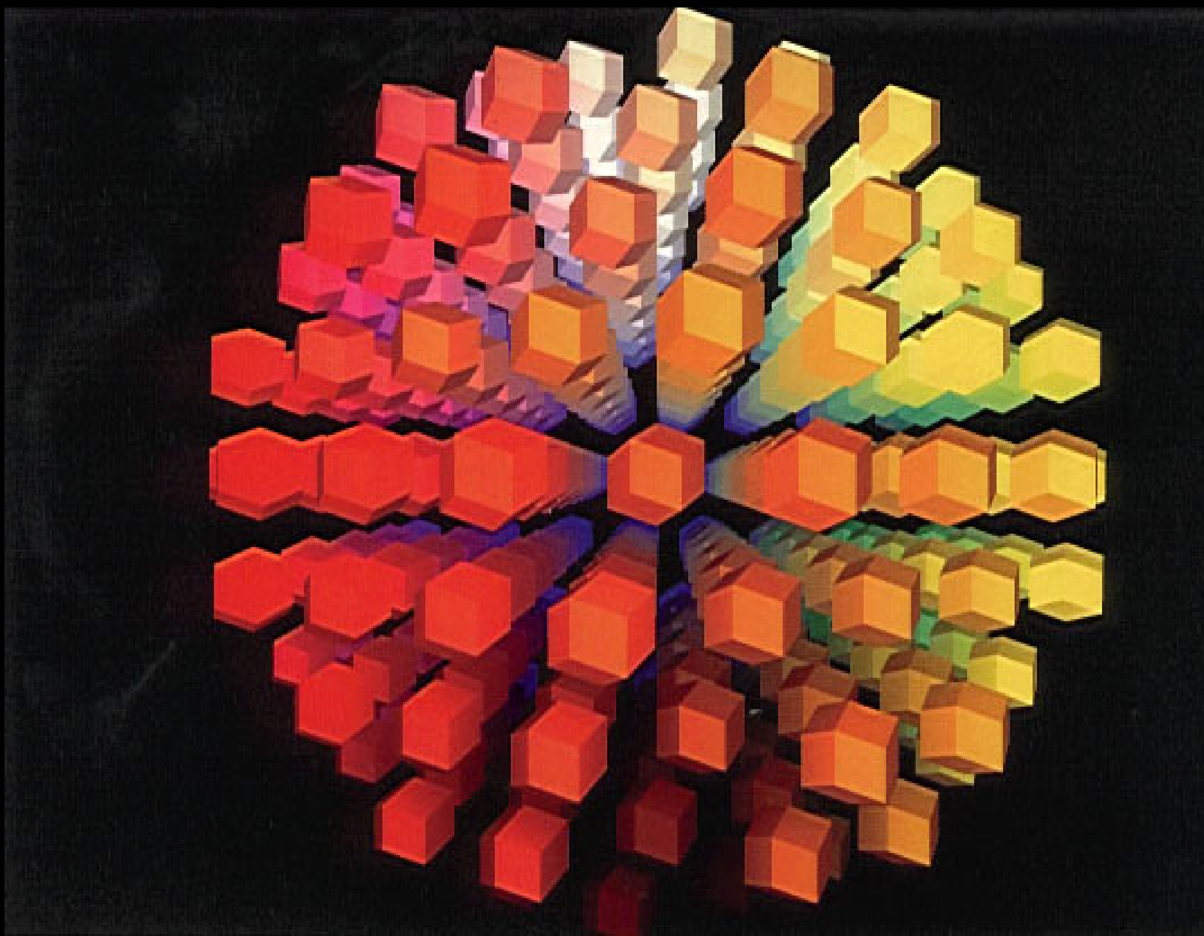
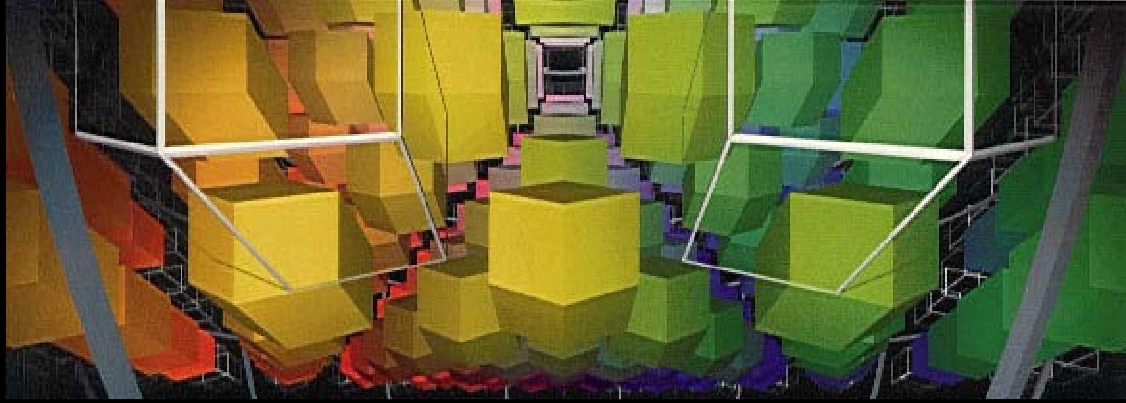
Color Theory

- Chapter 2 — Color Basics
- Color as Light
- Light as Color

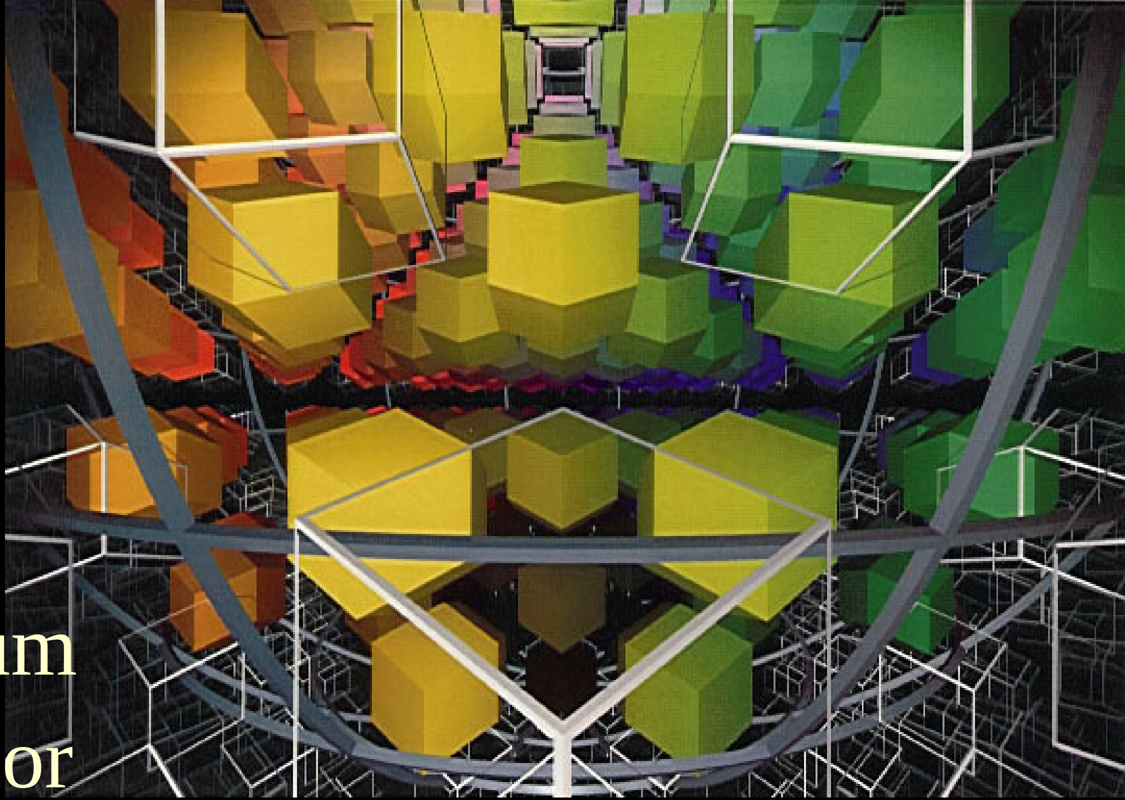


Last Class:



- Color Coding & Color as Communication
- Color as cultural & personal expression
- Current technology driving color availability and client expectations
- 3 dimensions of color
- Color Trends, Fashion & Forecasting
- Color Charting Intro

Basic terms & concepts:



- Color as light
- The visible spectrum
- Wavelengths = color
- White light = all
- Reflection, Transmission, Absorption, Refraction
- Additive Color vs. Subtractive Color
- Light Primaries vs. Pigment Primaries

So what is color?

- ***Its an old question —***
  the earliest western philosophers asked it.
  How does this common, powerful, varied experience happen?

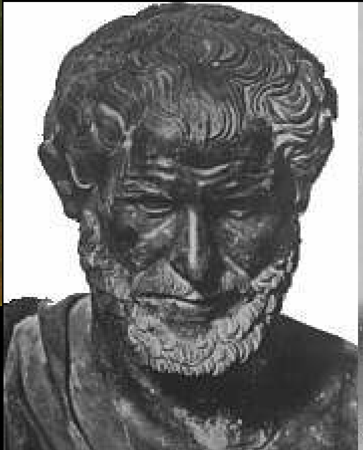
- ***What's it mean?***

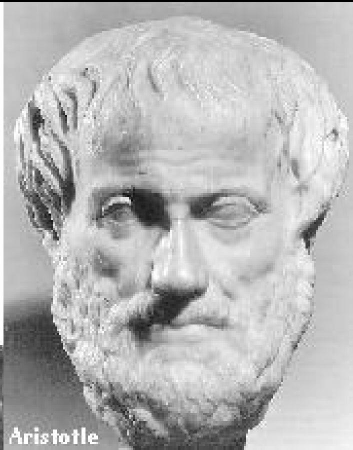
- ***Why is there color?***

Rembrandt's *Aristotle Contemplating a Bust of Homer*

Aristotle

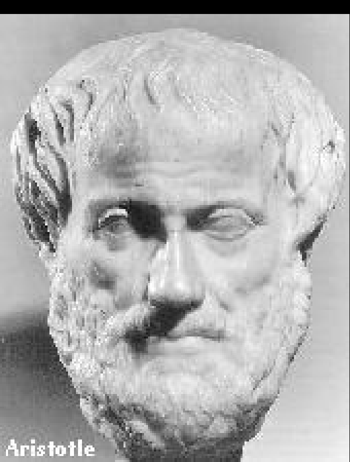
- ***384BC -- 322BC***
- ***Greek philosopher, scientist, physician.***

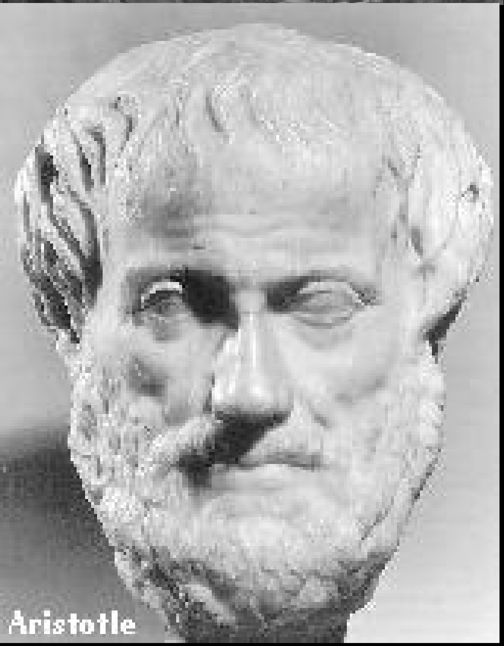




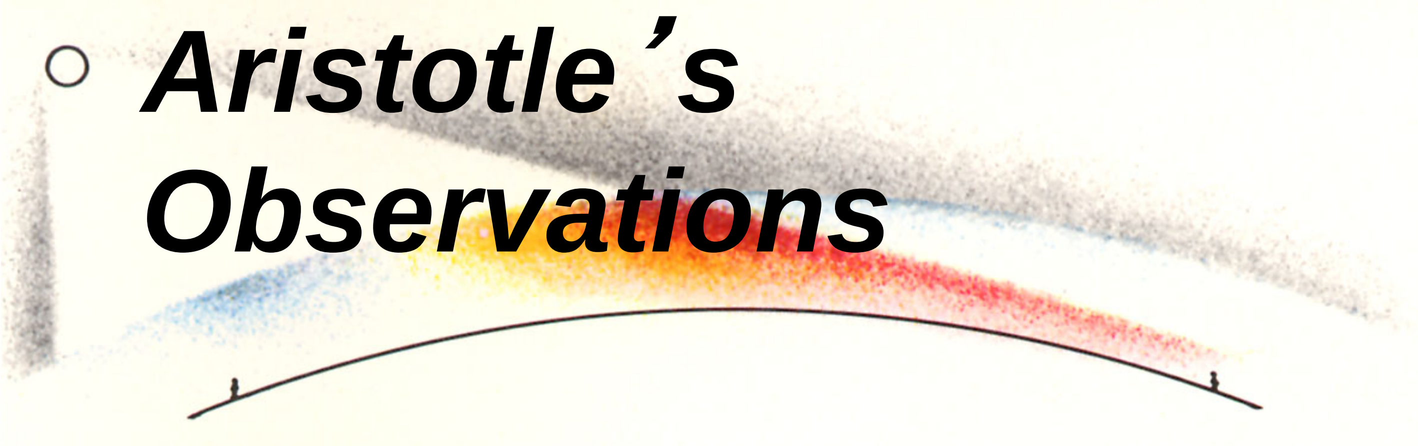
Aristotle

- De Coloribus
- Aristotle tried to explain what causes different colors—where do colors come from?
- His conclusion:
  Color comes from varying combinations of "sunlight and firelight, and of air and water"
- "Darkness is due to privation of light."
- All variations in color are the result of varied proportions of darkness and light.

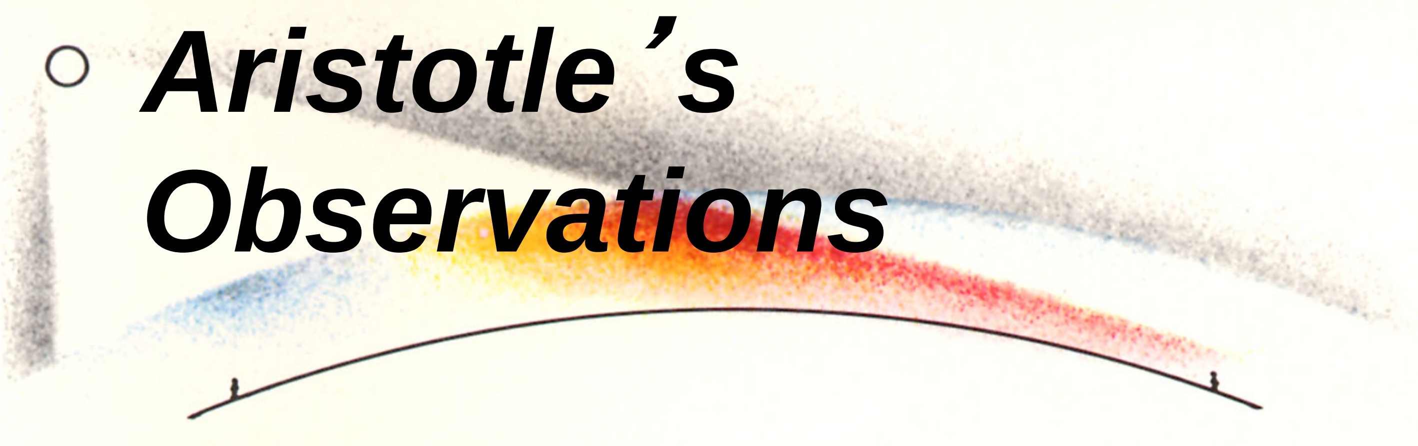




Aristotle's Observations



- ***He learned by looking at phenomena and considering what he observed.*** ***(dawn of observational science)***
- ***He watched the changing colors of the sky throughout the day.***
- ***At noon, the sun is yellow.***
- ***Later, orange, then red…***
- ***…the sunset can become green and dark violet…***



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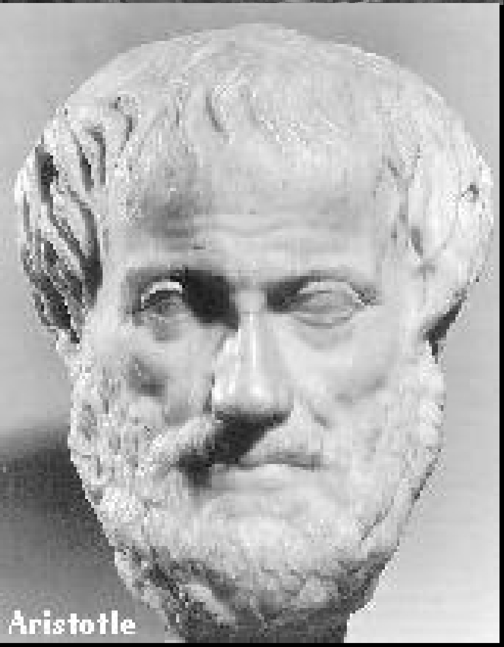


- *Ergo, the as sunlight increases and decreases, colors change.*
- *Colors are therefore due to the amount of illumination.*
- *Not quite. But it was a start.*

Color as Light vs. Pigment

- Since we *see* light, but we most often *mix* pigment – in paint, or ink, or dyes – *we must understand both color as light and color as pigment.*

  That is, we must understand…
  ***additive** color (**light**) and…*
  ***subtractive** color (**pigment**)*

Color is Light

- Every color you have ever seen was due to colored light.

- Not … “you need light to see color”

…color *IS* light.
Each color IS a different kind of light.

No light — no color.   Period.


Color as Light

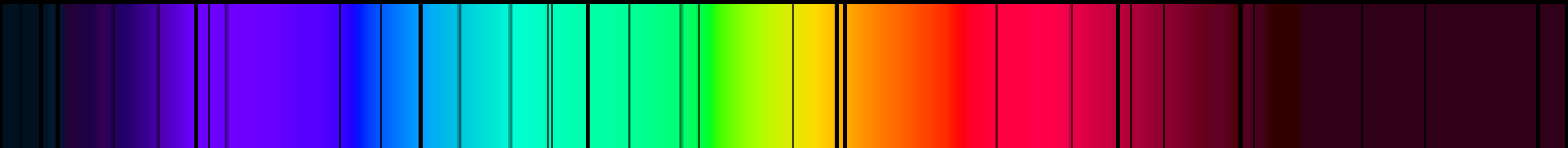
Light is a form of energy.
You happen to have cells that respond to *that* kind of energy.
Thus, you *see*.

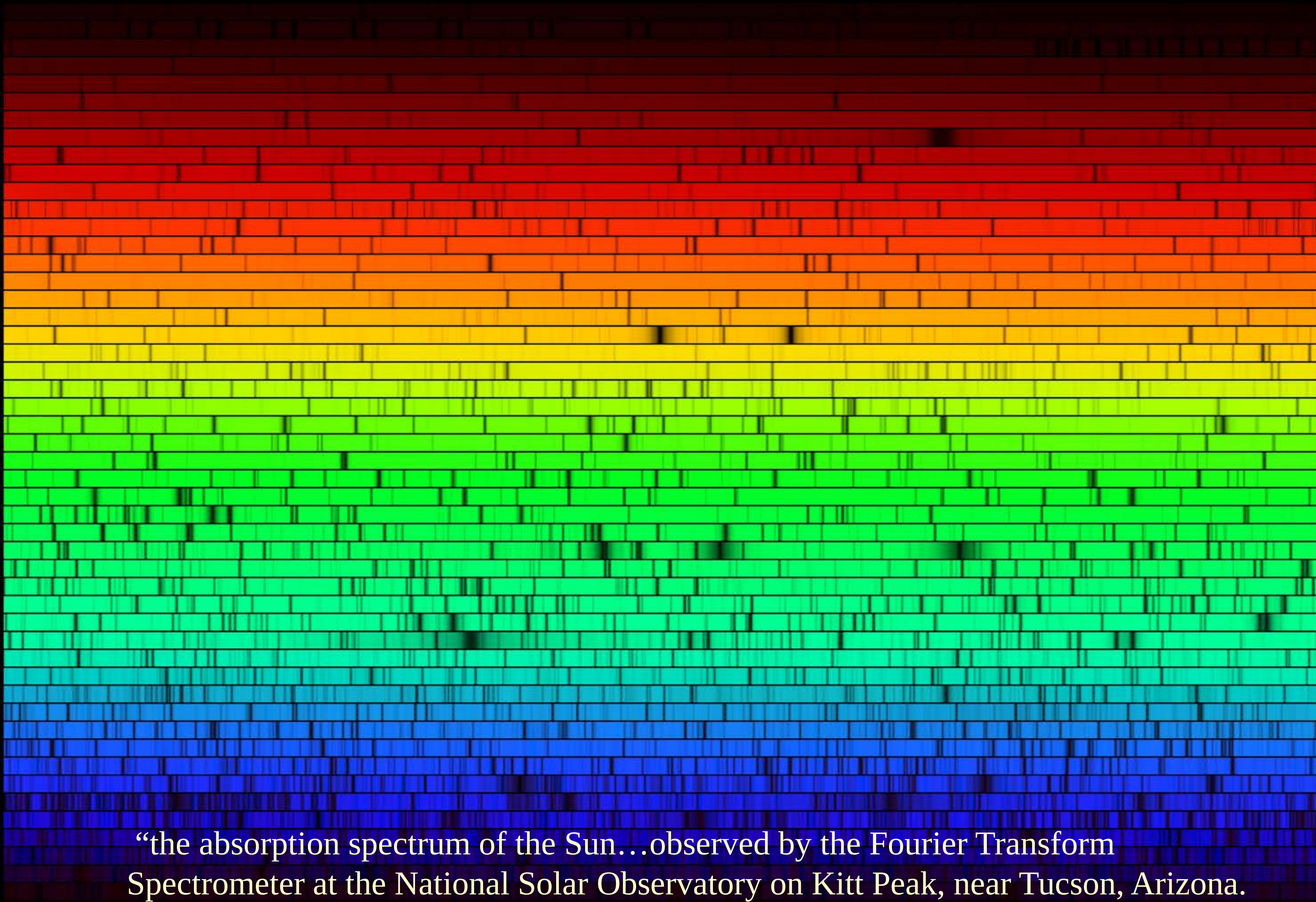
- Your eye sees *only light* – never the surface, never a pigment, paint or dye, and never the object.

- The nerves at the back of our eye are photo-sensors – they respond to light.

White Light

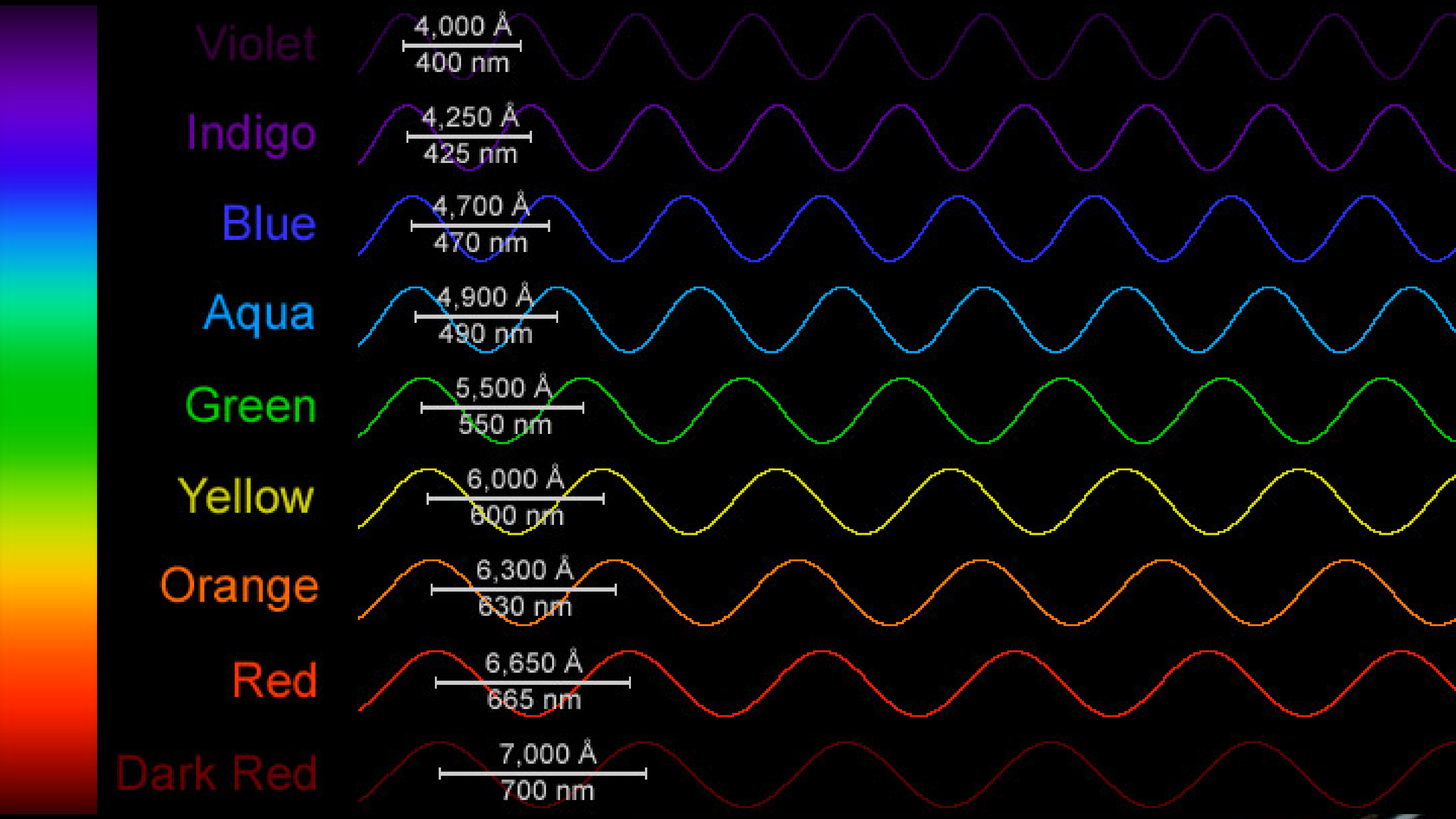
- White light from the sun *contains a mixture all of the colors of light* that the eye can see (the visible spectrum) — and radiates EM energy we can't see.
- (Actually a few very special wavelengths are missing – but we leave *Fraunhofer lines* to the physicists.)





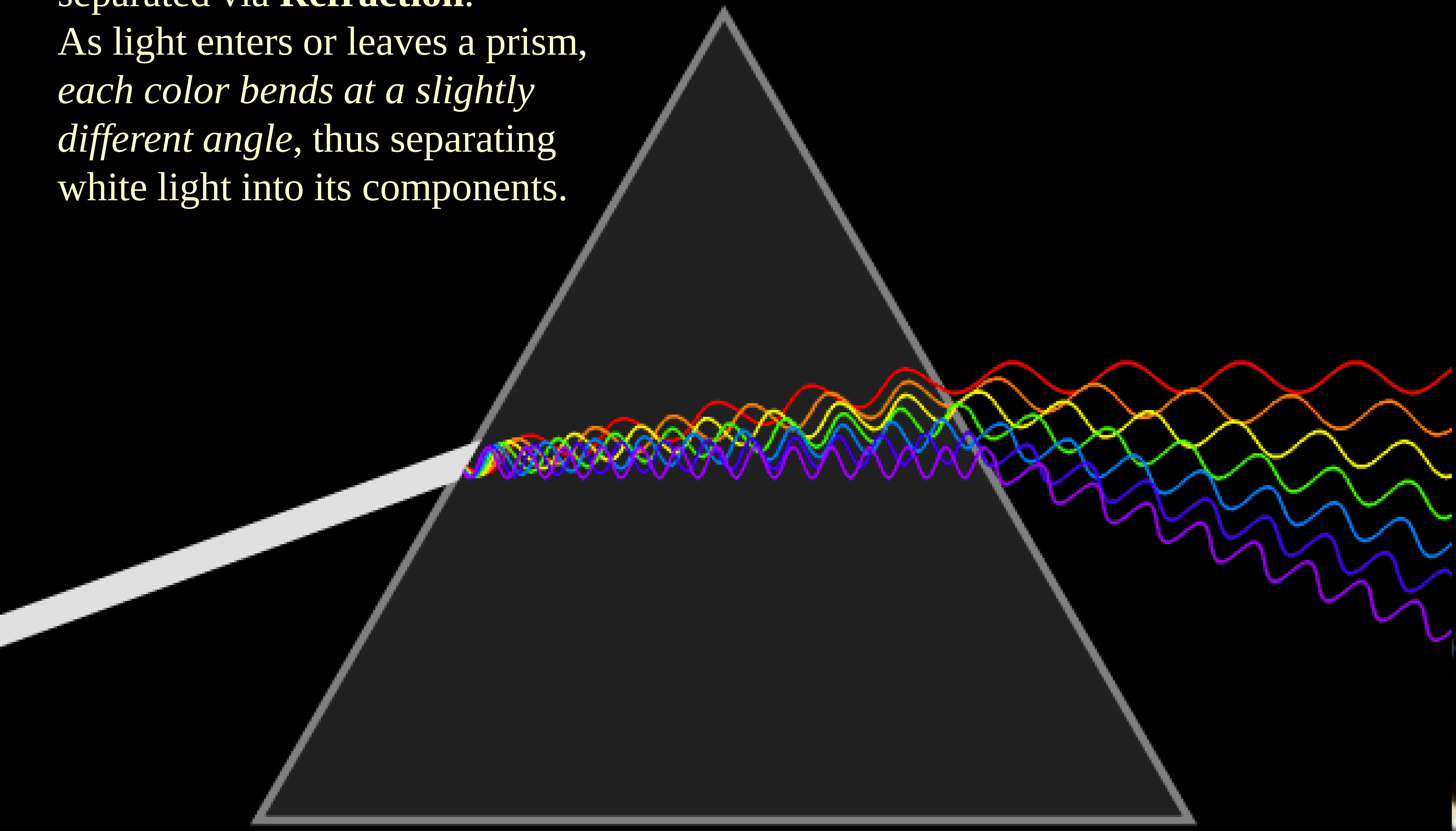
“the absorption spectrum of the Sun…observed by the Fourier Transform Spectrometer at the National Solar Observatory on Kitt Peak, near Tucson, Arizona. The data, which is in essence gathered by shining sunlight through a very accurate prism...”

http://www.extremetech.com/extreme/167878-

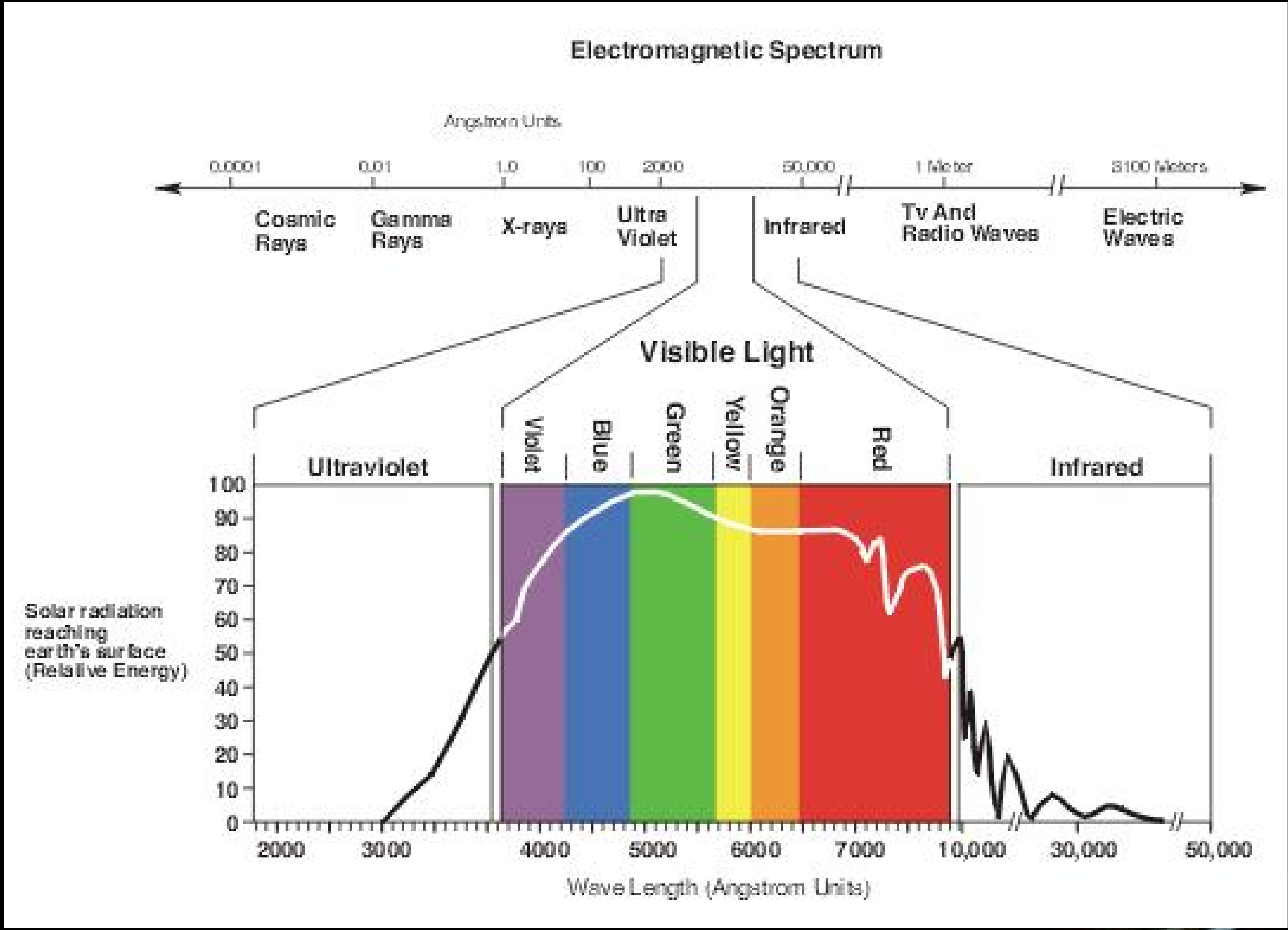


- White light from the sun *contains a mixture all of the colors of light* that the eye can see — the visible spectrum.

Each color or wavelength may be separated via **Refraction**.
As light enters or leaves a prism, *each color bends at a slightly different angle*, thus separating white light into its components.

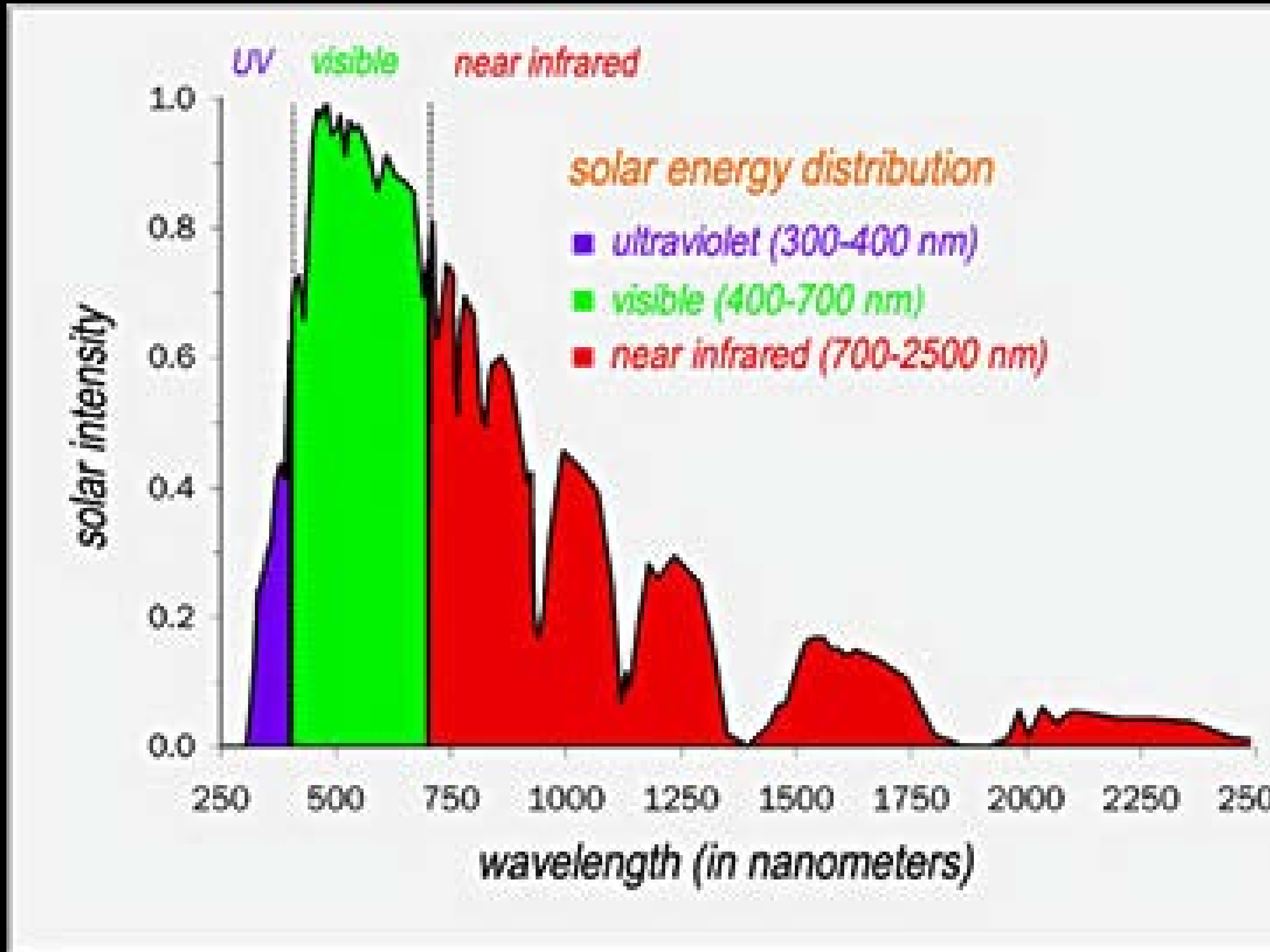


Sunlight: an uneven mixture of many colors



- White light from the sun *contains a mixture all of the colors of light* that the eye can see.

Sunlight: visible light and ***other*** *EM as well.*

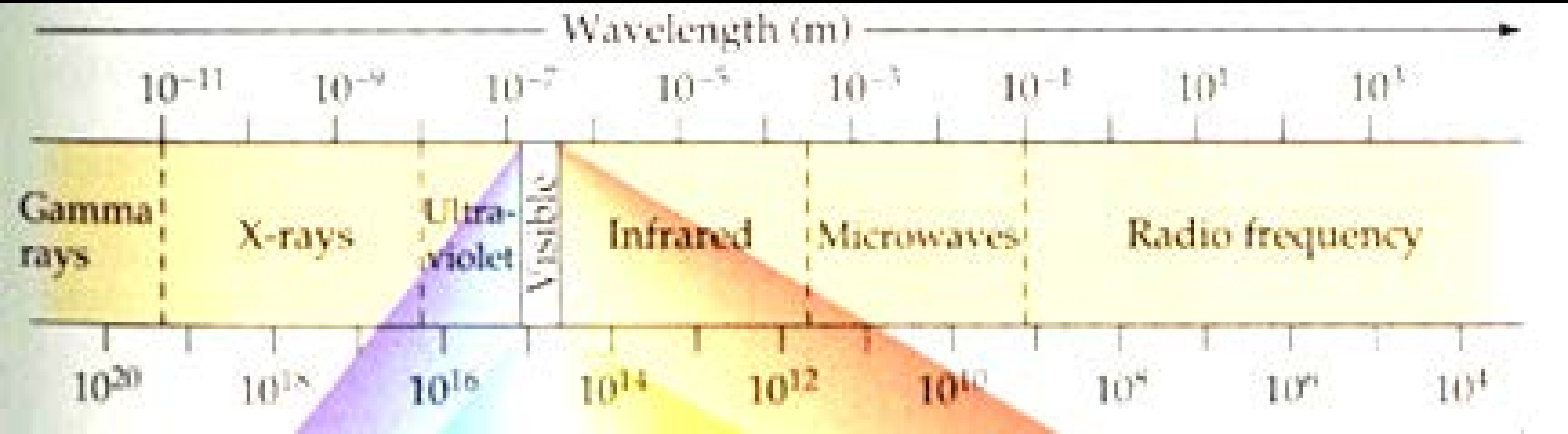


- Visible light is just one neighborhood in the broad range of electro-magnetic radiation radiating from the sun.

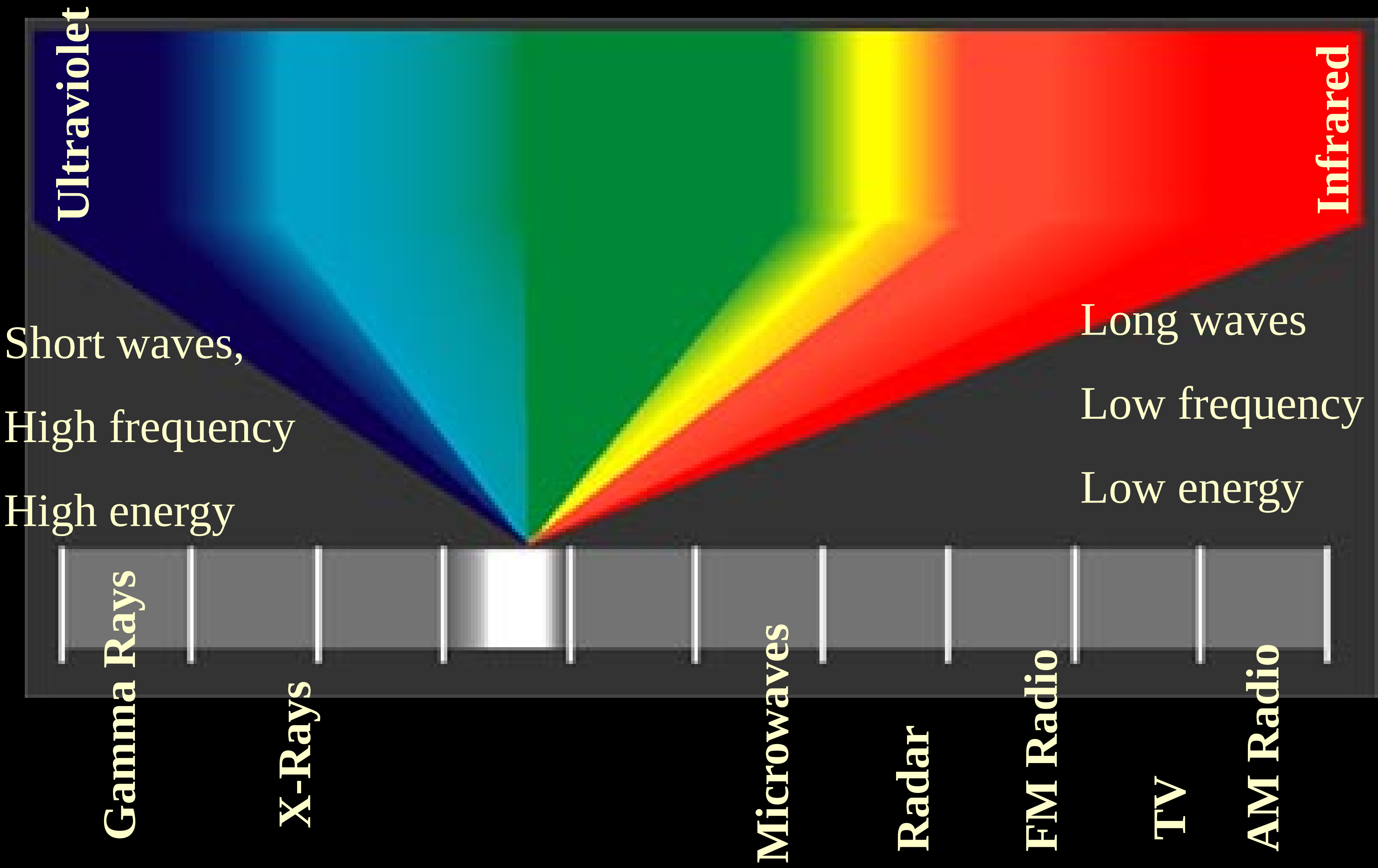
Electro-magnetic spectrum

- Light is only one of many kinds of electro-magnetic energy.
- Light is a cousin of X-rays, Gamma rays, microwaves, radar and radio waves.

The *only difference* is the *wavelengths* of the energy.



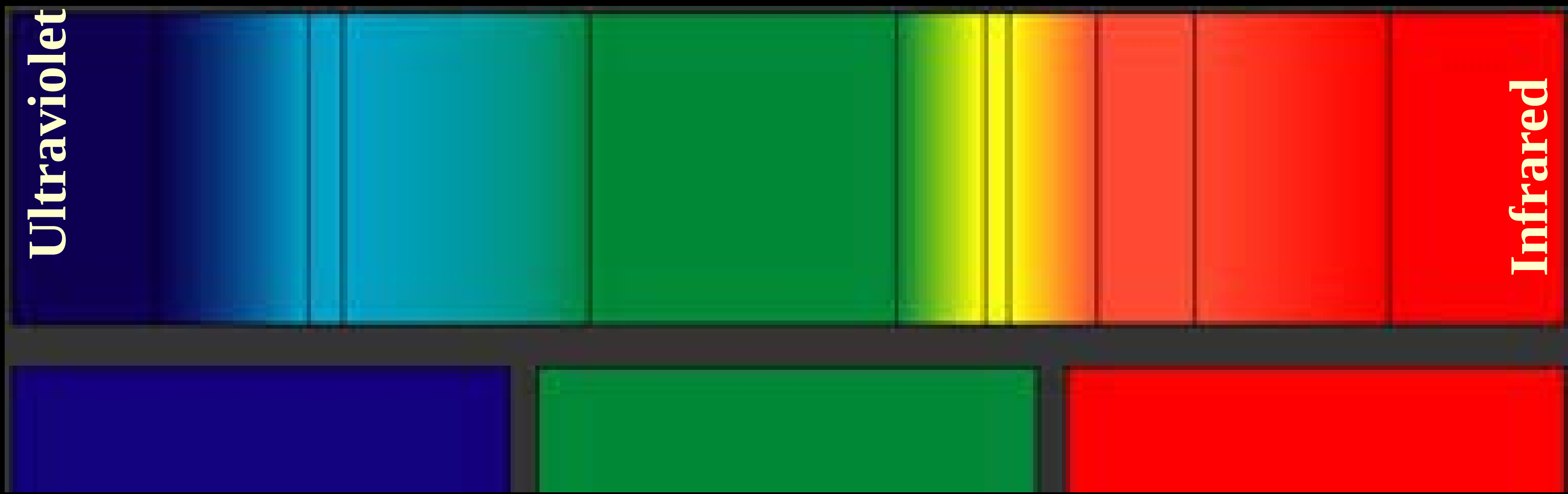
Visible light spectrum



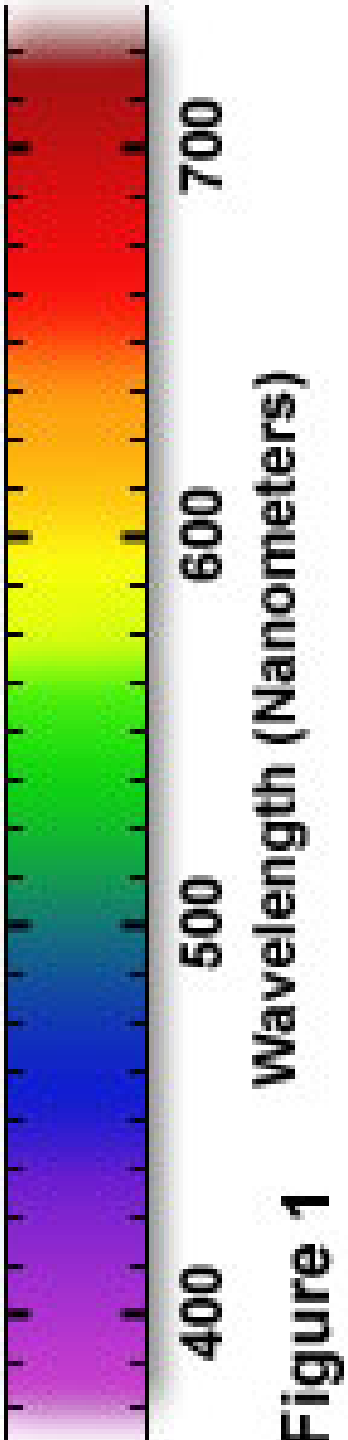
Visible light spectrum

- From a physical point of view, the light we actually see has nothing special about it *except* that our eyes can see it.
- Our eyes are designed to perceive a small portion of the many wave-forms that are around us all the time.

Visible light spectrum



- Our eyes sense (see) only a small portion of the electromagnetic energy that is all around us.
- Light is the same "stuff" as radio waves, microwaves, x-rays,…



*Colors **are** distinct wavelengths of light*

- Each color that we see is just one *very particular* type of electro-magnetic energy.
-

  That is, red is different from green because it has *a different energy level and a different wavelength*.

- **NOTE: Colored light has NO COLOR, except as the mind interprets energy sensed by the eye.**

  That is, *there is nothing red about red.*

Spectra From Common Sources of Visible Light

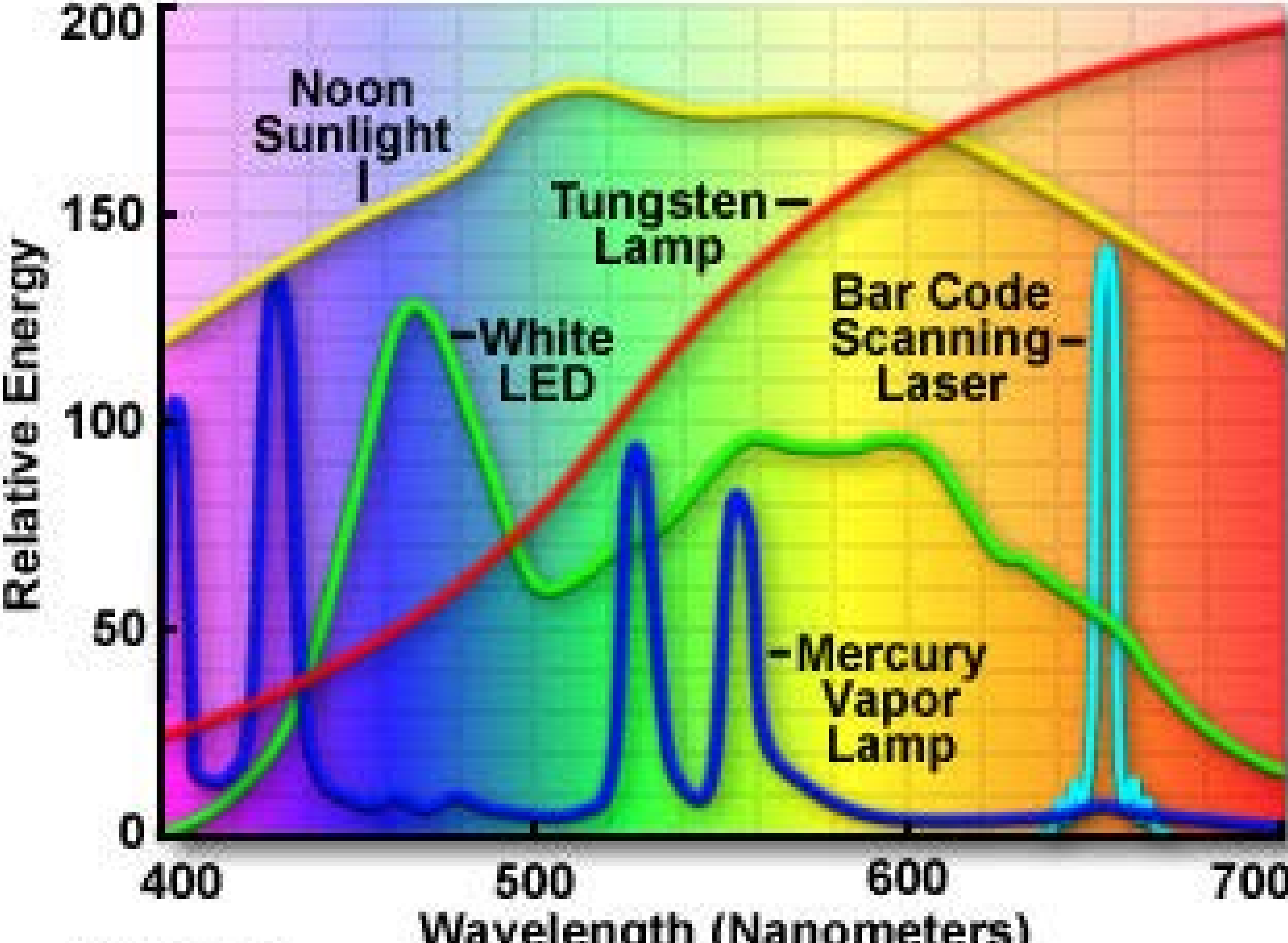
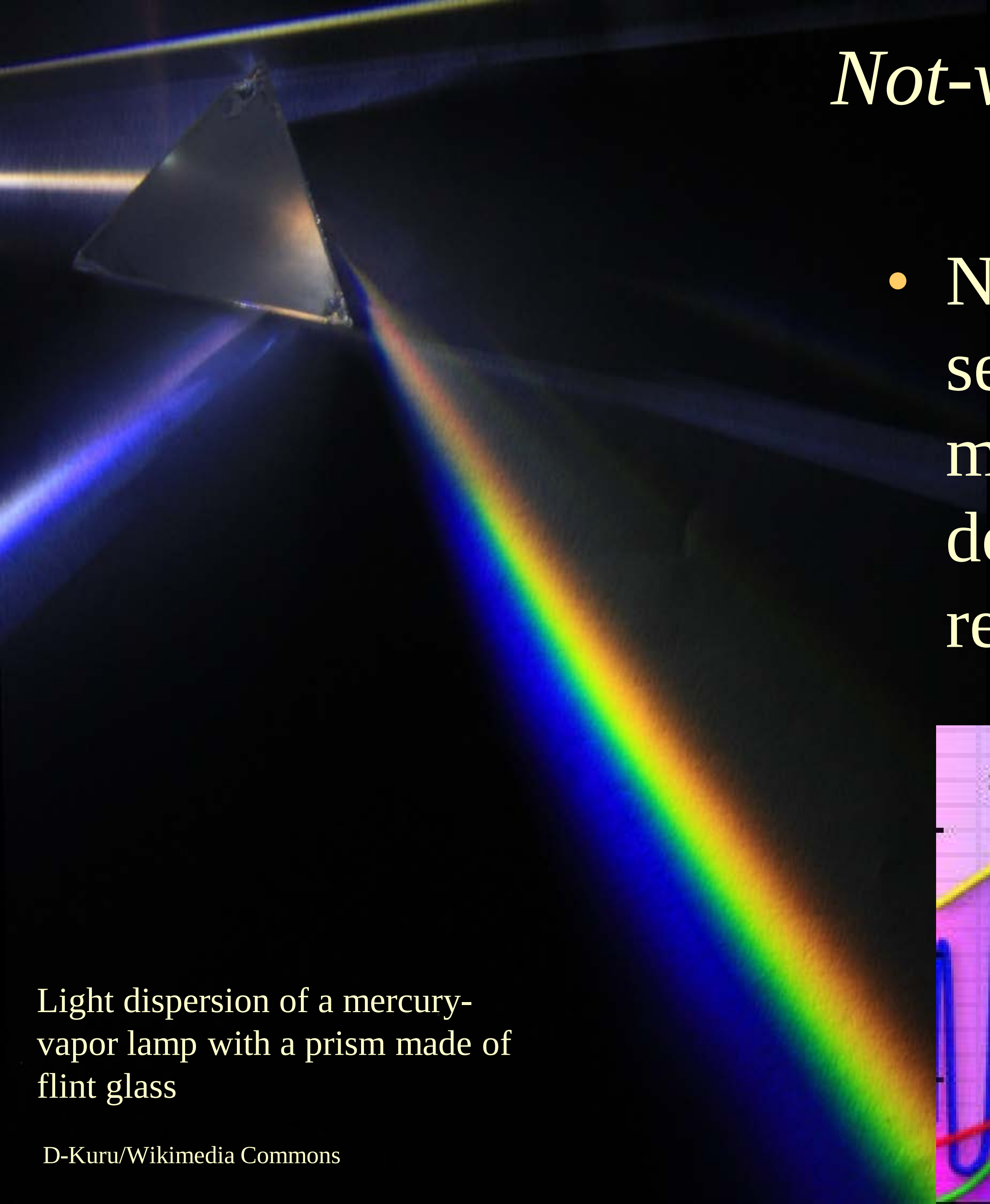


Figure 3

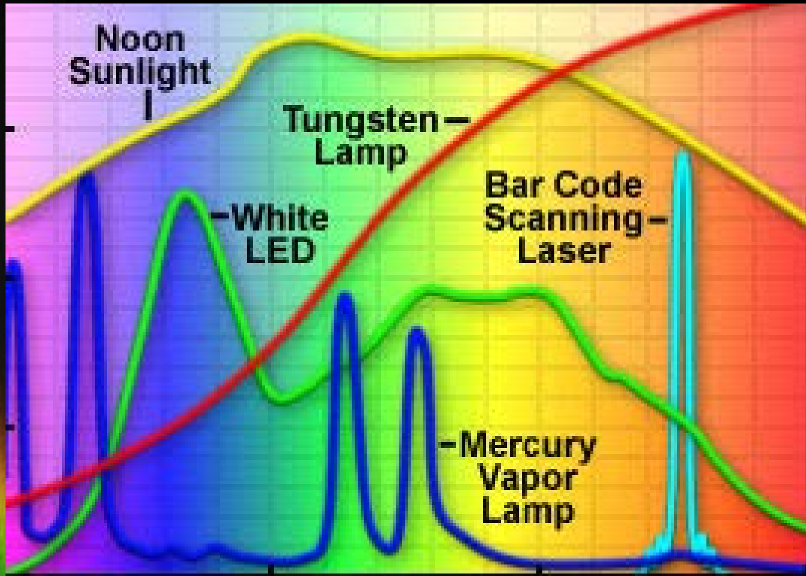
Not-very White Light: Mercury Vapor

- Note that the colors separated from this mercury vapor lamp don’t include the reds.



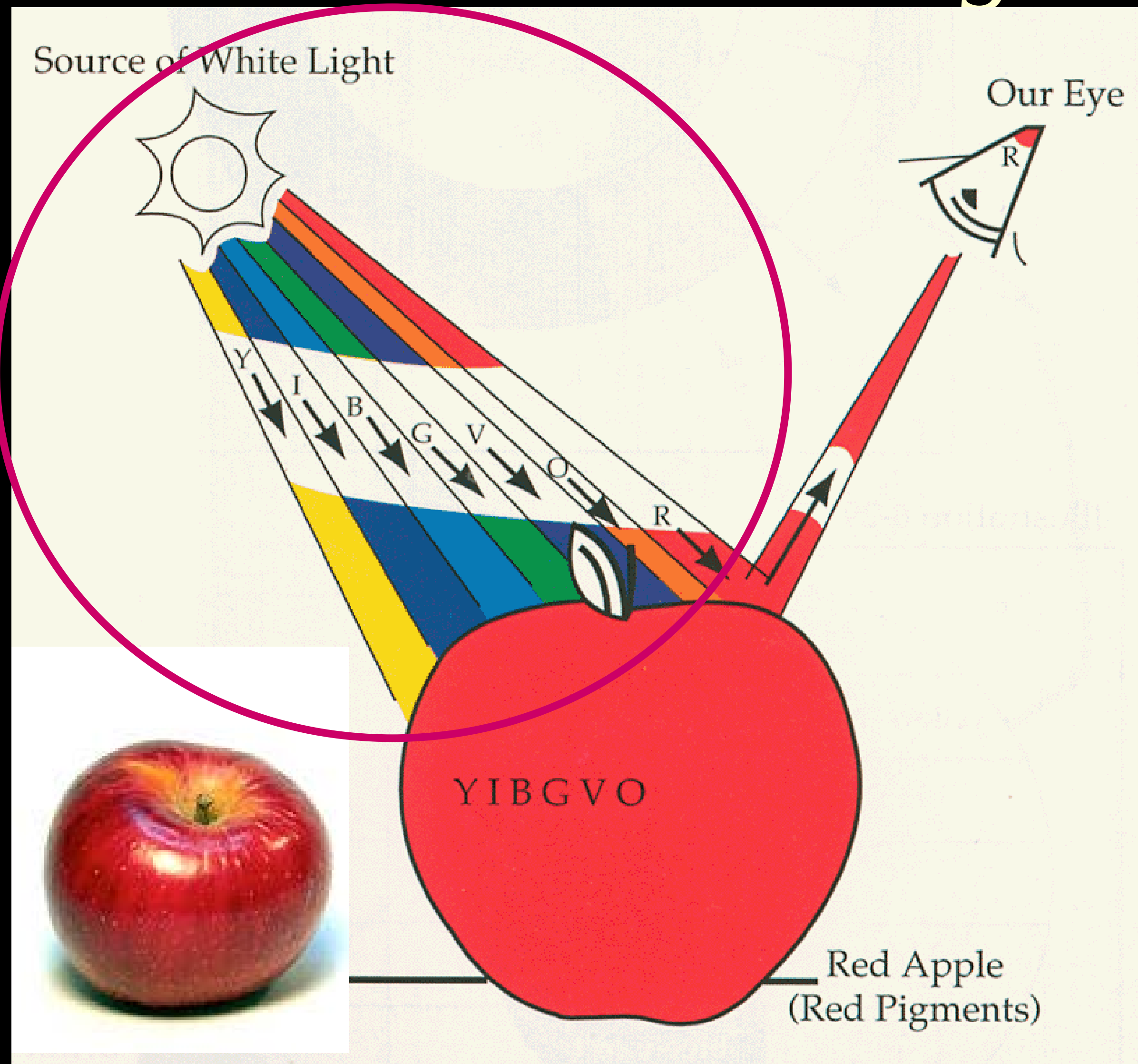
Light dispersion of a mercury-vapor lamp with a prism made of flint glass

D-Kuru/Wikimedia Commons



Color is Light

- All visual experience is based on light—a light source (one or more) illuminates objects and surfaces,
- some portion of the light reflects off of those surfaces and enters the viewer's eye.
- The colors and the forms we see are due to *how* surfaces and materials interact with illuminating light.
- Some colors are subtracted/absorbed, others are reflected.



We do not see *objects*; we see *light*.

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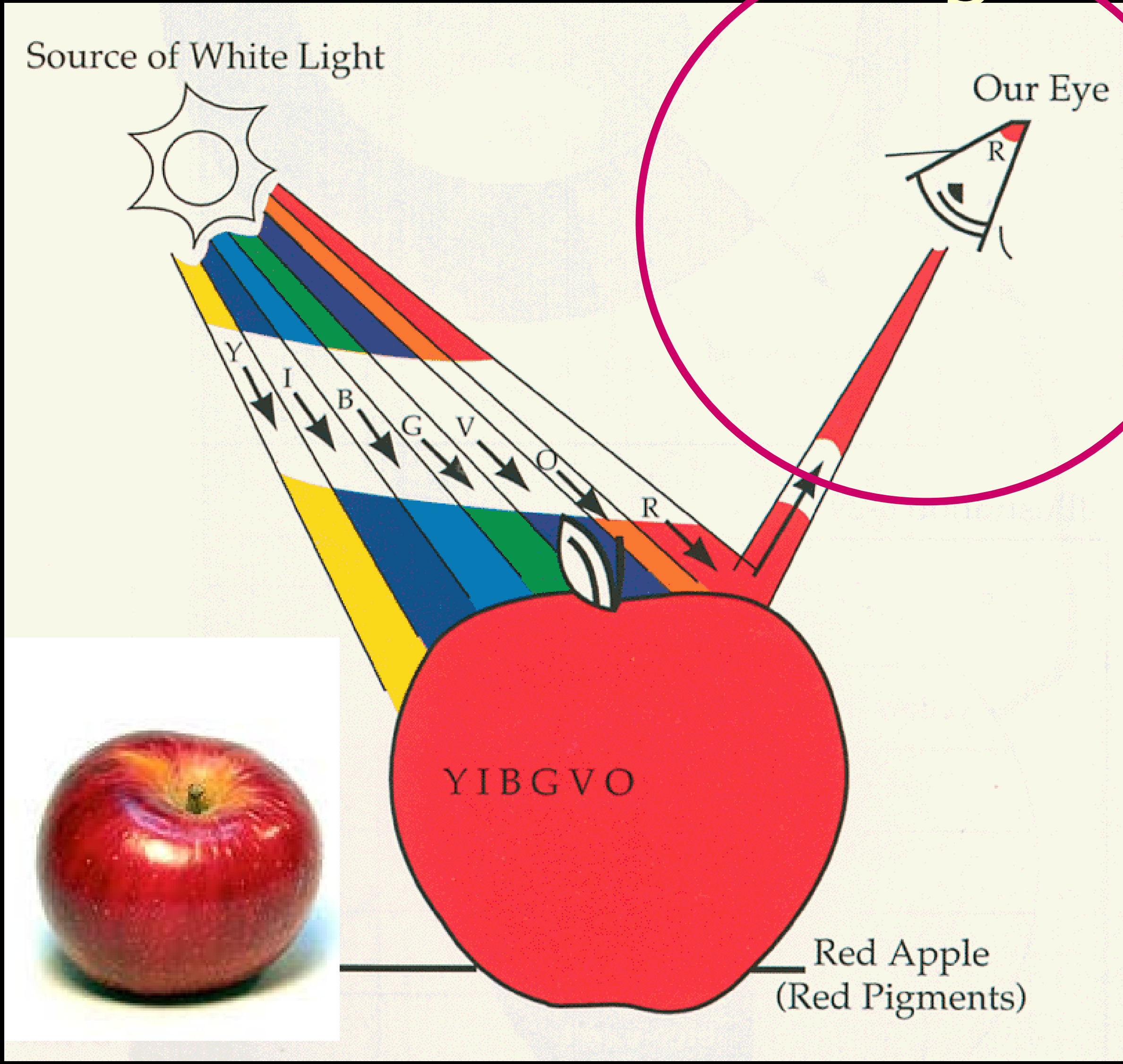

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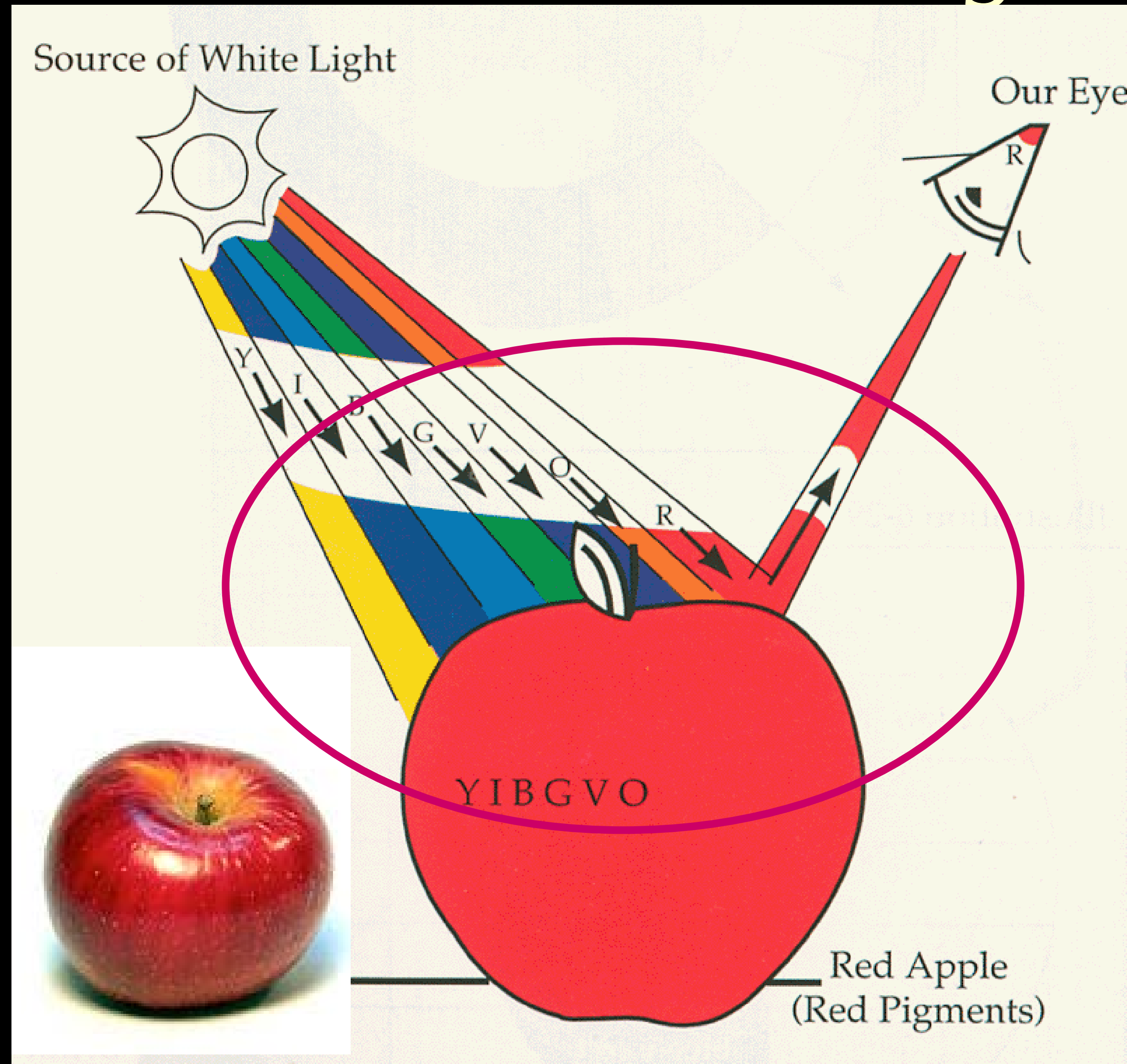

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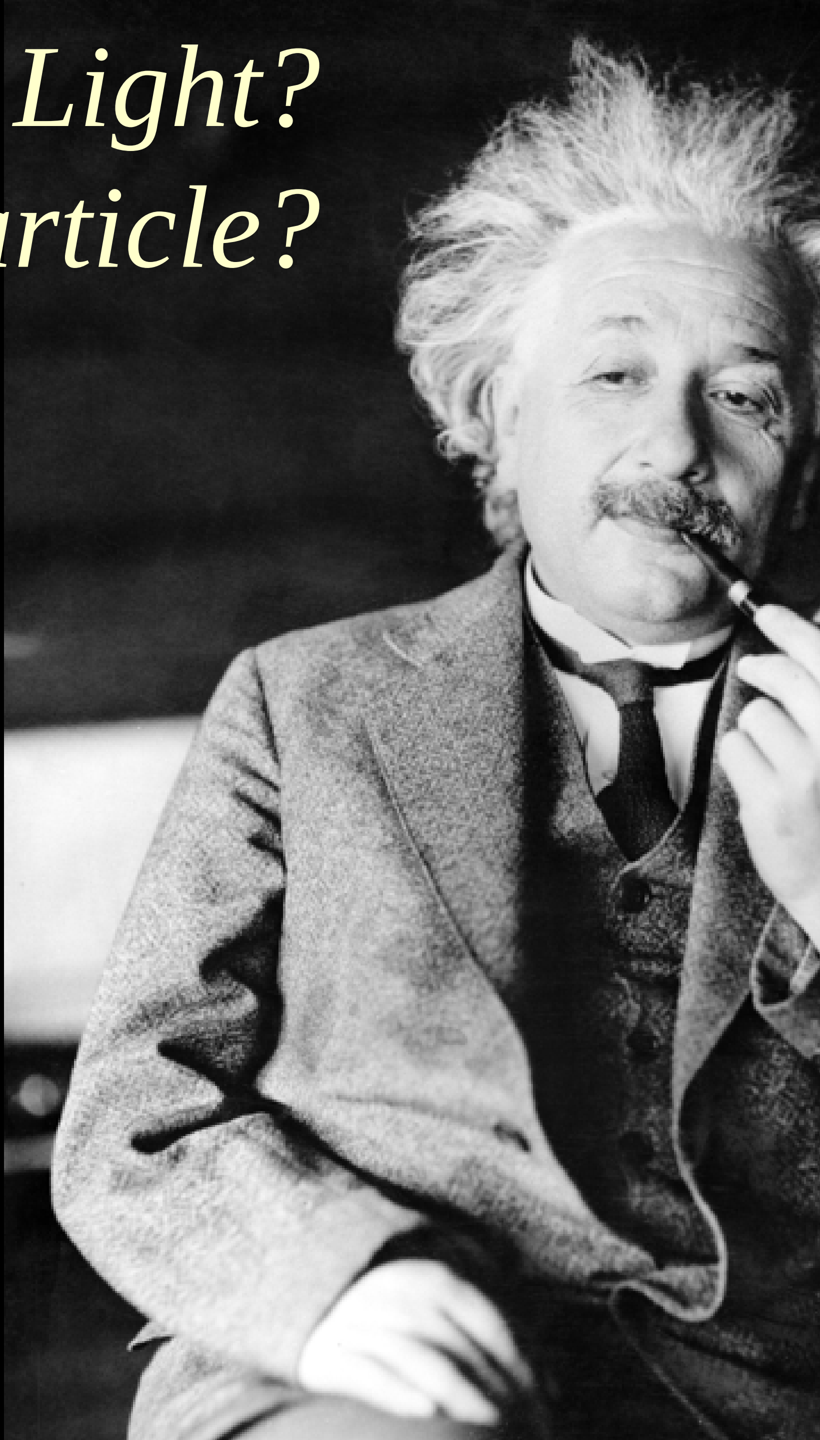
What is Light?
Energy wave, or particle?



- This is mainly a physics question, but the phenomena of light and color depend on it, so we explore a bit.

- Einstein and other physicists before him, debated just what light *is*.

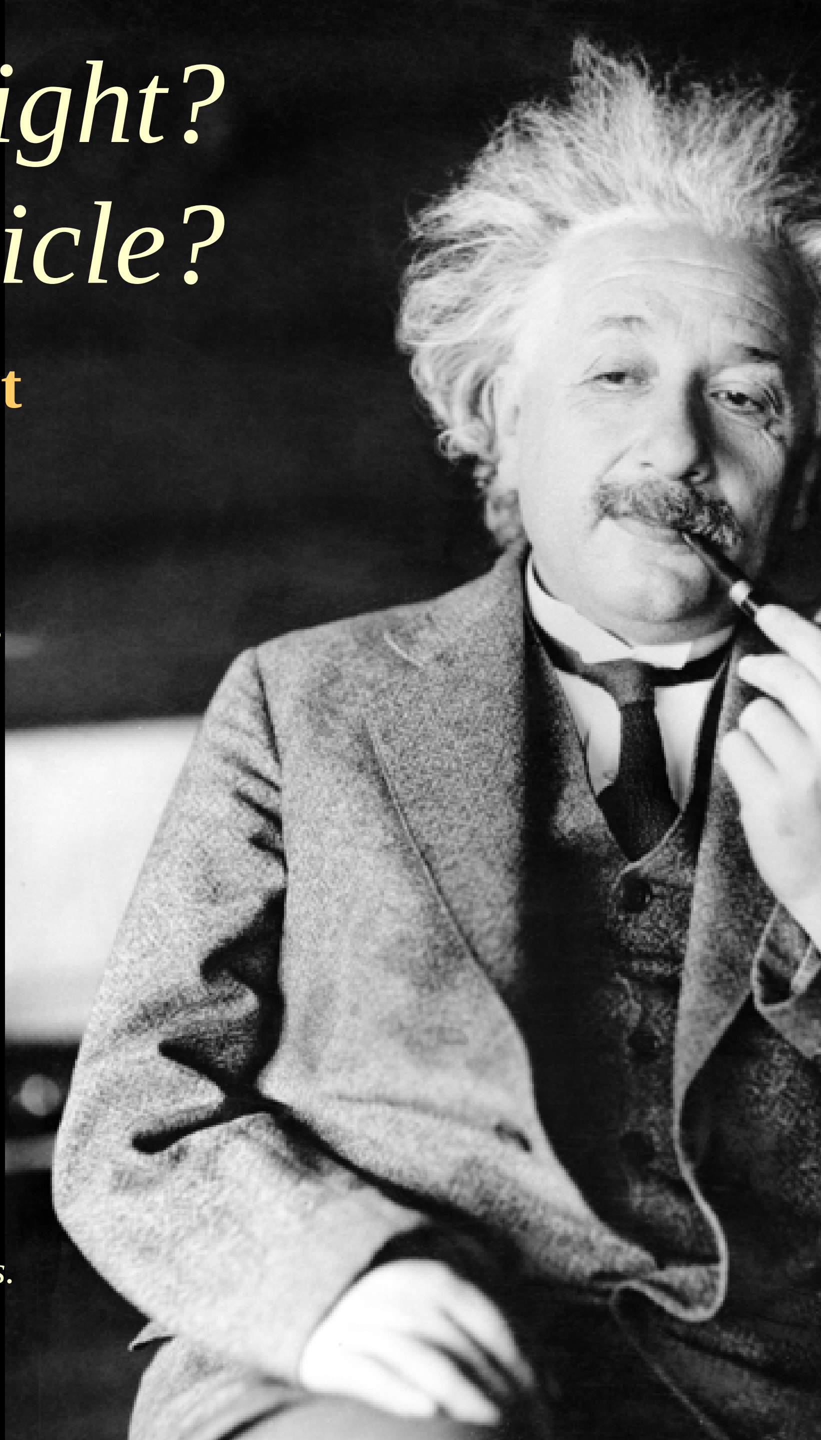
  They basically considered light to be *either* a wave or a particle.

What is Light? Energy wave, or particle?

- Eventually, they decided that **light is both** – which was first considered a contradiction, but later we decided it was a paradox.
-

  A particle of light — a *photon* — is a 2D object living in a 3D universe. *Kinda bizarre.*

- Basically, light and color, from a physical point of view, are amazing phenomena. *But we digress.*



Blue Skies and Rainbows: blue and violet are selectively scattered

Blue Skies: blue and violet are selectively scattered

- **“The familiar blue of the daytime sky is the result of the selective scattering of sunlight by air molecules.**
  Scattering is the scientific term used to describe the reflection or re-direction of light by small particles. … *Selective scattering*, also known as *Rayleigh scattering*, is used to describe scattering that varies with the wavelength of the incident light.
- Particles are good Rayleigh scatterers when they are very small compared to the wavelength of the light.”

  - www.spc.noaa.gov/publications/corfici/sunset/

Blue Skies: blue and violet are selectively scattered

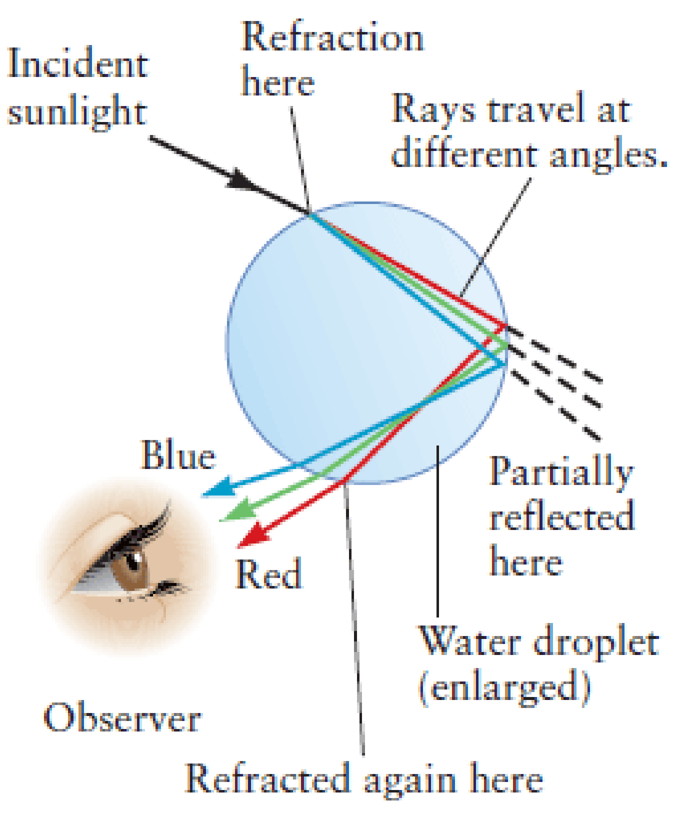
www.spc.noaa.gov/publications/corfici/sunset/

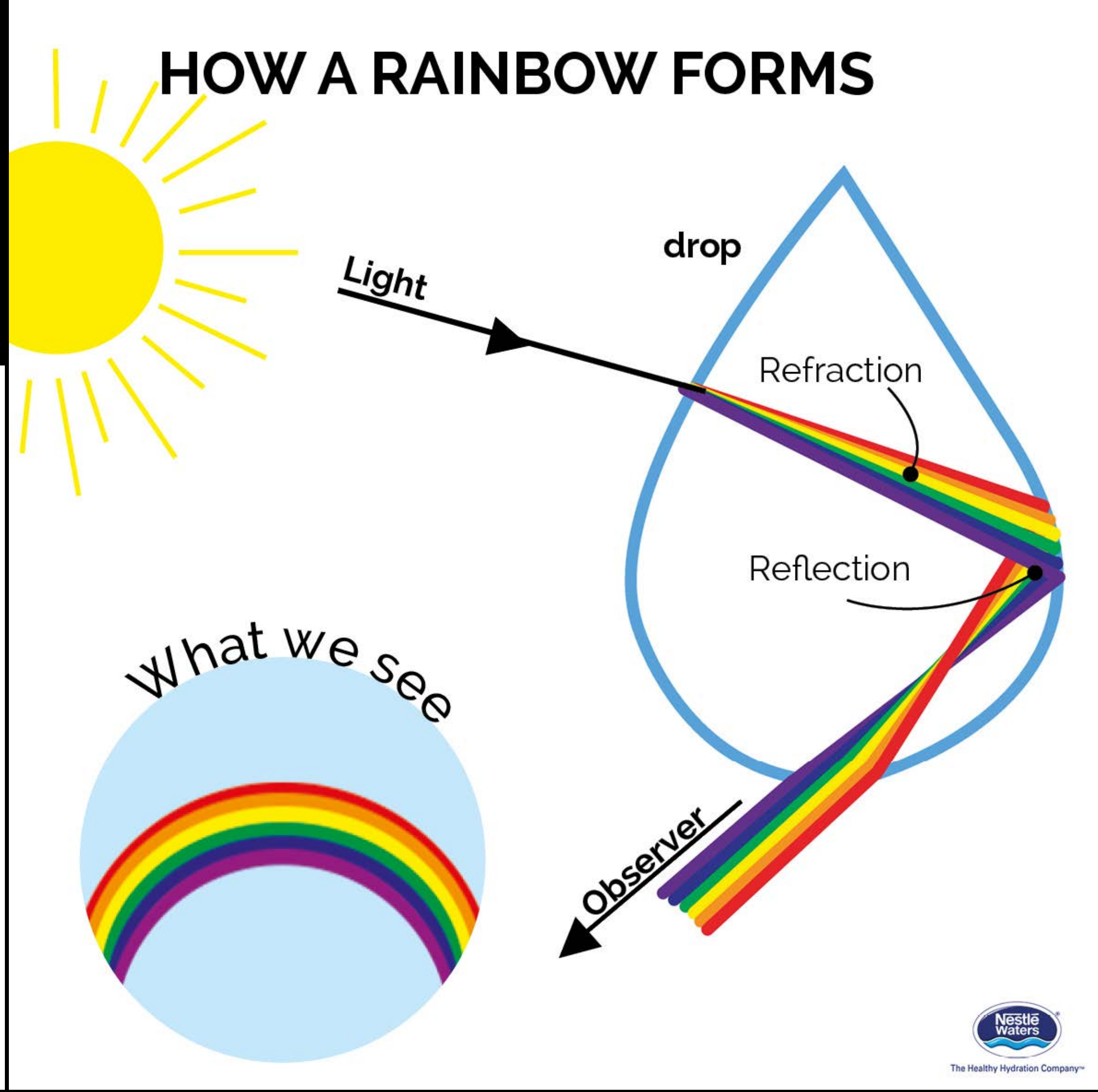
- "Ordinary sunlight is composed of a spectrum of colors that grade from violets and blues at one end to oranges and reds on the other. The wavelengths in this spectrum range from .47 um for violet to .64 um for red. Air molecules are much smaller than this --- about a thousand times smaller. Thus, air is a good Rayleigh scatterer.
- But because air molecules are slightly closer in size to the wavelength of violet light than to that of red light, pure air scatters violet light three to four times more effectively than it does the longer wavelengths. In fact, were it not for the fact that human eyes are more sensitive to blue light than to violet, the clear daytime sky would appear violet instead of blue!"

Rainbow: sunlight divided

- A rainbow is a result of white sunlight being divided (refracted) into its constituent colors — we get to see what's IN sunlight.

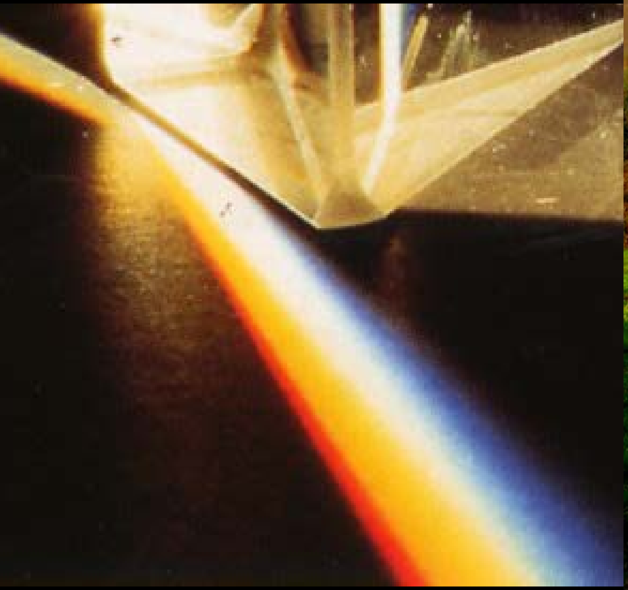
Rainbow: sunlight divided





waterstories.nestle-waters.com

Rainbow: sunlight divided



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Rainbow: sunlight divided

Blue Skies and Rainbows…

- http://www.webexhibits.org/causesofcolor/14.html
- http://www.webexhibits.org/causesofcolor/14B.html
- http://www.webexhibits.org/causesofcolor/14D.html
- http://www.webexhibits.org/causesofcolor/13.html
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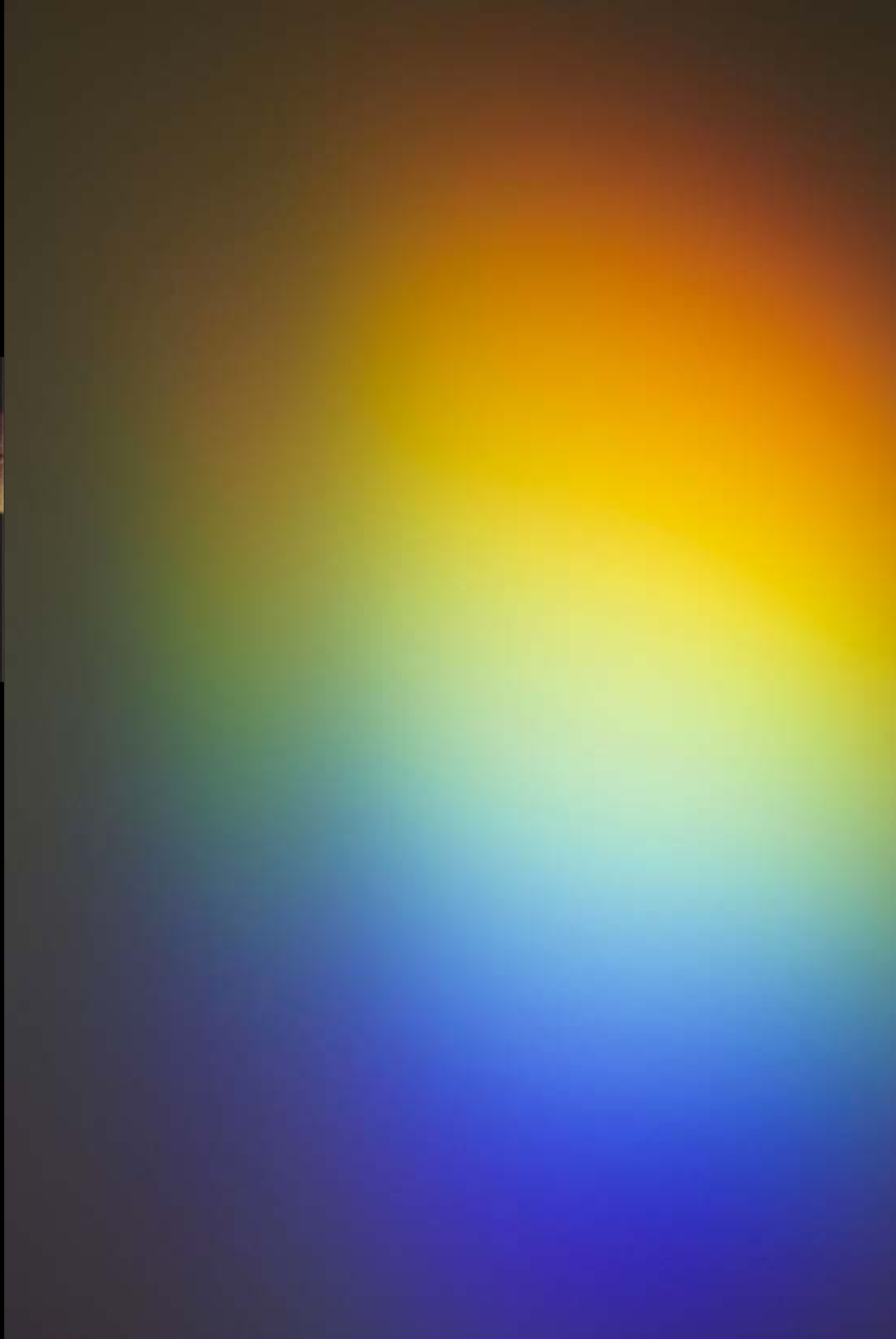
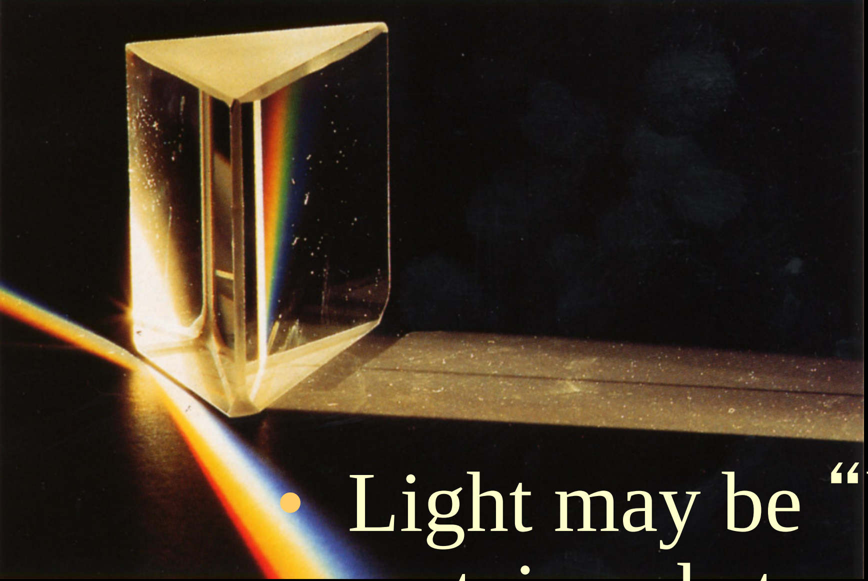


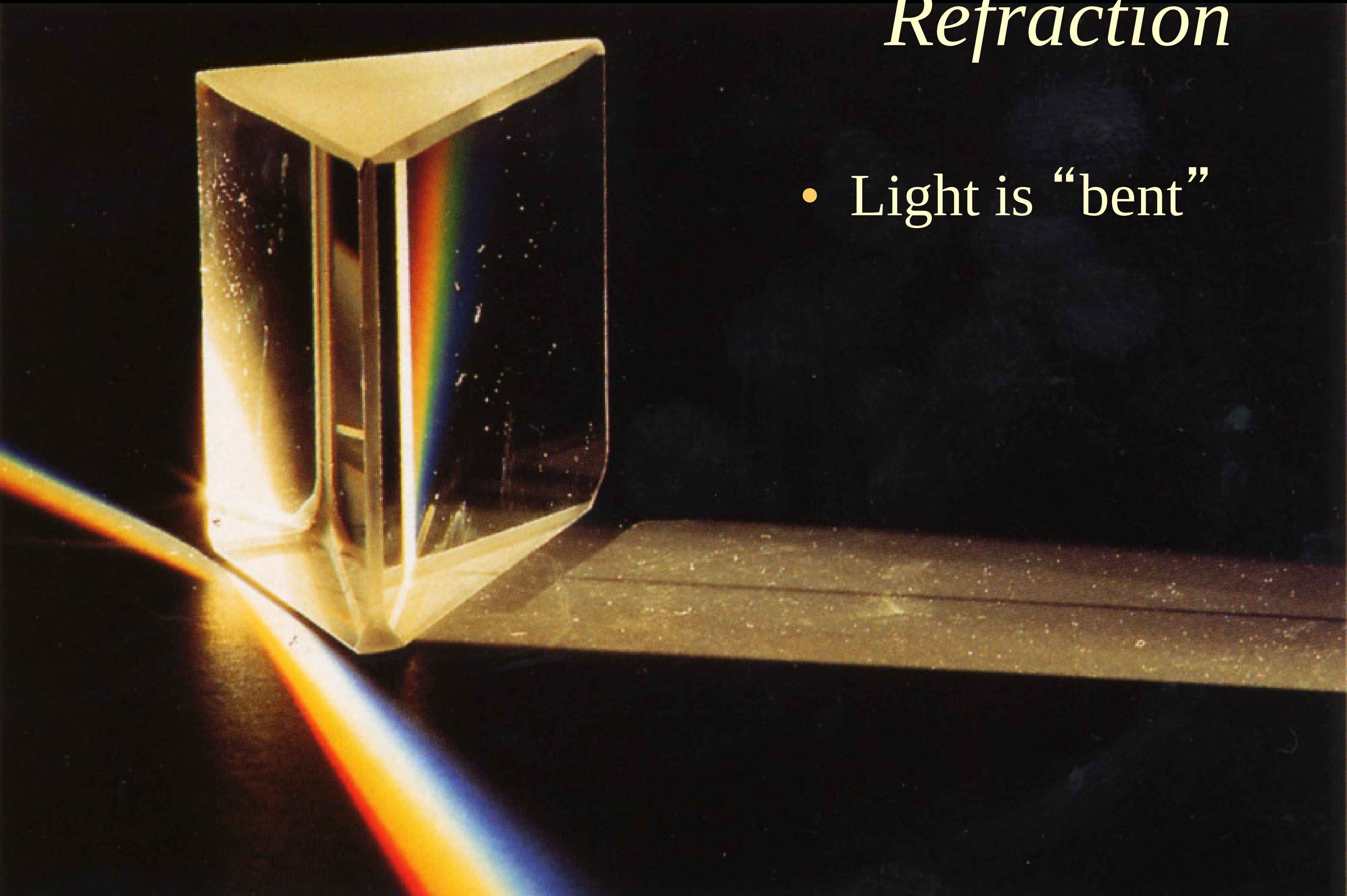


Refraction

- Light may be "bent" as it enters or leaves certain substances – such as glass.
- Light does not pass *strait though* glass, but turns a corner on entry and again on leaving the glass.
- This is what makes lenses possible – eyeglasses and contact lenses rely on the refraction.

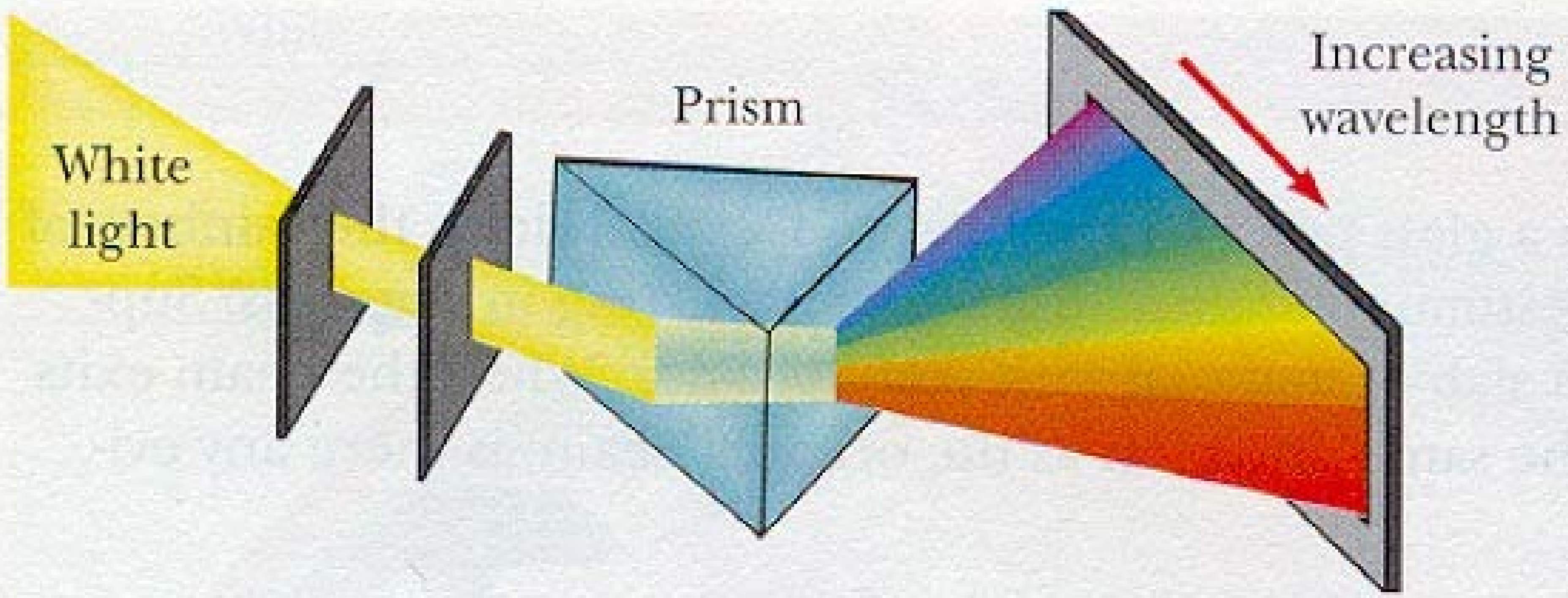
Refraction

- Light is “bent”

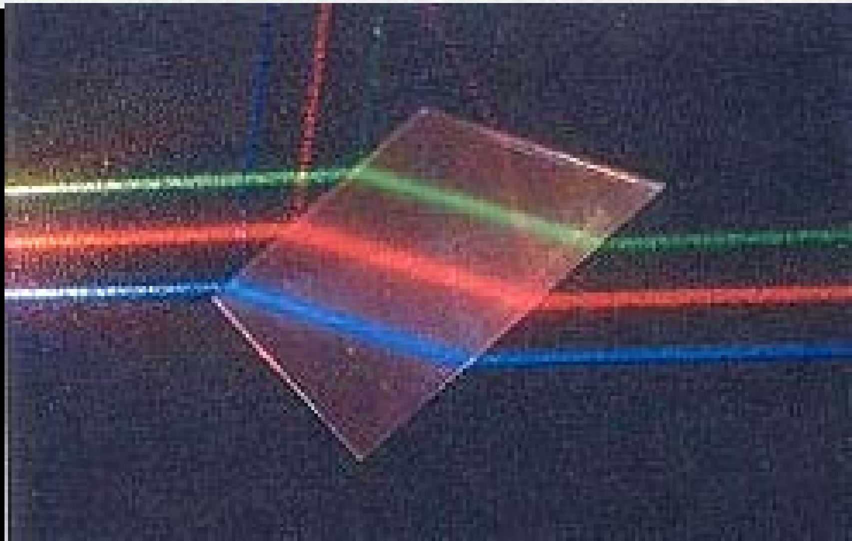


Refraction

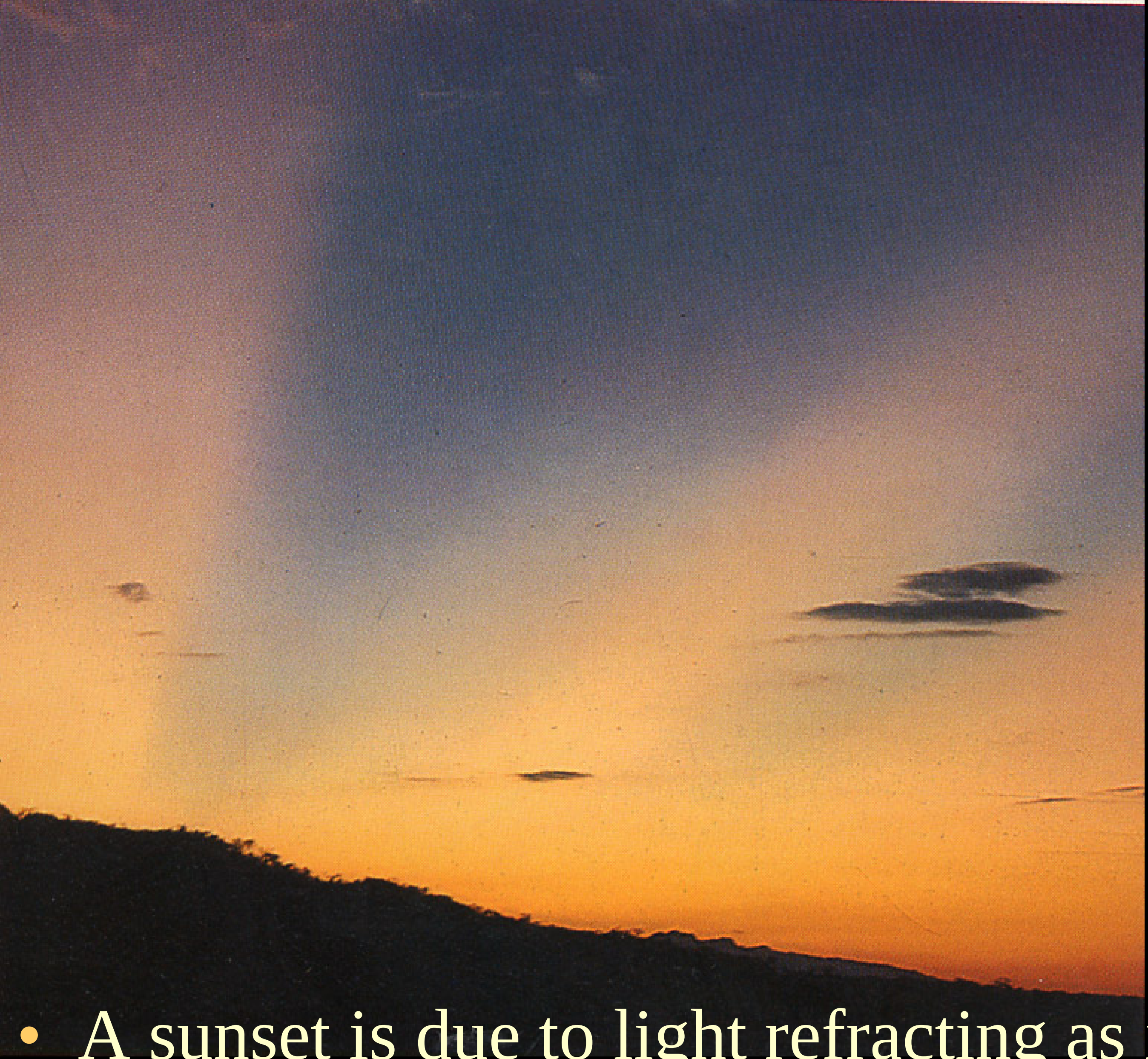
- A prism is the most distinctive example we see of refraction. White light enters a prism, is bent on entry and on leaving.
- However, ***different colors of light bend at different angles*.**
- This enables a prism to separate white light into its constituent colors.
- Rainbows occur when fine drops of water act as prisms -- refracting and reflecting light



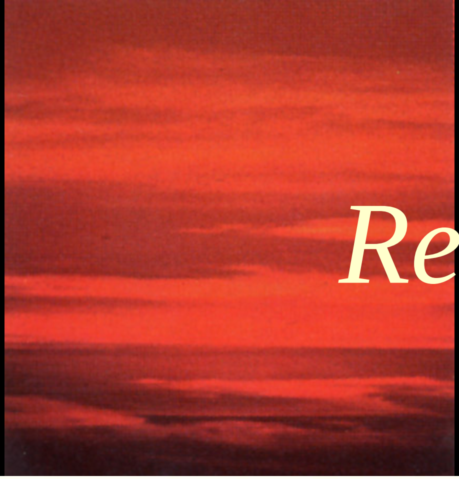
Each color/wavelength of light bends differently -- that's why a prism can separate white light into its constituent colors.



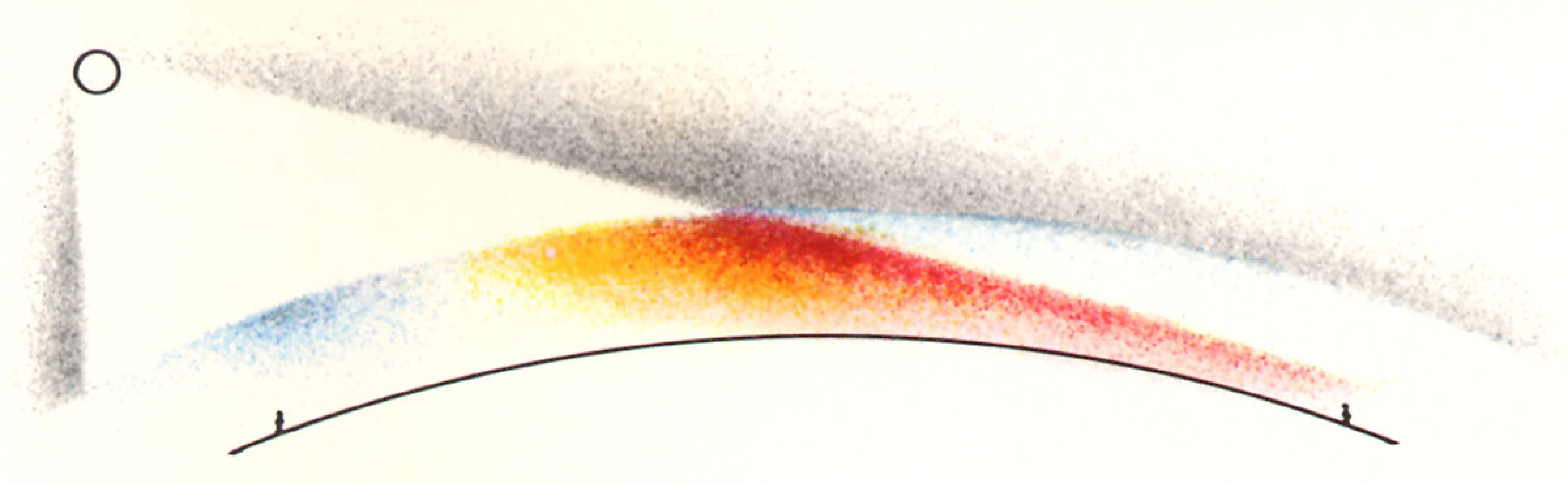
Refraction



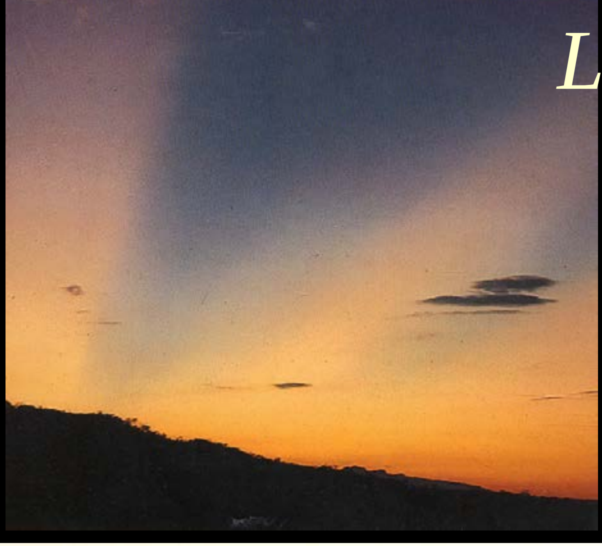
- A sunset is due to light refracting as it enters the atmosphere.



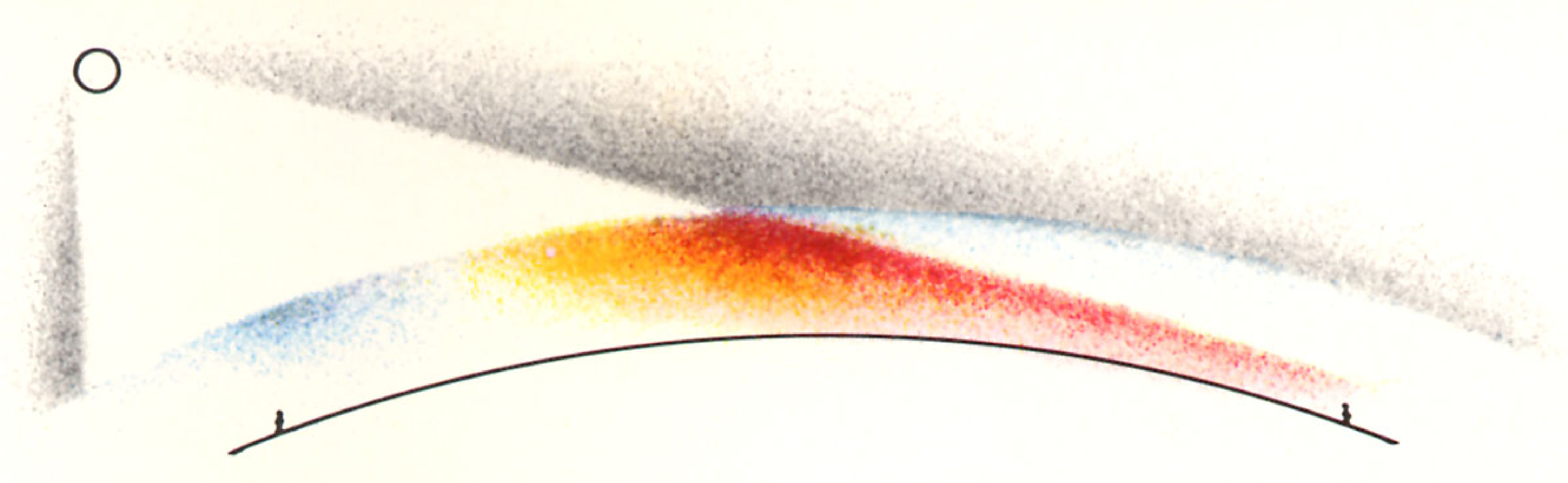
Refraction



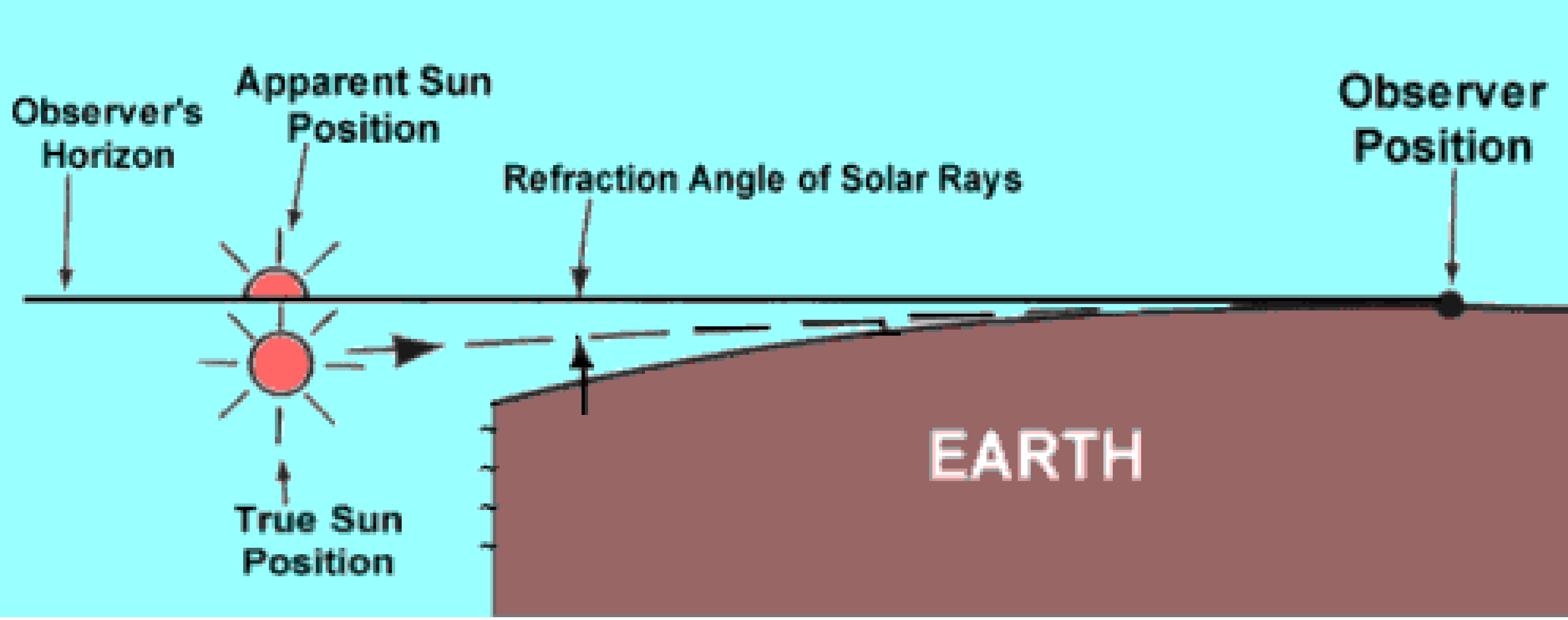
- At different times of day, the angle of the sun with respect to the sky changes, and so we see different colors (wavelengths) of light dominating.



Low frequency (blues, greens) light is disproportionately absorbed/disturbed by dust.



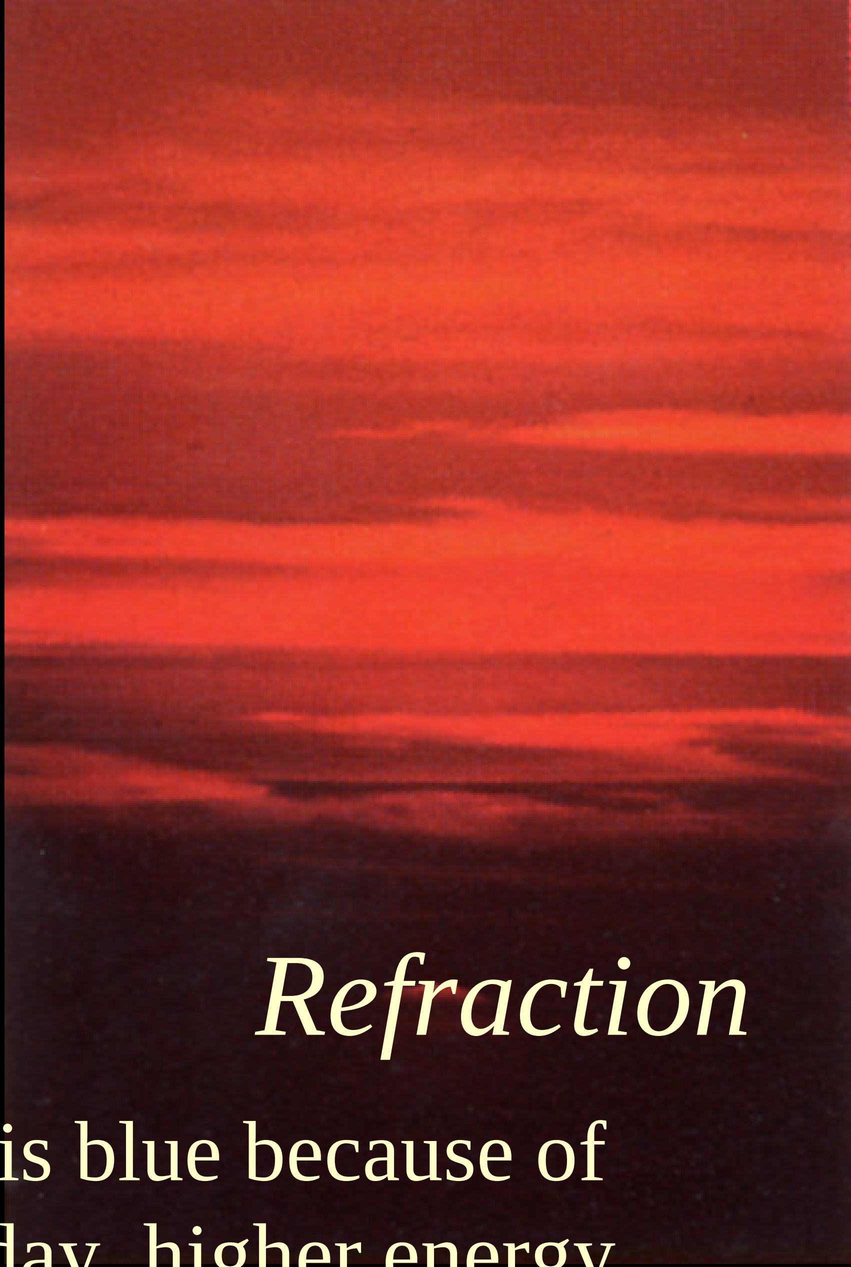
Thus, the more dust or atmosphere that light has to pass through, the more red will dominate the visible light. Late in day, light passes through a lot of air/dust.



Atmospheric Refraction Effect on Solar Light Rays at Sunset for Surface Observer
(scale exaggerated)

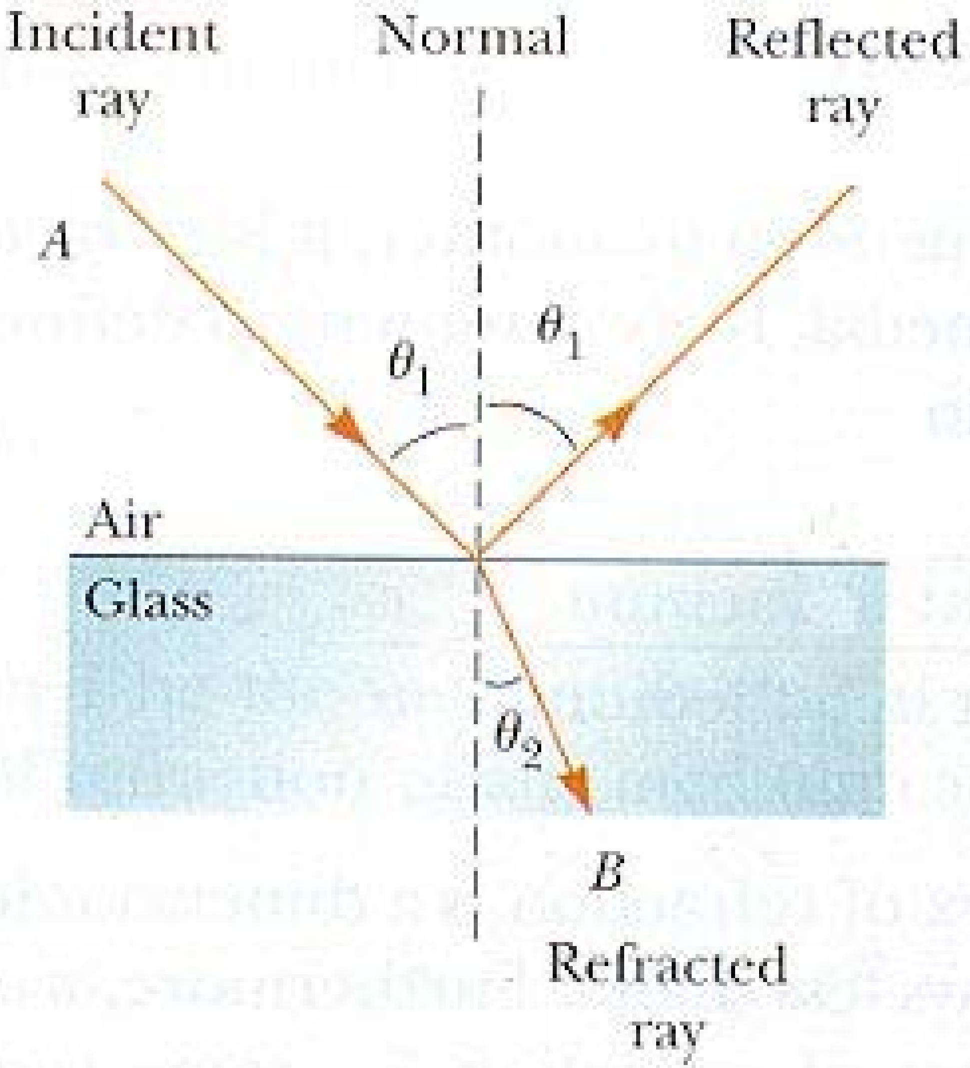
Refraction: the Sun..where is it?

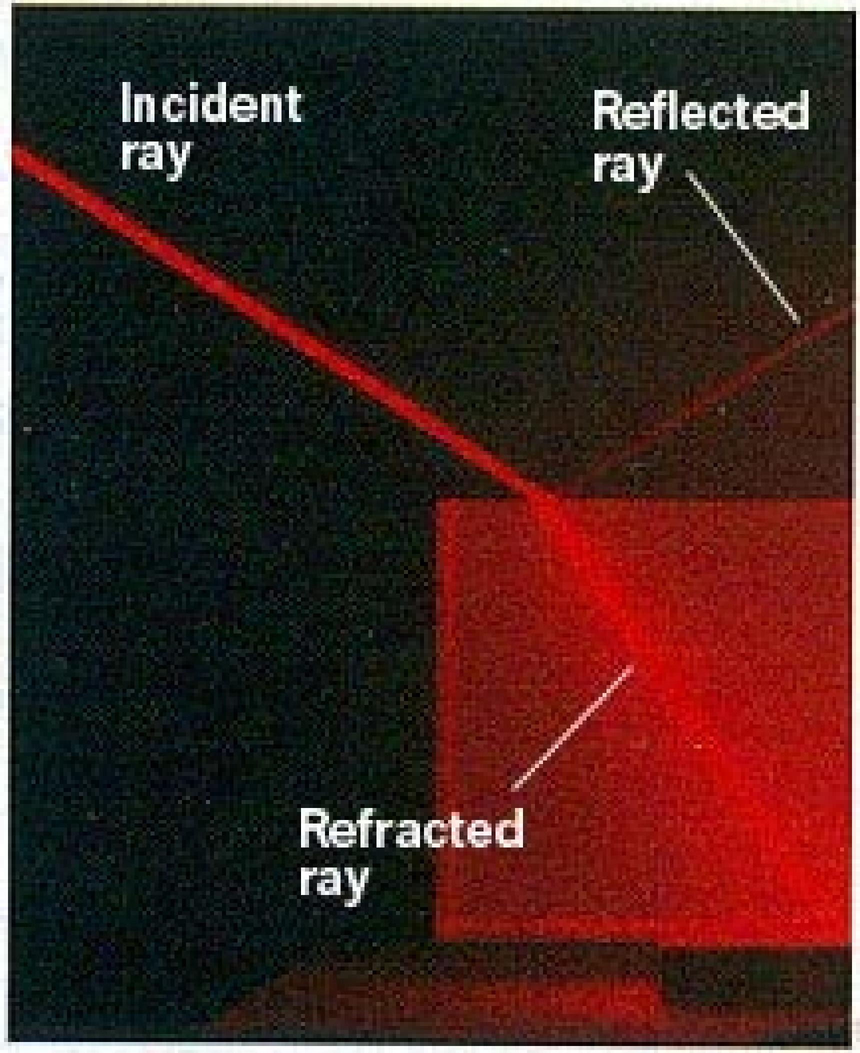
- At sunrise and sunset, refraction is severe --- so much that the atmosphere bends the sun's light like a lens--and makes the sun appear where it isn't.



Refraction

- During the day, our sky is blue because of refraction. Later in the day, higher energy colors/light “get in”.


Incident ray
Normal
Reflected ray
A
θ1
θ1
Air
Glass
θ2
B
Refracted ray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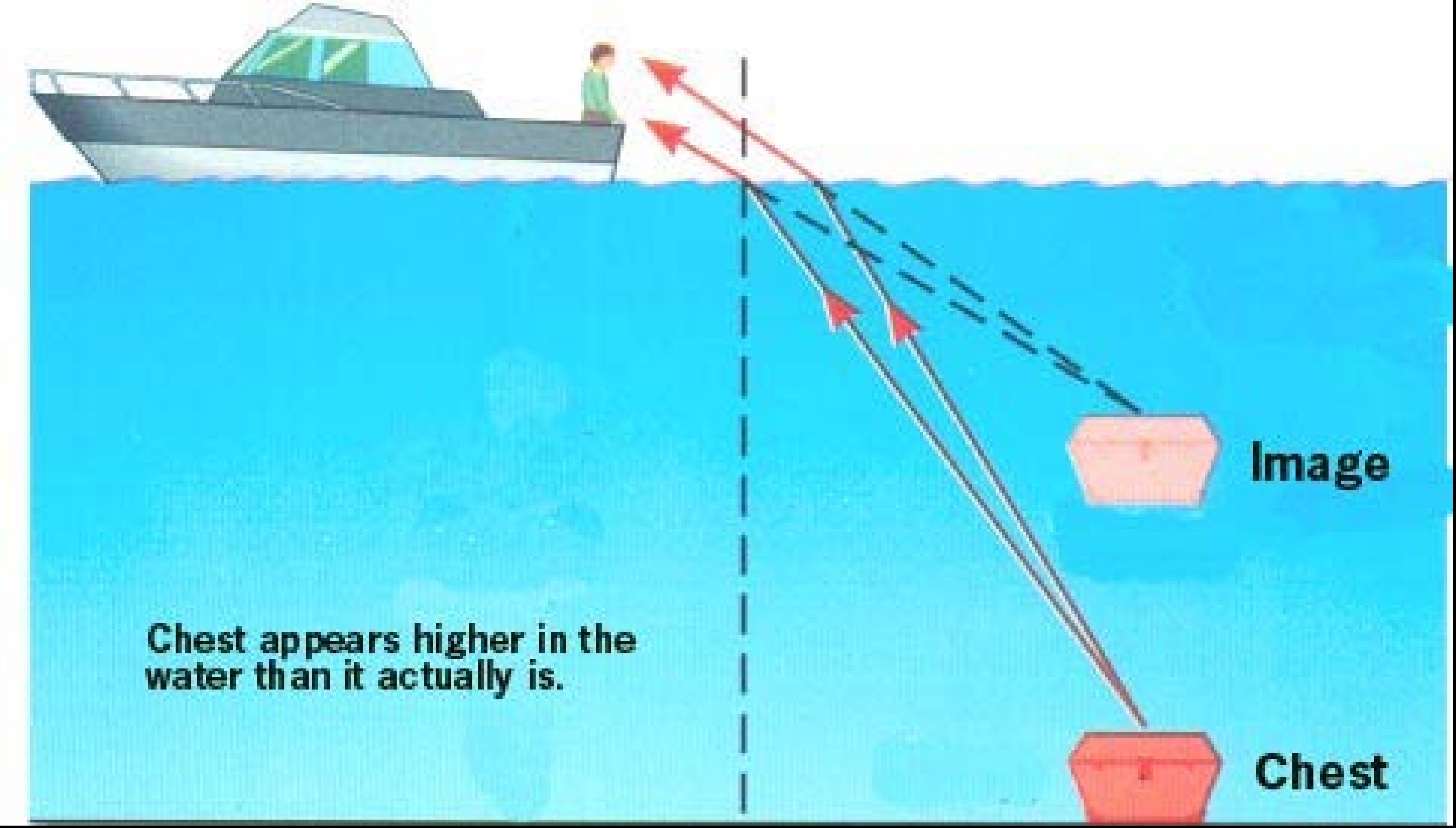
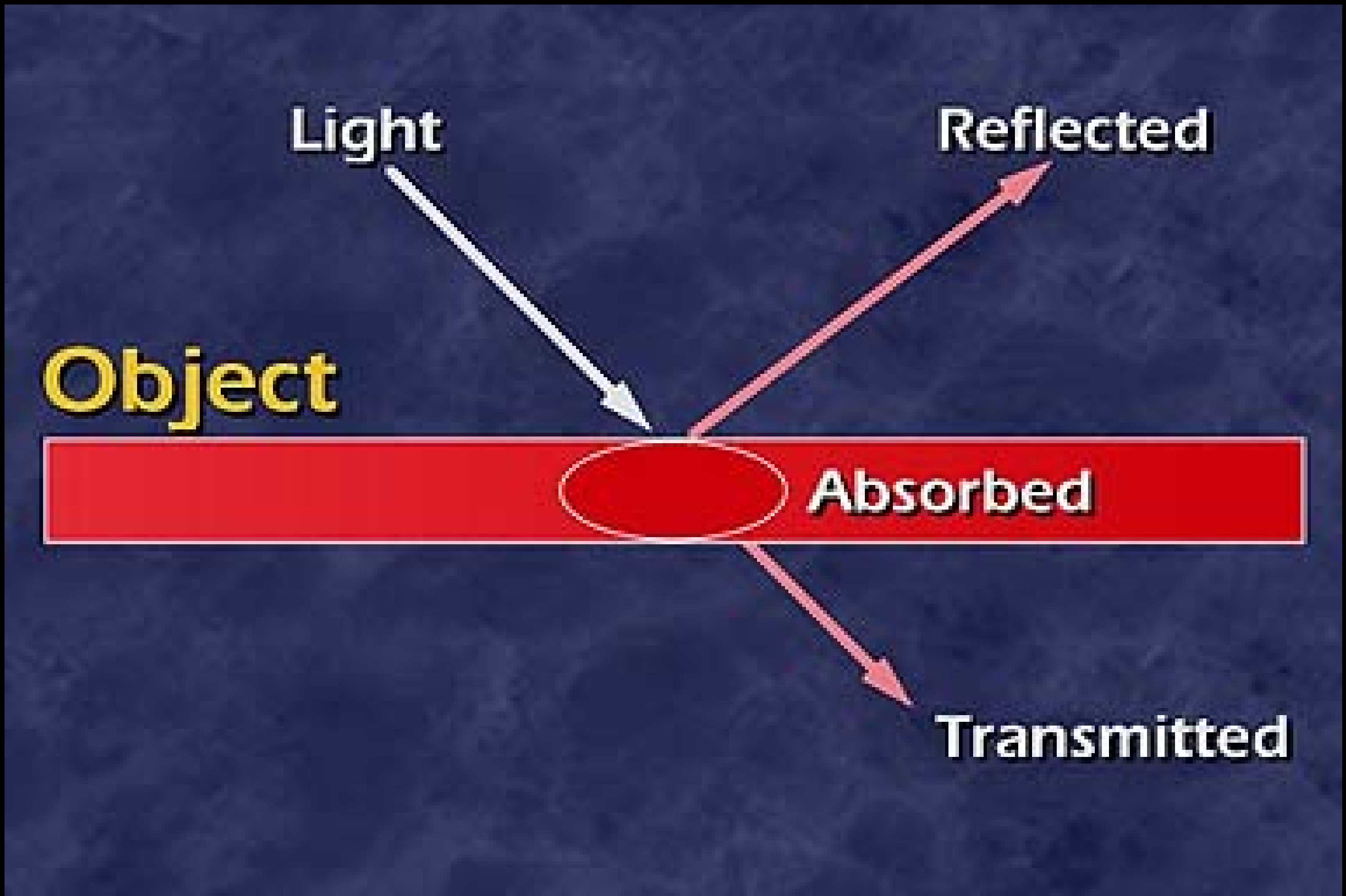


Refraction: makes deep stuff look shallow.

http://sol.sci.uop.edu/~jfalward/refraction/refraction.html

Where light goes: Transmission, Absorption, Reflection



Transmission

- Transmission is light **passing completely through a surface.**
- When we "see through" glass or clear plastic, we are actually seeing transmitted light.
- Note that light passing through glass is both transmitted *through* the glass, *and* refracted *at each surface* of the glass.

Transmission

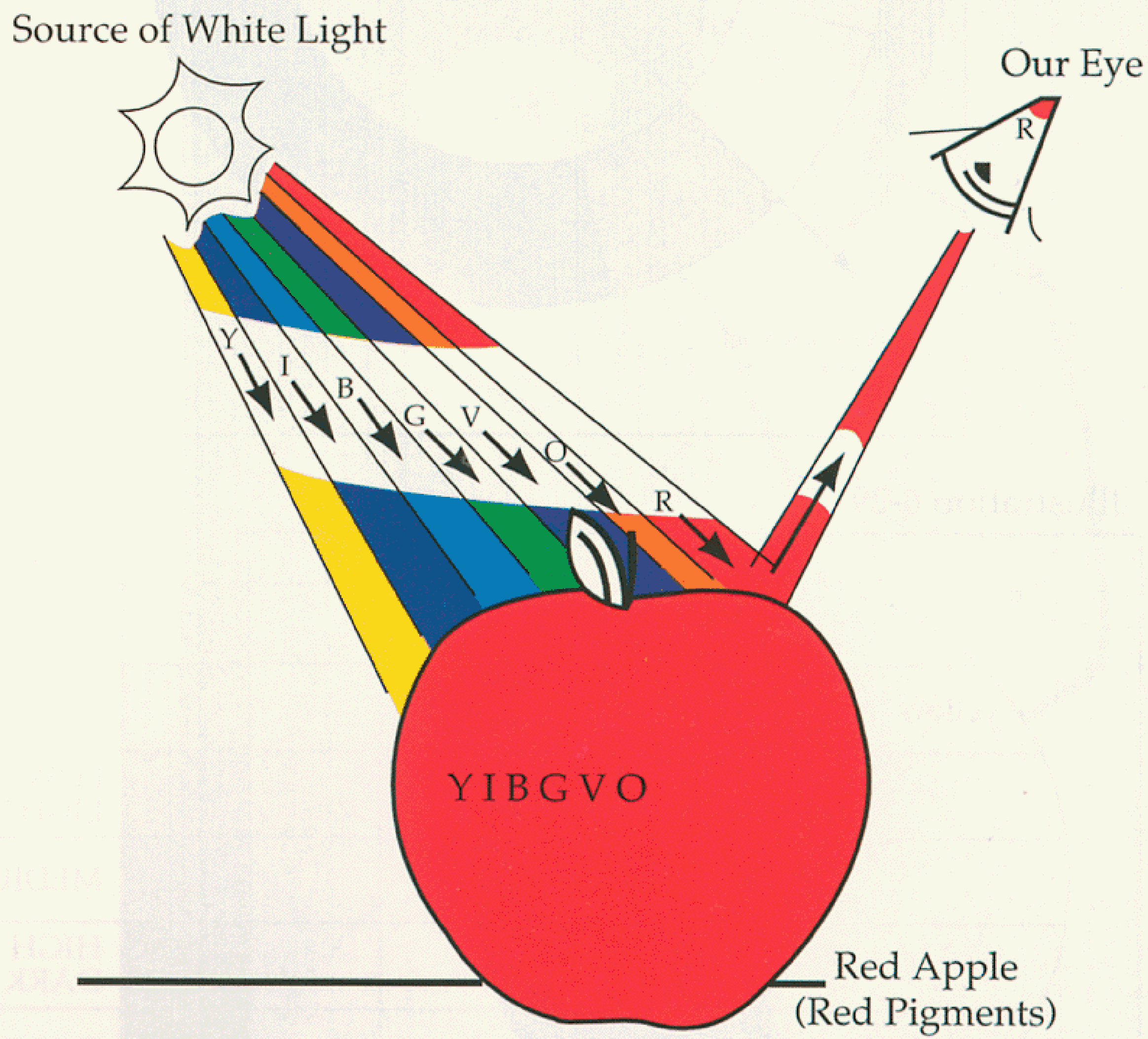
- In colored glass, pigments *within* the glass *absorb* some portion of the transmitted light – the remaining (unabsorbed) light provides the color we see.
- So transmission does *not* change the color of light, but selective absorption while transmission is occurring, *will* alter color.

Reflection

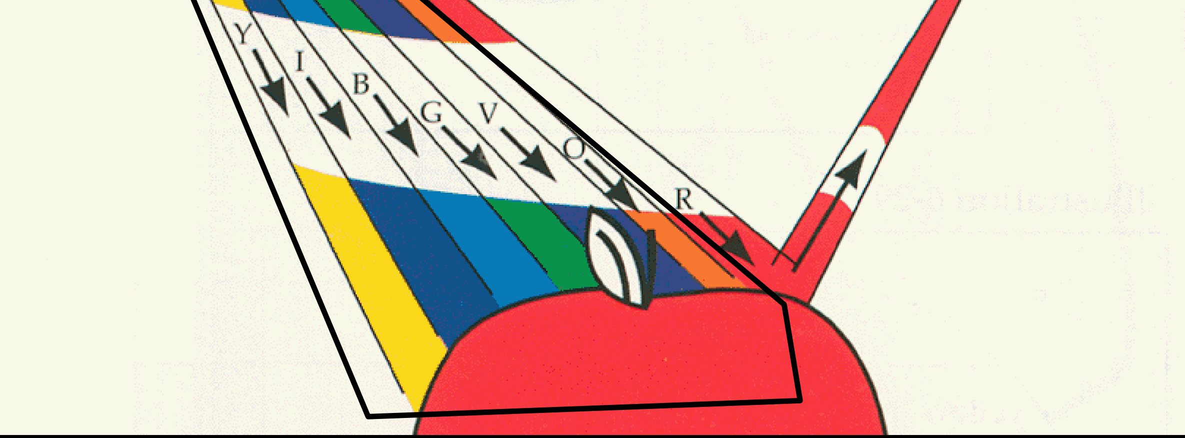
- Light is also reflected. We're accustomed to mirrors that reflect most of the light that hits them.
- But **every surface** that you have ever seen reflects light – otherwise you could not have seen it.
- When you see a red apple, you do not see the apple, strictly speaking. You instead see the light that reflects off of the apple towards your eyes.

Reflection

- Local color depends on ***light being reflected*** off of a surface.
- Surfaces that are **black** reflect little light.
- **White** surfaces reflect a lot of light – but not as much as a mirror – and white surfaces diffuse light — a mirror does not.



All wavelengths are absorbed by the pigments, except for that which we see reflected from the pigment.



Absorption

- When a light strikes a surface, some of the light is **absorbed** into that surface.
- The energy that ***is*** the light, enters and does not leave.
- That's why it is warmer in the sunshine than in shade – the light itself transfers energy from the sun to your skin.

Absorption

- The characteristics of the material determine how much light is absorbed and how much is reflected.
- A black surface is one that absorbs most light, and a white surface absorbs very little.
- That's why a black jacket is usually hot on a sunny day and a white jacket is cooler. (on the other hand, dark surfaces *radiate* heat better – but that's another issue.)

Selective Absorption and Reflection

- **The color of a surface depends on reflection and selective absorption.**
- When light strikes a surface, the surface will “keep” (absorb) some wavelengths (colors) of light and “let go” (reflect *or* transmit) of other types.
- A red painted wall “reflects” red light; a pane of red stained glass “transmits” red light.
- A surface absorbs some colors of light and reflects/transmits other colors – *selectively absorbing* some colors and selectively reflecting/transmitting other colors.
- This is what makes local color happen.

Selective Absorption and Reflection

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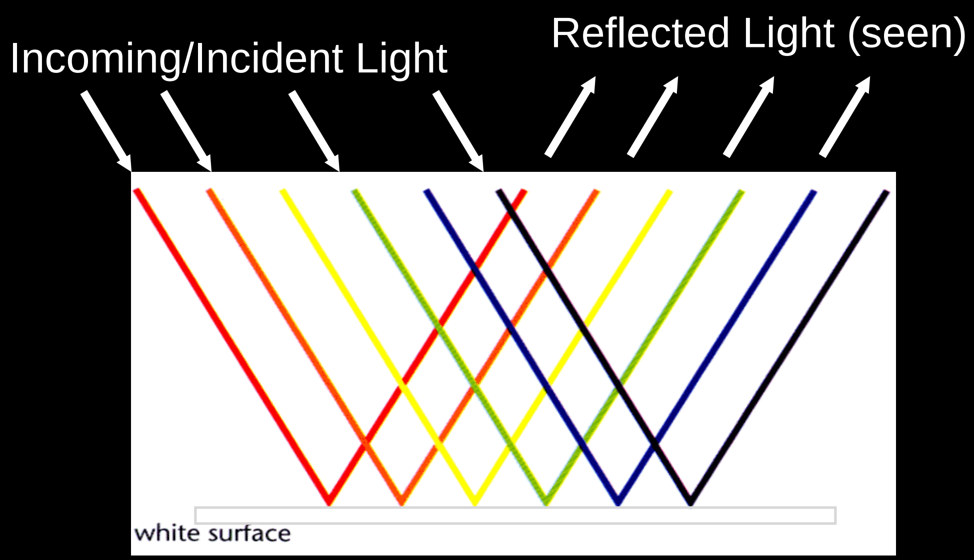

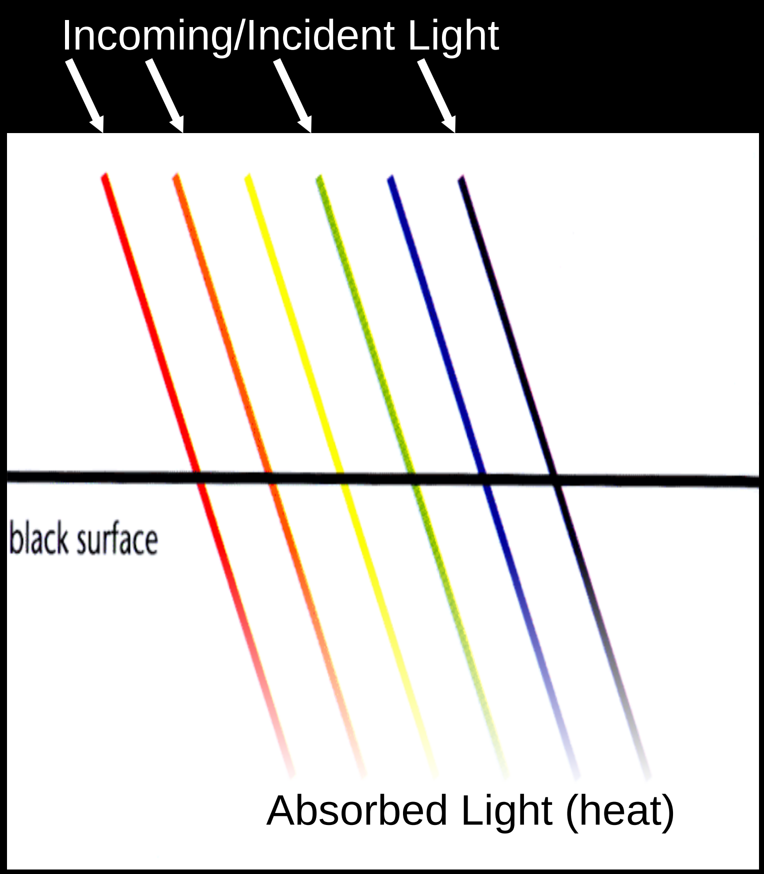

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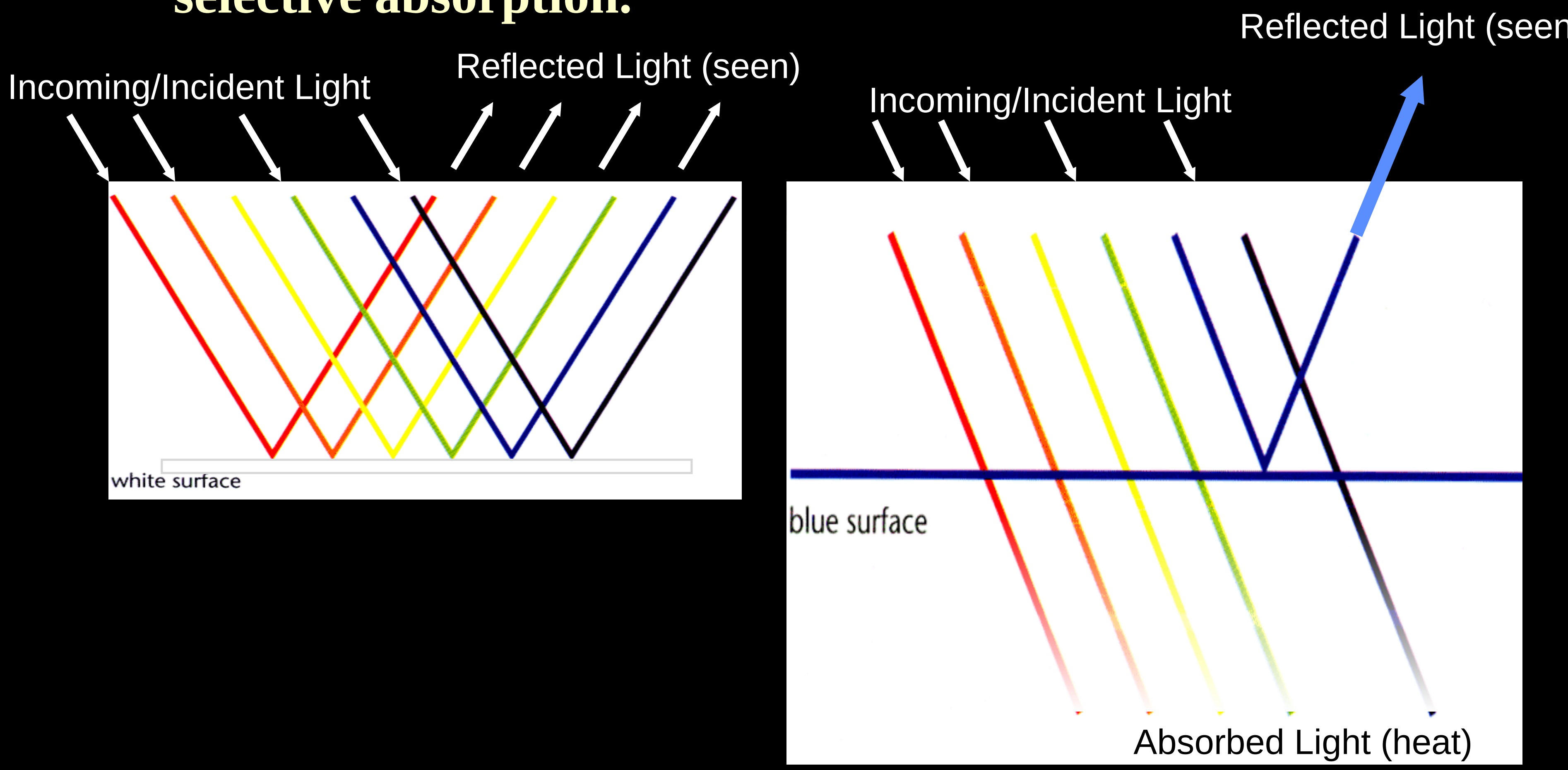

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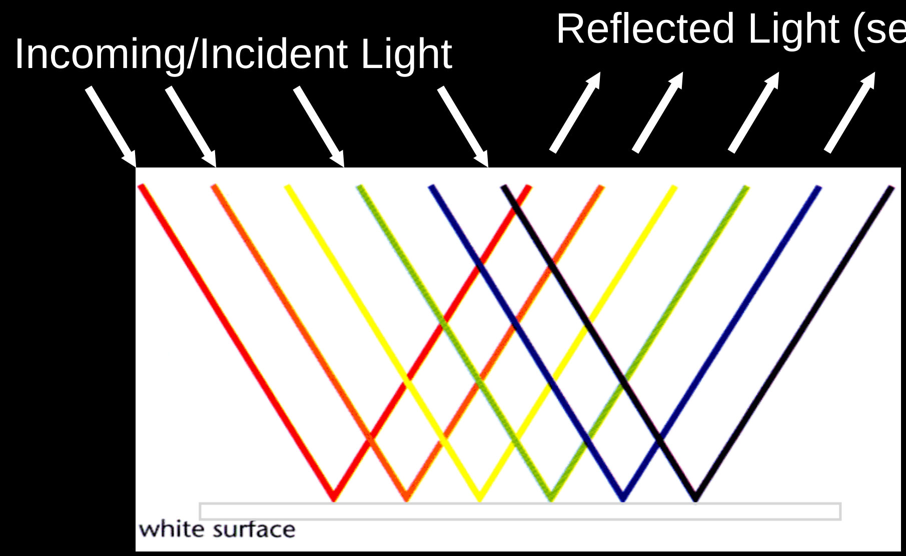
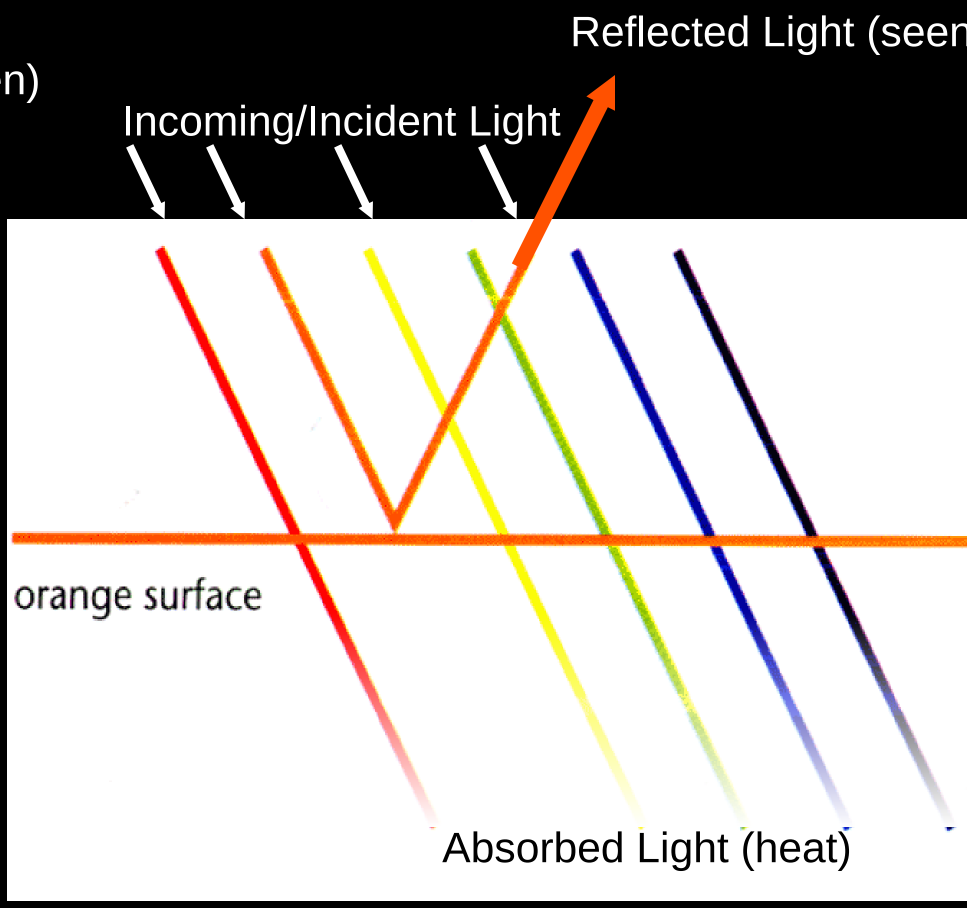
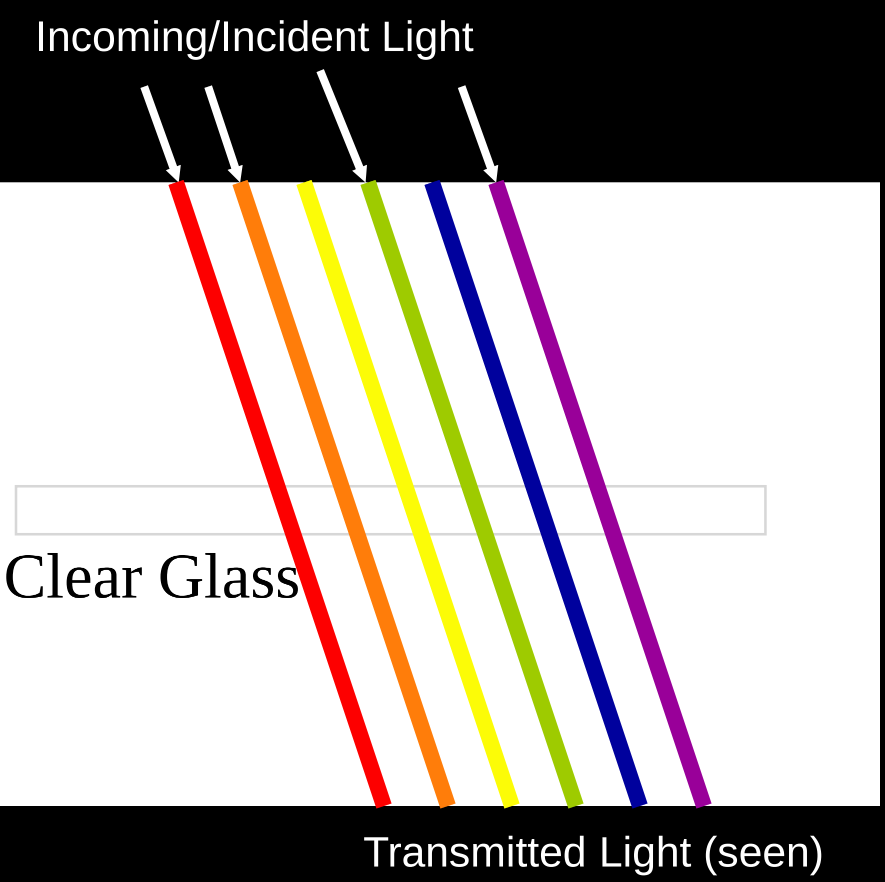
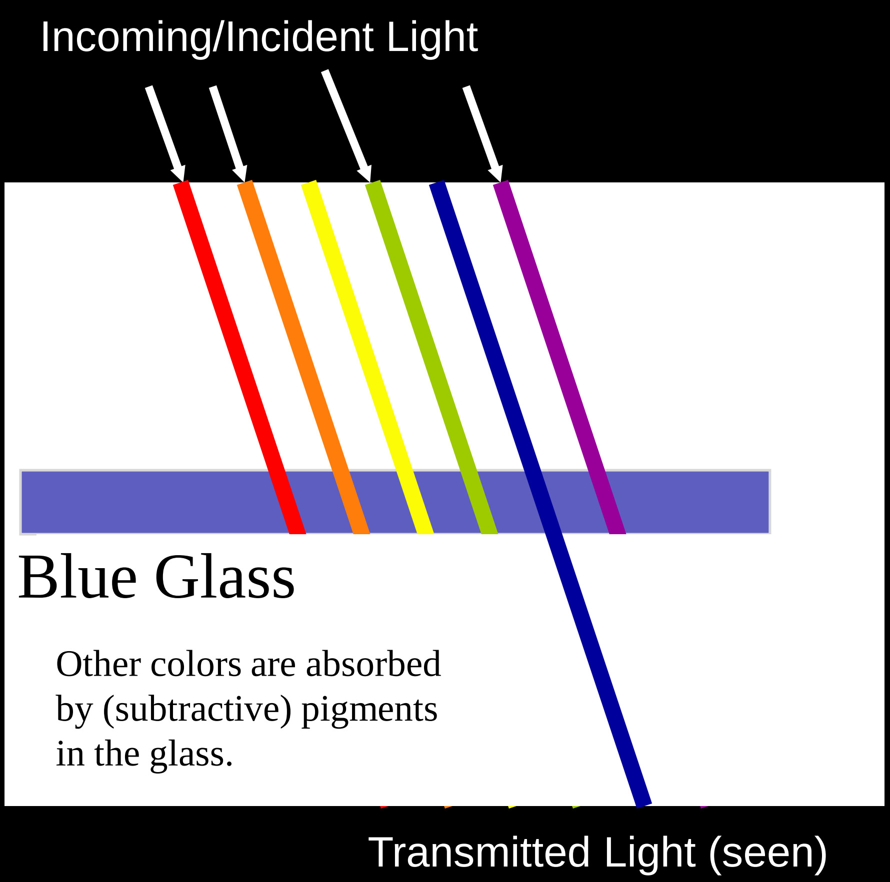


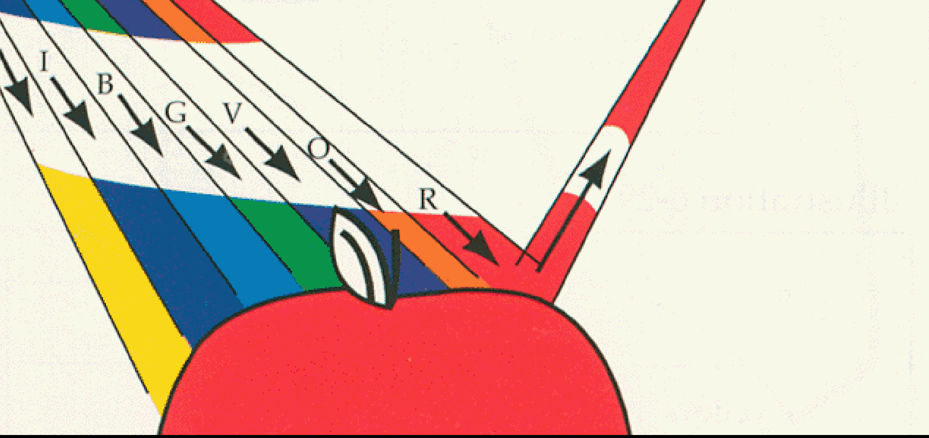


Selective Absorption and transmission

- **Color of *transparent* material depends on transmission and selective absorption. But color change is still due to *absorption* — the colors that are subtracted.**





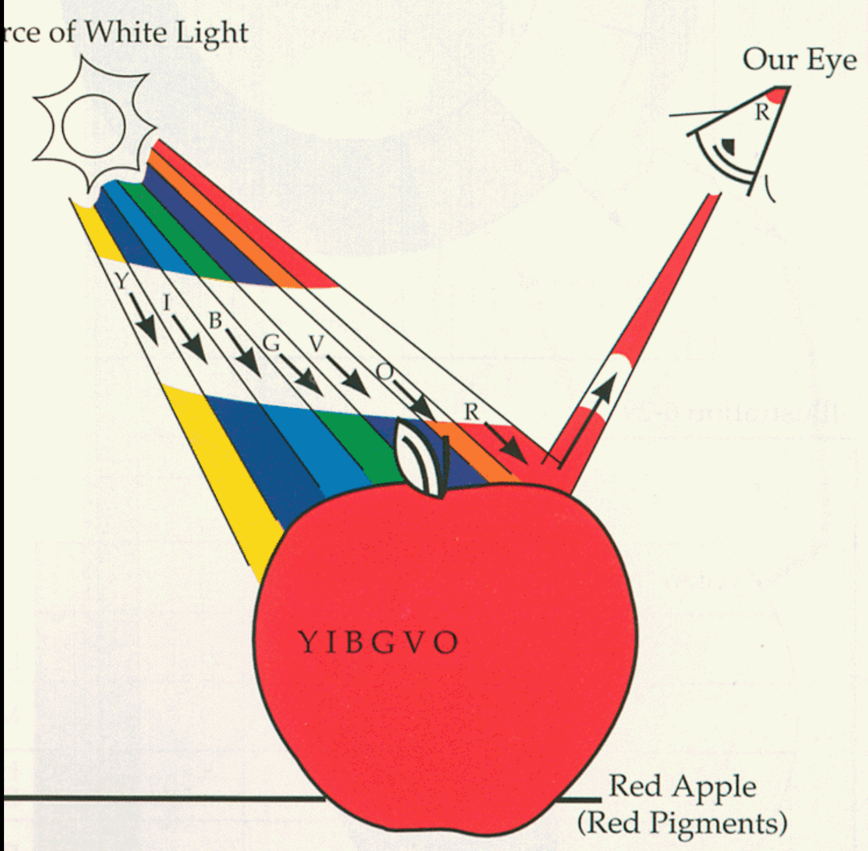


Selective Absorption and ***Subtractive*** *Color*

- If white light is shining on a red apple, we see the apple as red because the red is reflected and the ***MOST OF*** the other colors – greens and blues – are absorbed.
- Those absorbed colors are "***subtracted***" and predominantly red reflects to our eyes.
- We see the white light ***minus*** the greens and blues, leaving only the red lights.
- This is why pigments and reflective surfaces are said to rely on "***subtractive color mixing***".

Subtractive Color Mixing – Colored Pigments

- Most of the color mixing you have ever done involved subtractive color mixing.
- Whenever we mix paint, we are selectively eliminating (subtracting or absorbing) some colors from the ambient white light that strikes that surface.



surfaces under white light

- Tomato absorbs violet/blue/greens..
- Pepper absorbs reds, blues, violets…
- Hydrangea absorbs all but blue and violet.

- Tomato absorbs violet/blue/greens..
  …and reflect reds and oranges.

- Pepper absorbs reds, blues, violets…
  …and reflects greens

- Hydrangea absorbs all but blue and violet.

under cool/blue light…

Reds disappear from tomato and hydrangea

Yellow in RO tomato persists, along with green of pepper.

under magenta (RRV) light…

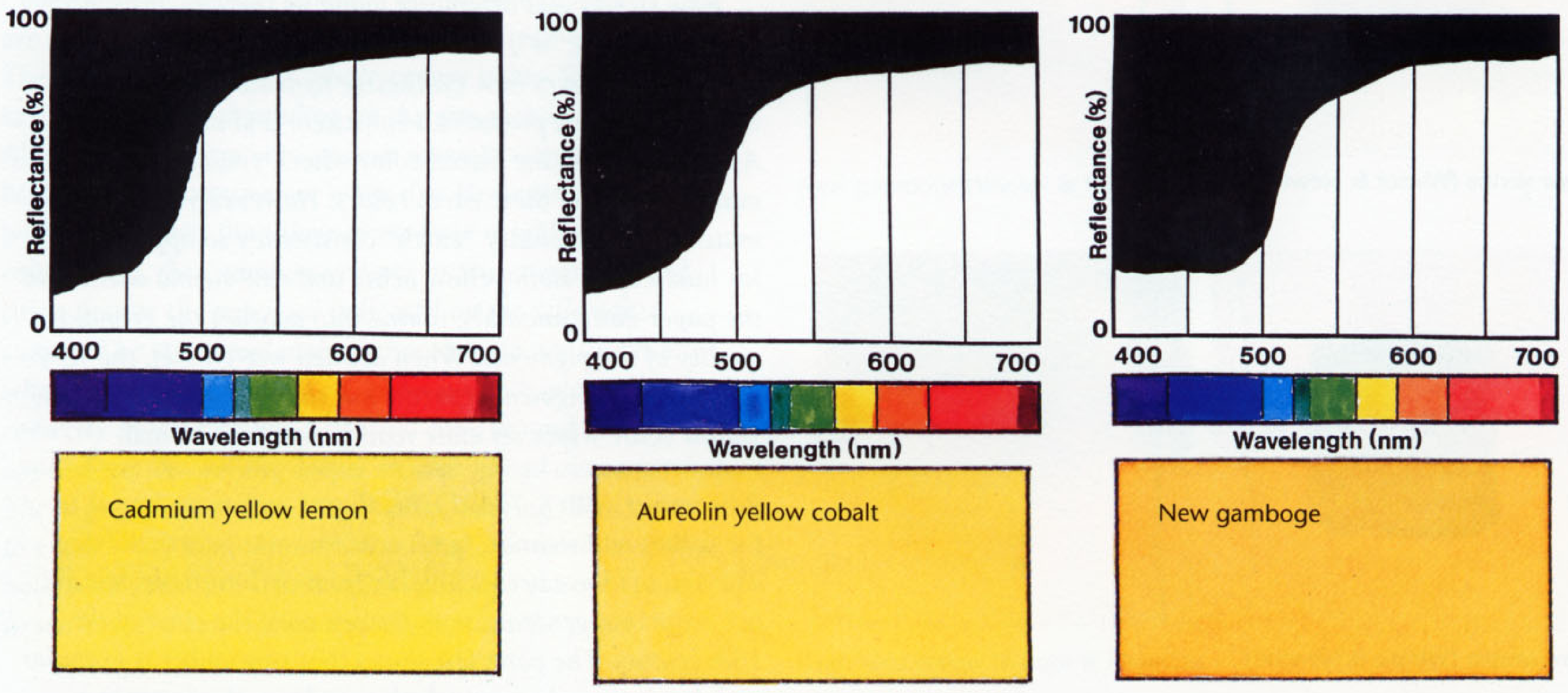
Reds persist in tomato and

Purple of hydrangea…but green pepper appears dark near-neutral.

under yellow-green light

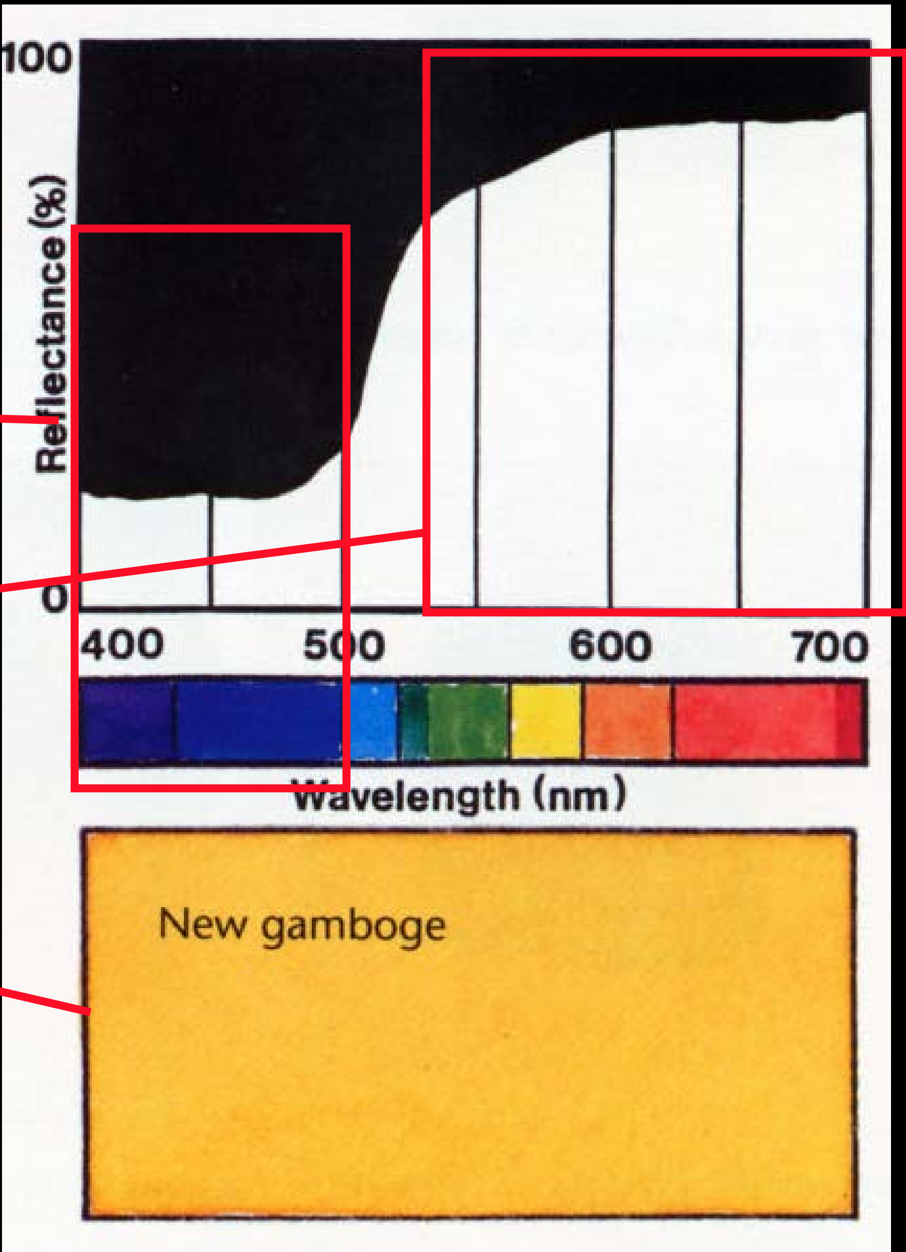
Color is Light Reflected

- Paint pigments vary according to the particular wavelengths of light that are reflected (seen) and absorbed (unseen.)



Color is Light Reflected

- The pigments of *New Gamboge* absorb most blue violet light and violet light..
- …and reflects most yellow, red and even green light.
- The net result is a YYO hue.



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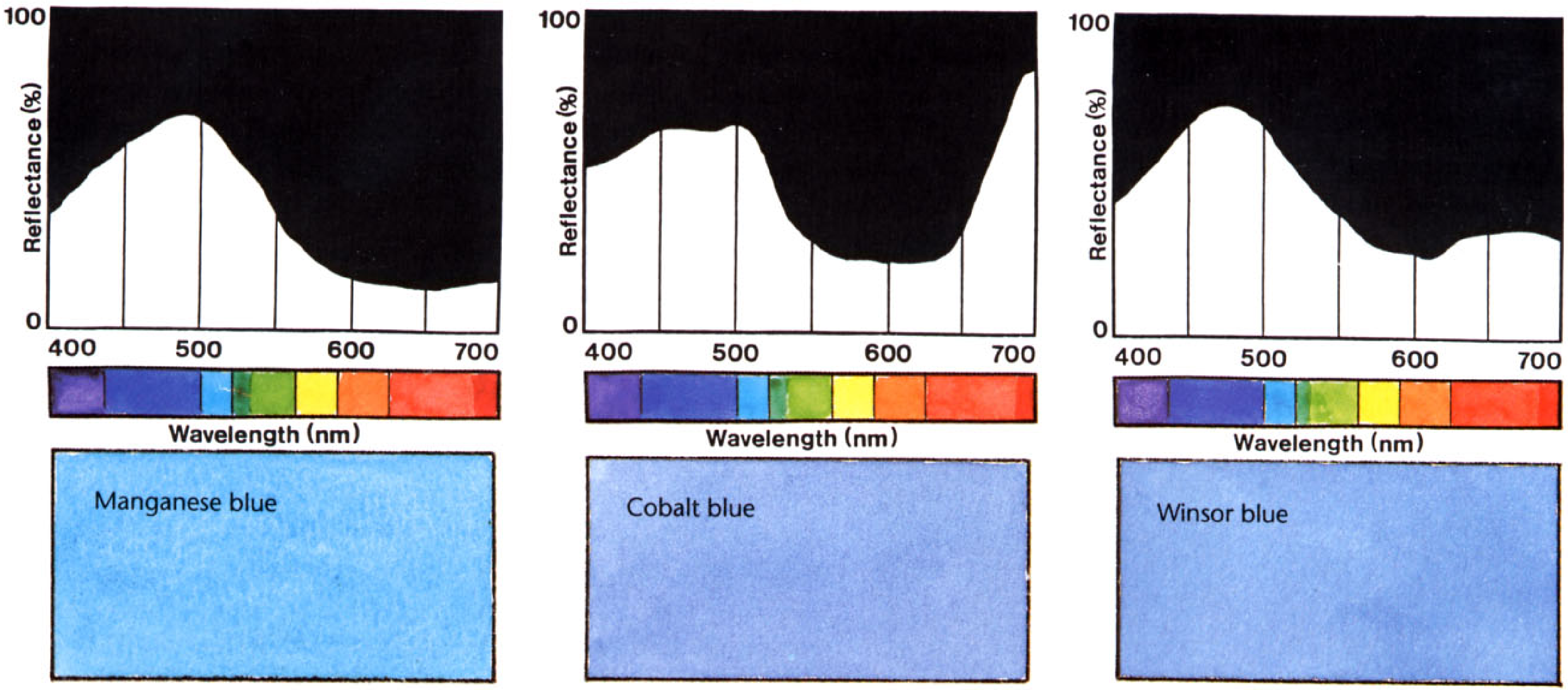

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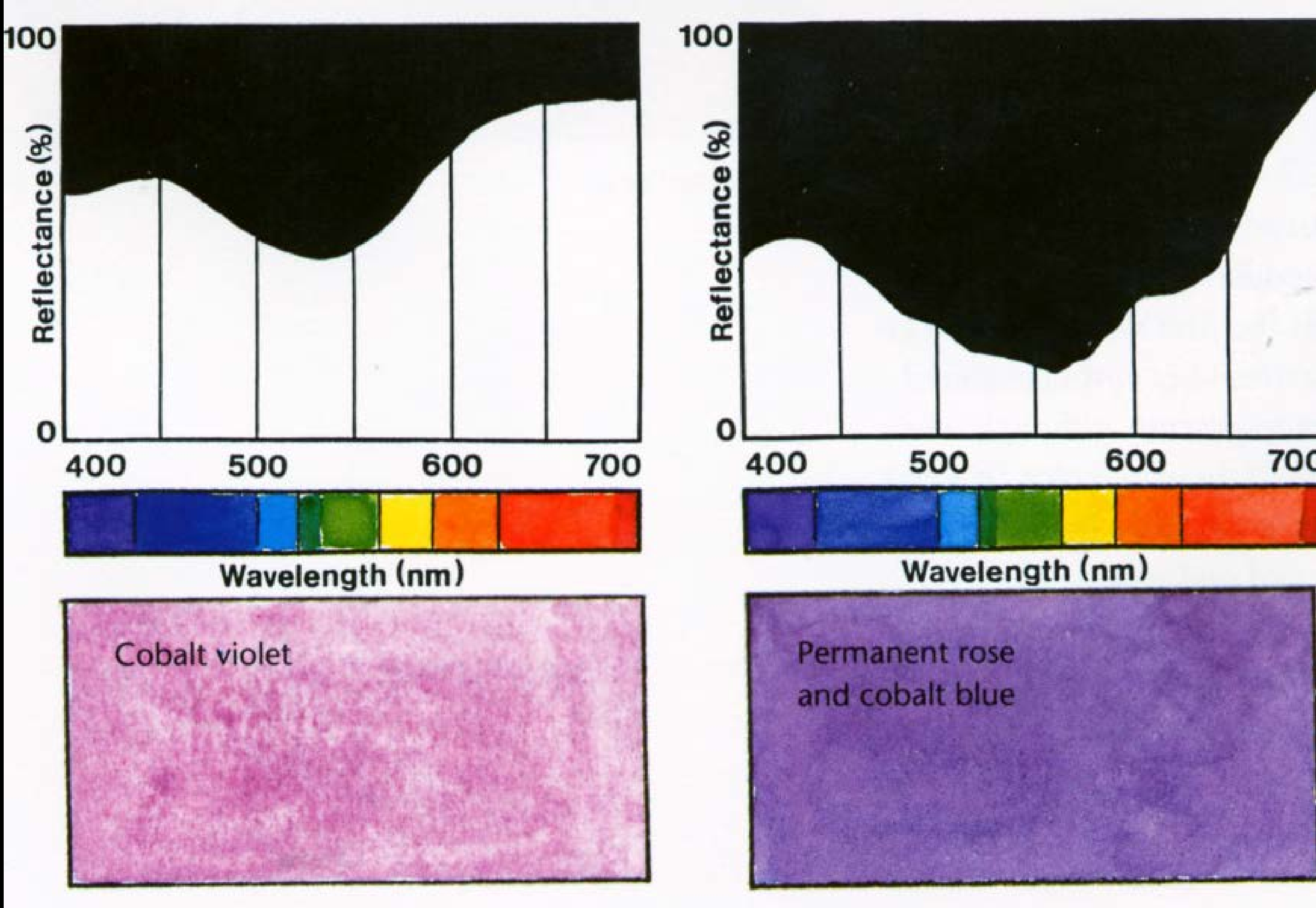
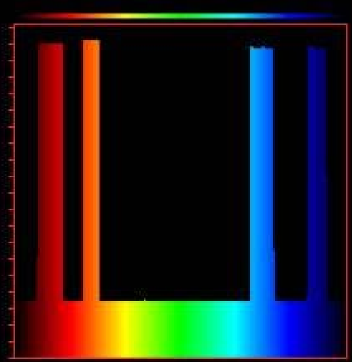
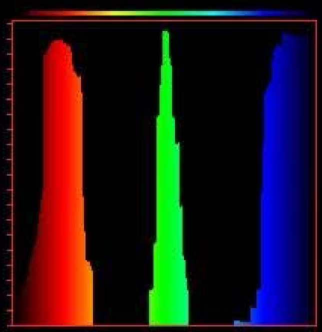
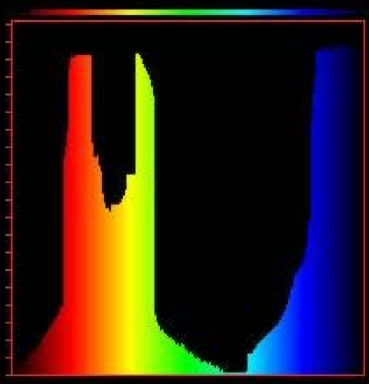


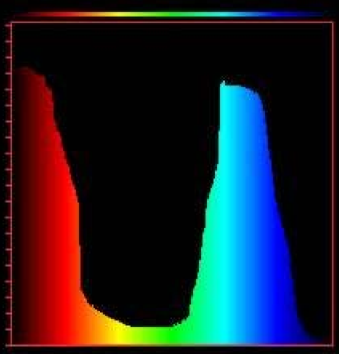
Many combinations produce same/similar color

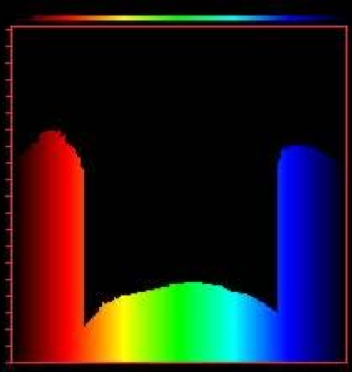
- The combination of colored light that appears purple may be constituted of vary dramatically.
- http://www.visualmill.com/

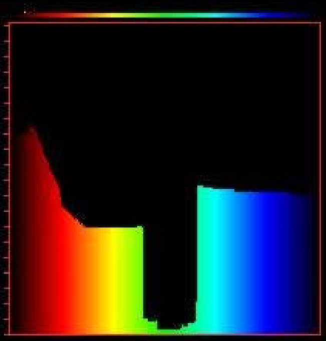






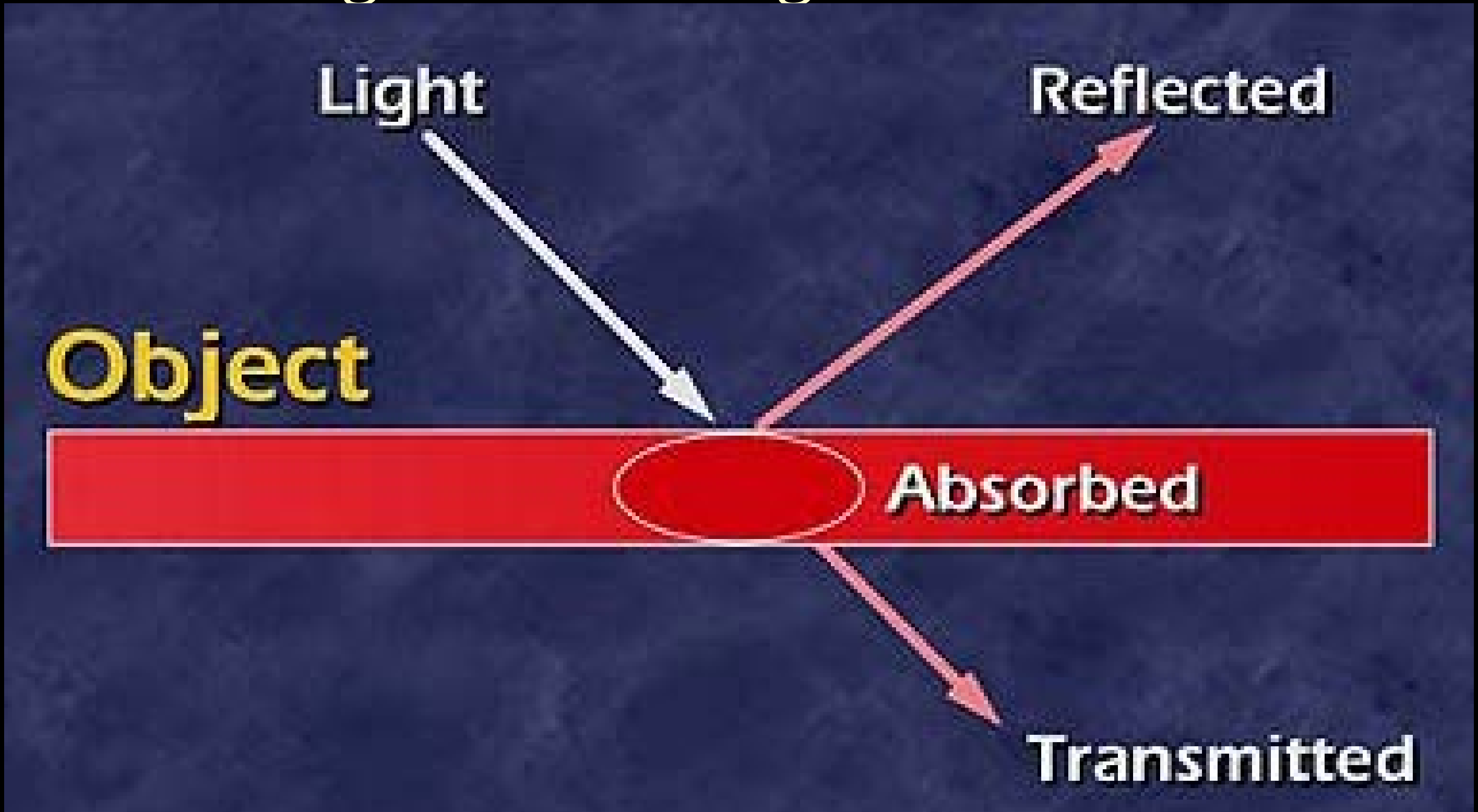




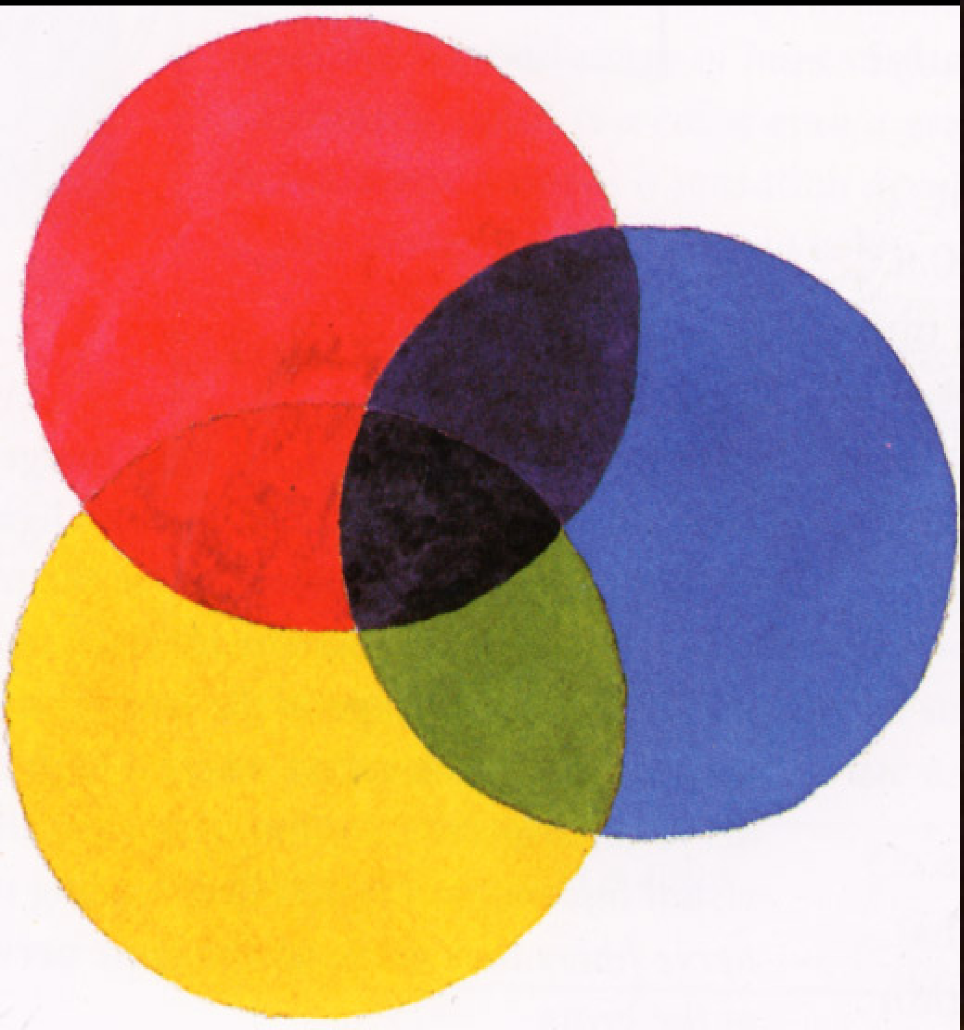


White-Light to Colored objects/surfaces:

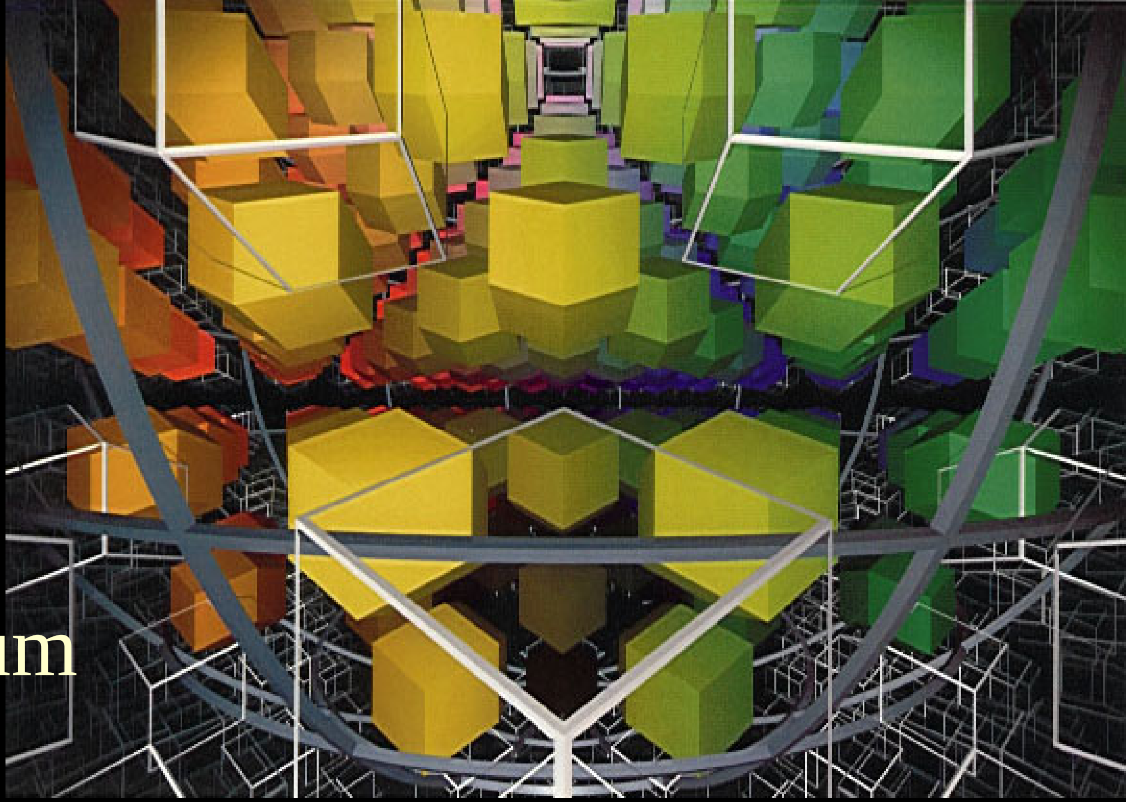
- Absorption is the main way that materials become "colored"—subtracting some colors from white light, and either reflecting or transmitting "colored" light.



Pigment vs. Light Primaries & Secondaries



Basic terms & concepts:



- Color as light
- The visible spectrum
- wavelengths
- White light
- Reflection, Transmission, Absorbtion, Refraction
- Additive Color vs. Subtractive Color
- Light Primaries vs. Pigment Primaries

For Next Class:

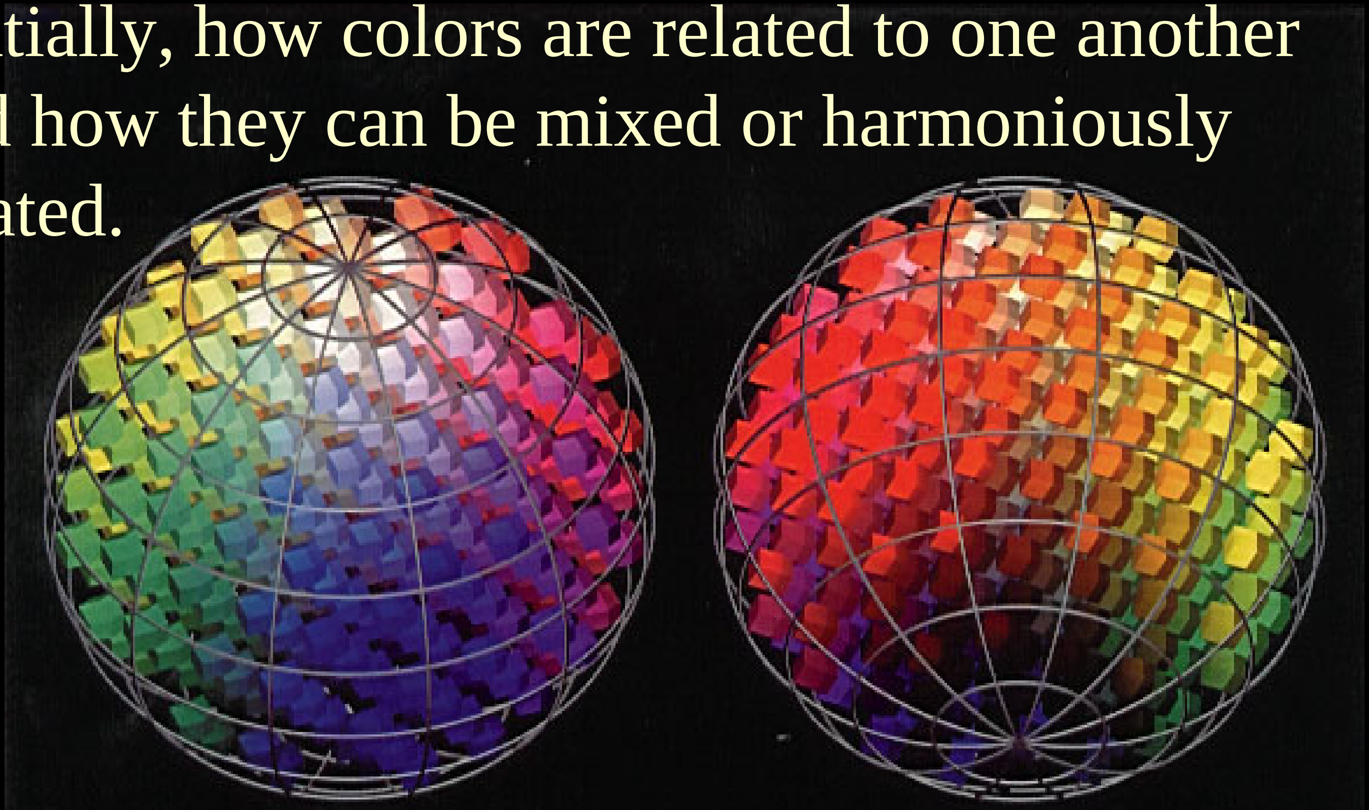
- **Read from "The Acrylic Book"** ;
  p. **5 - 11** (What are acrylics?) to (Clean Up)

  (see syllabus for web link to PDF,
  2003AcrylicBook.pdf)

- **Have painting supplies here.**

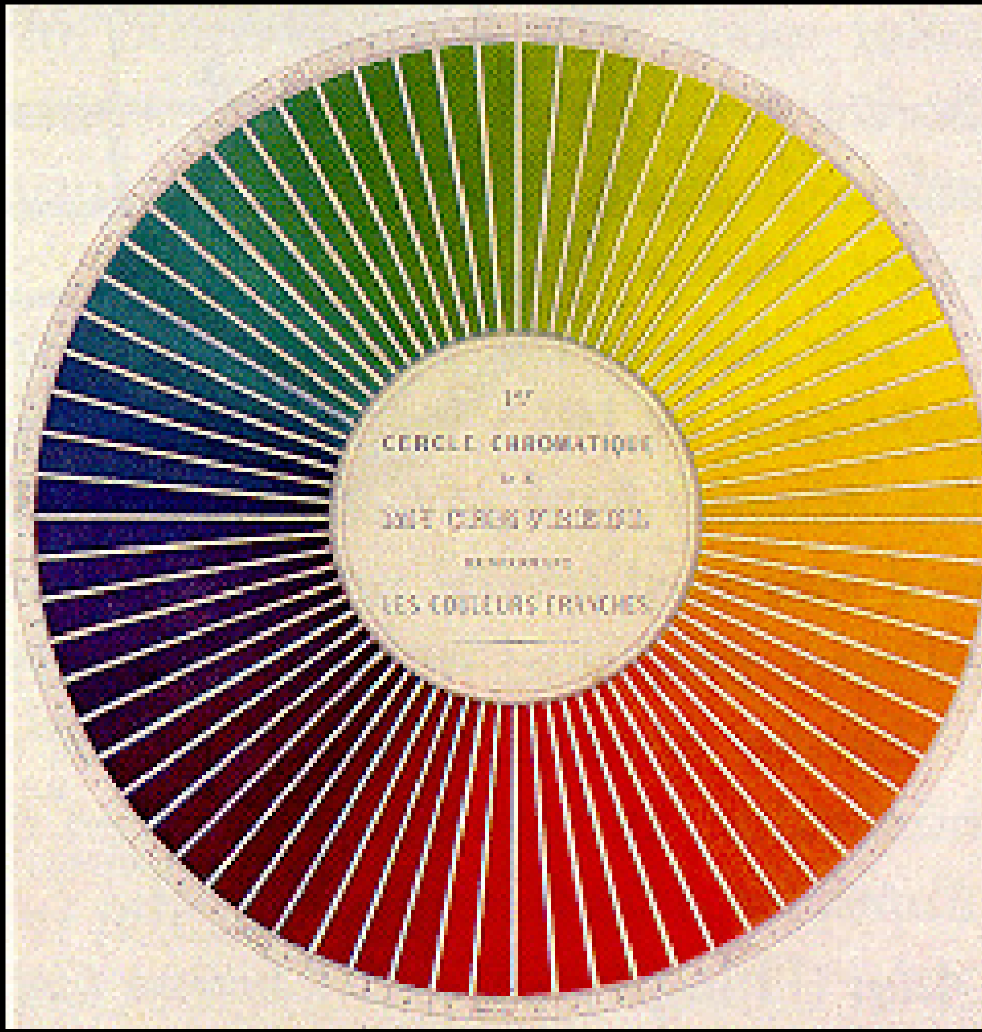
Color Theory and Color Models

- Color theories aim to predict how colors will behave.
  Color models often represent, graphically or spatially, how colors are related to one another and how they can be mixed or harmoniously related.



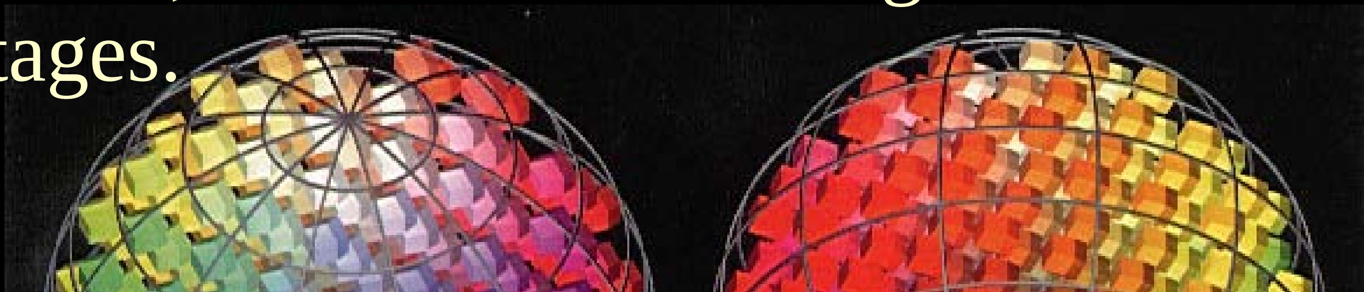
Color Theory and Color Models

- The most familiar and basic color model is the color wheel – invented by Sir Isaac Newton.
- This color wheel is by Chevreul -- one our major theorists.



Color Theory and Color Models

- There are many color theories and color models, each intending to serve some particular purpose or application of color.
- Some color models are most appropriate for painters, others for interior designers, others for computer-based design work.
- All color models have many similar characteristics, but distinct advantages and disadvantages.

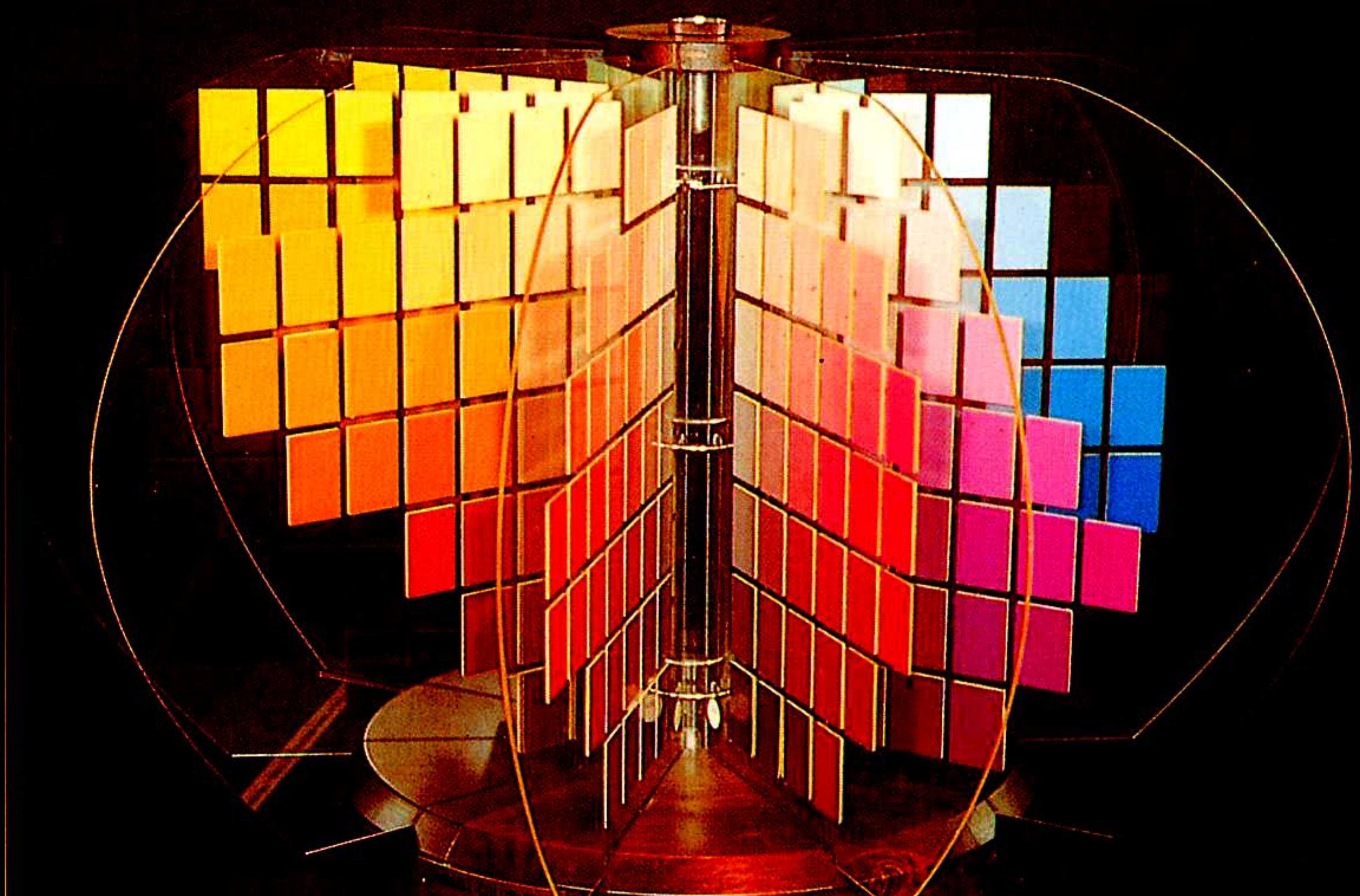


Three dimensions of color

- Just as a point is space can be defined by is position in the three special dimensions (height, width, depth) , color also has its own three dimensions. Any single color can be described by its three dimensions.

- **Hue**
- **Chroma**
- **Value**

Three dimensions of color - Munsell's color model



Three dimensions of color

- Hue
  - Commonly called “color” by non-artists and non-designers. This is the nameable color – red versus blue versus yellow.
- Chroma
  - Saturation, Intensity and sometimes “brightness” – though these last two terms are easily confused with “Value”. Purity of color.
- Value
  - The lightness or darkness of a color – that is, how close to white and how close to black is it?

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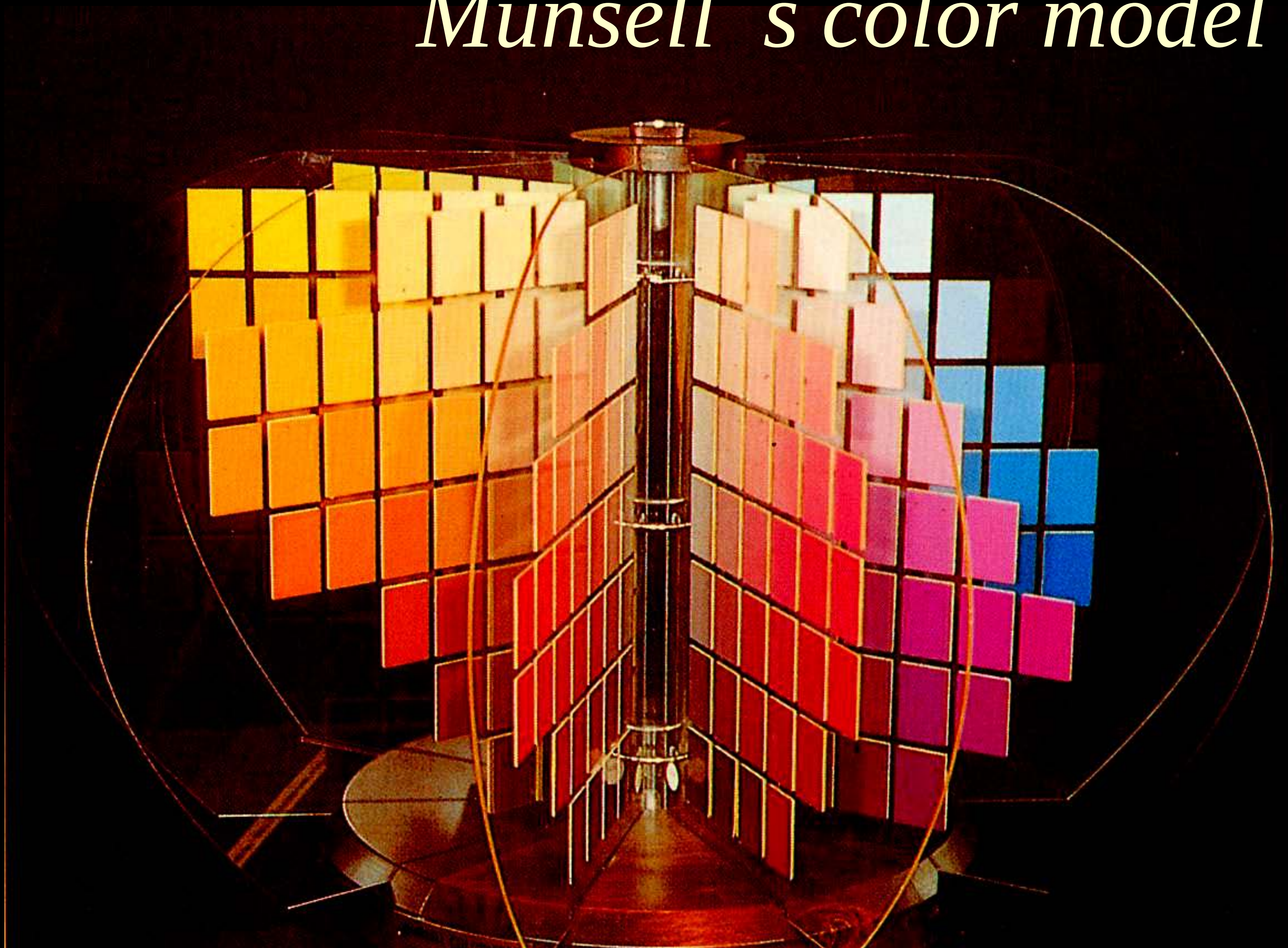

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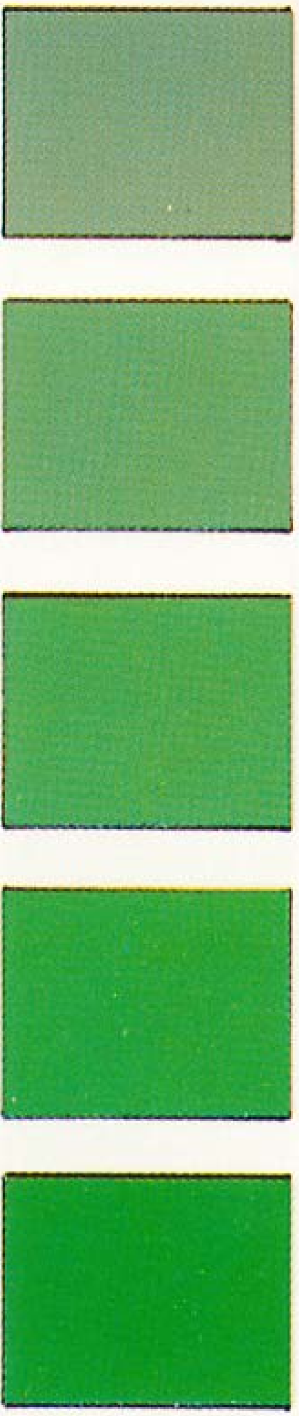
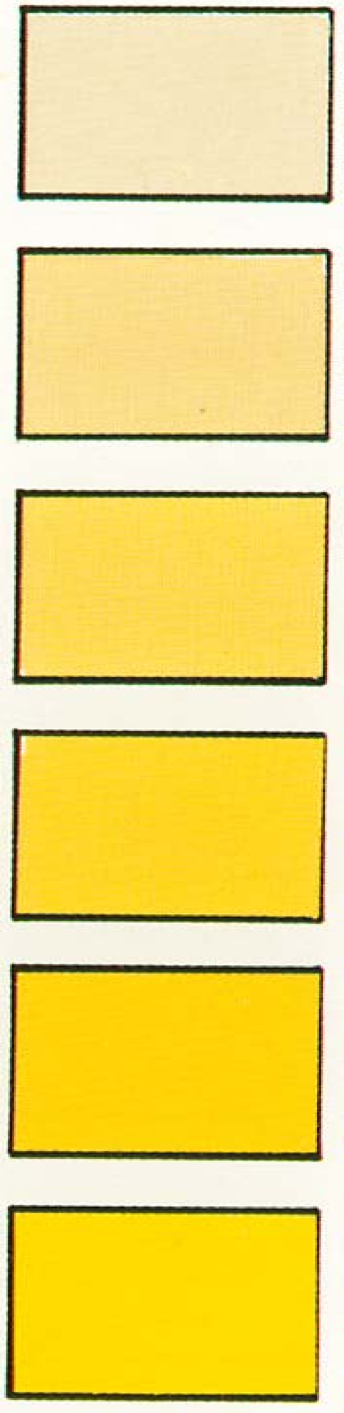


Chroma

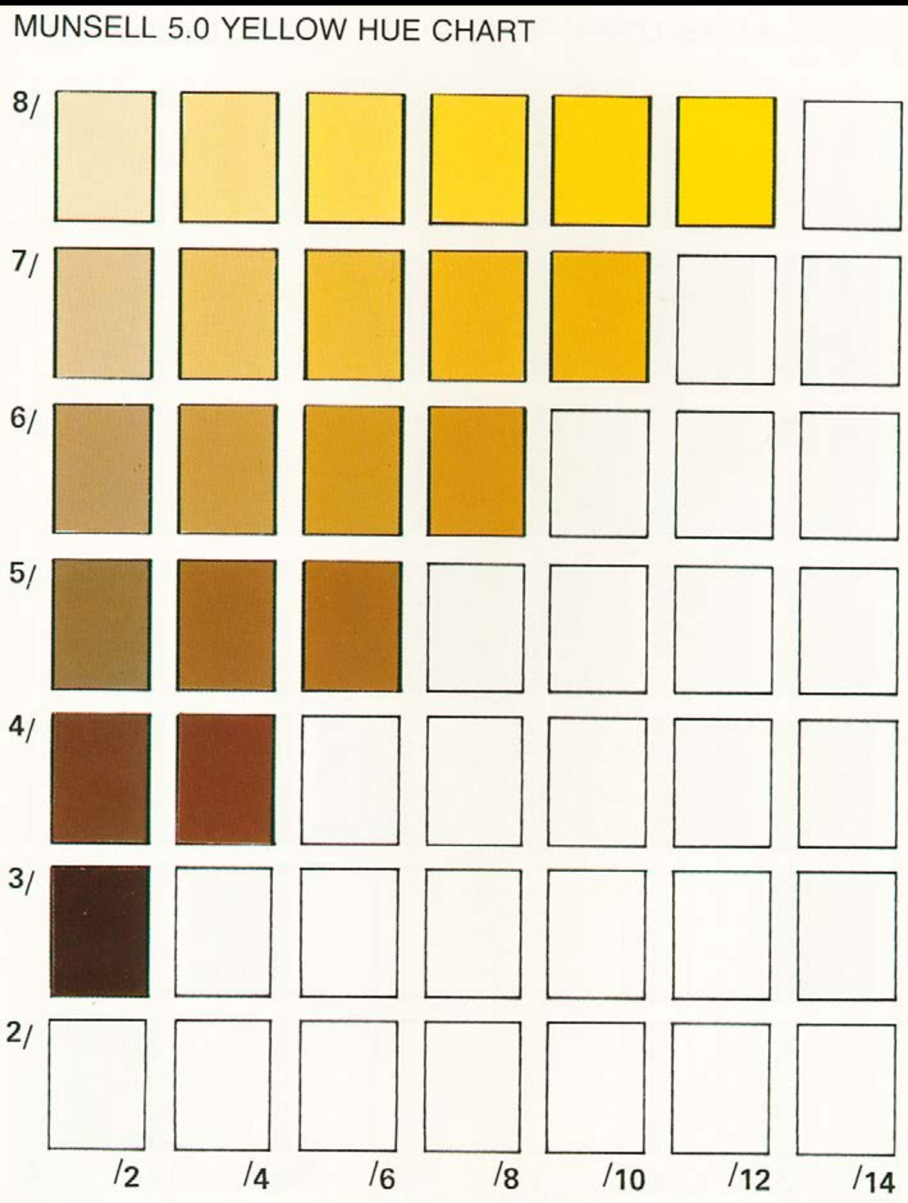
- Saturation, Intensity and sometimes “brightness” – though these last two terms are easily confused with “Value”.
- The purity of the color.
- The proportion of hue to neutrals.

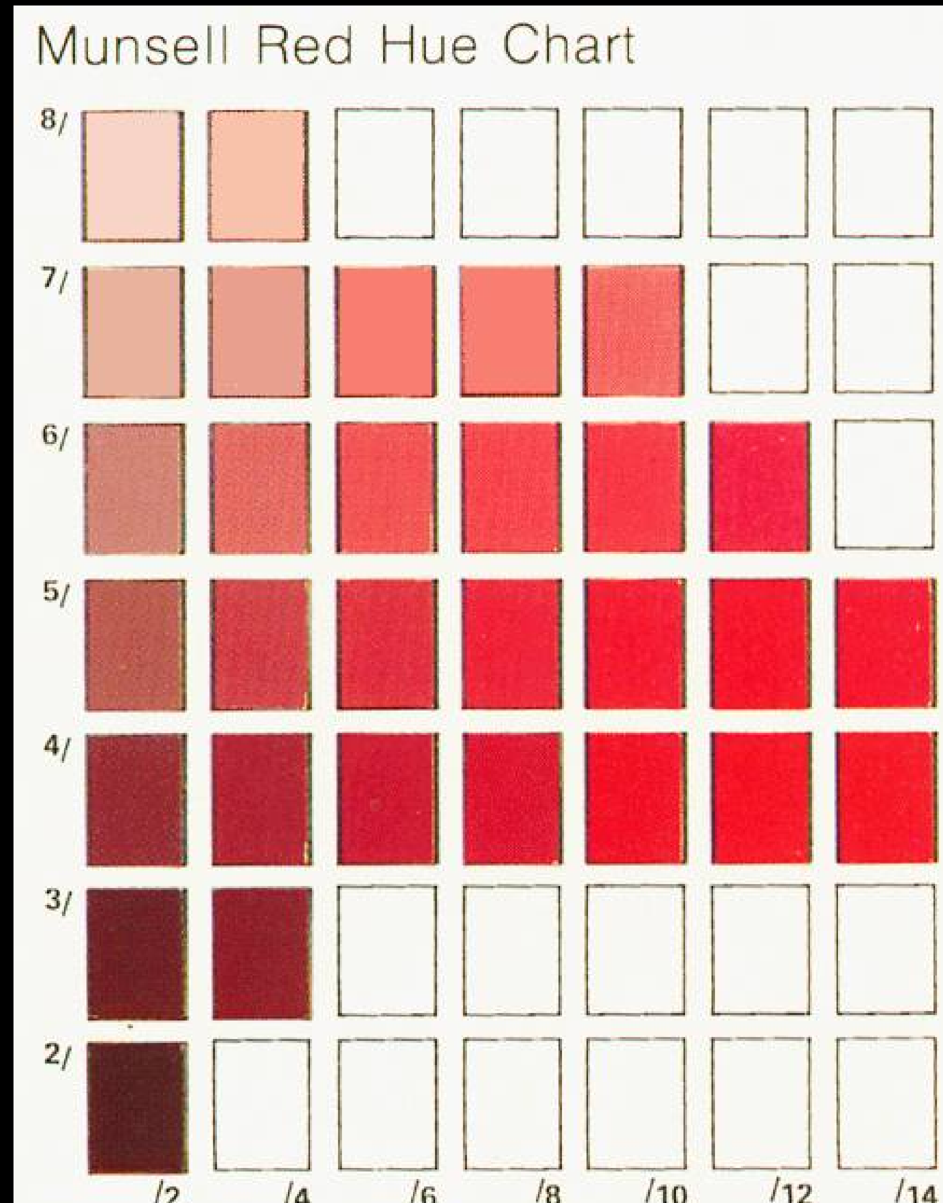


Value

- The lightness or darkness of a color – that is, how close to white and how close to black is it?
- High Value – lighter, closer to white.
- Low Value – darker, closer to black.

Constant Hue Charts





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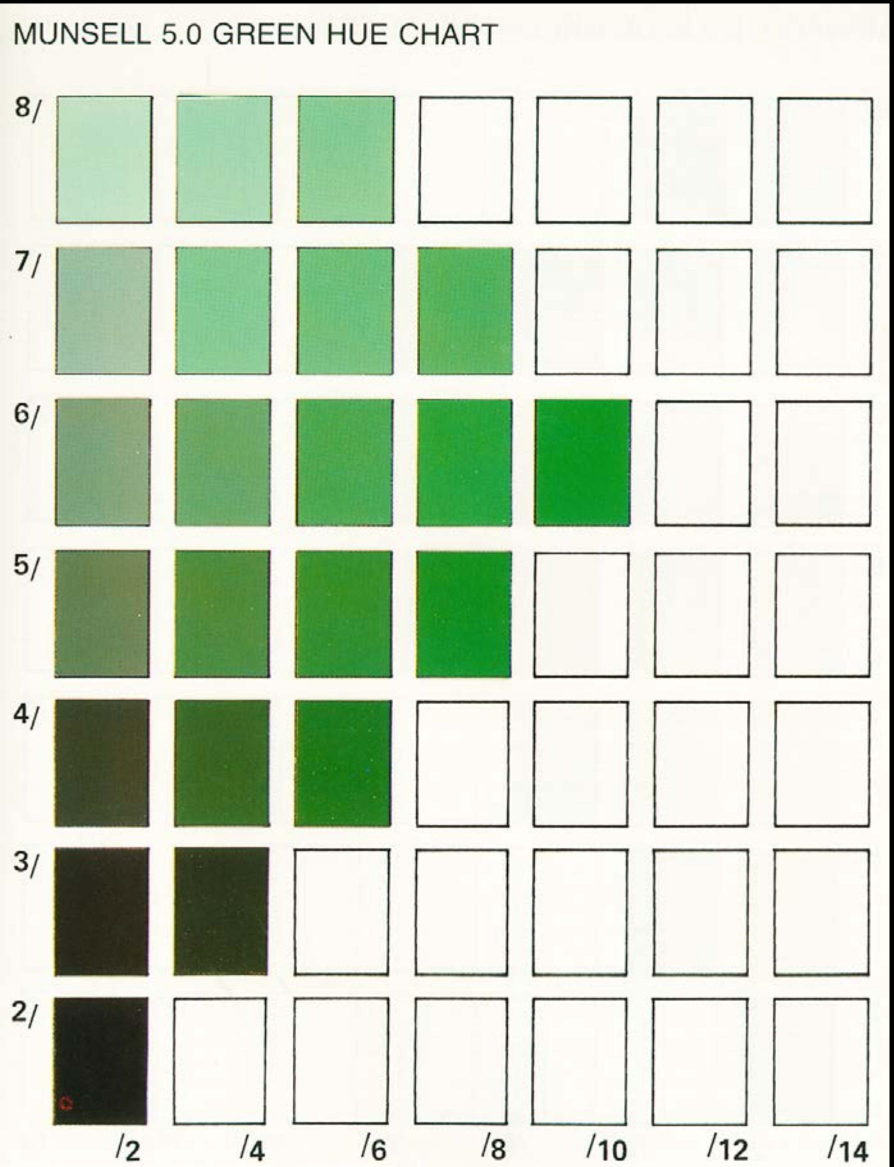

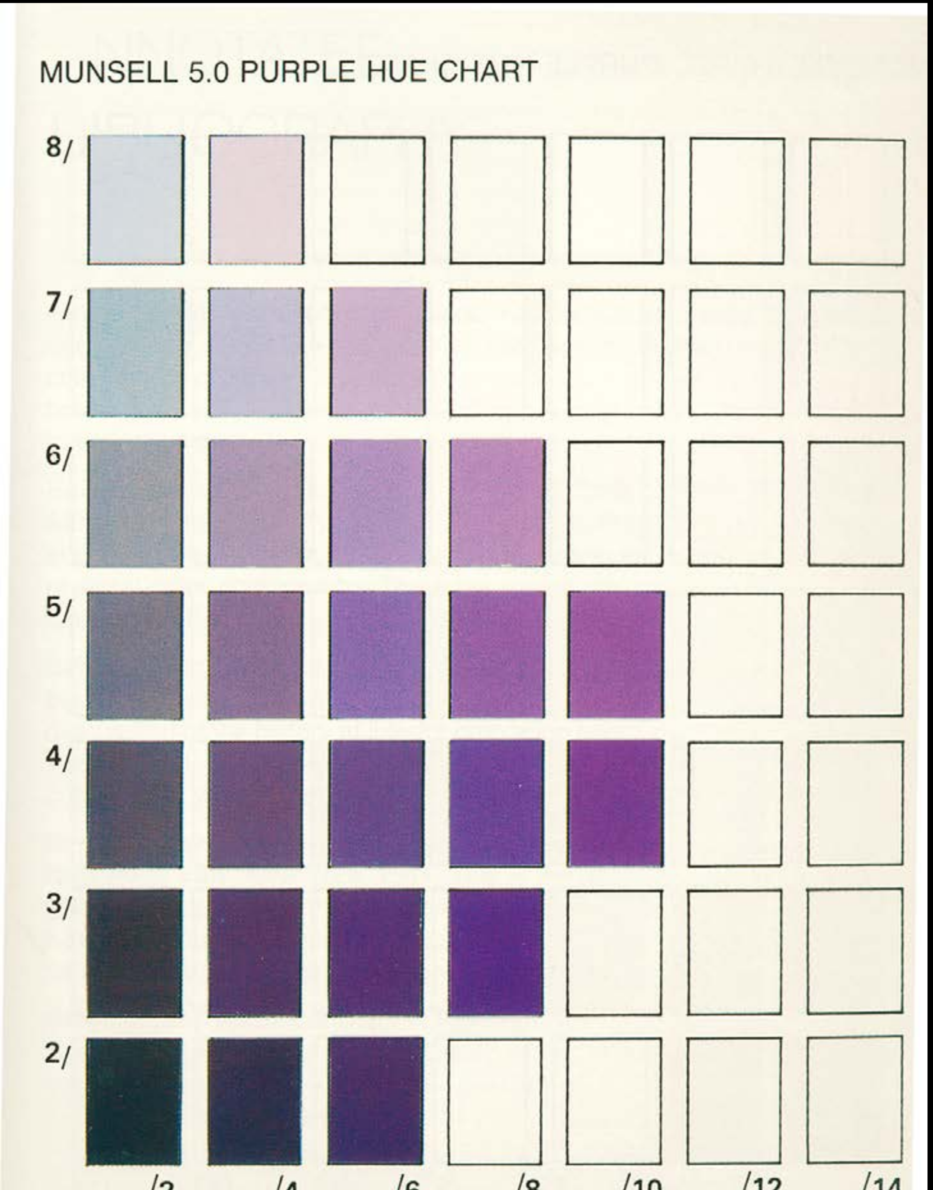

Value Scale

- A value scale is to value what a color wheel is to hue.
- It is simply a graphic representation of the full range of values from white to black. Often a value scale will be divided into even steps. For our charting and color planning we use a 9-value scale, with black at the bottom – numbered “1” and white at the top, numbered “9”.