing software is used to post process RAW files as film negatives were post-processed in the dark room.

Take a few minutes to look at the graphic comparing the HSL & HSV Scales.

Opening Photoshop and following along from here on out will ensure a firm understanding of this topic.

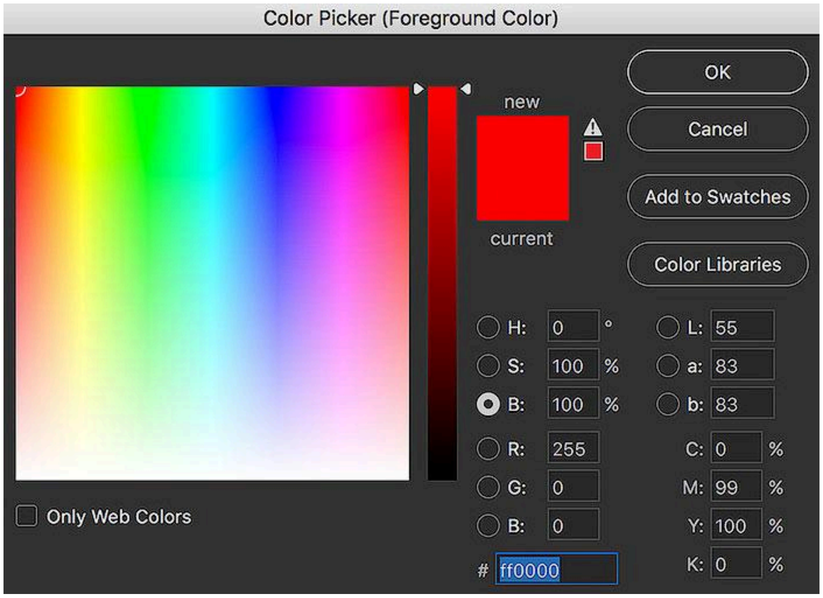
HSL vs. HSV in Photoshop

In both HSL and HSV color coordinate systems hue and saturation denote the same characteristics. The only difference between the systems, Lightness & Value.

Views ***b.*** & ***f.*** in the graphic above show the Lightness and Value Scales. Each of these systems communicates exactly the same colors, but they do it in a slightly different language.

The HSV/HSB Coordinate System

HSV can also be represented as HSB or Brightness in some circumstances. Value and Brightness are the same. The Color Picker in Photoshop utilizes the HSV/HSB Coordinate System.



The B (Brightness) Scale, selected in the graphic above, ranges from 0% which represents pure black to 100% which represents full brightness for all colors.

These brightness values can be adjusted by dragging the slider up and down or typing in different values for B.

The Color Picker Box shows the Hue & Saturation Axis for the specified levels of brightness.

Different hues are selected by dragging the color picker left or right on the horizontal axis.

Different saturation values are obtained by dragging the color picker up and down on the vertical axis, ranging from pure color (hue) at the top or 100% saturation, to pure white at the bottom, or 0% saturation.

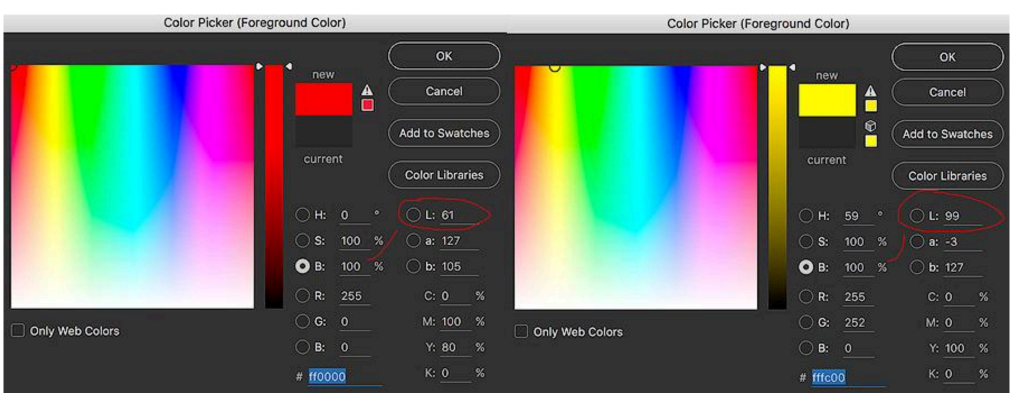
Dragging the slider down on vertical axis tints the color.

It's also possible to show the other color picker axis adjustments by selecting the "S" or "H" circles in the color picker box.

I prefer to leave the Hue Selected for the slider, showing Saturation & Brightness in the color picker box.

As seen below (right example), At 100% brightness, the lightness for a fully saturated yellow hue is 99.

In comparison to pure white yellow has 99% the lightness value. To the human eye, this hue and saturation of yellow is perceived to be 99% as bright as pure white.



Let's look at another pure color of 100% brightness and saturation. In this case, the color red has a Lightness of 61 at a brightness of 100.

Although both yellow and red can have the same brightness, pure red hue is only 61% as bright as pure white, whereas yellow is 99% as bright as pure white, as perceived by the human eye.

The HSL Coordinate System

The HSL Coordinate system (in Photoshop) uses lightness values scaled from Lightness = -100, which represents black, to Lightness = 100 which represents white. As previously discussed, lightness works on the tonal scale from black to white.

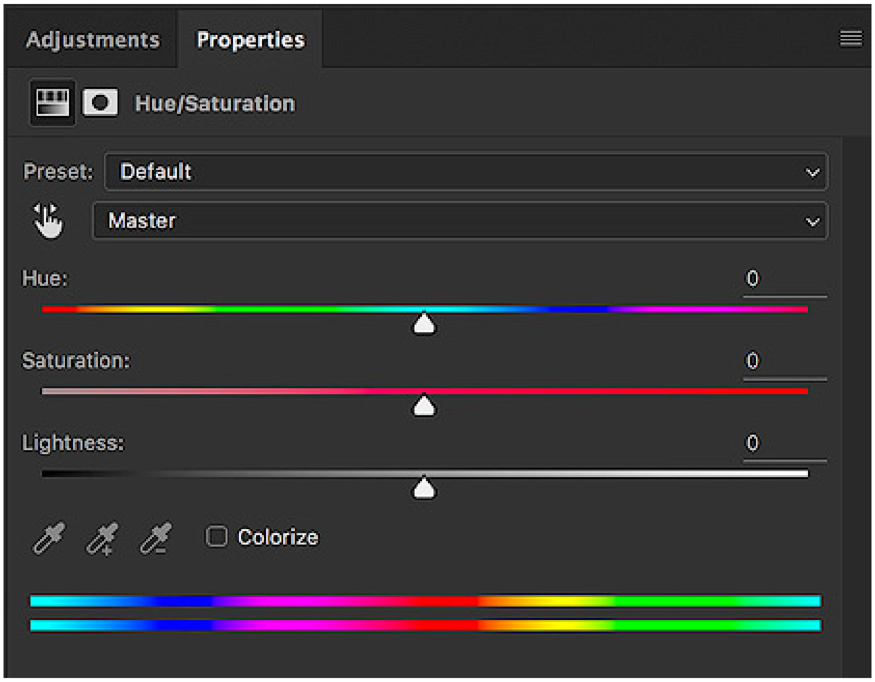
TECHNICAL NOTE: Some programs or graphics call the lightness of black, 50% gray, and white, 0, 1/2 and 1, respectively. Since lightness is a scale, the number designation does not matter, only the understanding of the concept.

While the HSV system requires a change in saturation value to obtain pure white, the HSL system does not.

This is the main difference in the two systems. The HSV System is on the brightness scale, while the HSL System is on the lightness (perceived brightness) scale.

Since hues are colors without any tint (white) or shade (black), they can only exist at Lightness = 0 for the HSL System, as seen in the Photoshop screen shot graphic. This graphic shows the HSL Adjustment within Photoshop.

The three sliders below allow the user to select any point in the HSL Coordinate System.



The saturation slider ranges from 50% gray at the far left to fully saturated color at the far right.

The lightness slider ranges from black at the far left to white at the far right. The hue adjustment is a standard 0-360 degrees.

Photoshop allows the selection of each color via a slider to reduce the number of sliders that need to be shown on the page whereas Lightroom shows each slider for each main color.

Key Points to Remember - HSL vs. HSB

The HSL Color System shows the entire range of any selected color from black to white.

The HSB Color System shows the entire range of color from black to full-color brightness.

White can only be obtained in HSB by decreasing saturation to 0%. HSB Condenses the same information into a smaller vertical axis.

These concepts will only start to make sense once you open Photoshop and start experimenting with the HSL Sliders & the color picker tool. This technique is shown in the video at the top.

Now that you understand the nature of color and light, and it's communication into the digital world, it's time to learn about color theory and color harmony.

Understanding Color Harmony

Color Theory provides the best practice methods for displaying & combining colors in ways that evoke certain feelings, moods or emotions. Science and psychology show that certain color combinations attract viewers while others repel them.

The human eye favors visually appealing color combinations known as color harmonies.

Photographers and artists can utilize this knowledge to create appealing works of art which communicate clearly with their audience.

Color Harmony

A color harmony is the display of two or more different colors, in close proximity, that complement each other and look appealing to the human eye.

Combining the incorrect colors produces an undesired & confusing effect, similar to screaming kind words in an angry voice.

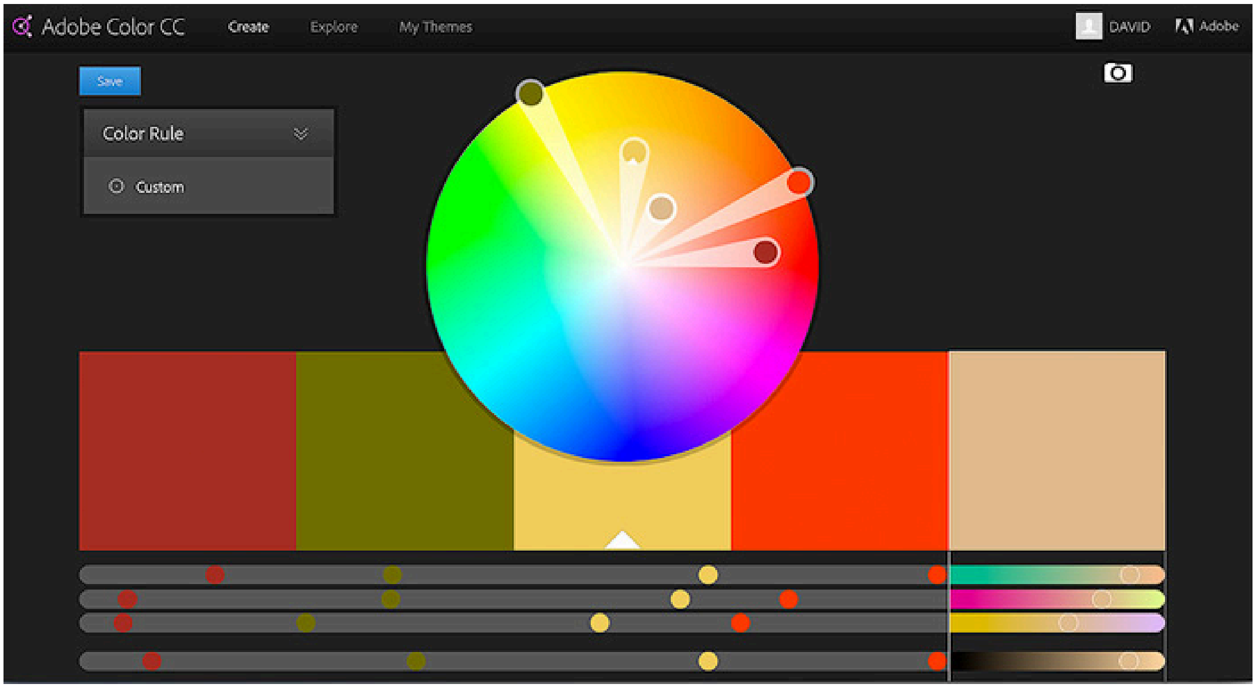
Combining the correct colors communicates the correct message from the photographer to the viewer, in complete harmony, without confusion.

- Nature provides the best examples of color harmony making these methods perfect for photographers & painters.
- Using a color wheel makes it much easier to select colors that provide harmony.

Shown below is a free color wheel provided by Adobe Kuler which also integrates with Photoshop as shown in the video above.

- The colors extending from yellow, orange, and red, to red magenta, are considered warm colors.
- The colors extending from magenta blue, blue, cyan, and green, to yellow-green, are considered cool colors.

The top graphic shows different arbitrary warm colors, while the bottom graphic shows different arbitrary cool colors.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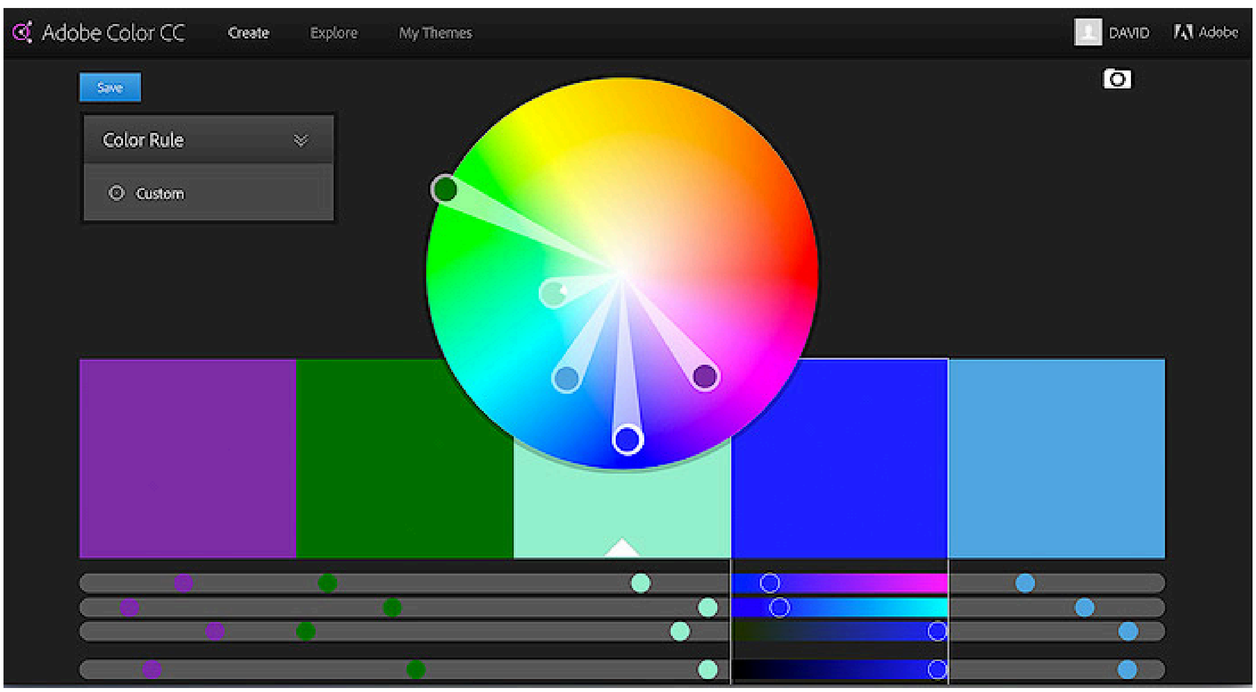
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The color wheel shows a 2D view of the Saturation and Hue Axis, while the Brightness Axis is accessed using sliders on Adobe's website.

- Full saturation and pure color (hues) are found around the circumference of the color wheel.
- Moving directly inward from each hue decreases saturation and adds white to the color, also known as tinting.

A Color transition moves your eyes through a photo by drawing them from warm to cool colors or other color harmonies. This is accomplished using color contrast.

Colors can also add mood or emotion to your photos. Red and orange provide feelings of energy or happiness, while certain colors of green and blue create calm or relaxed moods.

Types of Color Harmonies

Although photographers don't have as much control over color choices as do painters, they can still use color theory to their advantage.

There are 5 different types of color harmonies covered below which provide a nearly infinite number of color combinations. Other color harmonies exist, but a knowledge of the basics works perfectly.

Key Color is the main color which is selected for use in a work of art or photograph.

The key color is the single most important color in the image, without it everything else falls apart.

Most often the key color is the most dominant or frequent color in an image or work of art.

In the following examples, Albert Bierstadt's paintings are used to display perfection in color theory. Bierstadt was known for his renditions of the American West during the mid to late 1800s. He is my favorite artist:)

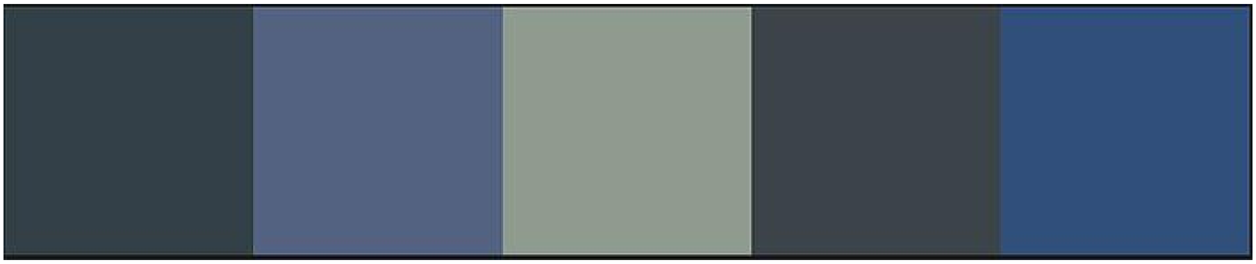
You can view all of his paintings here.

Key Color

In the painting below, blue was used as the key color. The entire top of the painting includes different tints and shades of blue.

By downloading Bierstadt's paintings each can be studied using the color picker in Photoshop or Adobe Kuler's photo upload option.

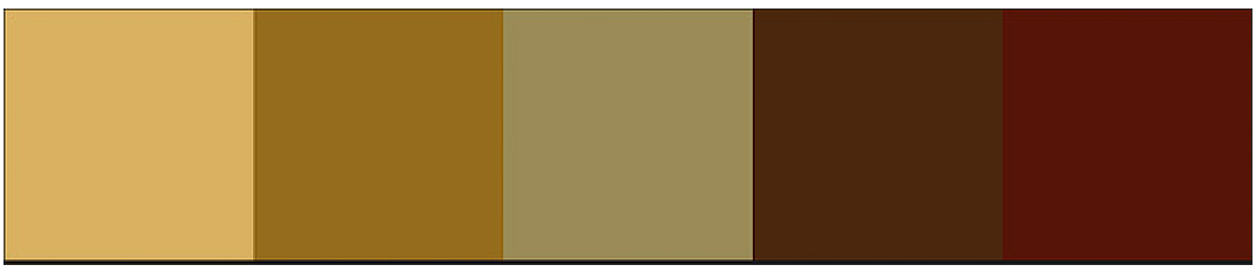
The following color pallet was created from the Key Color tones in the painting above.



Even the dark tones which appear almost black have a slight blue shade in them.

Dark shades in the shadows offsets the bright warm colors used to show vivid light hitting the righthand foreground and mountain peaks.

This is a color transition, which moves the eye through the painting, utilizing color contrast.



Color contrast is produced by colors of varying lightness or luminosity values. Blue has low lightness values whereas yellow has higher lightness values, producing contrast.

In nature, objects lit by sunlight produce warm colors while objects in shadows often produce cool colors.

Our mental idea of an object's color in a landscape, such as grass being green, is often incorrect when taking lighting into consideration.

Grass under bright sunlight, although green without lighting, takes on a yellow-green color.

Grass in dark shade, although green in standard lighting, takes on a cool blue-green color. I've provided some examples of this in the next section.

This offset of warm and cool colors is a specific type of color harmony. There are many different types of color harmonies, providing the best practice methods for aesthetically pleasing color pallets in photography & art.

Direct / Complementary Color Harmony

A direct color harmony, also known as a complementary color harmony, includes the key color and another color which lies directly opposite on the color wheel.

Using direct color harmonies produces a high contrast between colors known as color contrast. Color contrast is produced when warm & cool colors are displayed side by side, of varying lightness values, high and low.

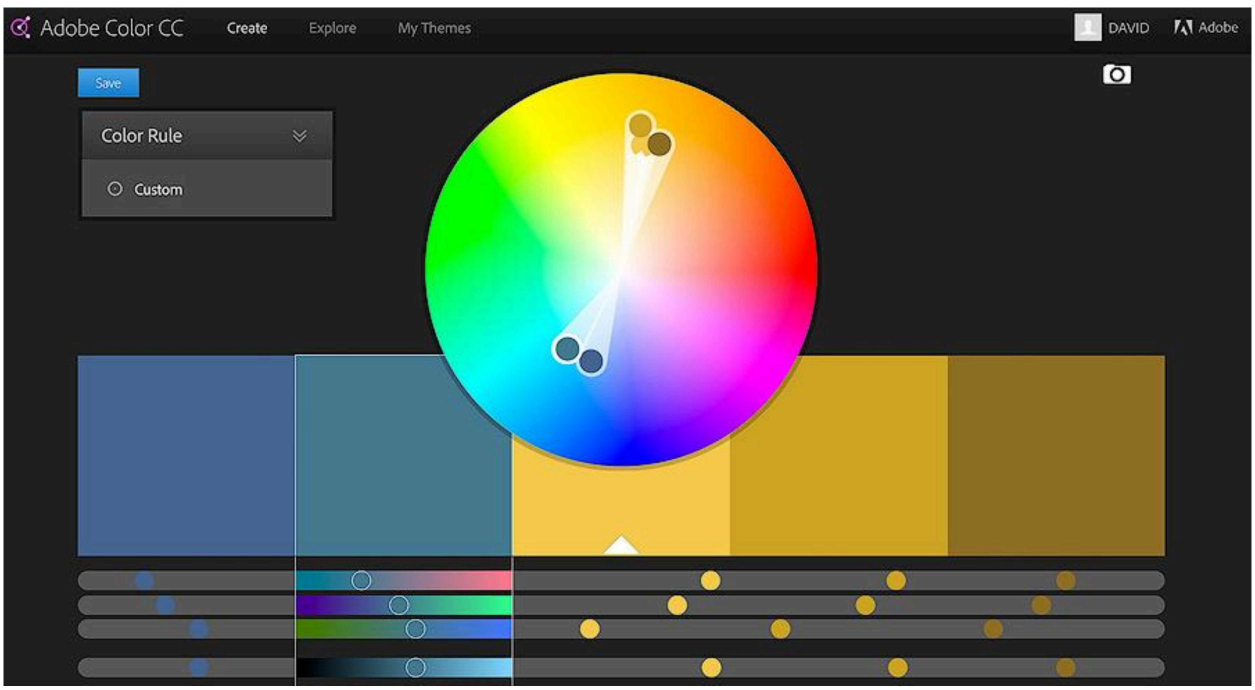
In the following image, the key color is blue and the complementary color is yellow. Different colors of blue and yellow are shown throughout the image, providing depth.

A dark shade (black added to a color) of green is present in the foreground but doesn't draw much attention.

Photographers can remove attention from unwanted objects by burning or darkening them in post processing.

This causes the viewer to look at the brighter & more vivid colors first.

Examples shown on next page….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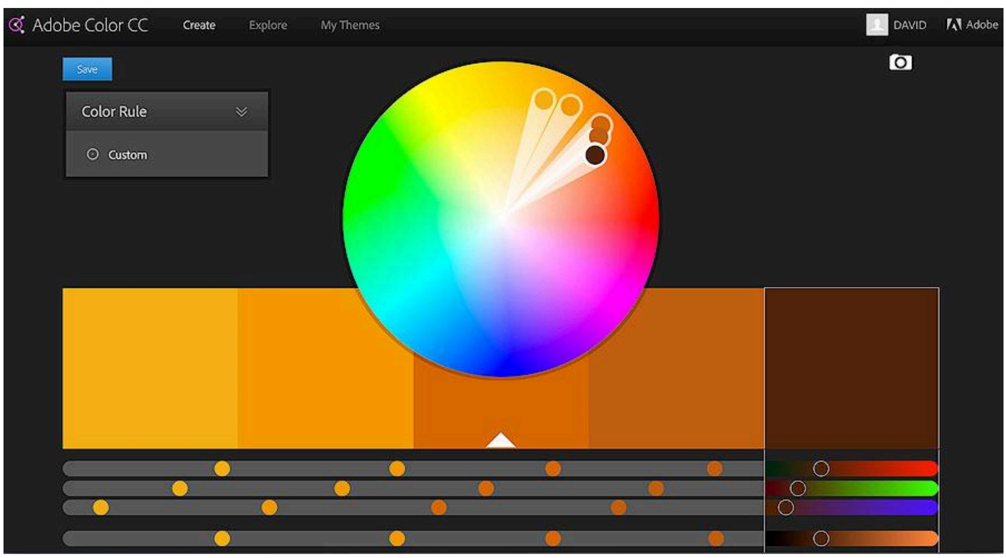
Analogous Color Harmony

Analogous colors lie directly next to each other on the color wheel. Different tints (white added), shades (black added), and tones (gray added) of orange are used in the painting below. The key color is clearly orange.



Analogous color harmonies are often found in nature and work very well for scenes with high tonal contrast. Without large areas of dark to offset the warm colors the painting below would be overwhelming.

Our eyes easily move around the painting due to the large numbers of different shades showing transitions from light to dark.

Triadic Color Harmony

The Triad or Triadic Color harmony uses 3 or more colors, spaced evenly, producing the points of a triangle.

Triadic color harmonies are often vibrant due to the spacing of the colors. Usually, the Key Color is dominant while the other colors are more subdued.

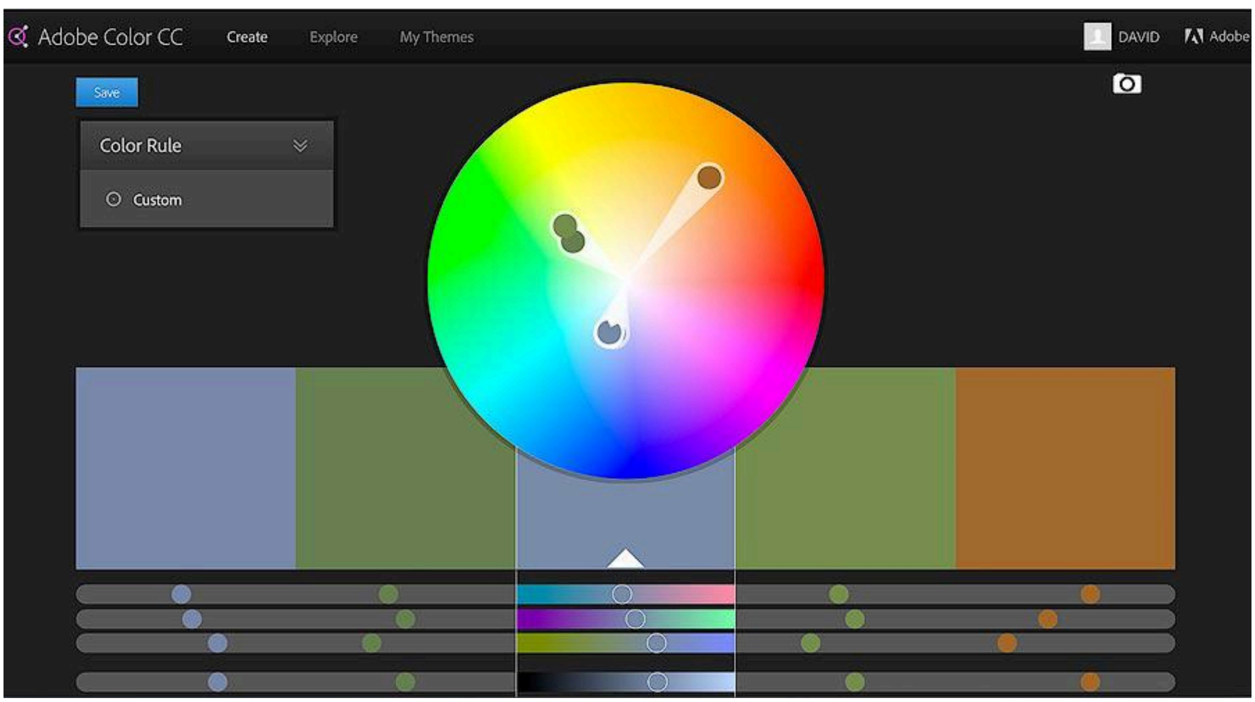
In the painting below, high contrast is used in the foreground with shades (black added) of orange and green, while low contrast is used in the background with tints (white added) of blue, green and orange.

Shading objects often makes them appear closer, and tinting objects often makes them appear further away.

Tinting the background colors provides the feeling of diffuse, dense, and humid air catching the sunlight.

A transition from dark to light adds a sense of depth to the entire scene. The cool colors of blue (sky) offset the warmer tints of orange (rocks), providing leading lines, moving your eyes from left to right through the painting.

On the right side of the large warm colored rocks a green shade is used to provide depth & detail to the shadows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Split-Complementary Color Harmony

The split complementary color harmony is easy to use and often found in nature. Most sunsets and sunrises display this color harmony.

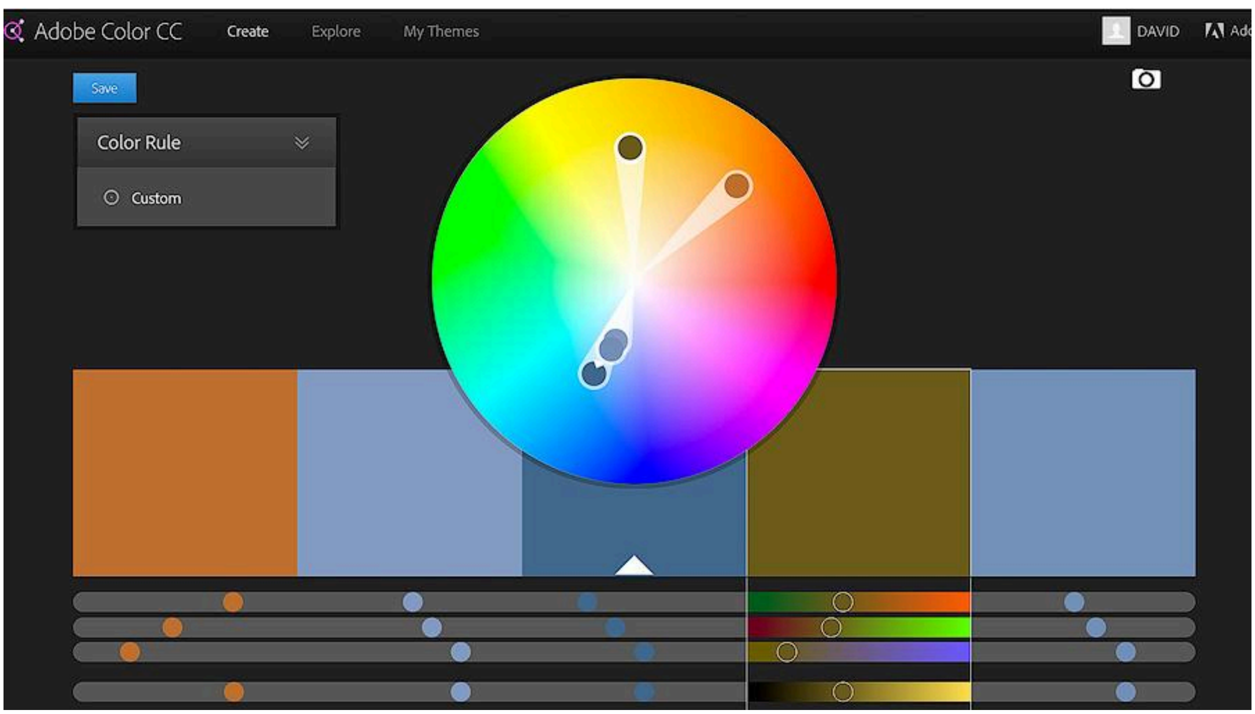
- After selecting the Key Color, find the complementary color that lies directly across from it.
- The split complementary colors are found on each side of the complementary color. They do not include the complementary color.

In the painting below blue is most likely the key color. It is found in the sky, waterfall, river, and shadows. Yellow and orange shades & tints are used as the split complementary colors.

Dark reds are used in the foreground producing an autumn scene, while saturated yellow is used in for the center trees signifying a source of light.

Objects hit by direct sunlight often appear much more saturated than the same objects untouched by light.

Examples shown on next page...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Square Color Harmonies

By selecting a dominant key color and 3 subdued colors, spaced evenly around the color wheel, the square color harmony is formed.

This can change to a Rectangular Color Harmony by slightly moving each color. Test it out and see what works!

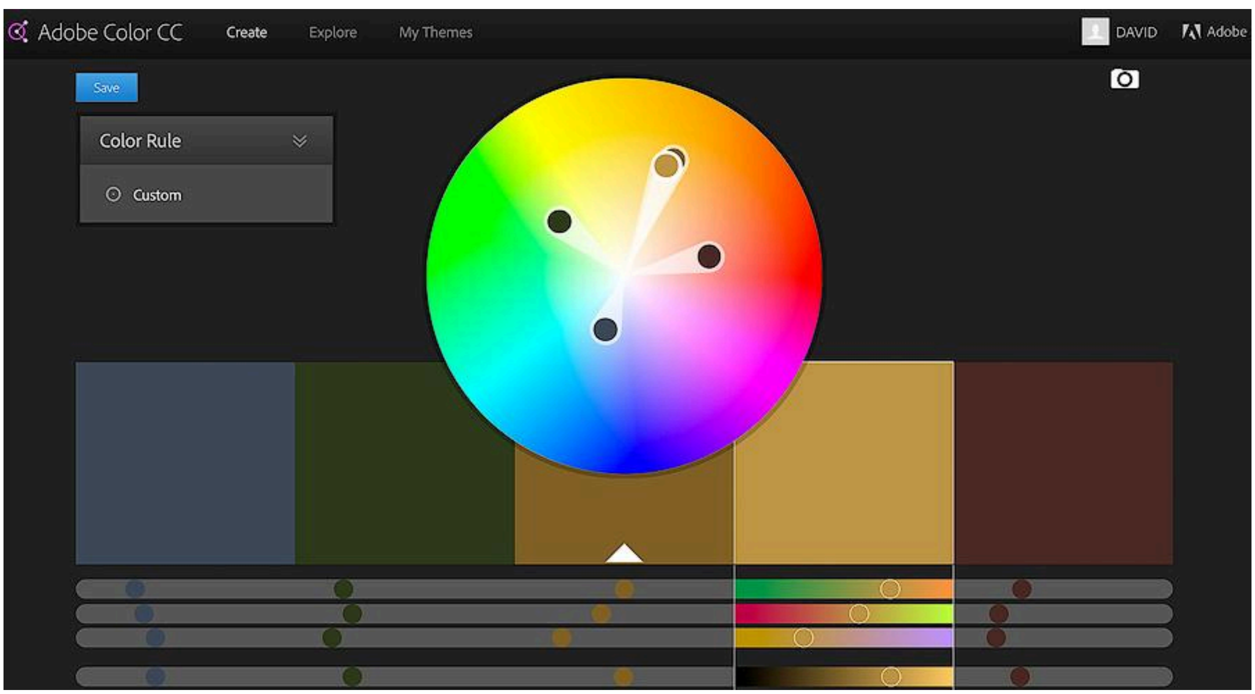
- The square color harmony is perfect for displaying the single most important object in a scene.
- All other subdued colors in the square are used to complement the key color and make the subject of the work stand.

Below, light yellow or blue is most likely the key color. Either will work in this case.

Without blue the mountain is not dominant. Without yellow, the mountain also loses it's power. Both colors provide a stark color contrast of low and high lightness values.

All other colors, such as dark green, dark blue and dark red complement and add more depth to the painting. The subject is clearly the peak, Mount Adams, which lies in the wilderness of my home state, Washington.

Examples Shown on Next Page...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Landscape Photography Tips for Color Theory

Through school, kids books & massive amounts of brainwashing, we have a conception of color in nature which is usually incorrect.

We think that grass is green, the sky is blue, clouds are white, the sun is yellow, and water is blue.

In reality, these objects reflect different colors, depending on the weather, lighting, and seasons.

Studying color in nature, by spending time outside is the only way to cure these misconceptions.

Looking at the color pallets used by Bierstadt you'll notice that high saturation is rarely used, and large dark areas make up most of the scene.

A few select colors are used, with only one or two pulling dominant attention.

Nature is often displayed in the same way. Most objects that are seen on a daily basis, even under direct sunlight, exhibit tones darker than 50% gray.

Look around right now, wherever you are, most objects are probably in the darker tonal range.

- Pure white rarely exists in nature without a source of direct bright sunlight.
- Pure black rarely exists either.

- Most of the natural world exists in the mid-tones, stretching from almost white to almost black, with a large portion near middle (50%) gray.

Provided below are some camera techniques and photo editing tips that will help you to achieve beautiful harmony for each color noted.

Blue & Turquoise

Blue is a cool color which can produce a great offset or complement to other warm colors found in nature such as orange or yellow.

When utilizing blue in images ensure that the saturation levels stays very low.

There are few situations where blue is displayed naturally with high saturation values. Look at the sky during the day, the saturation of blue is not extremely high, but the lightness value may be.

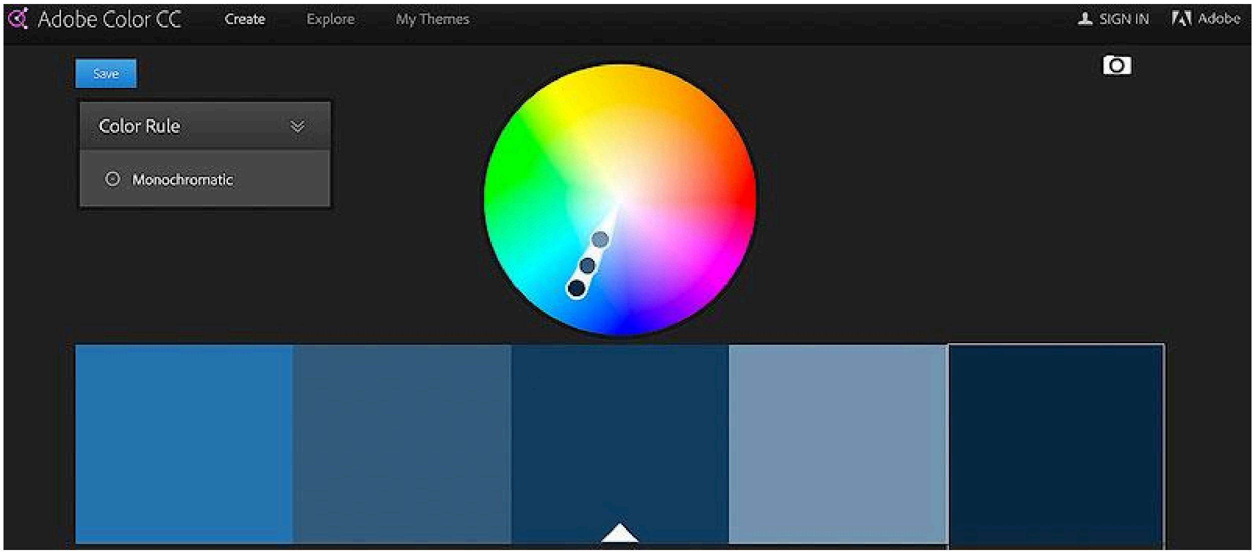
There are certain rivers, often produced by glacier melt, that display blue in a highly saturated manner. This also proves true for the late afternoon sky in high alpine areas.

All rivers are not blue & many oceans aren't either. Most contain many different cool colors depending on the intensity of the water movement or flow, such as rapids, waves or smooth water. This can also change with lighting.

It works best to use varying low levels of saturation within the same hue. If blue is the most dominant or key color, then select a well-balanced color harmony to balance it.

Blues that are found in shadows will usually maintain lower saturation values than blues found in direct light.

The following example shows some colors of blue that are often found in nature. Even the most saturated of these blues, on the far left, is still very subtle.



When blue starts to mix with green it produces Turquoise.

This color is not often found in nature. Alpine lakes, and some water sources display turquoise. When using this color ensure it's very subtle.

Most likely turquoise will not be the key color but it can add a fantastic complement to the color harmony.

Red, Orange & Yellow

Red, orange & yellow evoke feelings of intensity and are often found in sunrises, sunsets, flowers and fall foliage. They are also found in many desert regions, especially the American South West.

Beware aware of the excessive use of these colors in your images for sunrise & sunset, along with other highly saturated colors, as they are extremely dominant.

If they key color is red, orange or yellow, it usually works well to offset them with dark shadow areas, of little or no color, balancing out the scene.

This technique keeps the eye from becoming overwhelmed and allows it to move through the image.

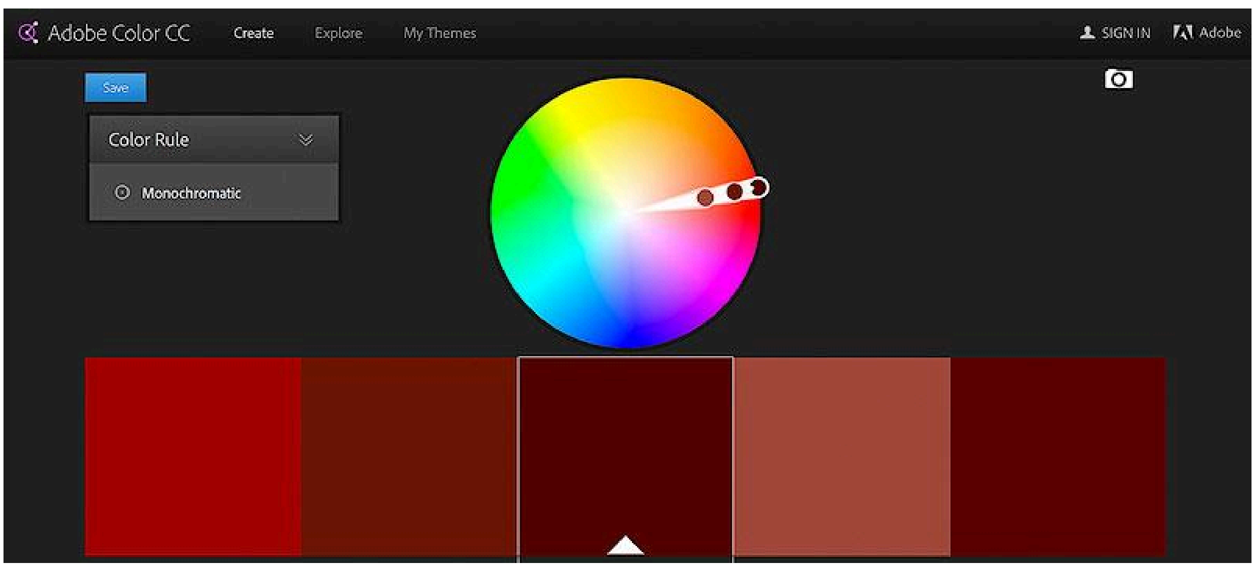
It's very easy to overexpose red while capturing images. If the sky is red during sunset and the image is overexposed, the colors will tend to come out too orange or too yellow.

If necessary take two separate exposures, one darker image to capture the bright red in the sky, and another brighter image, to capture the foreground detail.

Watch the Red Channel on your camera's RGB histogram, while capturing images, to ensure that red is not clipped off the right hand side. This will ensure easy post production of the RAW file with vivid true color.

Red is usually very saturated during sunrise or sunset, with low brightness levels, making it very vivid and colorful as seen in the example below.

Notice that these variations of red are very colorful and vivid, yet visually appealing to the eye.



Yellow and orange are often found to be slightly brighter, with lower saturation levels.

Pure yellow is rarely found in nature. The lightness of yellow is much greater than the lightness of red, so it will appear to be lighter in images but less dominant.

Keep this in mind when adding or saturating yellow, red and orange.

Green

Green is often found in rivers, oceans, trees, and foliage. Although our eyes think of trees as green, this is often not the case.

- Under direct light, green tends to push towards yellow.
- Under low light green tends to push towards blue, especially in forest scenes.

Green can be a very hard color to edit in Lightroom & Photoshop, but here are a few tips.

Green in Direct Sunlight

If the green in your images looks overly saturated or too dominant slightly desaturate & darken the yellows.

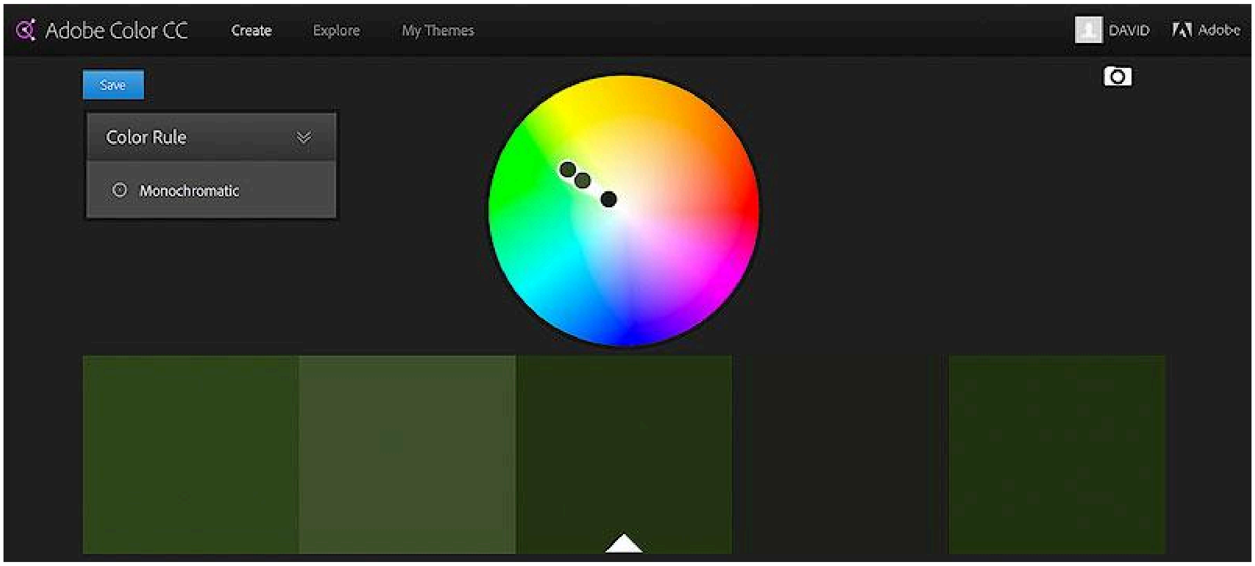
This can be done with the HSL sliders in both Lightroom, Adobe Camera RAW & Photoshop.

Yellow makes green look over saturated and out of balance since they don't produce a color harmony. This normally happens when shooting trees or forest scenes in direct sunlight.

Green is also a very easy color to overexpose. While capturing images watch the Green Channel on your camera's RGB histogram to ensure no data is lost off the right-hand side, also known as clipping.

When green is clipped in the RAW file it produces an ugly neon yellow color that can't be recovered in post processing.

The following example shows greens slightly shifted into the yellow hues, with low saturation and brightness levels. This keeps the greens looking natural, even under direct light.



By lowering the brightness of the greens in your image they will tend to look more natural as shown in the following example.

Green Without Direct Light

Through millions of years of evolution, the human eye knows what natural green looks like. This is why your eyes may reject an overly bright or saturated green.

The following example shows greens that are shifted centrally into the green hue, ensuring that yellow or blue do not show up in the color.

These are the colors of green that will display in a lush forest without direct sunlight. Notice how dark these greens appear.

If greens in your image appear too yellow or too blue, use the HSL Sliders (Lightroom, Camera RAW or Photoshop) to shift the yellow or blue hues very slightly towards green, respectively.

Use the color picker while editing your images to ensure your greens are kept at very low brightness.

Green in Shadows

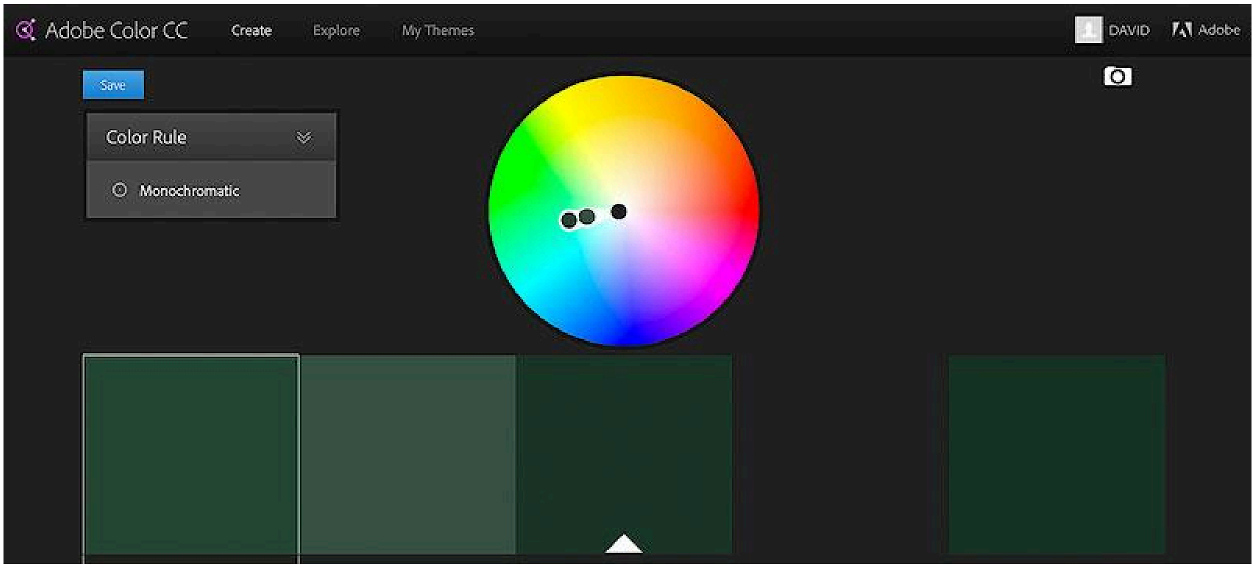
When green is found in shadows it appears to have a slightly blue color. This rarely has a negative side effect, providing that the greens don't push too far into blue.

Subtle shades of blue and green produce an analogous color harmony. As we discussed in the video, shadows often display very subtle shades of blue.

The graphic below shows greens that are shifted slightly into blue.

These colors of green would display very nicely in the shadow regions of a lush forest.

The slight blue shades in the shadows can complement any touches of yellow-green that are displayed on branches or leaves in direct light.



Magenta

Magenta is rarely found to be very bright or saturated in nature. During sunrise, sunset, and twilight very subdued colors of magenta are found in the sky. A variety of different flowers also contain the color magenta.

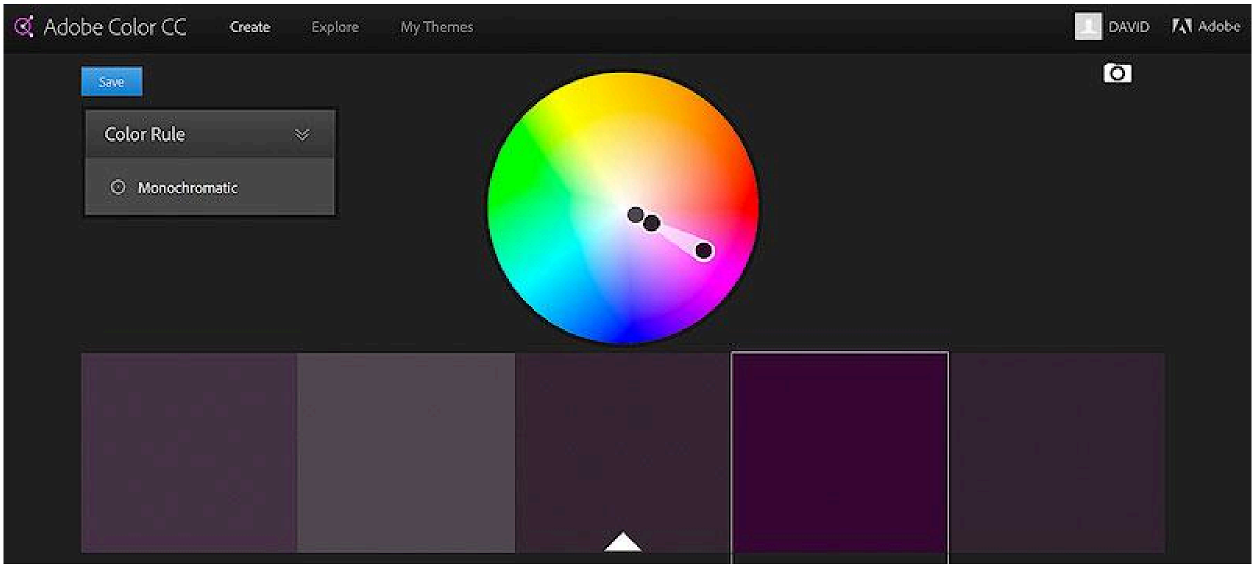
Magenta is a very dominant color making it easy to overuse in an image. The overuse will easily take over the image and remove all color harmony.

The most vivid magenta colors are usually found during twilight hours.

- During photo editing adding too much blue to magenta makes it appears muddy and gray.
- Adding too much red to magenta makes it appear too purple or neon.

By keeping the brightness and saturation values low, as seen in the following image, magenta continues to look natural.

Notice how the selection does not push into the red or blue colors, it's centered in magenta.



While editing photos use magenta very sparingly at low brightness & saturation levels.

If you are to increase the brightness or saturation do it at select areas throughout the image, but minimally. These areas will usually pull the viewer's attention immediately.

Color & Light in the Digital World

Understanding how camera sensors work is one of the most important aspects of learning photo editing.

By learning the first principles of color & light, editing photos becomes much less guess work and much more enjoyable.

What is a Camera Sensor?

The camera sensor, also known as an image sensor, is an electronic device that collects light information, consisting of color & intensity after it passes through the lens opening, known as the aperture.

Shutter speed defines the length of time this light information is collected by the camera sensor.

ISO determines the amplification the light information receives as it's conveyed into the digital world, where it's stored on a memory card as a picture file.

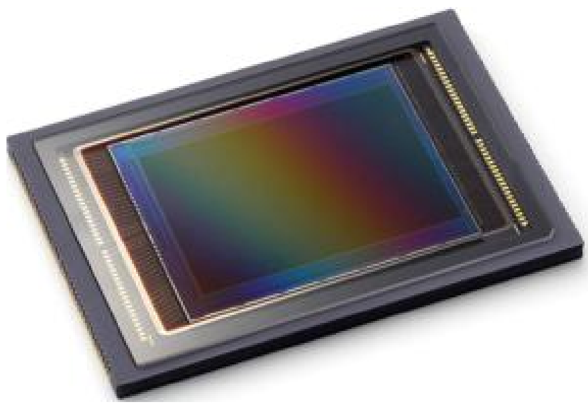
There are two popular types of image sensors, CMOS sensors (complementary metal-oxide semiconductor) & CCD sensors (charge-coupled device).

Due to the higher performance, especially in low light, and lower cost the CMOS Sensor is found in nearly all modern digital cameras.

CMOS Sensors are defined by their physical size (surface area for capturing light information) and the number of light information collecting pixels which make up this surface area.

What is a Pixel in Photography?

The camera sensor is a rectangular grid containing millions of tiny square pixels as shown in the graphic.



Attribution - Wikipedia

Pixels are buckets or wells for collecting & recording light information. They are the base unit of the image sensor.

Digital photography is the process of recording real world color and tones, from a scene or composition, using individual pixels.

Each individual square pixel represents a small sample of the image composition as a whole, consisting of a single color. No more.

The combination of millions of small pixels of varying colors creates the image as a whole.

Let's call this collection of all pixels the sensor grid.

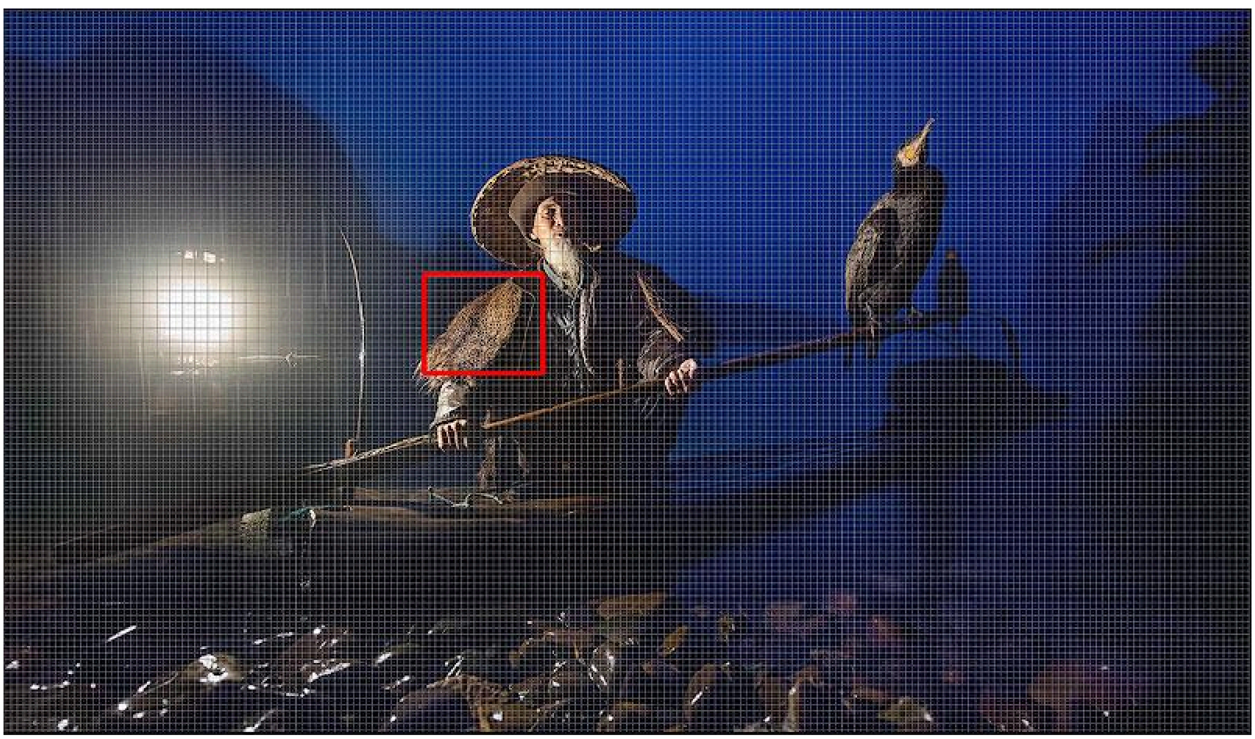
The "rainbow colored" rectangle on the graphic shows the sensor grid. Pixels are so small that it's hard to see each individual unit.

Creating Photographs - Pixels, Explained

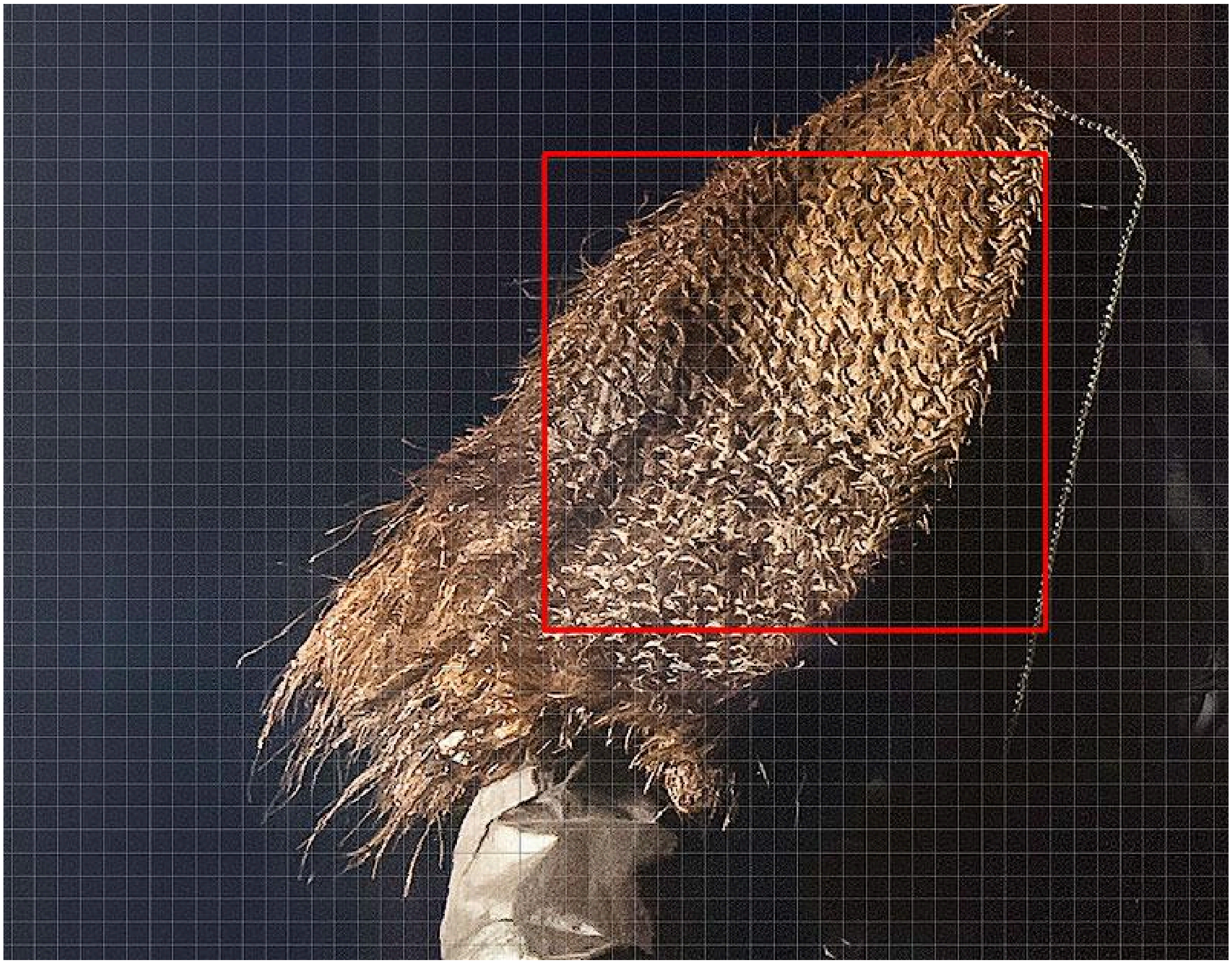
The goal if the following section is to help you conceptualize how pixels work.

Imagine an image composition, seen through a camera viewfinder, with an imaginary overlaid grid, containing millions of tiny uniformly sized squares, as seen in the graphic below.

Pretend the following graphics are the real world scenes that you're seeing through the camera viewfinder or on the back of your camera live view screen.

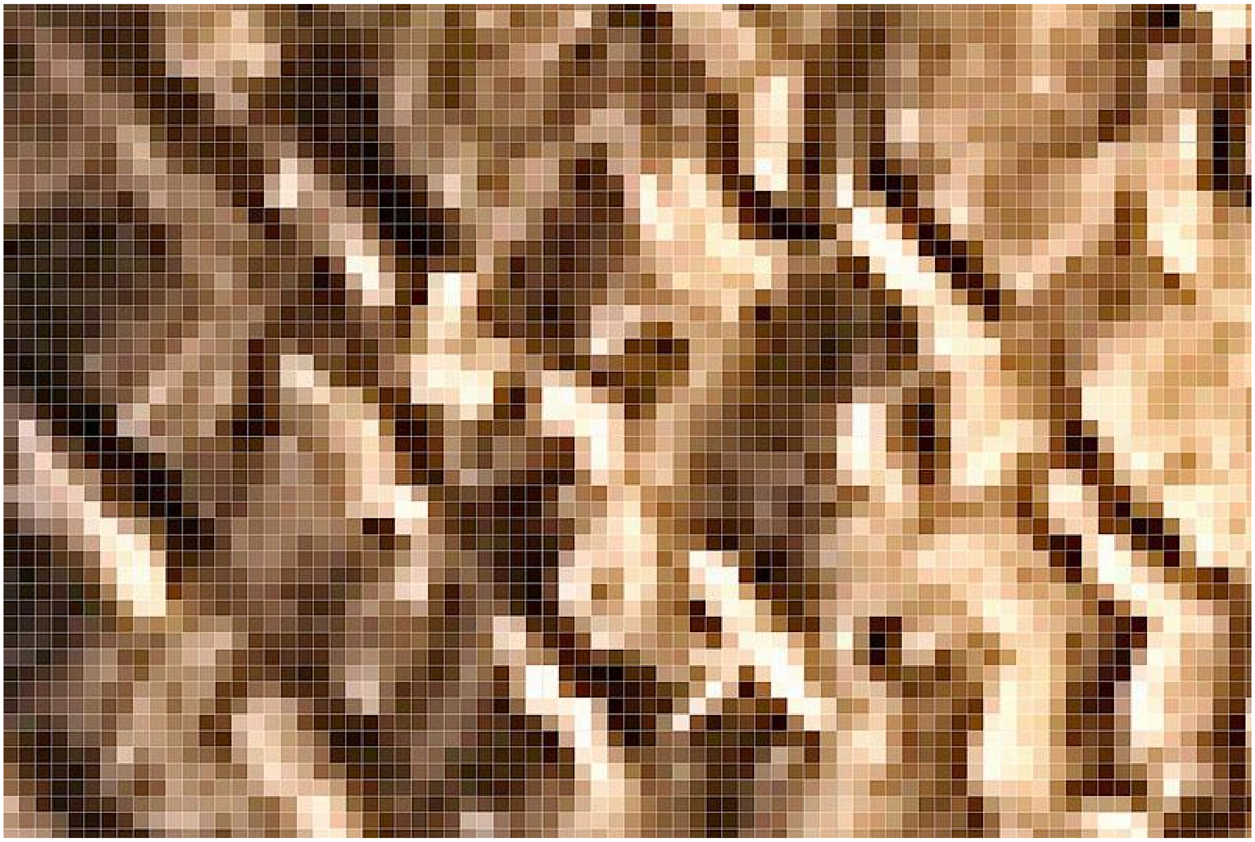


As we start to zoom in on the red box the squares become closer and closer to their actual size.



Finally, we zoom in so far that each individual square can be seen at its actual size.

These squares are so tiny that they contain no detail only a single color or tone, as shown below.



Take a look at different objects around you. If you look closely, under a large amount of magnification, everything becomes a single color on a very small scale.

The combination of all these small colored squares produces the scene or composition as a whole.

Let's call this collection of imaginary small colored squares the image grid.

NOTE: This image was captured before twilight, in the pouring rain, on the Li River in China. This shooting scenario is the ultimate test for a camera sensor.

Each square pixel on the sensor grid corresponds to a tiny square on the imaginary image grid.

- The sensor grid is an actual object that collects light information about a scene, using pixels.
- The image grid is an imaginary object which breaks the real world scene or composition into millions of tiny squares.
- The pixel's only job is to record the single specific color of each tiny imaginary square on the image grid.

Each pixel therefore only collects a single color corresponding to very small sample of the scene being photographed.

When the correct camera settings, shutter speed, ISO and f-stop, are selected, each pixel on the sensor grid will collect & record the exact color of the corresponding square on the image grid.

In turn, a digital image is produced, from millions of pixels, which matches the real world composition seen through the viewfinder.

In photography, this is known as the correct exposure.

When the incorrect camera settings are selected, the squares on the pixel grid don't match the squares image grid, producing a digital image that doesn't match the scene being photographed.

Digital photography is the process of recording real world color information represented by the image grid, and relaying it into the digital world represented by the pixel grid.

The photographer's goal is to select the correct camera settings relaying this information with precision & accuracy, producing a digital image that matches what they see through the viewfinder.

The camera sensor, which contains the pixel grid, is the tool used to collect this information & perform the task.

If any part of this section was confusing, watch the video provided at the top of this page.

Megapixels & Color: How Camera Sensors Work

Cameras are rated by the number of total pixels their sensors contain.

Mega is the mathematical term denoting 10^6 also stated as "10 to the 6th power" which can be written as 1,000,000 or 1 million.

Megapixel, therefore, means 1 million pixels. This is a standard unit of measure in electronics.

- For example, a 36.6 Megapixel (36.6 million pixel) camera sensor could be 7360 pixels wide and 4912 pixels tall.
- Multiplying the 7360-pixel width by the 4912-pixel height provides the 36.6 million pixel sensor rating.
- Simply put, this would be a 7360-pixel wide by the 4912-pixel tall grid, containing a total of 36.6 million pixels.

More Megapixels doesn't always equal better image quality!

Let's discuss...

Pixels - Wells for Collecting Light Information

Light is made of photons or small packets for carrying light information. Photons are elementary particles which have no weight but carry information about light.

When photons collide or interact with certain materials, such as silicon CMOS image sensors, free electrons are released from the sensor material, producing a small electric charge. This is known as the Photoelectric effect.

The free electrons are collected and counted by individual pixels on the sensor grid. Each pixel well has a maximum capacity of electrons it can collect. This maximum is known as full well capacity.

A pixel can only display a single color, including black, white, greyscale, and RGB Color values. The color of each pixel is determined by the amount & kind of light information it collects.

Determining Pixel Color & Tone

The number of electrons each pixel well collects determines it's brightness, also known as value, on a scale of black to white. The scale of black to white is known as the tonal range or tonal scale.

The brightness of each individual pixel, on a scale of black to white, is known as tonal value, or luminosity.

- The more electrons a pixel collects, the lighter it's corresponding tonal value in the image.
- A white pixel contains the maximum amount of electrons.
- A black pixel contains no electrons.
- All values between maximum and minimum produce greyscale tonal values.

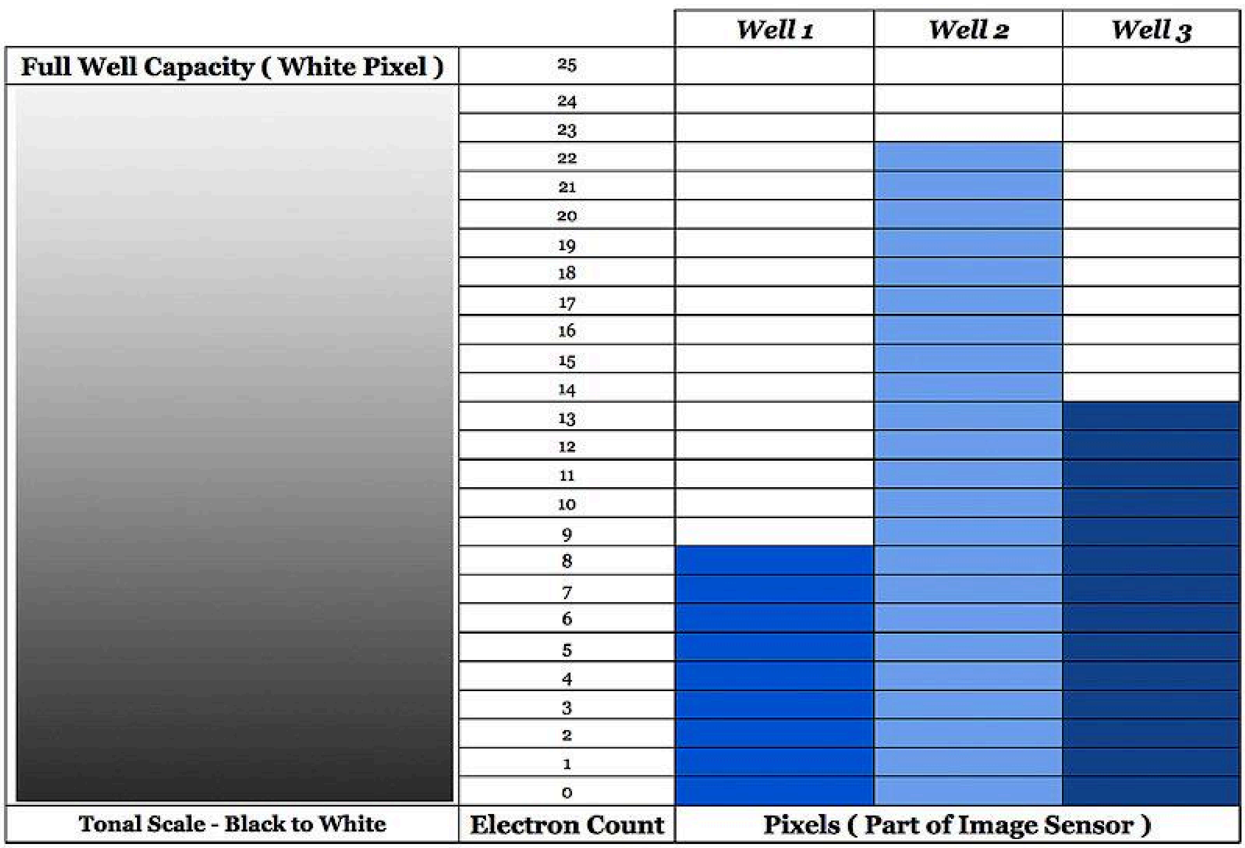
Electrons counts can't determine specific color information, therefore, a color filter is placed over each pixel helping to determine it's color. This is discussed in detail below.

By combining the tonal value & color filter information, the final color is determined for each pixel.

The graphic below shows the tonal range and an arbitrary number of electrons required to create each tonal value.

The goal is to visualize this concept. The number of electrons is made up & does not matter.

More Electrons Collected = Lighter Tonal Values = Lighter Pixels Displayed in Photo



For example, Pixel Well 1 collected 8 electrons producing a dark tonal value.

Pixel Well 2 collected 22 electrons producing a light tonal value.

Pixel Well 3 collected 13 electrons producing a mid-tone tonal value.

The number of electrons collected by each pixel well produces a corresponding tonal value for that pixel. This tonal value is displayed in the final photo, along with the color.

This information is relayed from the image sensor into the digital world using an electronic signal.

Digital Signal, Brightness & Tonal Value

Each electron produced during the Photon sensor collision carries a small electric charge. The more electrons a pixel collects, the more charge the pixel well contains. Electric charge is a physical measured value.

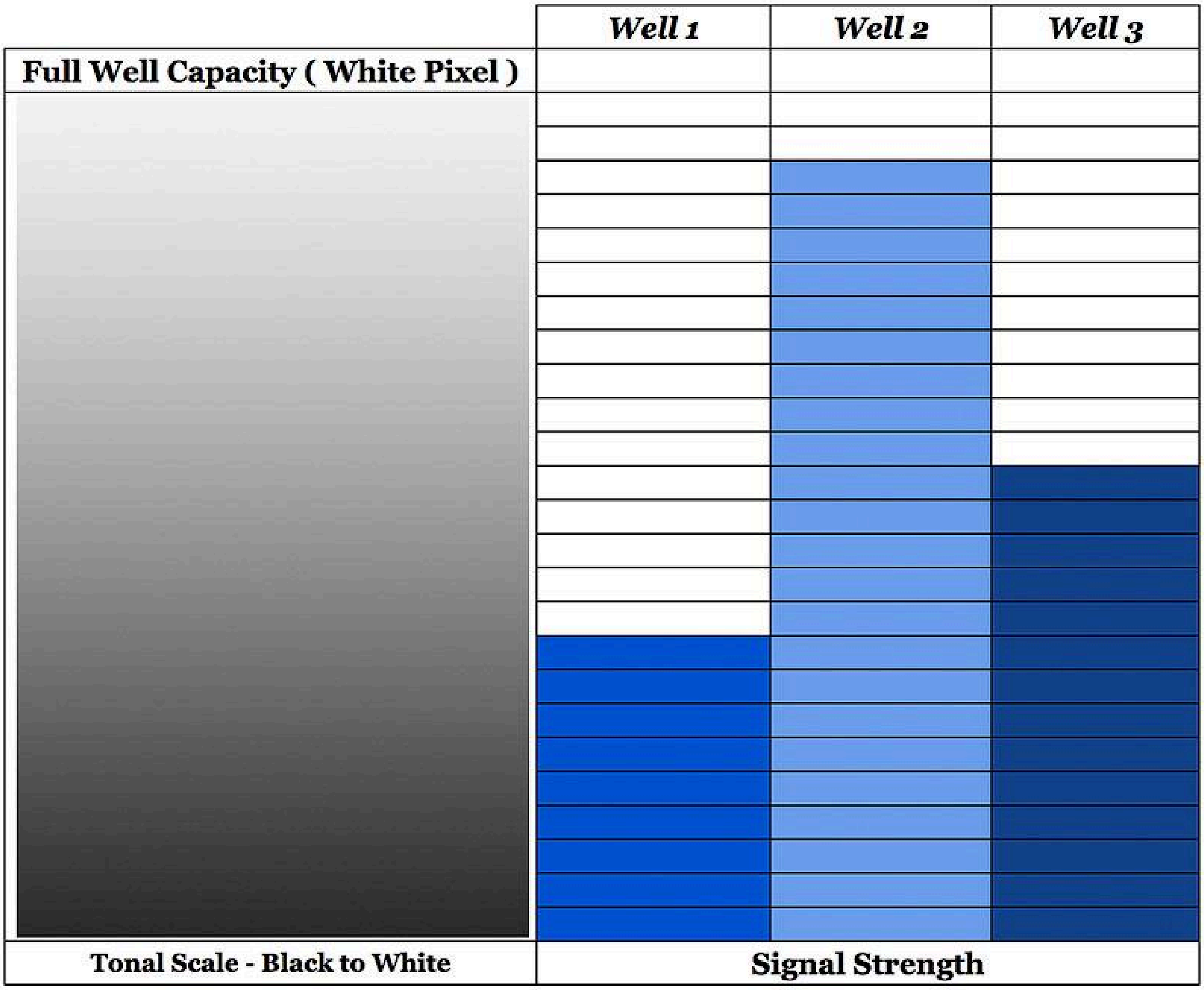
This charge is used to transfer the light information, collected by each pixel, into digital information which cameras & computers can understand.

Electronic signal communicates physical real world values into the digital world of binary code.

Each tonal value, on the scale of black to white, has a corresponding signal required to produce it. Specific signal levels produce specific tonal values. The more electrons a pixel collects the stronger the signal it creates.

Less Light = Less Electrons = Smaller Signal = Darker Tonal Value

More Light = More Electrons = Larger Signal = Lighter Tonal Value



When a pixel well fills to the top with electrons, creating the maximum signal, it's corresponding tonal value is white, producing a white pixel in the photo.

Since the pixel is full it can no longer collect light information. This is known as a fully saturated pixel well.

In photography terms, this pixel is "clipped", "blown out" or "overexposed". Each term refers to the same concept.

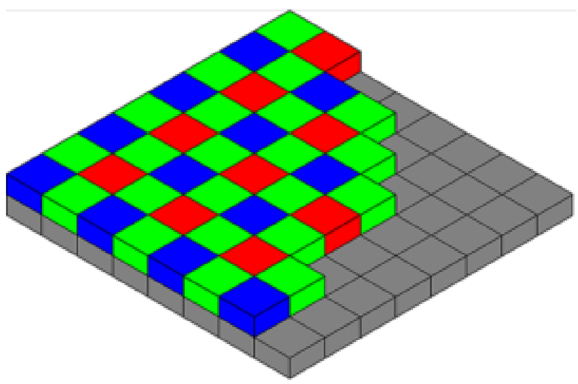
None of the information the pixel collected prior to filling can be recovered or used in the final image. It's gone forever!

When a pixel well contains no electrons it produces no signal. The corresponding tonal value is a black, producing a black pixel in the photo.

The tonal values produced by each signal are combined with collected color information to produce each pixel's final color within the photo.

Color & Light in the Digital World

Since color information can't be determined directly by the number of electrons in each pixel well, a color filter is placed over each pixel.



Attribution: Wikipedia

Most, but not all, CMOS sensors use a Bayer Filter which looks like a quilt of Red, Green, and Blue screens, with a single color screen covering each pixel as shown in the graphic.

Other color filter arrays, including the Bayer, are discussed in the Wikipedia link, below the graphic.

Each pixel is covered with a color filter, either red, green or blue. The color of each pixel is determined by the color of light (frequency of light wave) which passes through this filter.

The Bayer Filter is laid out with 50% Green, 25% Red, and 25% Blue pixel filters. To the human eye, the perceived brightness of green is greater than that of red or blue, thus green filtered pixels are represented twice as often in the Bayer Filter.

To the human eye, the perceived brightness of green is greater than that of red or blue, thus green filtered pixels are represented twice as often in the Bayer Filter.

Red light passes through the red filtered pixels, while green and blue light do not. Blue light passes through the blue filtered pixels, while red and green light do not. You get the gist…

Each pixel can only collect the primary color information of it's assigned red, green or blue filter, along with the number of electrons collected in the pixel well, which determine tonal value.

Using this information, and a series of algorithms & interpolations, the camera can determine the color of each pixel contained on the sensor grid.

The precision and accuracy which this information is communicated and displayed in the final image is determined by the bit depth.

Bit Depth, Color Depth & Image Quality

Bit depth specifies the number of unique color & tonal choices that are available to create an image. These color choices are denoted using a combination of zeros and ones, known as bits, which form binary code.

Bit depth is a rating system for a camera's precision in communicating color and tonal values.

A Bit Depth Analogy

An adult and a 2-year-old child looking at the same landscape see close to the same thing, consisting of color and tonal values (light intensity).

The adult can describe this scene in vivid detail using a large number of descriptive words & complex vocabulary.

The 2-year-old child, seeing the same thing, has a hard time describing the scene accurately, having a limited vocabulary.

They both see and collect the same real world information, but one can describe it in vivid detail, while the other cannot.

Larger bit depth systems, like a larger vocabularies, provide better precision when communicating information.

How Bit Depth Works in Photography

After the exposure time, defined by shutter speed, has elapsed, the signal information produced by each pixel is processed & converted into a digital language known as binary code.

The digital language takes the form of zeros and ones (bits) & communicates the values of color (Red, Green, Blue) & tone collected by each pixel.

The pixel specific tonal value is determined from the number of electrons (charge) collected and the color is determined using the Bayer Filter.

The precision of the communication is rated on the scale of bit depth. Larger bit depth systems allow more precision in describing the information collected by each pixel.

Binary Code & Bit Depth, Explained

We are used to numerical systems with a base of 10, such as 10, 20, 30, 1000, 100000.

Bits use a base 2 numerical system also known as binary.

A 1-bit system only has two possible outcomes. 1 or 0, on or off, true or false, yes or no, black or white.

A 1-bit photo only has two possible pixel colors, black and white.

Consider this like a child that only speaks two words, yes & no, black & white. You wouldn't depend on this child to communicate a landscape scene with a large degree of accuracy or precision.

As the bit depth of the system increases the combinations of different possible choices or outcomes also increases.

Calculating Bit Depth in Photography

A 2-bit system would contain 4 choices as follows, (0,0)(0,1)(1,0)(1,1).

A 2-bit photo would contain 4 possible choices, black, white, dark grey and light grey.

A 3-bit depth system would contain 8 possible choices or outcomes, ranging from (0,0,0) to (1,1,1).

For example, the number of possible choices for a 3-bit system is found by using the binary base 2 and raising it to the power of 3, $2^3 = 8$.

A N-Bit System contains 2^N possible choices for communication.

In photography, the number of bits determines the possibilities of color or tone a single pixel can display, known as bit depth.

This doesn't mean that each possibility will necessarily exist in a photo, but it could.

The example below shows the tonal values of black to white communicated with varying degrees of precision, by different bit depth systems.

The tonal range is the same for all bit depth systems, starting with black & ending in white.

The bit depth determines how many steps or possible choices within the tonal range can be communicated. Each step or possible choice is known as a bin. The more bins the more choices.

As shown in the graphic below, a 1-bit system can only communicate black and white. A 2-bit system can communicate black, white and two tones of gray.

The 3 & 4 bit systems provide a larger selection of choices used to communicate varying tonal values within the tonal range.

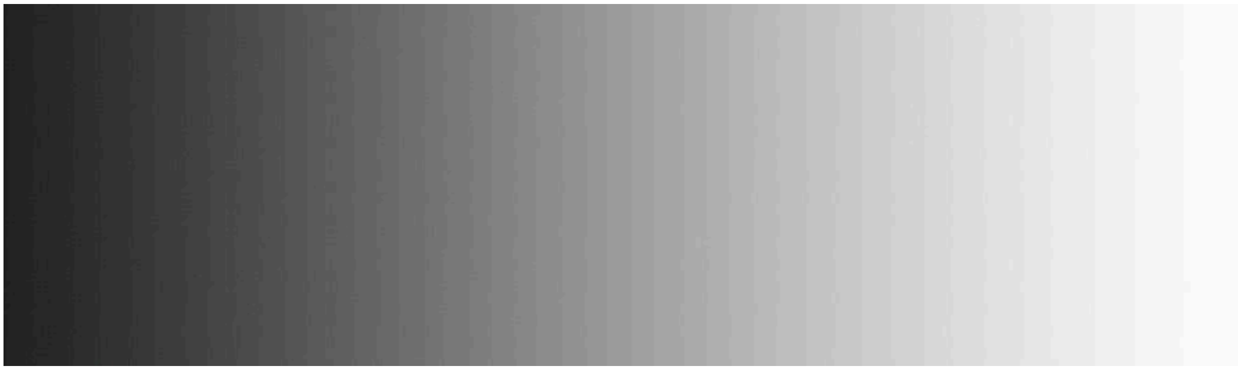
1 Bit (2 Tones)	2 Bit (4 Tones)	3 Bit (8 Tones)	4 Bit (16 Tones)
0	0	0	0
1	1	1	1
	2	2	2
	3	3	3
		4	4
		5	5
		6	6
		7	7
			8
			9
			10
			11
			12
			13
			14
			15

The change in the tones shown above is easily discernible to the human eye, which is unacceptable for photography.

Photographs must contain smooth transitions between color and tones, as seen in nature, producing realistic images.

As the bit depth of the system increases the degree of precision which information is communicated from the real world into the digital world also increases.

The graphic below shows an 8-bit system with 256 or (2^8) different bins. Due to the vast number of possible tonal choices the transition from one to the next isn't discernible to the human eye. A JPEG image is 8-bit.



Color Channels & Color Depth

The example above was for black and white photographs only. Most digital cameras take color photographs.

These color photographs are produced using the three primary colors, red, green, and blue determined by the Bayer filter.

These are known as color channels. The tonal value associated with each color is determined by the signal strength.

JPEG files are usually 8-bit whereas RAW files are usually 12 to 16 bit. Some cameras have the ability to change their current bit rating through user defined settings.

On the Nikon D810 this is noted as "NEF (RAW) Recording" in the shooting menu.

Google your camera "brand-model" + "bit depth settings" for specific info on this setting.

The example below shows the 4-bit color scale for RGB Primary colors red, green and blue. Bin 15 in each of the color channels is pure fully saturated color, also known as hue.

NOTE: Not all cameras process color the same way. The following example allows you to conceptualize this concept. It's not meant to be technically accurate for a specific camera.

4 Bit Color - RGB Color Model		
Red (16 Choices)	Blue (16 Choices)	Green (16 Choices)
0	0	0
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9
10	10	10
11	11	11
12	12	12
13	13	13
14	14	14
15	15	15

TECHNICAL NOTE: Although each of the color channels have the same amount of steps, the variation of green can still be seen all the way down to 1, where it's hard to tell any difference in red at 1, and blue drops off at 2.

Humans perceive green as the brightest, red as the second brightest, and blue as the darkest, out of the three primary colors. This perception of color brightness, known as lightness or luminosity, is only a function of the eye's physiology. Remember the Bayer Filter!

Calculation for 4 Bit RGB Color System

2^N-Bit = 2^4 = 16 color choices per primary color channel, as shown in the graphic above.

Each of the primary color channel bins can combine with each other to create new colors.

For example, Red (12), Blue (6), Green (15) would create unique color and Red (1), Blue (2), Green (4) would create another unique color.

When a bin is set to 0, such as Red (0) that color is turned off, in other words black.

When a bin is set to (15), it is on, producing pure color and full saturation, known as a hue.

Red (15), Blue (0), Green (15) = Yellow (15) or pure yellow.

Red (15), Blue (15), Green (15) = White, since the RGB Color Model is additive.

Red (0), Blue (0), Green (0) = Black, since all colors are turned off.

The total number of possible color choices, per pixel, for this small 4-bit system, is calculated as follows;

Total Color Choices Per Pixel = 16*16*16 or 16^3 which equals 4096 total choices. 16 represents the number of color choices per channel. There are 3 primary color channels.

Each pixel on the image sensor can communicate color using 1 of 4096 possible choices.

---

8 Bit JPEG File vs 14 Bit RAW File

Both files use the same three primary color channels, containing red, green and blue.

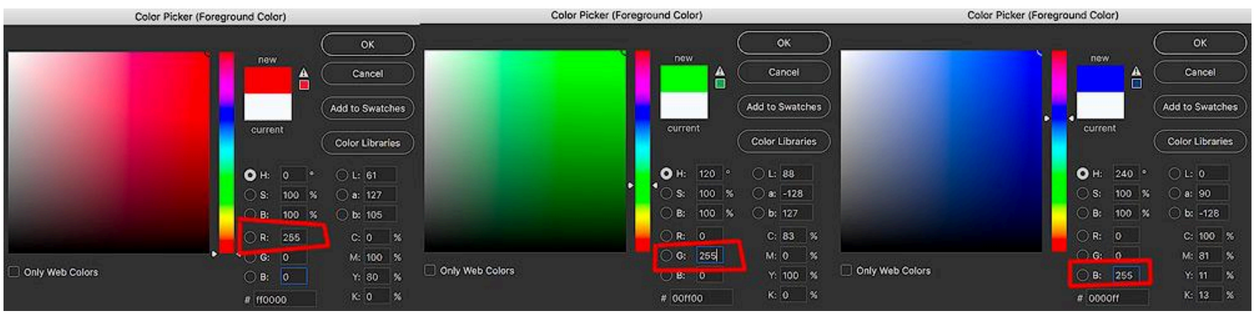
An 8-bit jpeg can record, 2^8th power or 256 possible outcomes for each of the 3 color channels.

The red channel can display 255 different variations of red, the green can display 255 variations of green and the blue, 255 variations of blue.

Variations of color = 255, not 256. Black isn't on the primary color scale but is used to calculate overall color.

The Photoshop Color Picker displays 8 Bit Color. The following example shows:

- Pure Red, R(255), G(0), B(0)
- Pure Green, R(0), G(255), B(0)
- Pure Blue, R(0), G(0), B(255)



Each color channel has 256 possible outcomes or choices it can produce.

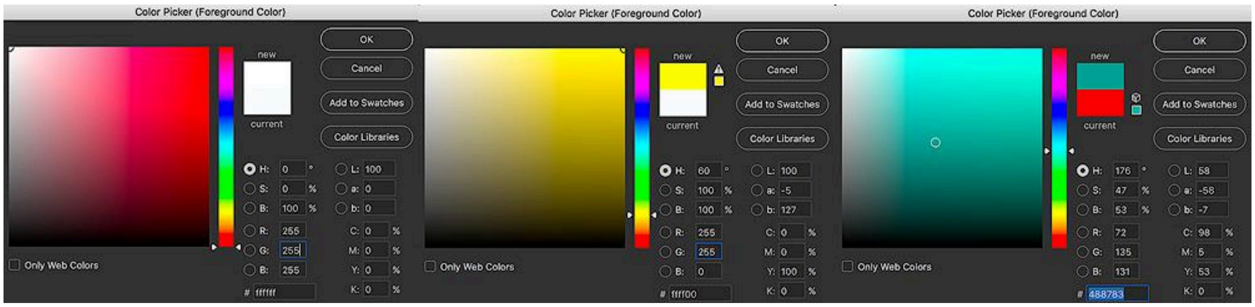
Therefore the number of possible choices, for each pixel, in a small 8-bit file is 256^3 power, or 256*256*256 which equals 16,777,216.

That's almost 17 million different possible choices for every single pixel. There are millions of pixels on each sensor! This is a small JPEG file that the worst modern digital cameras can capture.

The graphic below shows:

- White, R(255), G(255), B(255) - Remember the RGB Color Model is additive.

- Yellow, R(255), G(255), B(0)
- And another random combination of color Cyan-Green, R(72), G(135), B(131)



The 14 Bit RAW File

The 14-bit file contains 2^14th power of possible variations for each of the 3 color channels. That's 16,384 possible choices per color channel.

Since there are 3 color channels, red, green and blue, 16384^3 or 16,384*16,384*16,384 which equals 4,398,046,511,104.

# Bit	Choices per Channel	Choices per Pixel
1	2	Black & White
2	4	64
3	8	512
4	16	4096
5	32	32768
6	64	262144
7	128	2097152
8	256	16777216
9	512	134217728
10	1024	1073741824
11	2048	8589934592
12	4096	68719476736
13	8192	549755813888
14	16384	4398046511104

That's approximately 4.4 trillion different possible choices for each pixel. There are millions of pixels on each sensor.

We have surpassed the 2-year-old child that can barely speak, we have surpassed the adult with a vivid and detailed vocabulary, we have arrived at a degree of precision that only machines can record and communicate.

The human eye, the second most (known) complex object on the planet, after the brain, has no problem discerning approximately 12 million different colors.

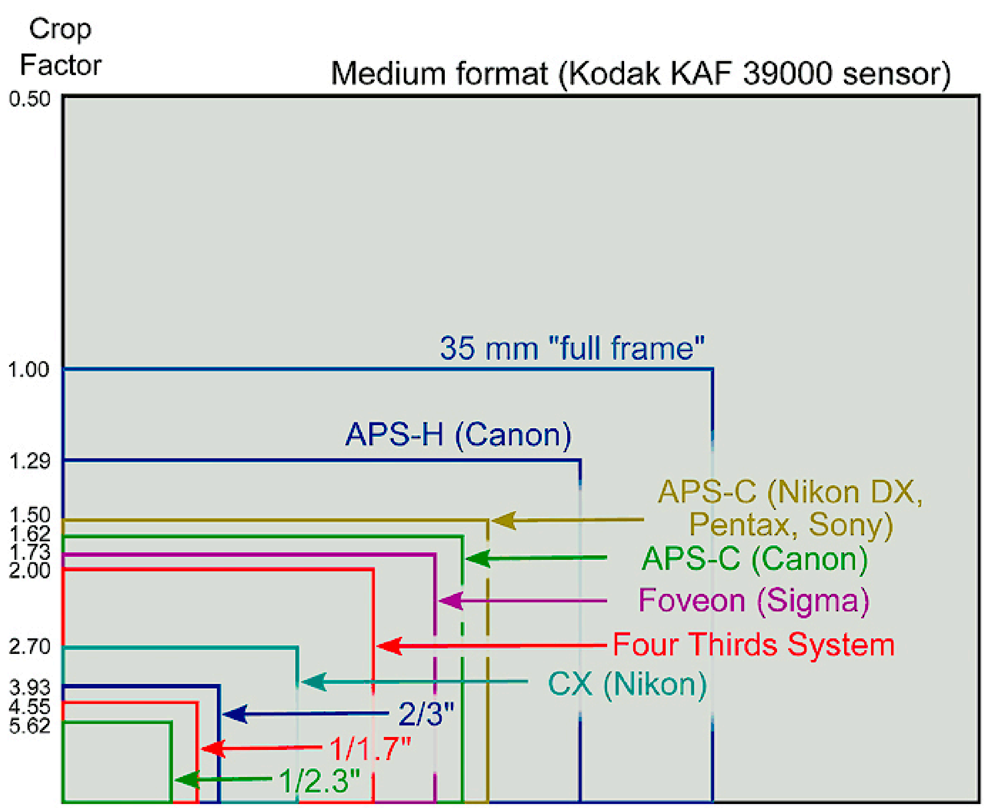
In terms of color & tone, machines have bypassed the precision that the human eye, engineered by trial and error, through millions of years of evolution, can discern.

Camera Sensor Size - Overview

Along with the number of pixels, sensors are also rated in terms of physical sensor size or surface area. The sensor surface area also determines the size of each pixel.

Physical sensor sizes are provided in terms of width and height, usually in millimeters. A standard sensor size such as 36mm × 24 mm is known as a full frame 35mm format camera.

The following graphic shows a camera sensor size comparison for varying popular sensor formats.



Larger sensor widths yield larger sensor surface areas providing more area for the capture of light information over a standard interval, known as exposure time.

Think of a sensor like the sail on a boat. The larger the sail, the greater the surface area, the more wind it will catch.

The larger the sensor, the greater the surface area, the more light (photons) it will catch.

Notice the massive difference in light collecting surface area between the APS-C vs full frame camera sensors. These cameras will produce much different overall image quality, with the larger far exceeding the smaller.

There is a much smaller difference between the APS-H vs APS-C. These cameras will produce close to the same image quality, with slight variations.

This is explained in detail in the following sections.

Camera Sensor Crop Factor

The crop factor is a dimensionless reference number, associated with image sensors. It compares the diagonal distance across each specific camera sensor to the diagonal distance across the full frame camera sensor.

For diagonal distance think of a straight line from the top right corner to bottom left corner. This is also known as the hypotenuse.

Knowing the sensor width & height in millimeters, this distance is easily calculated using the Pythagorean Theorem.

Diagonal Distance = SQRT((Width^2)+(Height^2))

Where SQRT is the callout for Square Root.

If you don't like math then Google, "Pythagorean theorem calculator".

For example, the diagonal distance or hypotenuse of the 36mm by 24mm full frame can be found as follows: =SQRT((24^2)+(36^2)). The outcome is approximately 43.3mm.

Camera Crop Factor = 43.3 / Camera Sensor Diagonal Distance

A full frame camera would have a Crop Factor of 1, 43.3mm/43.3mm.

Smaller camera sensors such as a standard 22.3mm width, APS-C Sensor (see graphic above), would have a crop factor of approximately 1.6.

Quick Reference - Standard Camera Sensor Crop Factors:

- Full Frame Sensor Crop Factor = 1
- APS-H Sensor Crop Factor = 1.29
- APS-C Sensor Crop Factor = 1.5 to 1.6 depending on model.
- Foveon Sensor Crop Factor = 1.73
- Micro 4/3 Sensor Crop Factor = 2

Full Frame, Medium Format & Crop Camera Sensors

Digital cameras can be broken up into 3 different categories for sensor sizes, largest to smallest respectively, Medium Format, Full Frame, and Crop.

When making the following comparisons of image sensors, assume that each sensor compared is from the same fabrication year.

For example, although a crop sensor usually provides less quality & detail than a full frame sensor, a crop sensor from 2017 would most likely provide more quality and detail than a full frame sensor from the year 2000.

Types of Camera Sensors:

- **Medium Format (Crop Factor > 1):** Largest camera sensor size and usually highest cost. Medium format cameras are usually very bulky and heavy due to the large image sensor contained in the camera. They produce fantastic detail & color at the cost of weight & money.
- **Full Frame (Crop Factor = 1):** Standard for professional photographers & serious hobbyist. Provides fantastic image quality and dynamic range without the added bulk, weight, or cost of the medium format camera.
- **Crop Sensor (Crop Factor < 1):** Cheapest and smallest option. Smaller camera sensor size provides lower quality images with increased noise and less dynamic range compared to larger formats. For many photographers, the crop sensor camera is perfect for their specific skill level or use. They are not bad cameras, they just aren't as good.

Camera Sensor Size - Why It Really Matters

A larger number of megapixels doesn't always yield increased image quality.

There are mobile phones that capture 40-megapixel images which are not high quality.

The combination of the following, provide a reasonable estimate of a camera's image quality. They are discussed in further detail below.

- **Sensor size:** Determines the light collecting surface area of the sensor.
- **Sensor quality:** The quality and age of the hardware used to fabricate the sensor. Newer hardware will yield better image quality, given everything else is constant.
- **Underlying software quality:** Algorithms and code running the camera's operating systems & image processing. Newer software usually yields better image quality, given everything else is constant.
- **Pixel width:** Also known as pixel pitch. This is the width of each square pixel, which also determines its surface area.
- **Megapixel count:** How many pixels total are contained in the sensor.
- **Bit-depth settings (see section above):** How many colors and tonal values the sensor can capture and display in the final image.

Let's Discuss...

For the following example, assume the latest pro model full frame camera from Nikon or Sony. The exact model does not matter.

Both of these companies produce the best image sensors currently on the market.

This does not mean that you need the latest & greatest camera to capture really high-quality images.

It only means that each generation of camera will get slightly better in the areas noted above, as software, hardware, and engineering improves.

A full frame camera sensor has a larger surface area to capture more light information over a standard amount of time.

This allows it to perform better in low light shooting scenarios than a crop sensor camera.

Having a larger sensor surface area also yields the ability to contain more pixels than a smaller crop sensor camera.

The more pixels a sensor contains, the more detail about the scene it can collect.

Remember, each pixel is a single color or tonal value.

For example, envision a photo, printed on a wall, that's 3 feet or approximately 1 meter, wide.

It would be hard to tell what was going on in that photo if it was captured using a 10-pixel sensor.

There would only be 10 colors are tonal values used to portray the entire scene.

It would be very easy to decipher each exact detail in that photo if it was captured using a 40,000,000 pixel sensor.

Smaller pixel pitch (width), combined with larger sensor size, and the latest software & hardware, will produce the best image quality.

Now let's discuss noise...

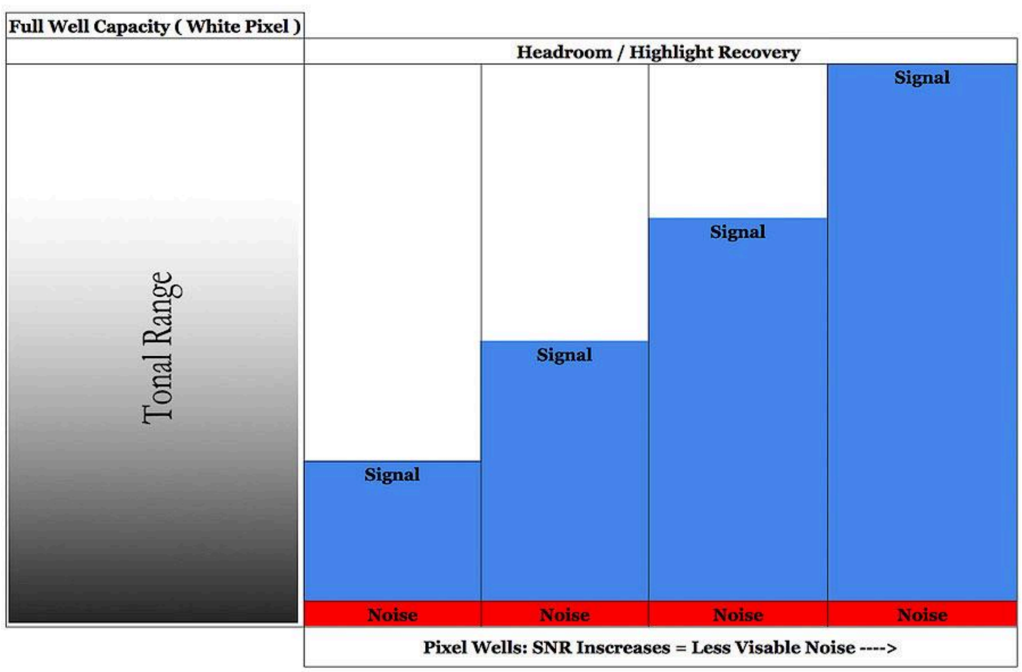
Picture Noise & Sensor Size

CMOS camera sensors and pixels inherently produce a small amount of noise. This is similar to radio static heard at low volumes in headphones. Even the best cameras with the optimal settings create small amounts of noise.

Noise is dependent of camera make and model as well as settings. Different types of noise makeup the overall noise profile for a given image.

As a sensor collects more light, producing a larger signal, less overall noise is seen in the final image. The Signal to Noise Ratio (SNR or S/N) is used to describe the phenomena.

In the graphic below, the pixel wells on the left have lower signal to noise ratios where the pixel wells moving towards the right have higher signal to noise ratios.



- Low signal to noise ratios exhibit a higher percentage of noise per overall signal produced, showing more overall noise in the image.

- High signal to noise ratios exhibit a lower percentage of noise per overall signal produced, showing less overall noise in the image.

The goal is to fill each pixel well to it's corresponding tonal value maximum without clipping or losing data off the top end, thus increasing the Signal to Noise Ratio and image quality.

Images that contain larger proportions of dark tonal values will inherently have lower Signal to Noise Ratios revealing more visible noise. This is one reason low light and night sky images contain so much noise.

Images that contain larger proportions of lighter tonal values will have higher Signal to Noise Ratios revealing less visible noise.

The video provided at the top of this page shows different examples of this concept.

Due to this fact, slightly overexposing images, known as Expose to the Right or ETTR , provides higher Signal to Noise Ratios and overall better image quality, provided that the brightest pixels are not "clipped" or "blown out".

In some shooting scenarios such as star, Milky Way & night sky photography, the light levels are so low that the image noise will be very high. Even the best camera sensor for low light, such as models made by Sony, still produce some noise.

Using simple Noise Reduction Techniques it's very easy to combat this problem in Photoshop.

Dynamic Range, ISO & Sensor Size

Dynamic Range is defined as the difference or range between the strongest undistorted signal (brightest tonal value) & the weakest undistorted signal (darkest tonal value) captured by an image sensor, in a single photo.

The larger the dynamic range the larger the range of tonal values and colors each image can capture and display.

For example, a camera with high dynamic range capability could shoot directly into the bright sunlight & still collect information from dark shadow regions, without producing much noise. This is shown in the video above.

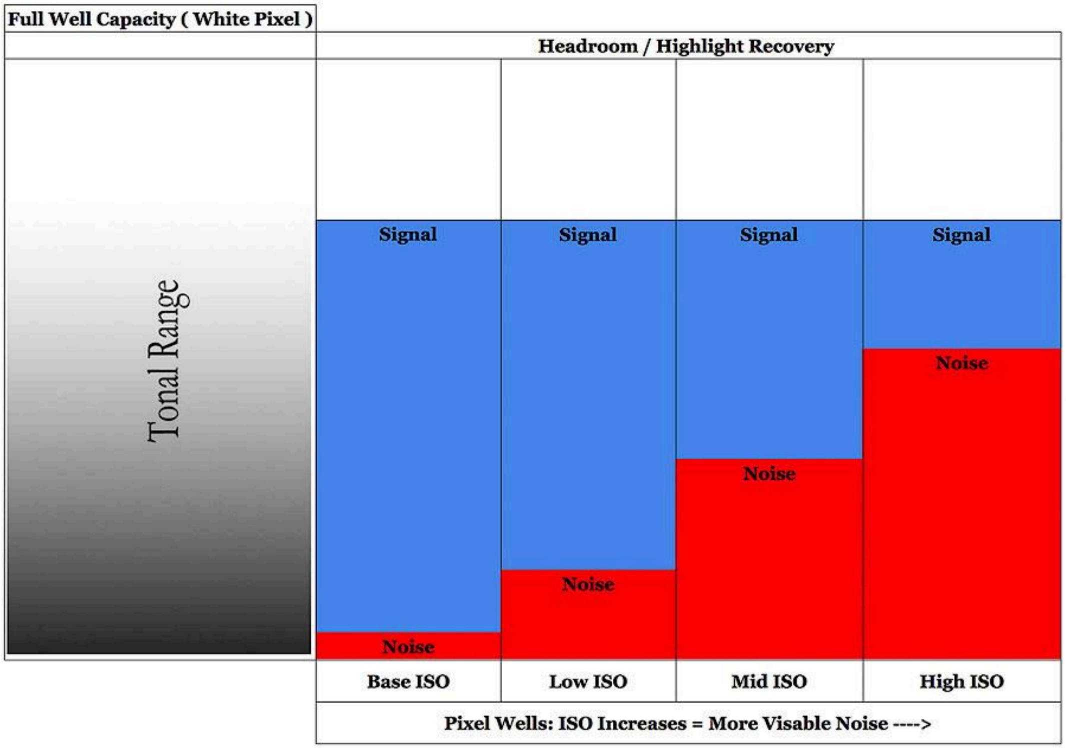
Due to this fact, larger physical sensor sizes combined with larger megapixel counts provide increased camera performance, with less noise, especially in low-light shooting situations.

The aperture diameter & shutter speed control how much light is captured by each pixel, thus increasing or decreasing the signal strength.

The ISO determines the amplification of the signal & inherent noise. The ISO also determines how much light is required for the optimal exposure.

Higher ISO Values = Less Scene Light Required = Smaller S/N Ratio = Smaller Dynamic Range = More Image Noise

Lower ISO Values = More Scene Light Required = Higher S/N Ratio = Larger Dynamic Range = Less Image Noise.



In the graphic above the ISO is increased, which amplifies the baseline inherent noise seen in the Base ISO Column.

As the ISO becomes larger less overall light (signal) is required to produce the same tonal value. As the ISO increases the noise levels are amplified creating more overall noise in the image.

As ISO increases the amount of undistorted signal which reflects the dynamic range, also decreases.

No matter the camera, higher ISO values will always produce more overall noise and less overall dynamic range in the final RAW file.

Unlike megapixel counts, having a larger dynamic range is always a positive camera attribute. Dynamic range is provided in stops, which is a measure of light. For each stop increase the amount of light information collected doubles.

Sony currently produces some of the highest dynamic range sensors on the market for full frame cameras. These camera sensors are rated at approximately 14.8 stops. Many Nikon cameras use Sony sensors due to this fact.

These new sensors also produce an extremely low amount of noise at very high ISO values such as 5000 or 6400.

Canon continues to produce their own sensors which significantly lack in dynamic range, comparatively, rated at approximately 11.8 stops for their top model cameras. They also produce a much larger amount of noise at high ISO values.

This is a scientific fact, there is no dispute. Sony makes better sensors than Canon for landscape and outdoor photography.