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MK350 Series

Survival Handbook

台灣精品 2015 TAIWAN EXCELLENCE

國家品牌玉山獎 2014

OPTO TAIWAN 2014

Made in Taiwan

台灣精品 2015 TAIWAN EXCELLENCE

MK350S

MK350N PLUS

MK350D

Advanced S

Basic N+

Compact D

Available on the App Store

Google play

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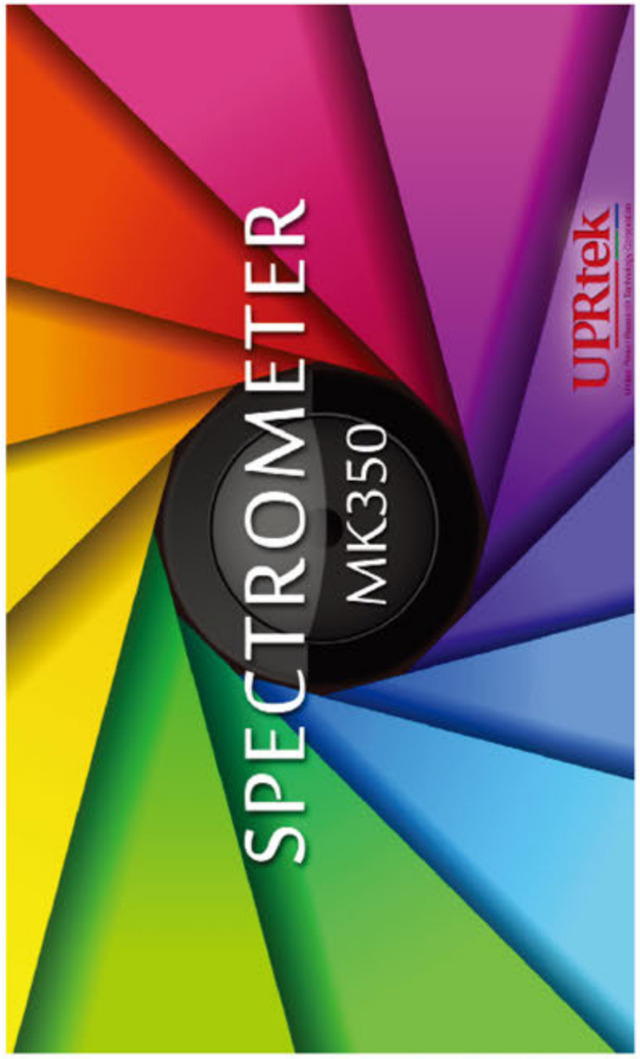

It’s the Question that drives us ...

- The Matrix -

Introduction

The overwhelming flood of LED lighting in the market is undeniable – LEDs are energy efficient, longer lasting, cooler, shockproof and non-toxic and this is why this guide will focus on LEDs. However, there are challenges to LED lighting - namely, that LED light quality and color can be quite inconveniently unpredictable.

Therefore, you need measuring equipment to gauge LED light quality. However, light is about physics and precision equipment and is highly specialized, bulky, expensive and for the most part impractical. This is where the MK350 Spectroradiometer makes its timely entry into the market, a hand-carry, cost-effective light meter that provides precision light measurement outside the confines of laboratory space and into our everyday working and living environments.

Why the MK350 Survival Handbook?

The MK350 series devices are designed to measure the quality of light. As simple as that may sound, understanding the importance of good lighting and how the MK350 devices work can be quite challenging. This handbook is a survival guide to help you through the complexities of light science and to teach you the great advantages of MK350 technology.

This handbook …

- is customized for learning the MK350 devices, light and lighting
- is easy to follow (like a “Dummies” Book)
- theoretically requires no prior knowledge

Our Goals

- Goal 1 - Fast Track to MK350 knowledge
- Goal 2 – Become a Lighting Expert
- Goal 3 – #1 Customer Service/Sales Force

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3 Common Types of Artificial Lighting

Let's first discuss the 3 common types of Lights:

Incandescent Lighting
Fluorescent Lighting
LED Lighting

The traditional Incandescent bulbs were first on the scene . Next, came the Fluorescent Lights and then LED Lights, both bringing advantages in bulb lifespan and energy savings. However, they are all three, still in use with their own distinct advantages and disadvantages.

Thomas Edison did NOT invent the Incandescent Bulb ... but he did make it commercially viable!

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ONE

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Incandescent

- Commercial use - mid 1900s
- Uses lots of energy
- Generates heat - hot to the touch
- Needs to be replaced often
- Shatters easily
- Light quality is very consistent and close to the quality of Sun light.

TWO

Sun Ladder - Creative Commons Attribution-Share Alike 3.0 Unported

Fluorescent

- Commercial use - 1930s
- Cool to the touch
- Lasts longer than Incandescent
- Uses less energy than Incandescent
- Still shatters easily
- Contains dangerous mercury - poses a hazard when broken or during normal disposal.

THREE

LED

- Commercial use - Early 2000s
- Cool to the touch
- Lasts longer than Fluorescents
- Uses less energy than Fluorescents
- Does NOT shatter
- LED quality is not consistent during production and needs to be classified and sorted at different quality levels after production.

Artificial Lighting

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Incandescent Lighting

uses heat to make light ...

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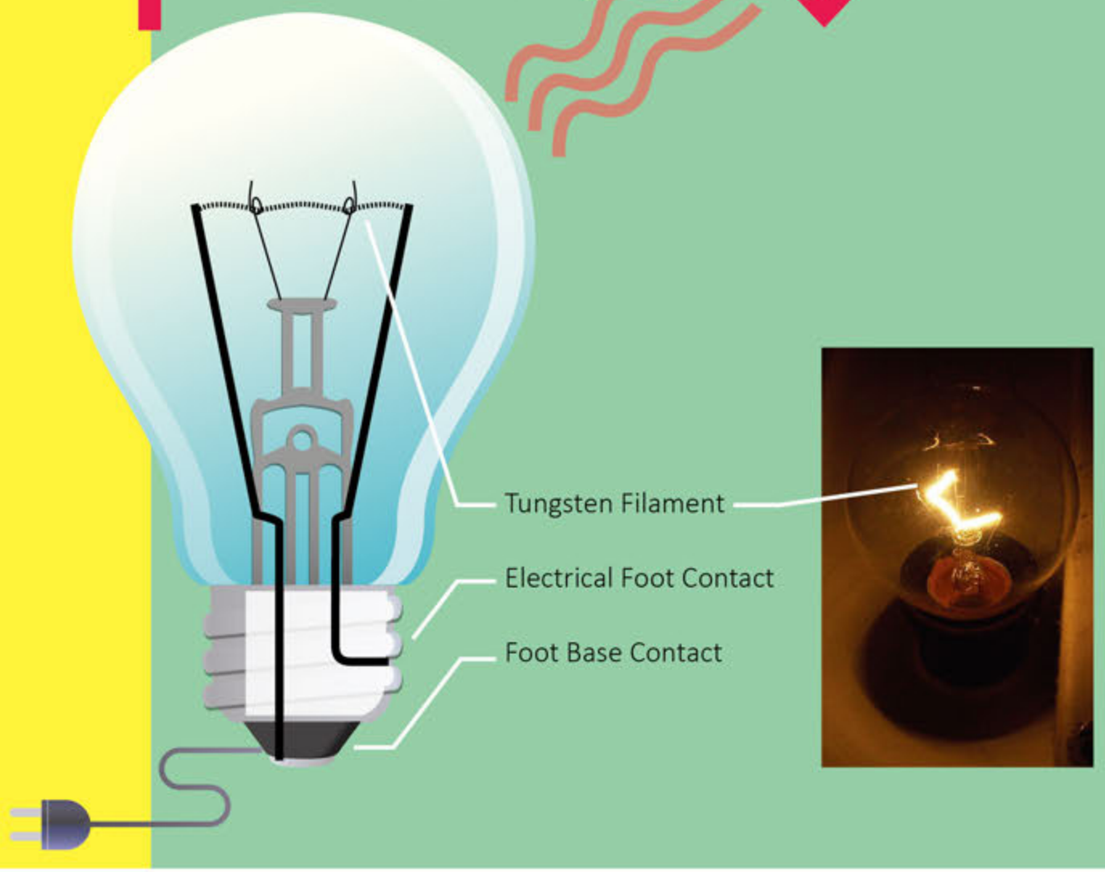
Incandescence

uses heat (thermal radiation) to produce light. **Sunlight and Candle-light** are generated in this way. Incandescent Light Bulbs also generate heat (thermal radiation) through a "filament" - the filament heats up to produce light like a candle.

The **great advantage** is that this type of light quality and color is generally very consistent between most brands. Its color qualities are also very close what the Sun produces.

The **great disadvantage** is that this type of bulb requires lots of energy which is wasted as dissipated heat (90%). Also, the intense heat causes faster degradation of the filament leading to a shorter lifespan of the bulb.

Heat means Lifespan



TELL ME MORE

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Tungsten is a hard metal that doesn't melt or degrade easily, and so it makes a good material for a filament.

Halogen lights are a type of Incandescent Light but contain Halogen gas inside the bulb to slow down degradation of the filament, allowing it to withstand more heat, and making it suitable for high intensity lights (e.g. car head lights).

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Fluorescent Lighting

uses UV radiation to make light ...

Fluorescent Lights have been commercially available since the 1930s as long **Fluorescent Tubes**. A smaller bulb-like **CFL (Compact Fluorescent Light)** only became widely available in the 2000s.

These lights use a **mercury vapor** (steam) inside the tube; electricity is applied within the tube, which causes the mercury vapor to emit UV light, or more accurately UV radiation. The UV radiation hits the inside surface of the tube which is coated with a phosphor material. The UV radiation causes the phosphor to glow.

Sun Ladder - CC-BY-SA-3.0

Christian Taube, White Balance Degle6328 - CC-BY-SA 2.0 - Germany

Their **advantage** is that they are cooler and more energy efficient than Incandescent.

Their **disadvantage** is that Mercury is dangerous - if the bulb is broken, it can present a health hazard. Used bulb disposal is also problematic.

Image: © Nevit Dilmen found at Wikimedia commons - CC-BY-SA-3.0

TELL ME MORE

Fluorescence uses light (or electromagnetic radiation) to make light - it's related to phosphorescence (watches).

Image by I, Autopilot - CC BY 2.5 Generic

Arc Lamp - Fluorescent Lights are a type of Arc Lamp that produces light, typically through a non-conductive medium, like air. Lightning is similar, a type of natural Arc Lamp.

Ziemor at pl.wikipedia - CC-BY-2.5-Generic

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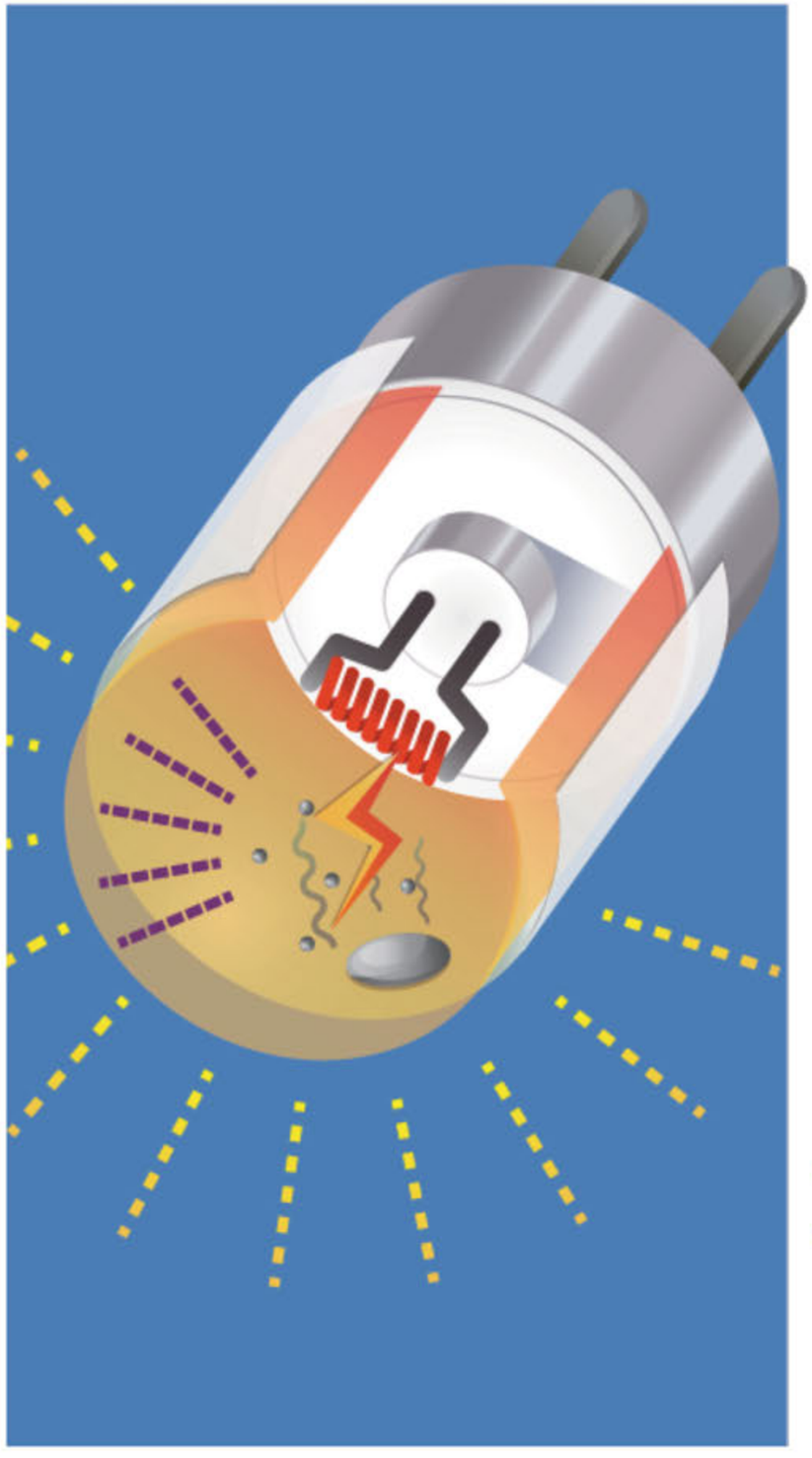
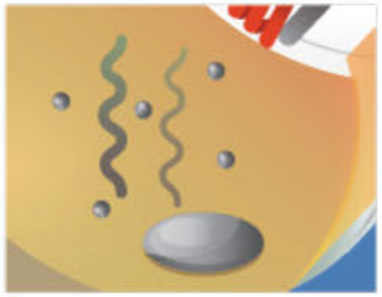
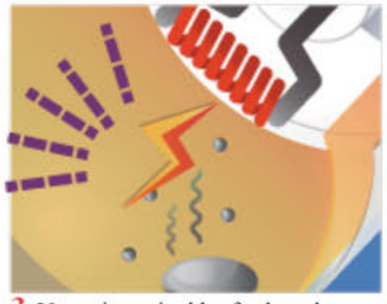


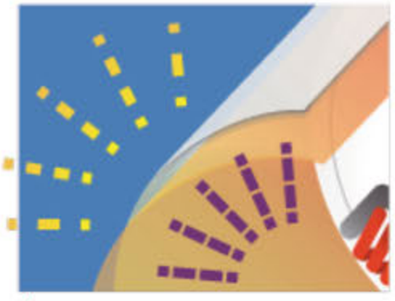
1. Electricity warms the tube.



2. Mercury turns to vapor.



3. Vapor is excited by further electricity and UV light is emitted.



4. UV light hits the inside surface of tube, which is coated with Phosphor material, which then glows (emits light) - i.e. **Using light (UV light) to make visible light.**

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Early LED bulbs (from 1960s)

Aftank99 - CC-BY-SA-2.0 Generic

LED Lighting

uses semiconductors to make light ...

Early LEDs (Light Emitting Diodes) were used mainly for small indicator lights for applications like display panels - they have been used in this way since the 1960s and they looked like the bulbs at the top of this page.

During the early **2000s**, we began to see LED technology used for environment lighting as well (e.g. homes, offices, factories, schools) and LED bulbs began to look much like our traditional light bulbs. They even produced LED strips to look like Fluorescent Tubes.

LEDs use **semiconductors**. Yes, it's similar to the material used on processors for circuit boards. However, the materials used in LEDs are for the purpose of producing light.
In addition to being **cooler** and more **energy efficient** (like Fluorescent Lighting), LEDs have an added value of **lasting a VERY long time**, in addition to being **shatter/shock proof**.

Circuit Board Processor made from semiconductor material

LED strips used for tube lighting.

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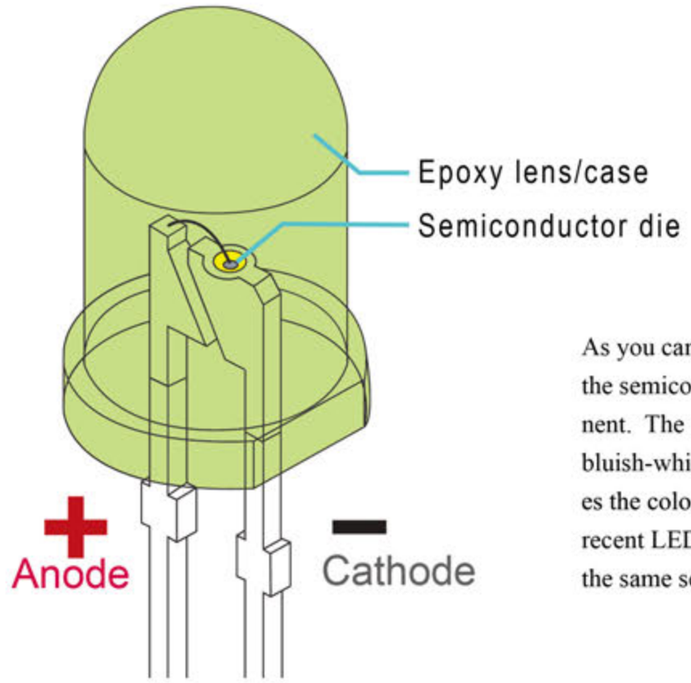
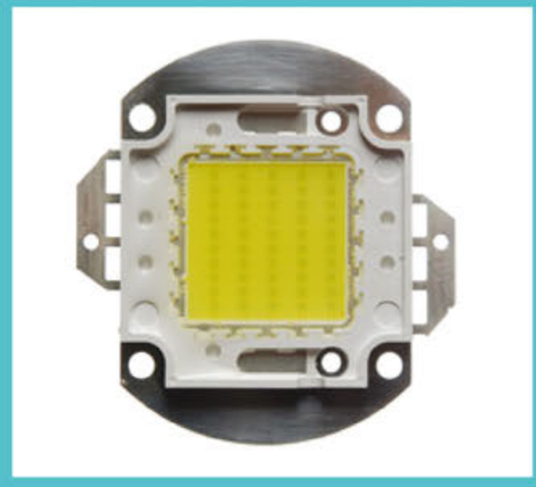
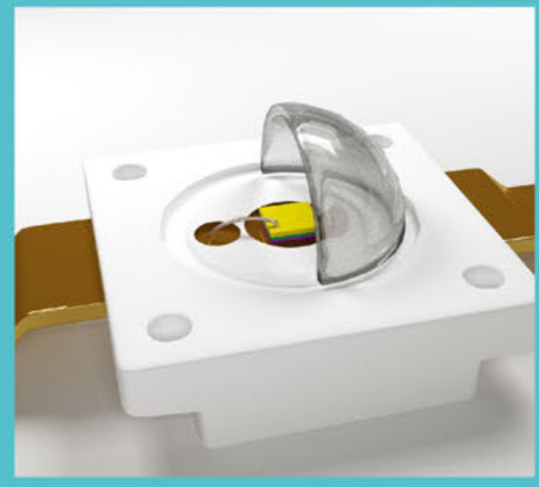


As you can see from the early LED lights, the semiconductor is a very small component. The semiconductor itself produces a bluish-white light and the lens/case changes the color to fit the application. More recent LEDs might appear as below, but the same semiconductor principles apply.

Modern LEDs may look like this ...



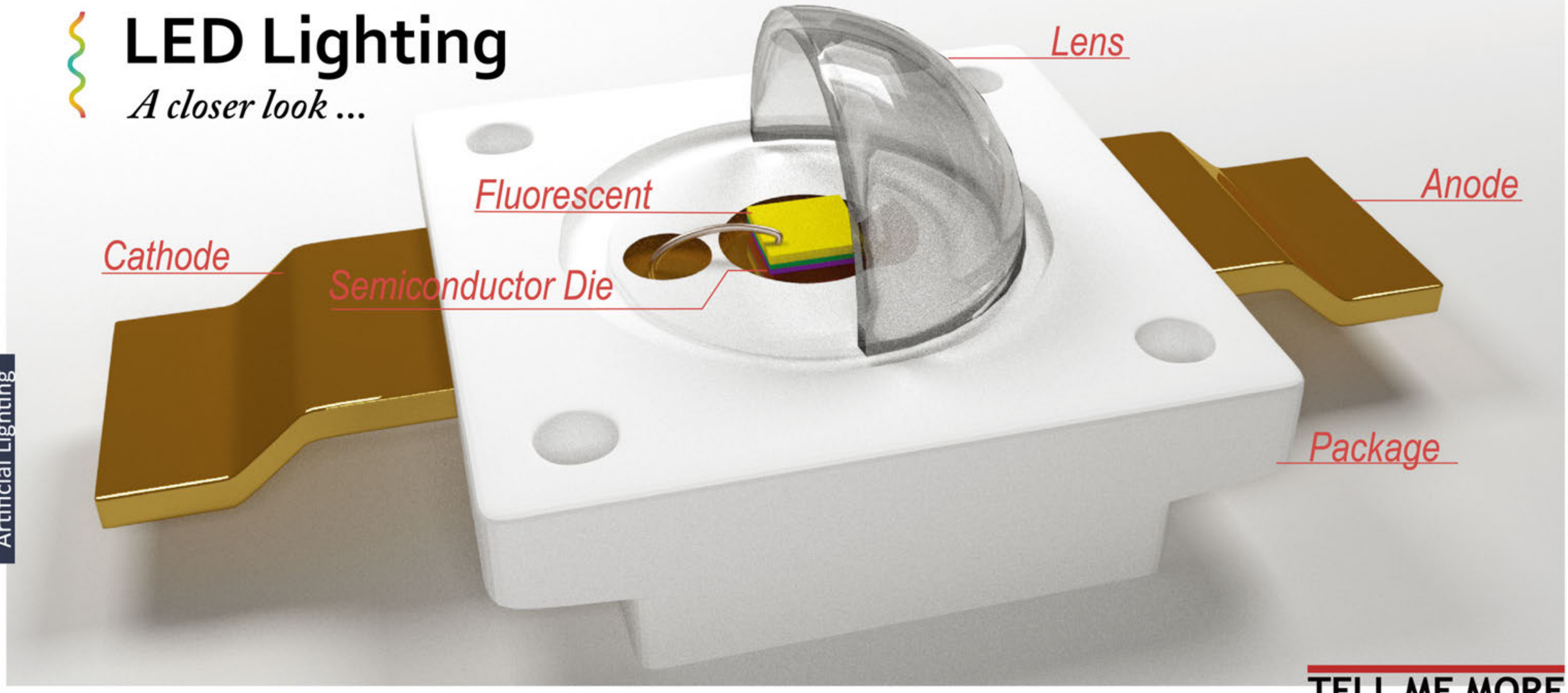
or like this ...



or like this ...

LED Lighting

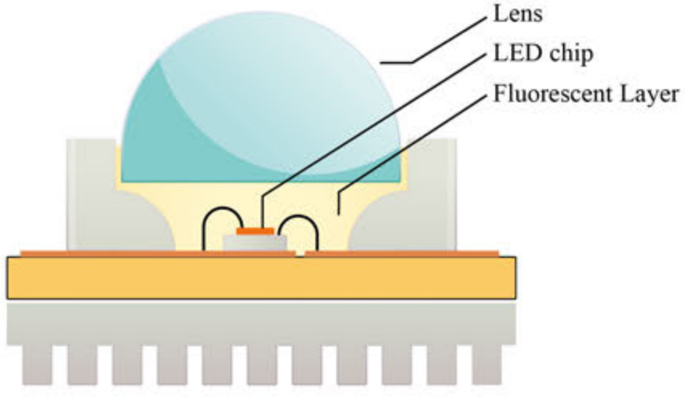
A closer look ...



LED lights work when electricity is run through the semiconductor die, which makes it produce a bluish light.

Notice the yellow layer on top of the semiconductor - it changes the semiconductor's bluish light to become more of a comfortable white light - sometimes this yellow layer is referred to as the Fluorescent layer or Phosphor layer.

The LED may have a lens on top to redirect the light to obtain uniform overall intensity.



TELL ME MORE

Phosphorescence vs. Fluorescence
Both use "light to make light". However, phosphorescent material does not immediately re-emit the radiation it absorbs.

Die or Diode - these words may sometimes be used in place of LED chip or semiconductor chip.

LED Package - this is the entire housing (i.e. package) for the LED.

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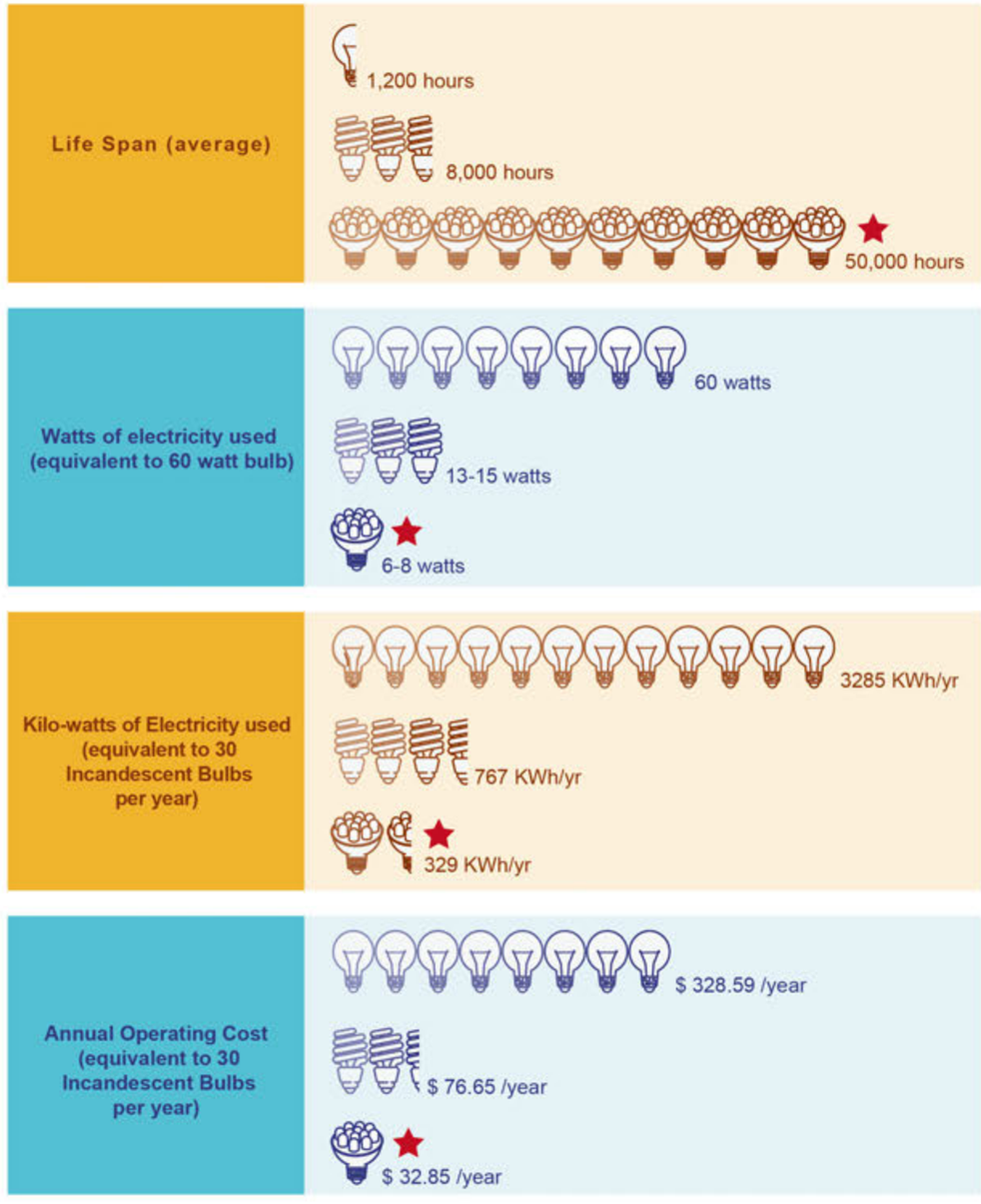
Artificial Lighting

Advantages & Disadvantages



Practically and economically speaking, LEDs seem to have a huge advantage and this is why most newly built facilities in developing countries are choosing LEDs for most of their environment lighting (e.g. factories, offices, libraries, museums).

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So why continue to buy Incandescent Lights?

For the consumer, it is the out-of-pocket expense that is a significant factor. A retail LED (as of this writing 1/2014) may cost $15 out-of-pocket but an Incandescent bulb may cost you only $3. Which would you buy? What if you had to replace 2 bulbs ($30 vs $6).

The Incandescent light also comes as close to natural sunlight compared to the other two, and its light quality is close to Sunlight, which is the gold standard for light because, as evolutionary beings, our eyes have become accustomed to sunlight and the rich colors it produces.

Why people still use incandescent bulbs (USAtoday 12/27/2013)
http://www.usatoday.com/story/news/nation-now/2013/12/27/incandescent-light-bulbs-phaseout-leds/4217009/

So why continue to buy Fluorescent Lights?

Fluorescent Lights fall between Incandescent and LEDs. It lasts much longer than an Incandescent light, but it's cheaper than an LED light.

It's ideal for places that are not assured a long term location (e.g. for a convenience store that is renting space, why would you buy a 50,000 hour LED light?).

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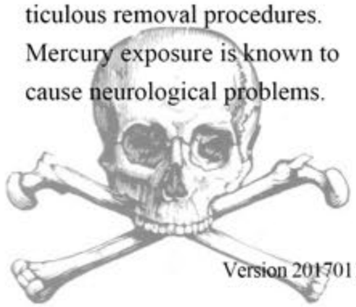
Disadvantages ...

Fluorescent Light - Health Issues

The fragile Fluorescent tube can **easily shatter** and presents a health hazard when the toxic **Mercury** liquid is exposed; clean up requires careful, meticulous removal procedures. Mercury exposure is known to cause neurological problems.



Fluorescent Lights use **UV light** inside their tubes, but small amounts do escape - UV light is harmful to the eyes and skin. Fluorescent Lights have also been known to **Flicker** - studies indicate that long term exposure to light flicker is harmful to our eyes.

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Incandescent Light

The most troublesome aspect of incandescent lights is its indiscriminate use of energy.
90% of the energy used is dissipated as heat - only about 10% is released as light.

LED lights
Not all LED chips are created equal

LEDs use semiconductors - though you may think this type of technology is quite sophisticated, the actual production of the LED chip is not always an exact science - LED light quality can vary quite greatly between batches and each batch may be categorized and sold as different qualities of color and intensity.

In fact, CPUs used in computers are also semiconductor based and have similar issues - they cannot guarantee the same exact performance from batch to batch and measures must be taken to moderate performance expectations (e.g. over-clocking).

http://www.designrecycleinc.com/led%20comp%20chart.html

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Artificial Lighting

The Market

A changing world - What we know

- There are still lots of people who use incandescent lights (mostly in homes).
- There are still lots of Fluorescent Lights in public places (e.g. hospitals, offices etc.).
- Lighting designers are saying new facilities (factories, hospitals, libraries etc.) are most likely to install LEDs.
- Some existing facilities are changing out their lights completely for LEDs, already realizing the long term cost savings.
- Most developed countries are exercising phase-out plans for use of incandescent bulbs.
- The price of an LED bulb is dropping to the point that they will start to compete with CFLs for market share and eventually surpass them in a few years (maybe by 2015).

Bottom Line:

LEDs are on course to take over the world.

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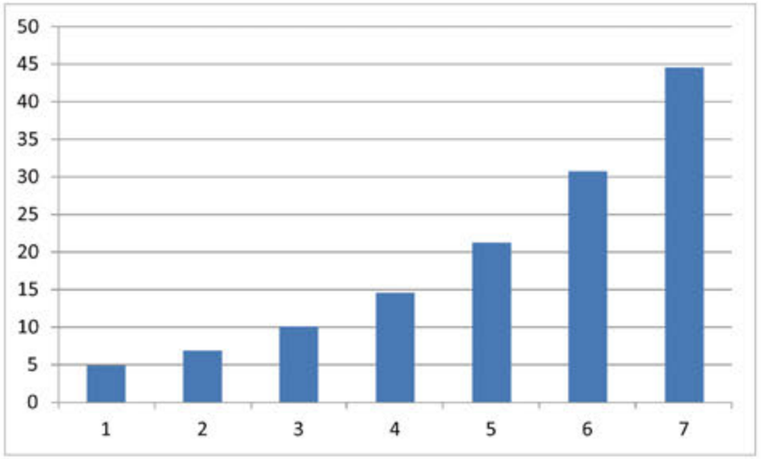
G'bye to Incandescent

Countries exercising full, partial, planned bans of incandescent bulbs or exchange programs. (according http://en.wikipedia.org/wiki/Phase-out_of_incandescent_light_bulbs as of this writing 02/2014)

Original by Ukelay33 - GFDL - CC-BY-SA-3.0 - Adapted for this topic

Hello to LED

Estimated North American LED market to grow about 45% every year over the next 7-8 years.



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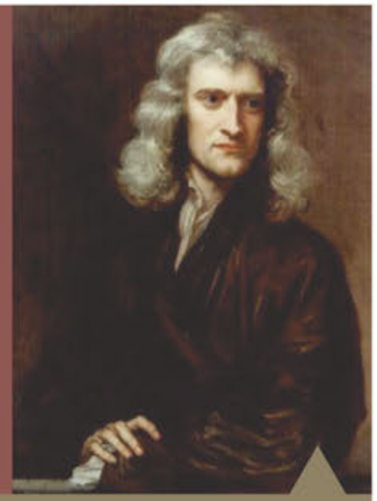
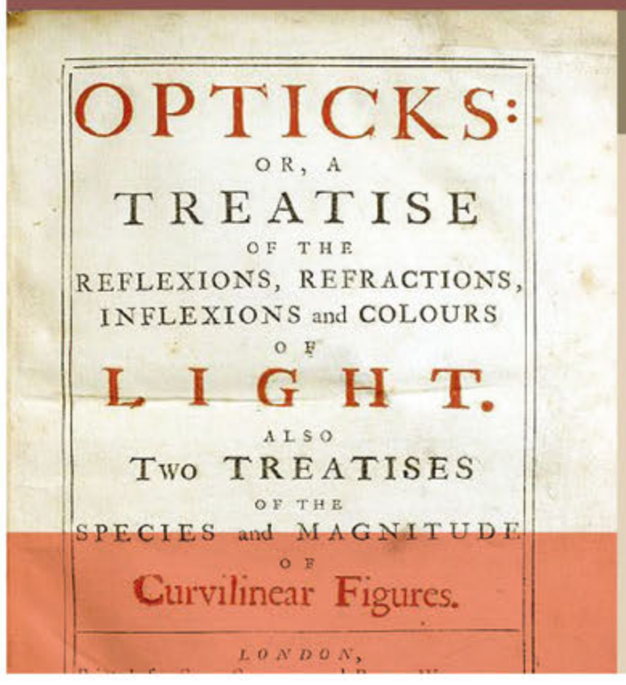
Where does Light come from?

A little Science and Magic ...

The importance of understanding light.

Understanding the basics of what light is and where light comes from is the key to understanding LED lighting and MK350 devices. However, we must first get our feet wet in the world of Science, particularly Physics and Chemistry. This section explains the lighting fundamentals in layman terms, in a straight-forward, concise and practical way, without any MATH!

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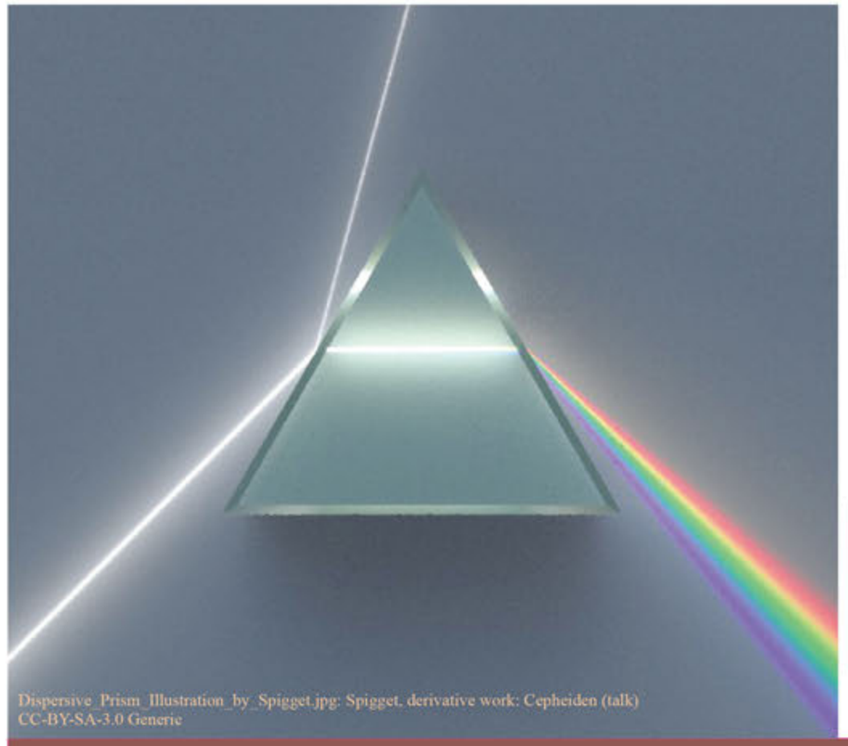
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Turning your world upside-down

Before we begin, we must set some expectations. Physics and Chemistry are like Magic - there are things you will see that will amaze and confound you at the same time. So it's important to prepare yourself to turn your world upside-down and be ready for anything.

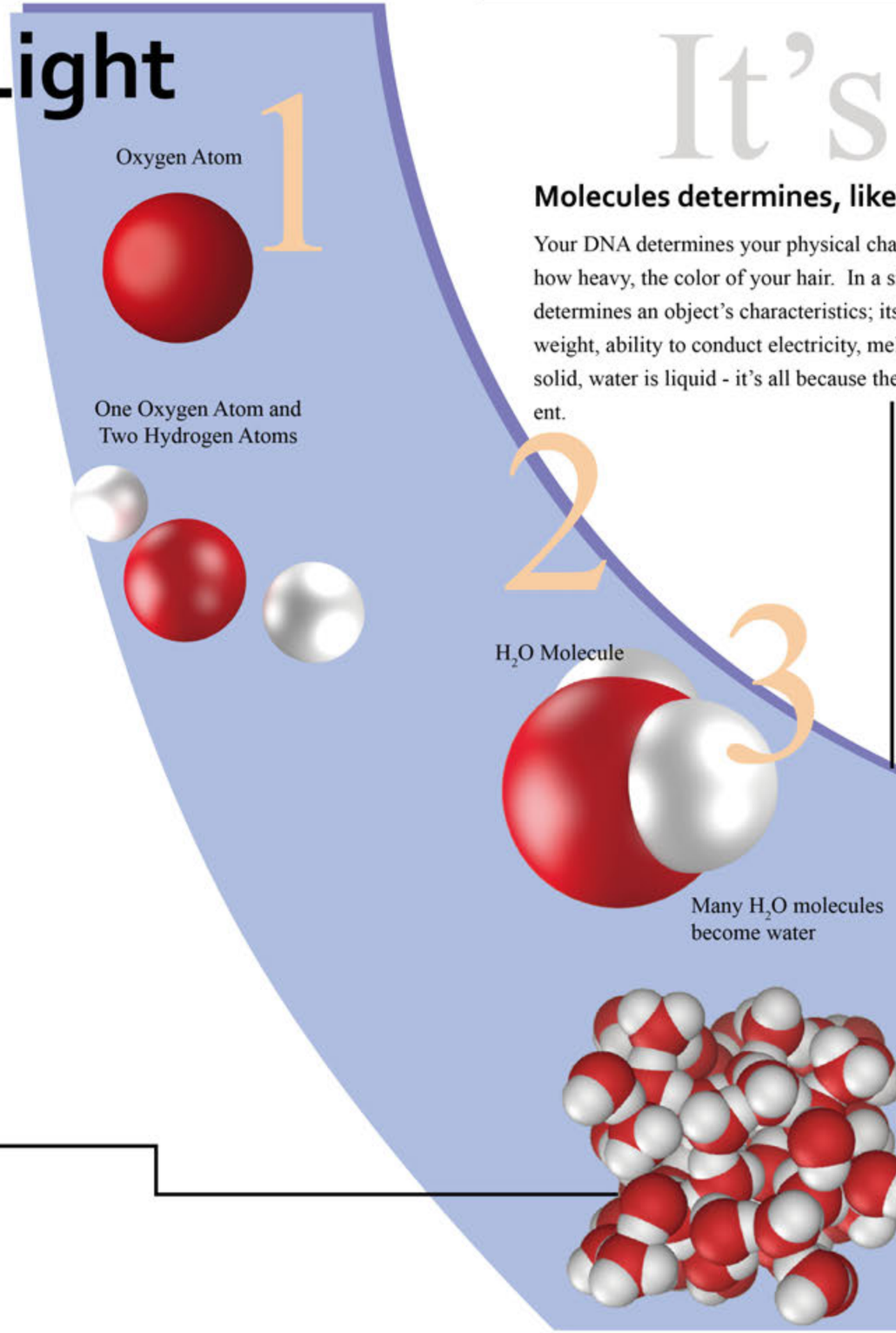
Atoms Make Light

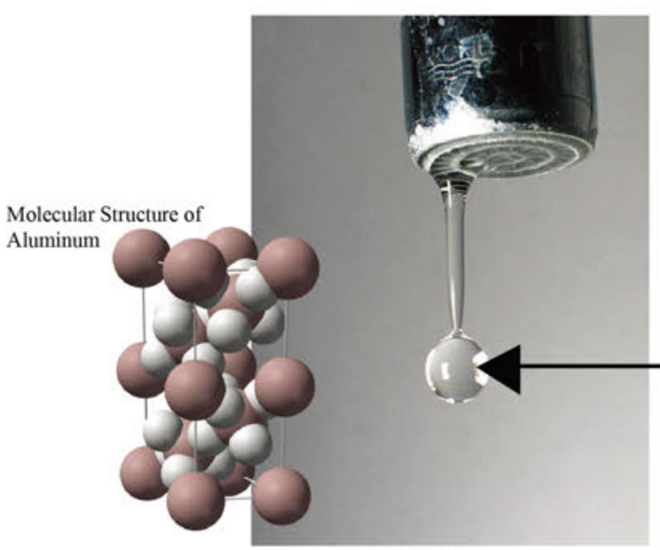
What is an atom?

Light comes from atoms, so we need to first understand what an atom is. Everything is made of atoms. The table, the wall, your cell phone, oxygen ... even you. Actually, an atom is so small that you can't really see one - but, when you combine them together, they become things, like water.

What is a molecule?

Atoms in an object are usually arranged into groups of atoms called molecules. For example, if I take one Oxygen (O) atom and add two Hydrogen (O) atoms, I get an H_2O molecule. These atoms are attracted together by forces (electrostatic forces). Many molecules form an object - sometimes these molecules are loosely held together like water, or sometimes they are tightly held together like metals. It all depends on the **molecular structure.**





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It's Like

Molecules determines, like DNA determines

Your DNA determines your physical characteristics; your gender; how tall, how heavy, the color of your hair. In a similar way, Molecular structure determines an object's characteristics; its color, its texture, its smell , its weight, ability to conduct electricity, melting temperature etc. Metal is solid, water is liquid - it's all because their molecular structures are different.

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Molecular Structure Determines

- Color
- Texture
- Smell
- Weight
- Conductivity
- and more ...

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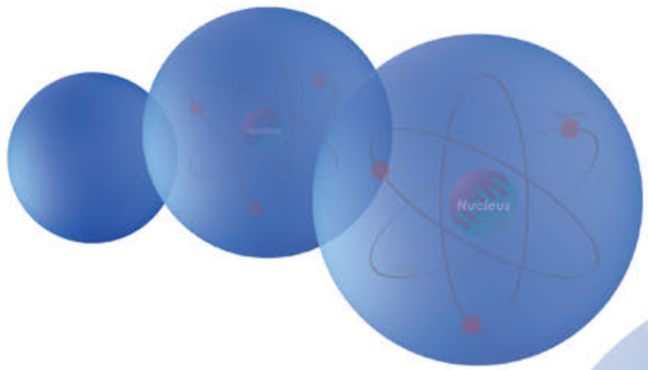
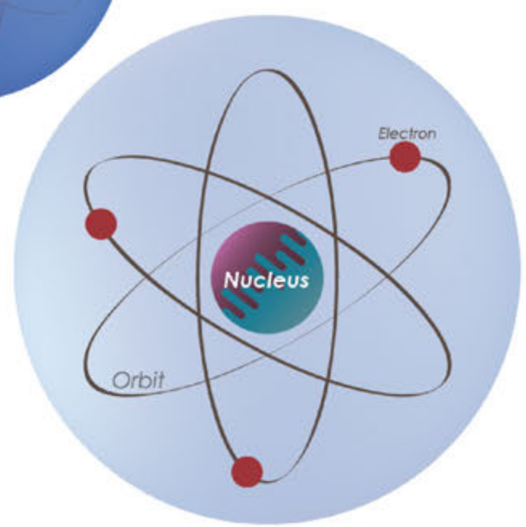
Let's take a closer look..





Making light from an atom is an easy process. You just need a little imagination. Inside an atom, there is a large nucleus - then there is a small electron (s) that flies around the nucleus in a fixed orbit - you can think of it as the Sun (nucleus) with the smaller Earth (electron) orbiting it. When energy is thrust upon the atom, the electron flies out to a higher orbit. When it returns to its original (natural) orbit, light is emitted.

It's Like

Electrons are the Key

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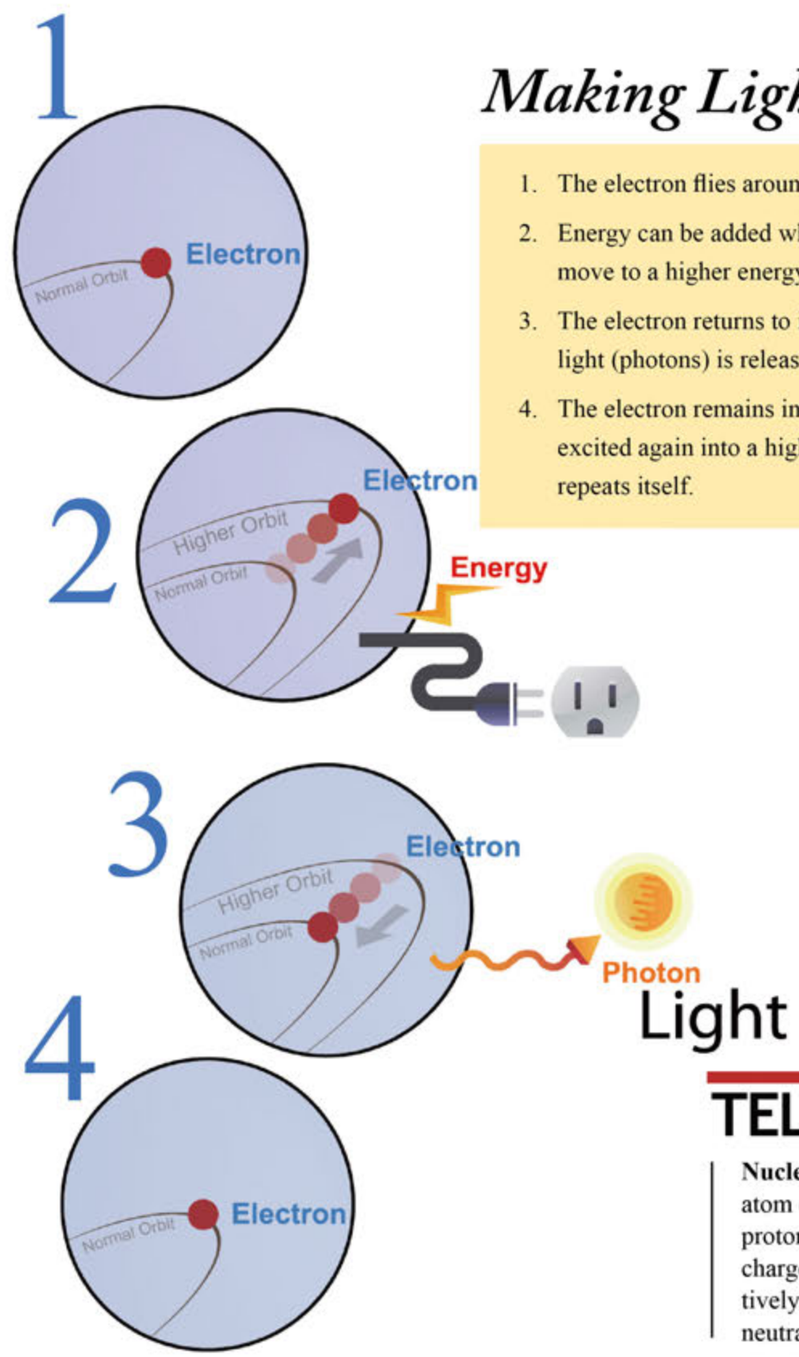
Atoms make Light



Making Light of Things

1. The electron flies around in its natural orbit.
2. Energy can be added which causes the electron to move to a higher energy orbit for a short time.
3. The electron returns to its lower natural orbit and light (photons) is released (energy released).
4. The electron remains in its natural orbit, until it is excited again into a higher orbit and the process repeats itself.

TELL ME MORE

Nucleus -The Nucleus of an atom contains neutrons and protons. Protons are positively charged, Electrons are negatively charged and Neutrons are neutral (no charge).

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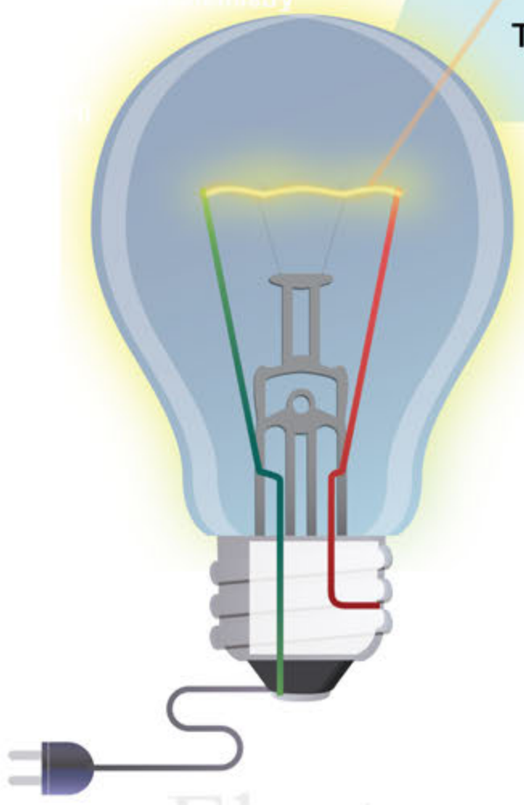
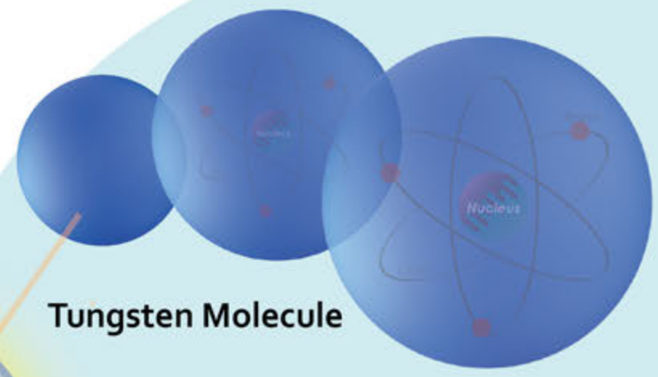
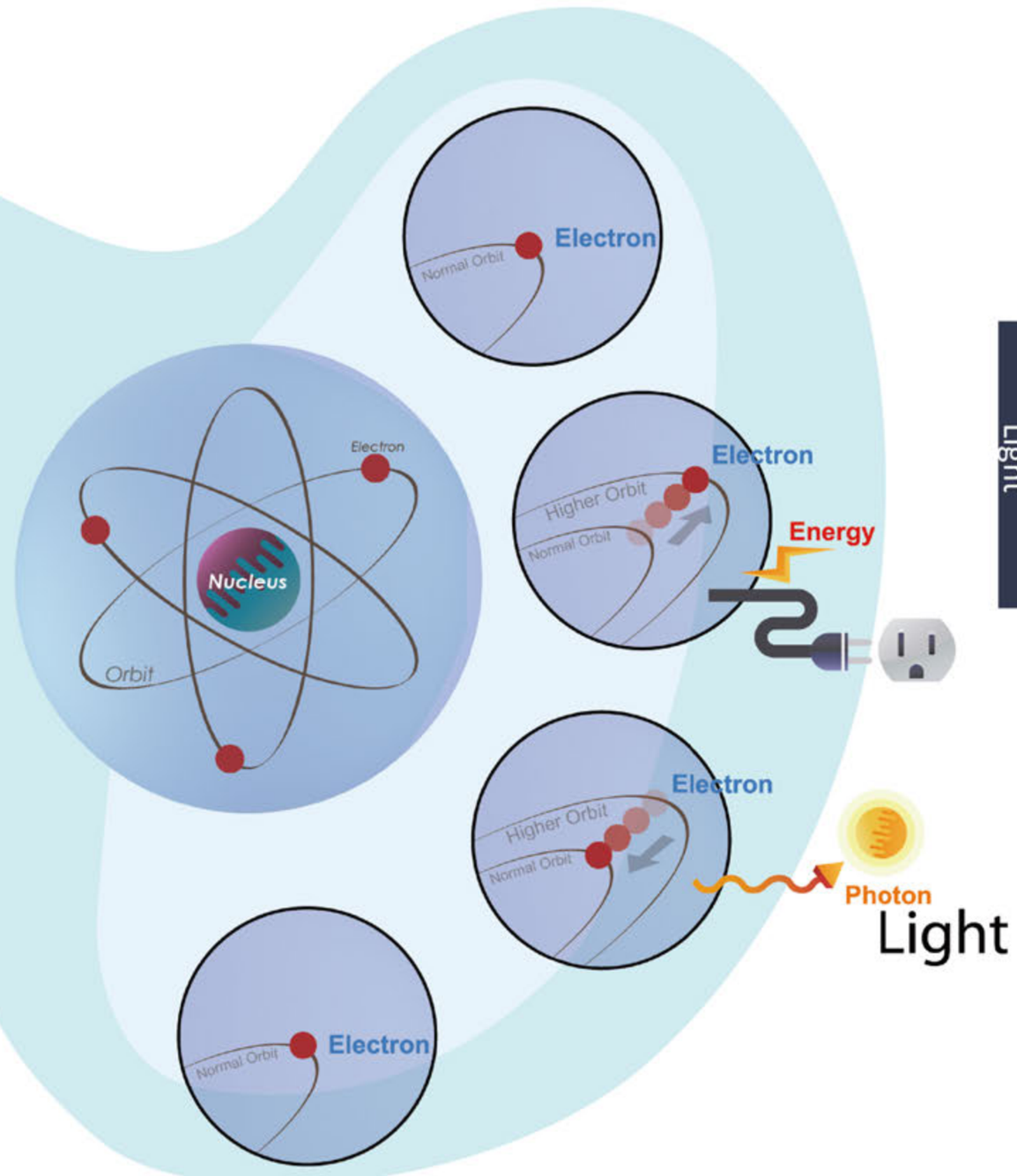
How does an Incandescent bulb make light?

Inside an Incandescent bulb, electricity is used to heat up the Tungsten Filament. The electrons in the Tungsten Filament begin to jump out to a higher energy orbit for an instance and then drop back to its natural orbit, releasing light.







Electrons are the Key

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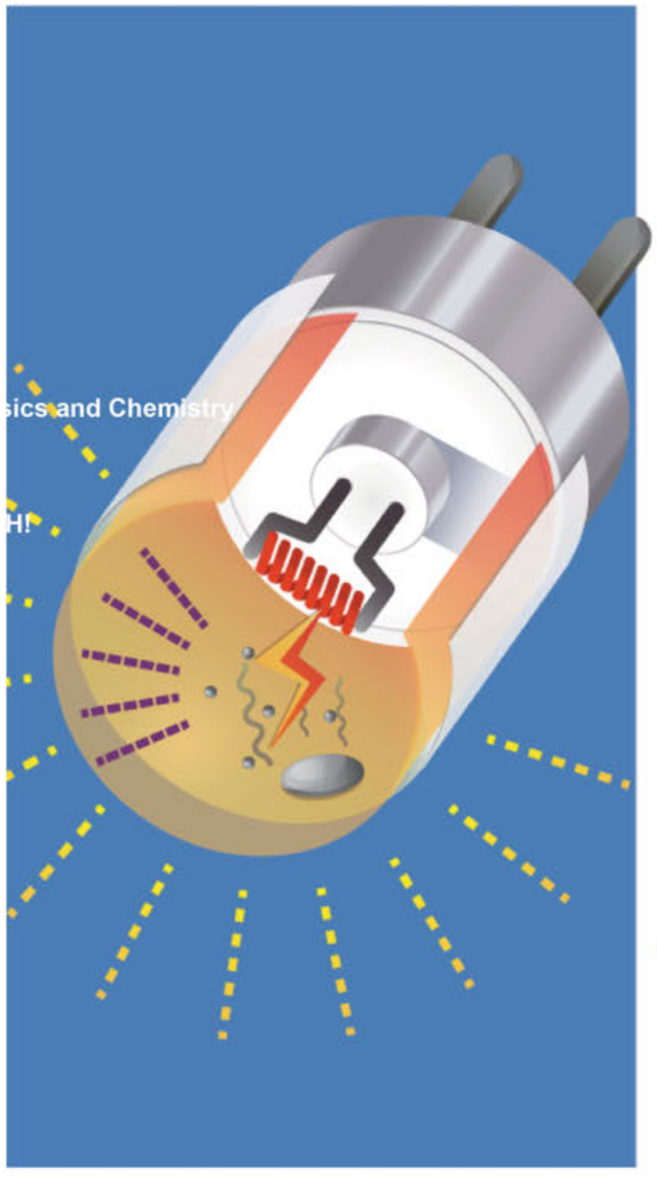
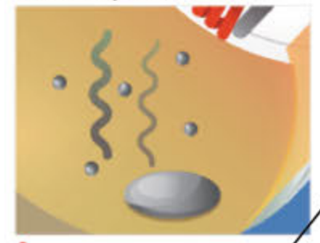
Light

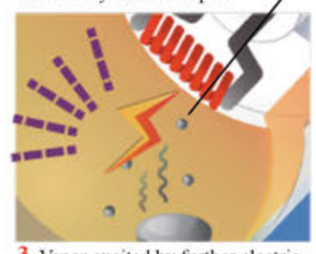
How a Fluorescent Light makes Light



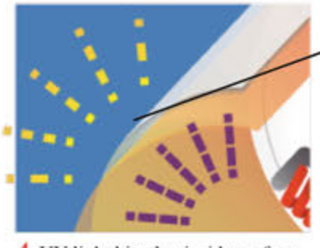
1. Electricity warms the tube.



2. Mercury turns to vapor.

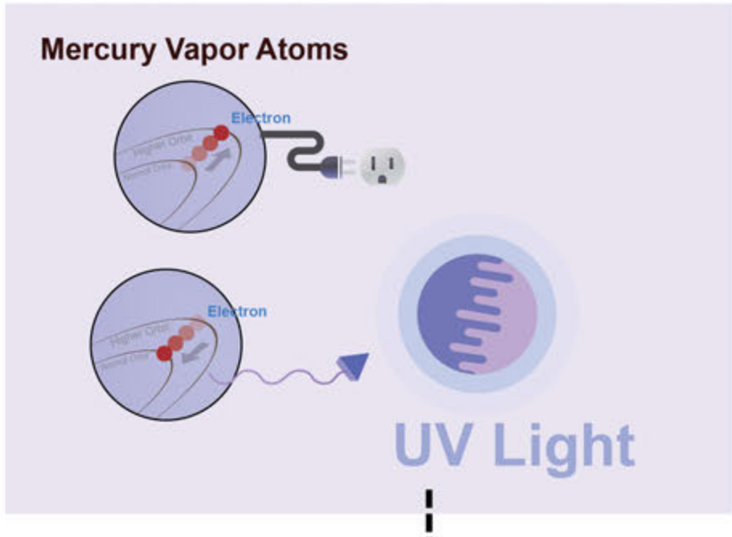


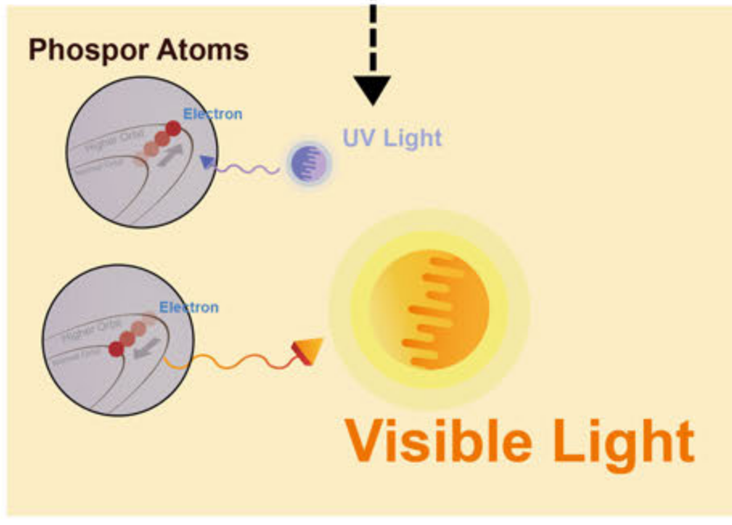
3. Vapor excited by further electricity and UV light is emitted.



4. UV light hits the inside surface of tube, which is coated with Phosphor material, which then glows (emits light) - **Using light (UV light) to make light (visible light).**

As we mentioned, a Fluorescent Light makes light in two separate steps; electricity causes mercury vapor to emit UV light, the UV light strikes the Phosphor inner lining and causes the Phosphor to emit visible light. In both cases, the same mechanisms of Energy-Atom-Electron-Photon are in effect.





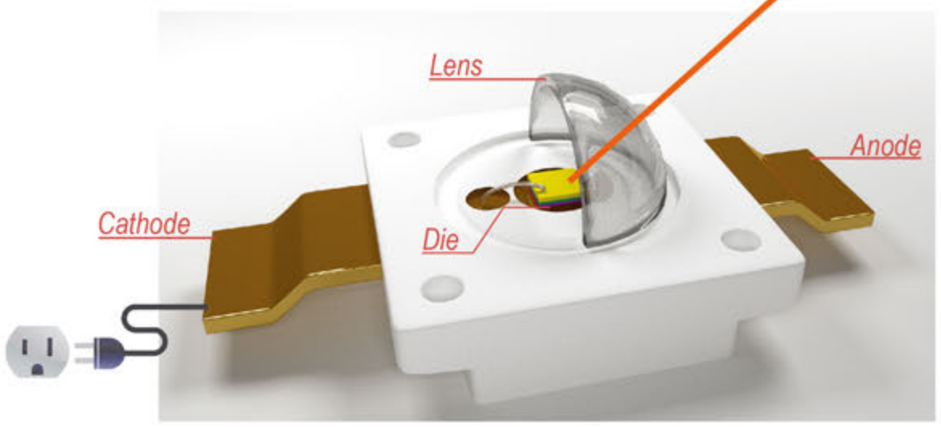
How does an LED make light?

Electron movement in Semiconductors

As we saw on the previous page, electrons at higher orbits that drop back to lower orbits, release photons of light. In LED semiconductors, a similar strategy is at work. Electrons jump from higher energy states to lower energy states.

LED semiconductors have two layers. The top semiconductor layer, called n-type, is modified to have extra free electrons. The bottom layer, called p-type, is also modified, but to have positively charged "electron holes" (but not really "holes", more like pockets), which can attract free electrons.

When current is passed through these two layers, the electrons and holes move toward each other - when an electron is close enough to a hole, it falls into it, going from a high energy state to a low state (hole) and as we already know, this releases a photon.



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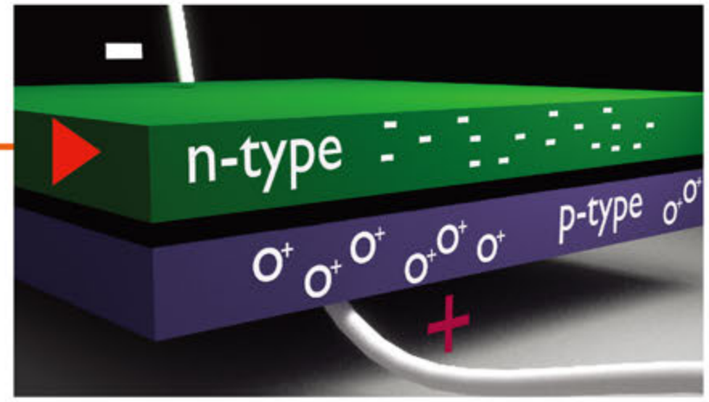
Electrons are the Key

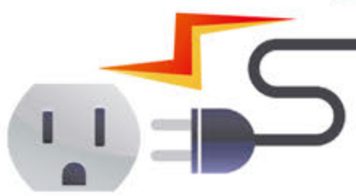
1

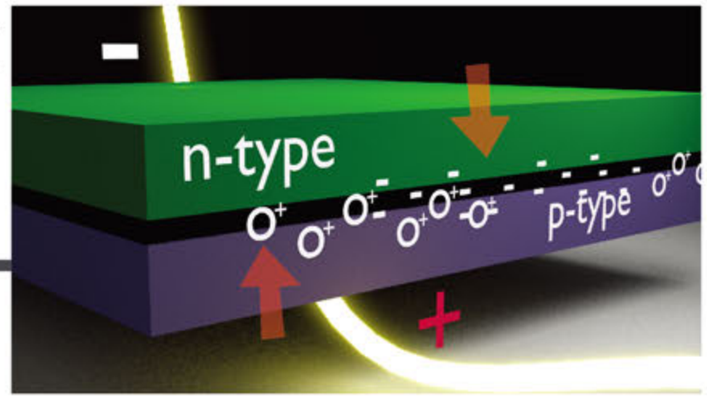
Negative free electrons in n-type layer and positive holes in p-type layer are in a steady state.



2

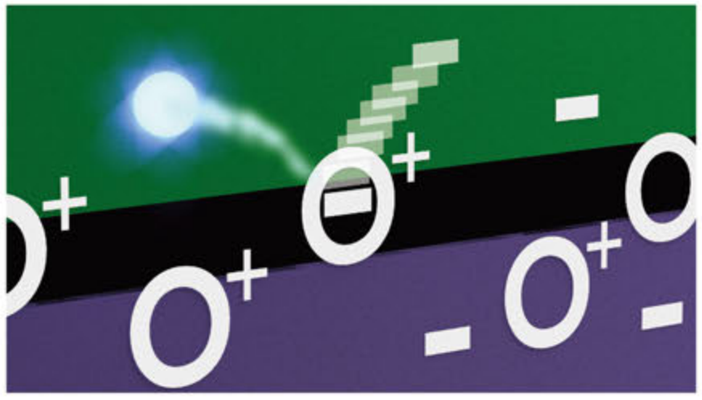
Current is applied from top to bottom - the positive holes moves toward the negative pole of current, electrons move toward the positive pole.





3

As an electron (at a higher energy state) passes a hole, it falls into it (lower energy state). The release of energy emits a photon of bluish color.



Watch a Video

www.youtube.com/watch?v=BH9U973H8w

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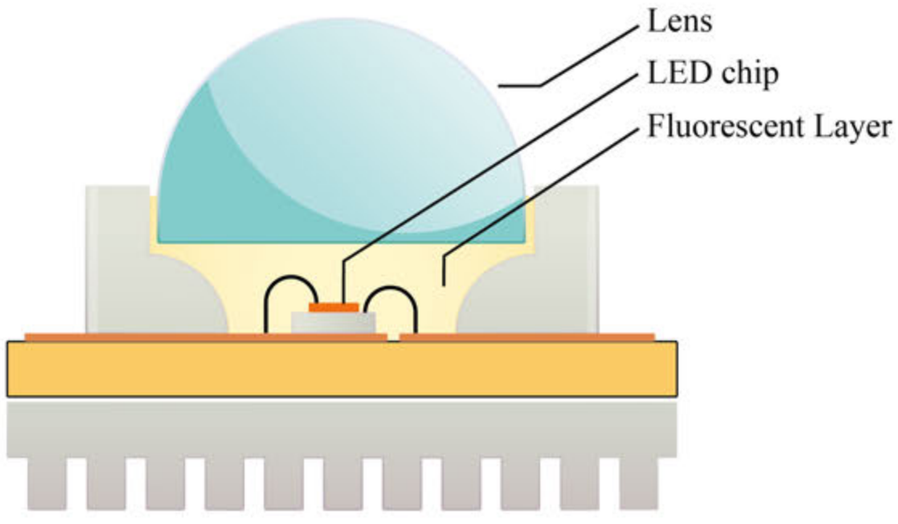
Fluorescent Yellow

Blue + Yellow = White

Fluorescent Yellow

Different materials used for the semiconductor will produce different wavelengths of light - however, if LEDs use AsGaAl, the resulting light will be bluish, which would not fare well as a white light. So, on top of this type of semiconductor you will find a yellow film. This film is made from a Yellow Fluorescent Powder - but don't think of it as just a filter - it makes light by itself. If you remember how Fluorescent Lights work - they use UV light to make light. It's the similar process with LEDs.

1. The blue light, emitted from the semiconductor, excites the electrons in the Fluorescent film to a higher orbit. The electrons then return to their natural orbit, emitting a yellow light.
2. This yellow light mixes with the blue light (which still is coming from the semiconductor) to make white light - this process is called "color mixing", which we will talk about later.



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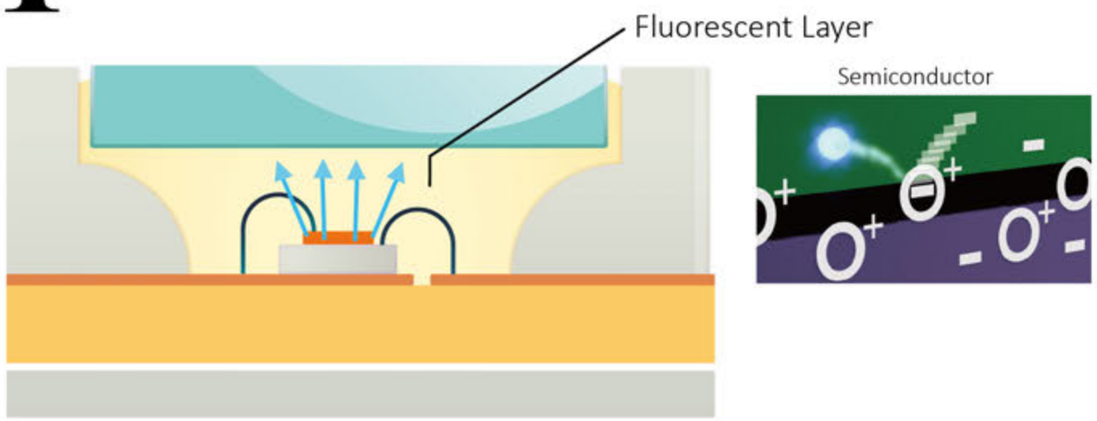
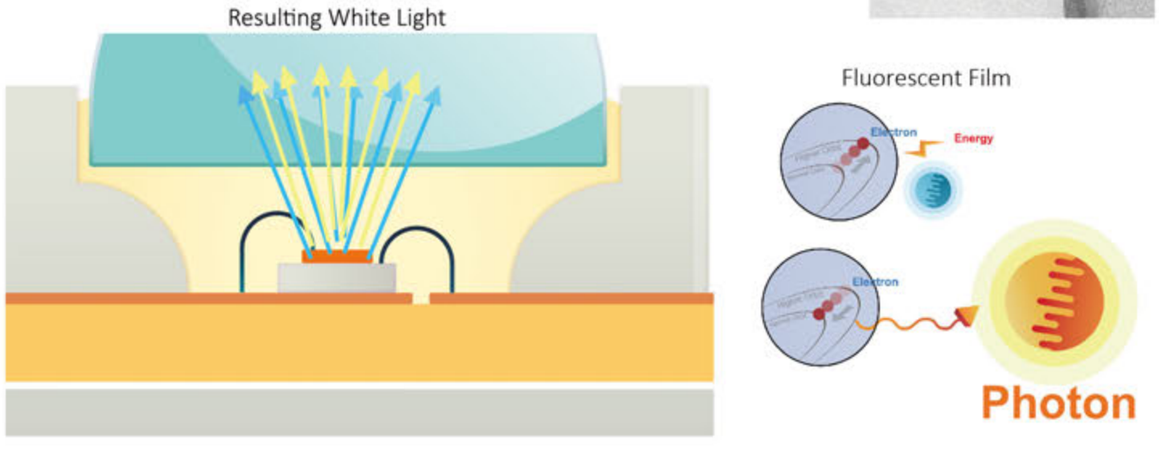
1 Energy causes the semiconductor electrons to emit blue light.



2 This blue light causes the electrons in the Fluorescent Layer to move to a higher orbit. When the Fluorescent electrons return to a normal orbit, a yellow photon (light) is emitted. The blue light is still transmitted through the film, but mixes with the yellow light to produce a white light (we'll talk more about mixing lights later).



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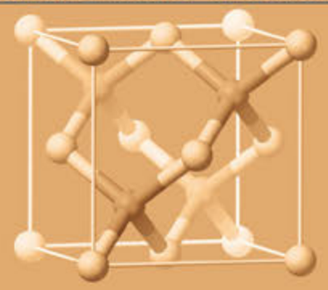
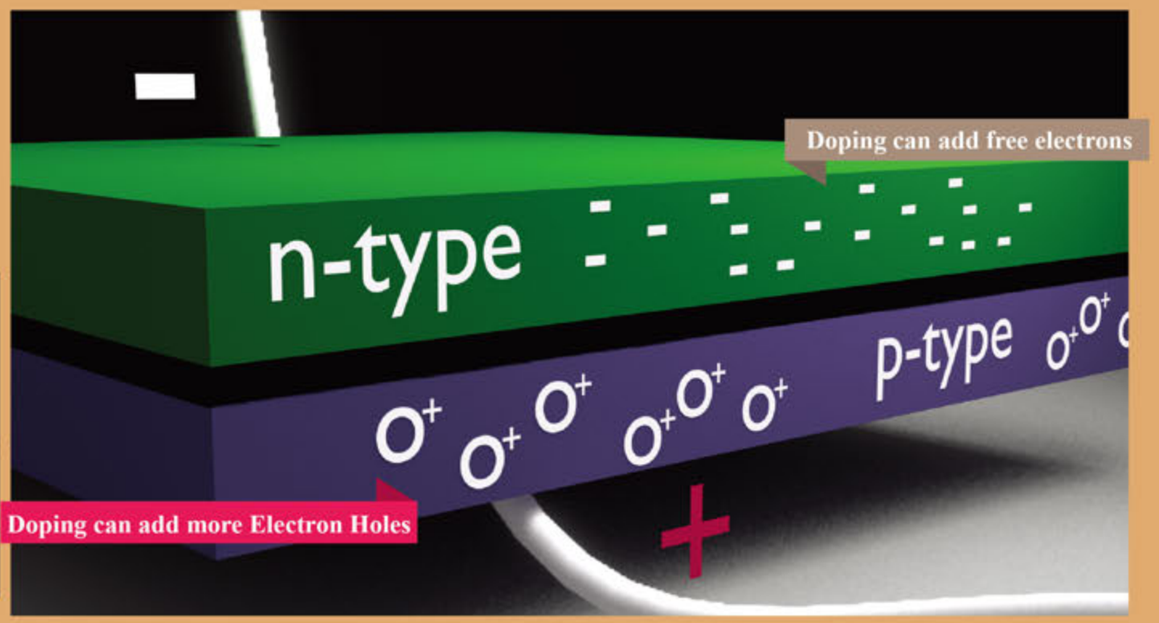
Why LEDs *use Semiconductors?*





A suitable material for LEDs

Early experiments (around 1955) found that low levels of infrared light could be detected when running an electrical current through Gallium Arsenide, a semiconductor material. Throughout the years, other materials have also been added (e.g. Nitrides, Aluminum) to further upgrade the viability of semiconductors as a practical LED light source.

Perfecting LEDs

Actually, pure AlGaAs is a poor conductor of electricity - however, you can add impurities, a process called "Doping". Doping adds more free electrons to the semiconductor material (n-type). You can also use Doping to create more electron holes in the material (p-type). This entire process of making semiconductors is not always an exact science, and the final product is not always predictable.

Why not use plastic?

Why not use wood, glass, cotton or plastic? It's because of the molecular structure. In some materials it is difficult to manipulate the electron because of the electron's attachment to its nucleus - if you can't move an electron, you can't create light from it.

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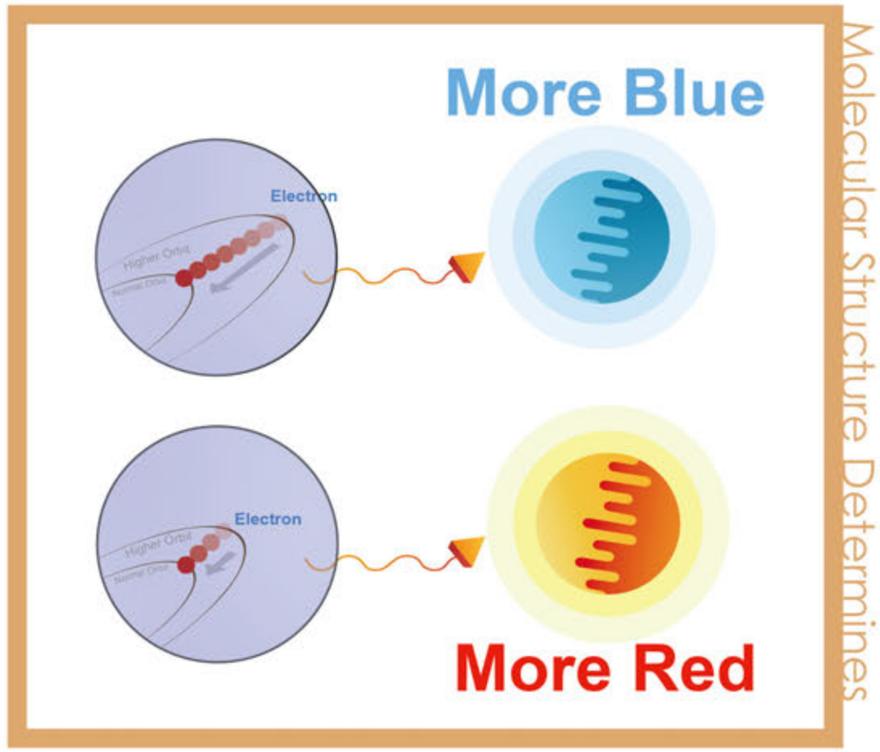

The Rubber Band Experiment - Pull a rubber band apart and let go of one end - notice the sound of the snap. Now pull a rubber band farther apart and let go, and notice the louder sound (ouch!). The farther apart means more energy released.

Why is the Semiconductor light blue?

LED semiconductors are known to produce a bluish light. The color of light from any atom depends on how far the electron falls from its higher energy state - the farther the fall, the more energy released and the higher the frequency of light (low frequency = more reds, higher frequencies = more blue). Aside from AlGaAs, other materials such as Indium, Phosphide, Nitrides, Silicon, are used because their molecular structure can produce other colors of light.

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How does light work?

Two famous experiments ...

Famous Experiment 1

Light

What is a Rainbow?

The first famous experiment was performed by Isaac Newton . Basically, he was able to simulate the phenomenon of rainbows and in doing so he made an important discovery.

Light is made of many different colors.

Newton pointed a light beam at a prism. The light, as it went through it, bent or refracted and separated the light into different colors. It basically proved that light is made up of many colors. In a rainbow, the clear rain droplets act as small prisms, also dispersing light into different colors.

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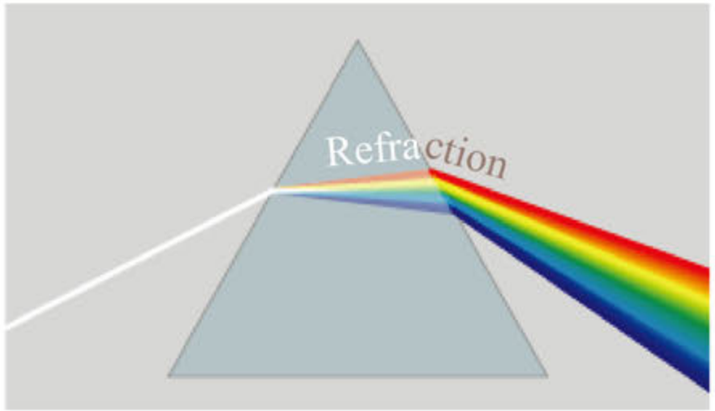

Why does light bend, as it passes through a prism? Think of refraction as a car entering water at an angle.

The right tire hits the water first while the left keeps going at the same speed. The angle of the car begins to turn or "bend".

It's Like

Refraction or bending of light occurs when light enters another medium and slows down. The light disperses (separates) because of the different wave frequencies of color bend at different angles (we will talk about light waves later).

Light

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Famous Experiment 2

Is Light particles or waves?

Early researchers were fairly certain that light was made of particles, because of the way that light bounces off of things like walls or even mirrors - like a ball.

However, a famous experiment called the Double-Slit Experiment was performed by Thomas Young in the early 1800s. It proved that ...

Light also behaves like waves.

Young understood how water waves worked. Let's look at the stones-in-a-pond example.

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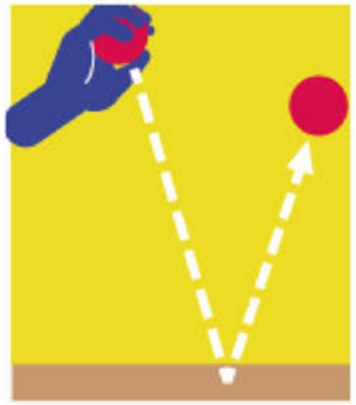

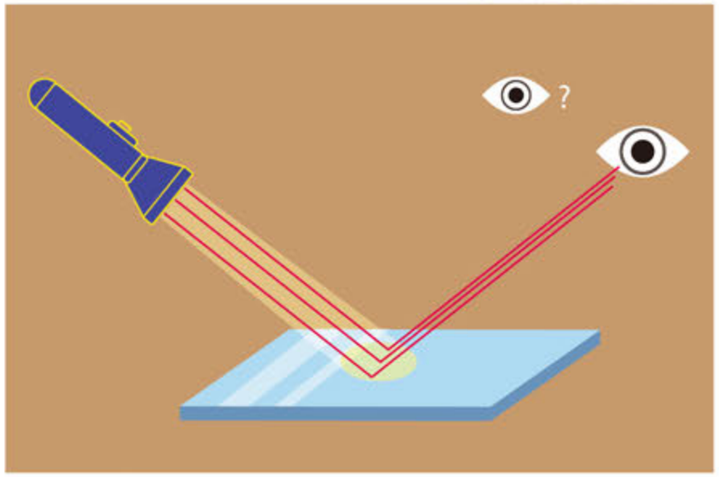

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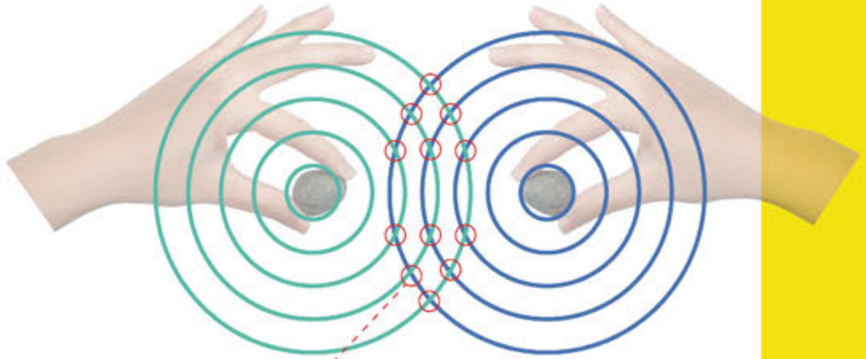
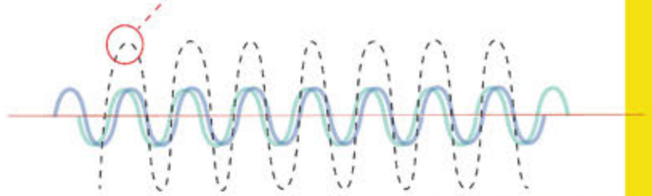
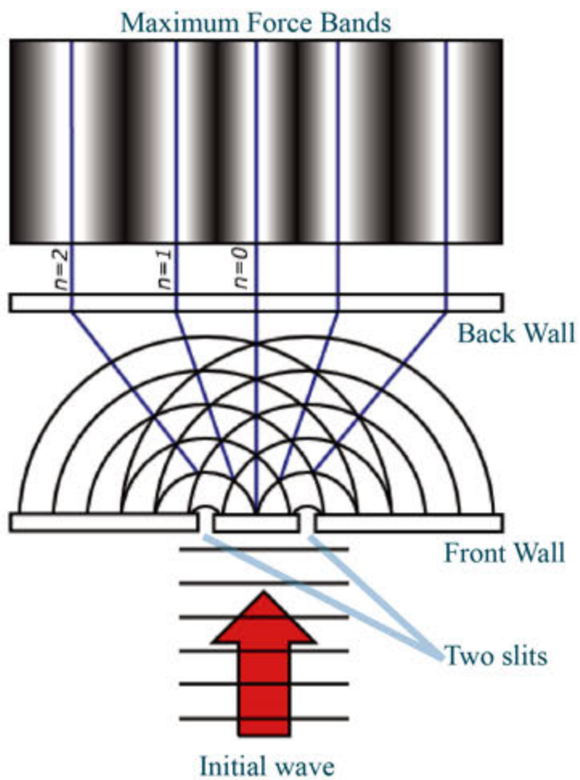


When you drop two stones (at a distance) in a pond of water, two rings of waves emanate from the center of both drop-points. When two wave peaks meet (red circles), the resulting wave peak is a bigger wave equal to the two wave peaks added together. The interesting part is that when the 2 waves pass each other, they go back to their original form.



In a more controlled two-slit experiment, Young sent an initial water wave through 2 slits on a front wall. Two separate waves were created at each slit opening. They interacted with each other and eventually hit another back wall. When the waves interacted they created super-sized wave peaks where they intersected - these high wave peaks impacted the back wall at the same place creating bands of force with each band representing the intersection of the two waves. This is how water waves work.



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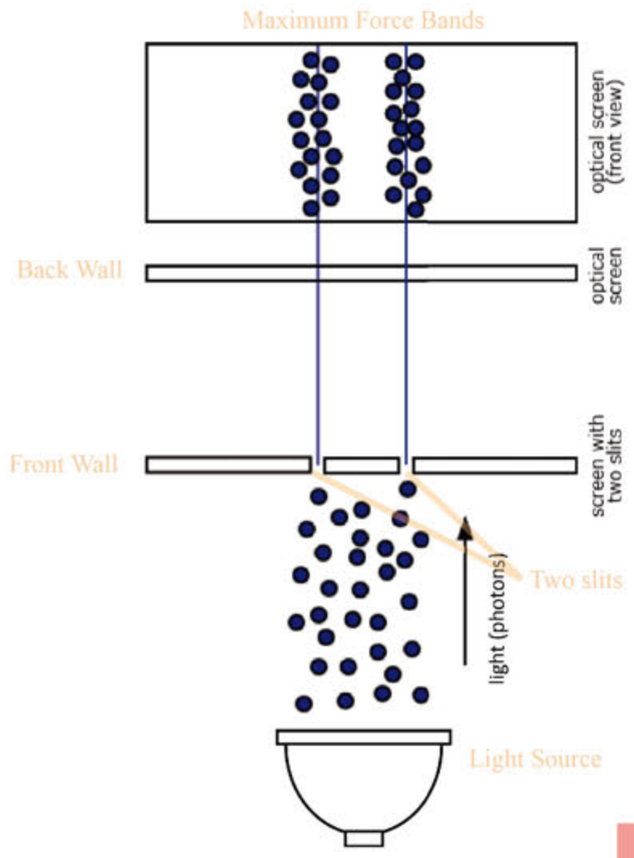
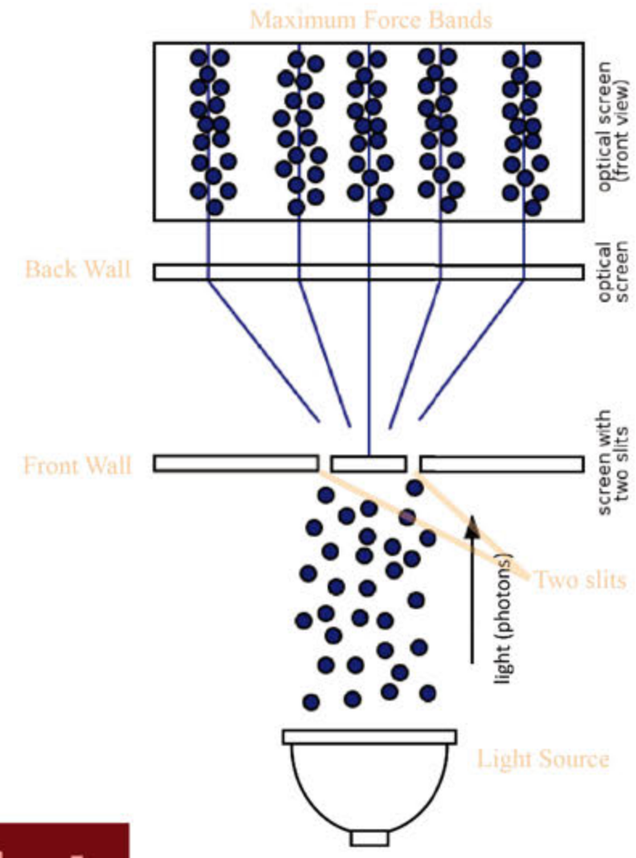
What We Expected & Got

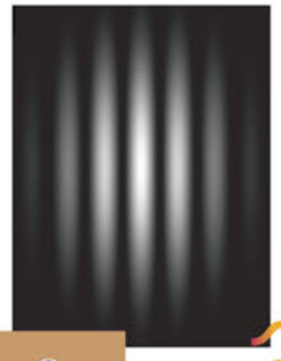


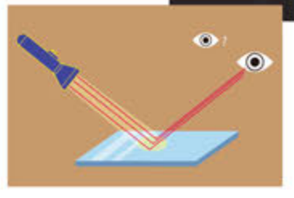
Let's try the same idea using light. Since we think that light is particles, we can expect the photon particles to hit the back wall with only two bands (as shown above).

Watch a Video

http://www.youtube.com/watch?v=DfPeprQ7oGc







However, when Young tried this experiment, to his surprise, he saw the same wave banding against the wall - light behaves like water waves too! He couldn't actually see "waves" of light, however it was the result that was convincing. So light behaves both as particles and waves!

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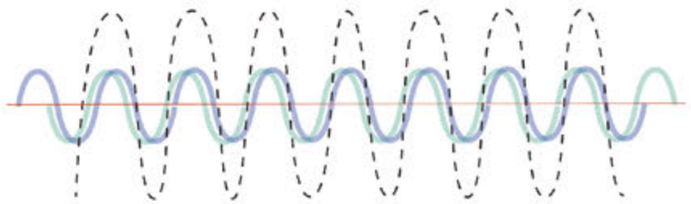
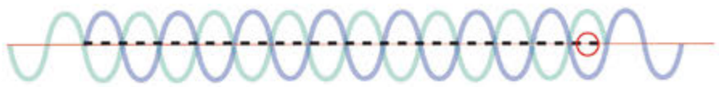
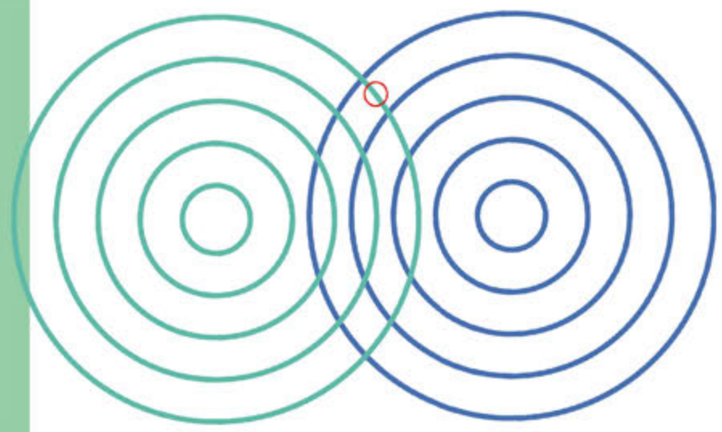
Wave behavior



Super-sized waves - 2 peaks meet



Canceling waves - 1 peak meets 1 trough



Remember that when two wave peaks meet, they make a super-sized wave? Another phenomena occurs when a peak passes over a trough - they cancel each other out - and when they pass each other, they revert back to their original forms.

The basic idea is that several waves can exist at the same time and place, change each other, while still being distinct.

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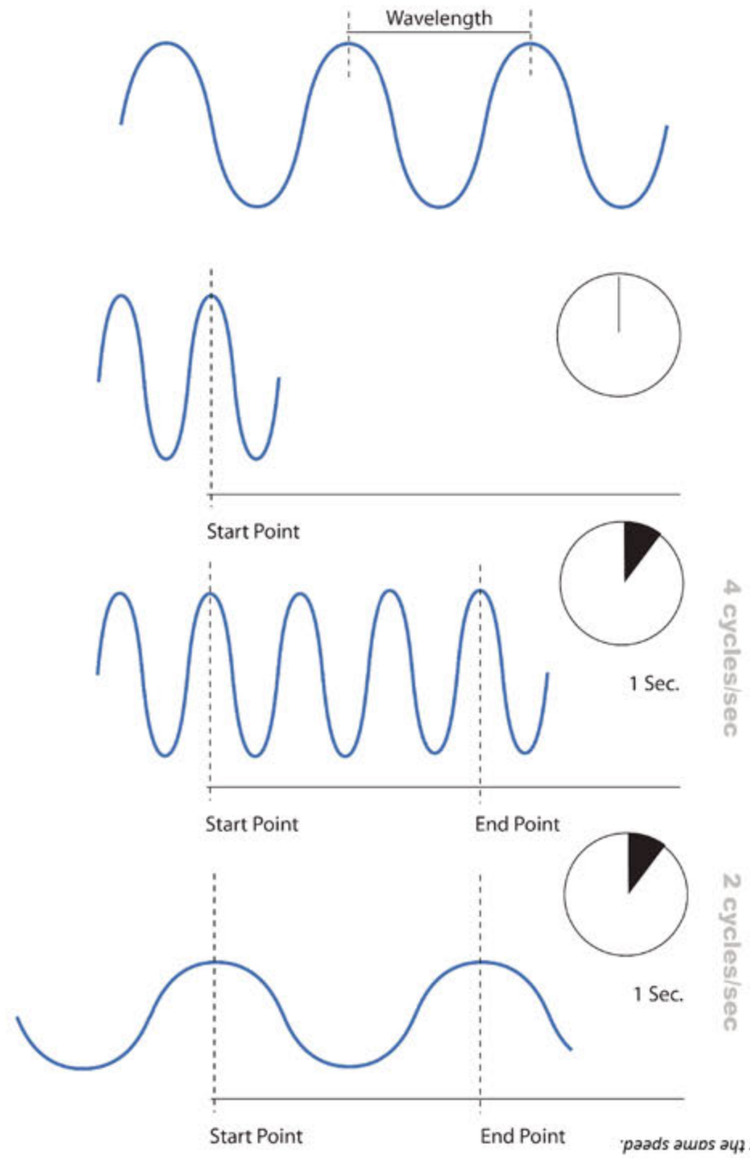
"Two waves can exist in the same place, same time and still be distinct"



In our pond wave examples, both of the two waves were basically the same size. However, there are two other things that also make waves different, which are frequency and wavelength. Wavelength is the distance from one peak to the next.

Frequency is the number of peaks that pass a fixed point (Start Point) in a fixed amount of time. In the first example, 4 peaks travel past a fixed point in one second - the frequency is 4 cycles /sec.

The second example has a frequency of 2 cycles per second. Which wave travels faster?

All light, no matter the frequency, travels at the same speed.

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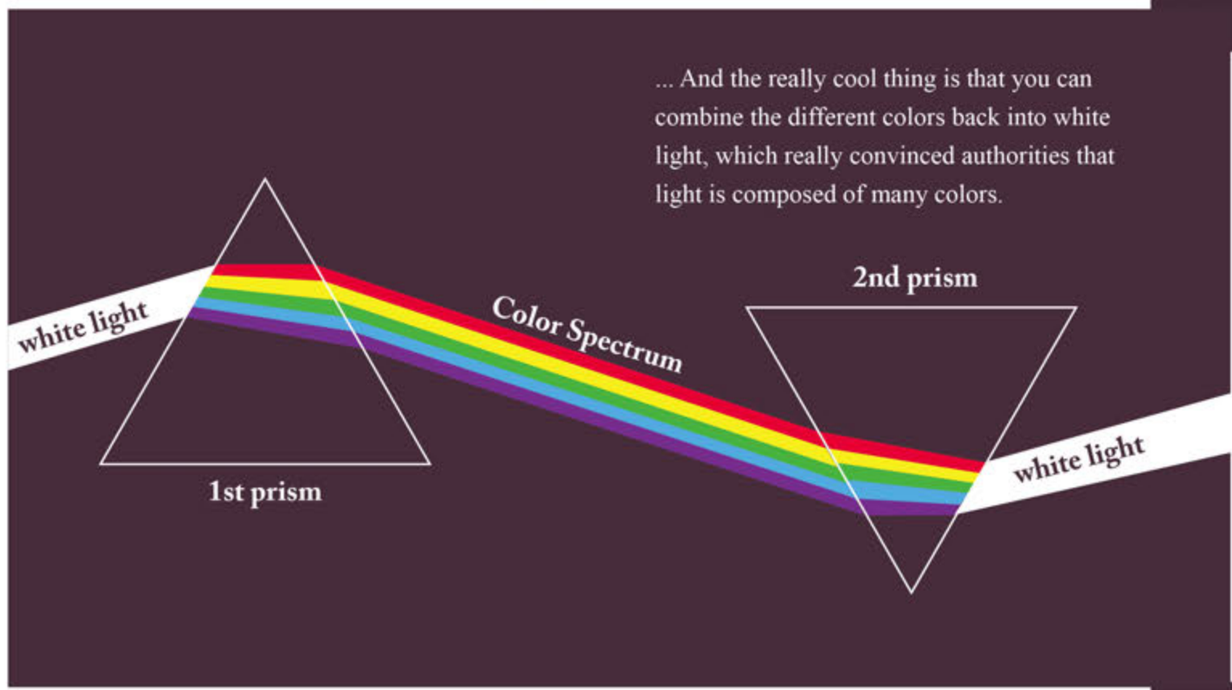
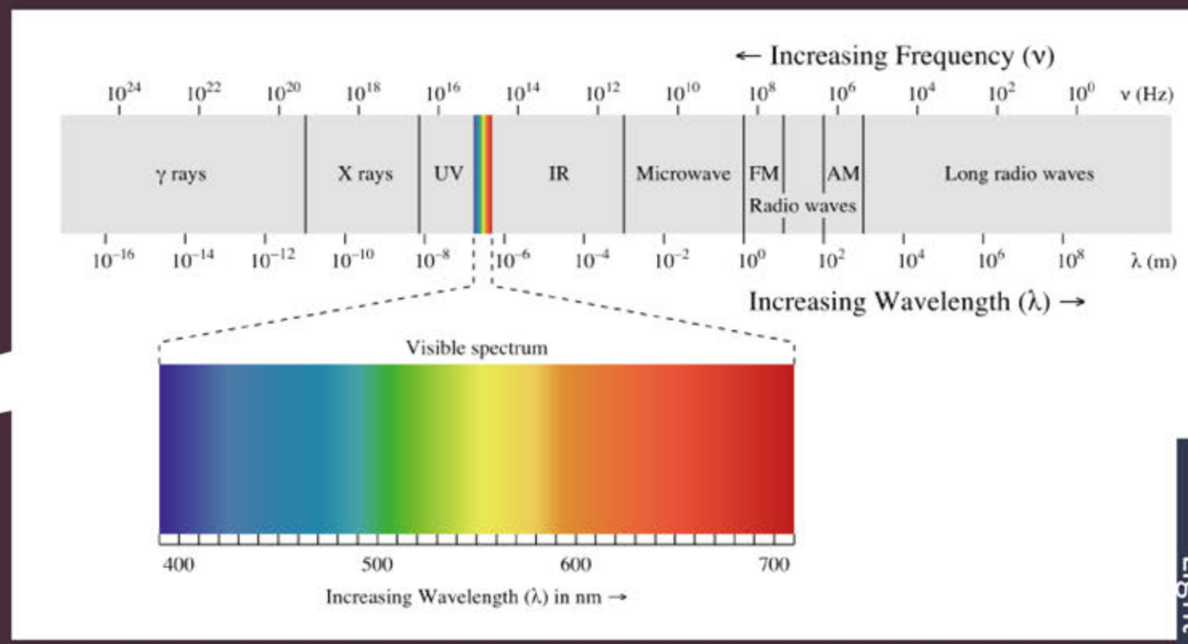
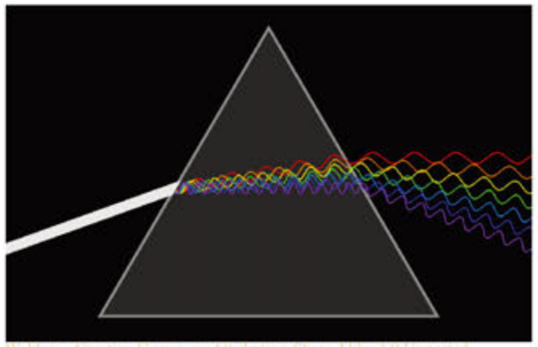




So now we know that light behaves like waves. Why does light disperse going through a prism? There must be something different for the different colored waves in white light. Can you guess?



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Frequency and wavelength.

Each color inside white light has a different frequency and wavelength and this is what causes each to bend slightly differently.

Blue light slows down more than red light and will therefore bend more than red light. Since light behaves like waves, several colors can exist at one time in one beam of light and still maintain a distinctive wave shape.

Light is considered electromagnetic radiation, which is a general term that includes all visible and invisible sources of electromagnetic waves, ranging from UV light, x-rays, visible waves, infrared to radio waves. As you see above, the Visible Light is only a very small portion of that.

This much we know - all forms of electromagnetic radiation carries energy.

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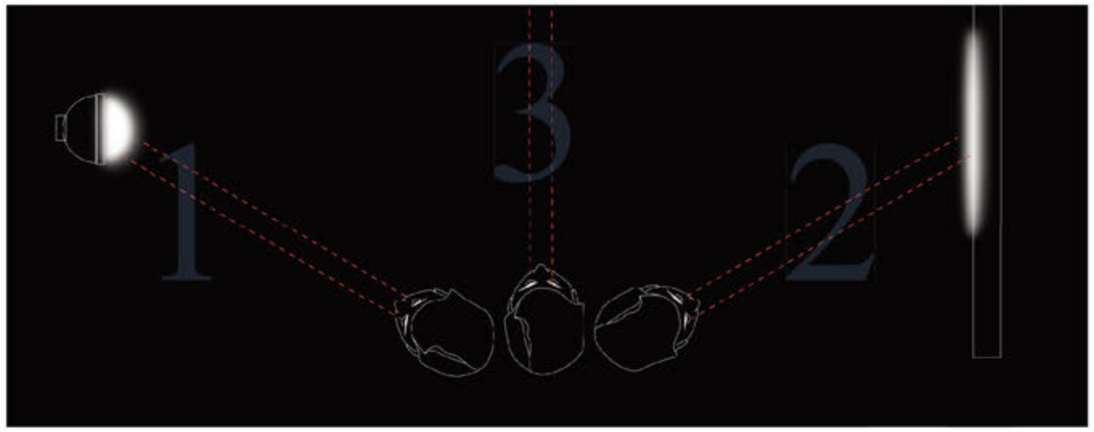
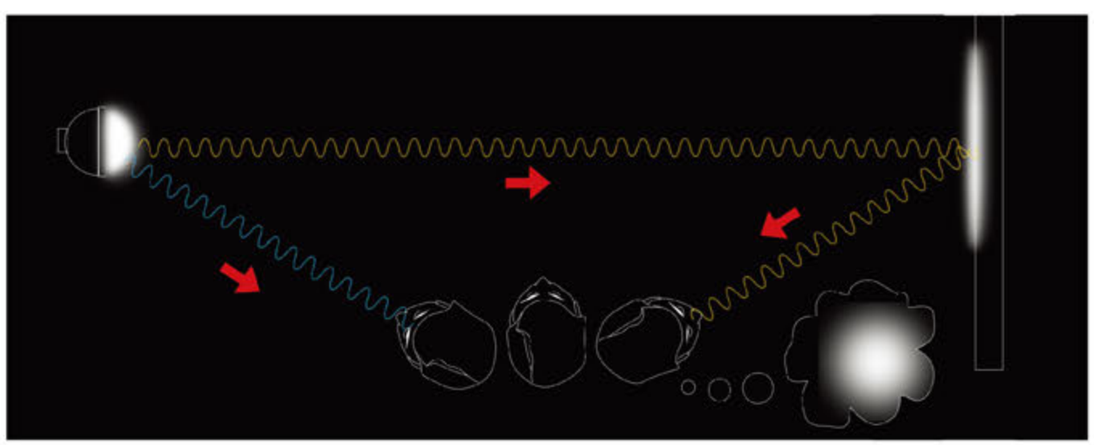
See Light or Sense Light?

For Your Eyes Only

You are standing in a dark room. There is a flashlight on the left pointing to a wall on your right.

1. I can see light if I look left, directly into it.
2. I can see light if I look right, directly at the wall.
3. However, if I look straight ahead, I cannot see the light traveling in front of me. Why not?





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You don't really "see" light - because light is invisible.

You sense light when it hits your eye as waves of energy and it's only then that it stimulates your brain to make a picture of what is in front of you, very much like a camera.

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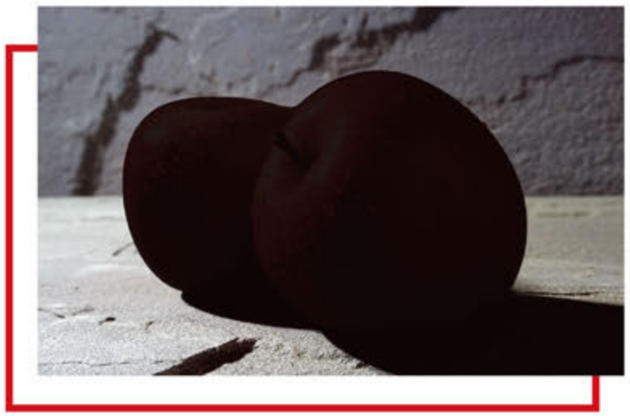
So what is color?

Nothing "has" Color



Let's continue with Sir Isaac Newton's exploration into light and color. As we discovered, light from the Sun is a composite of different colors.

Newton also established that the colors that we see on objects (e.g. apples) are not attached to those objects - the colors come from an original light source. In other words, nothing inherently has color - just turn off the light and you will "see".

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The red that you see in the apples come from the original light source, the sun, which reflects off the apple and reaches our eyes.

What happened to blues, greens, yellows?

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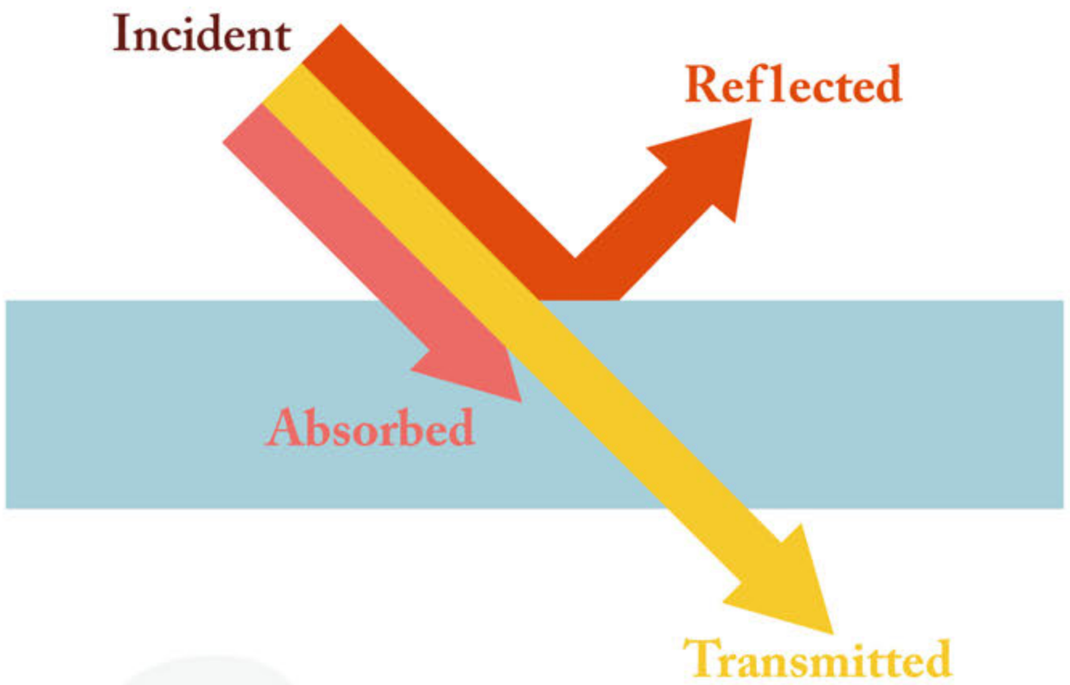
Reflection, Absorption, Transmission *Dance of Light*



When light comes from a source and hits an object, three things can happen:

Reflection is when the light (e.g. red light) reflects off a surface. A white surface reflects all light.

Absorption - This is what happened to the other colors in the apple example on the previous page. The blues, yellows, greens were absorbed by the apple! The absorbed energy turned to heat in the apple. A black surface absorbs all light and this is why black is referred to as the absence of light.

Transmission - This is what a prism does, it lets the light go through (with a little refraction/bending).

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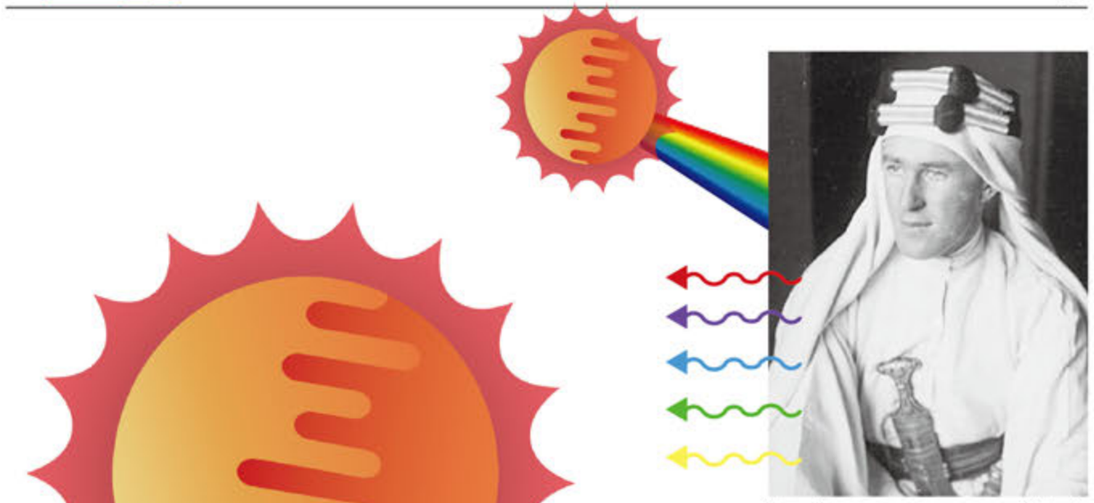
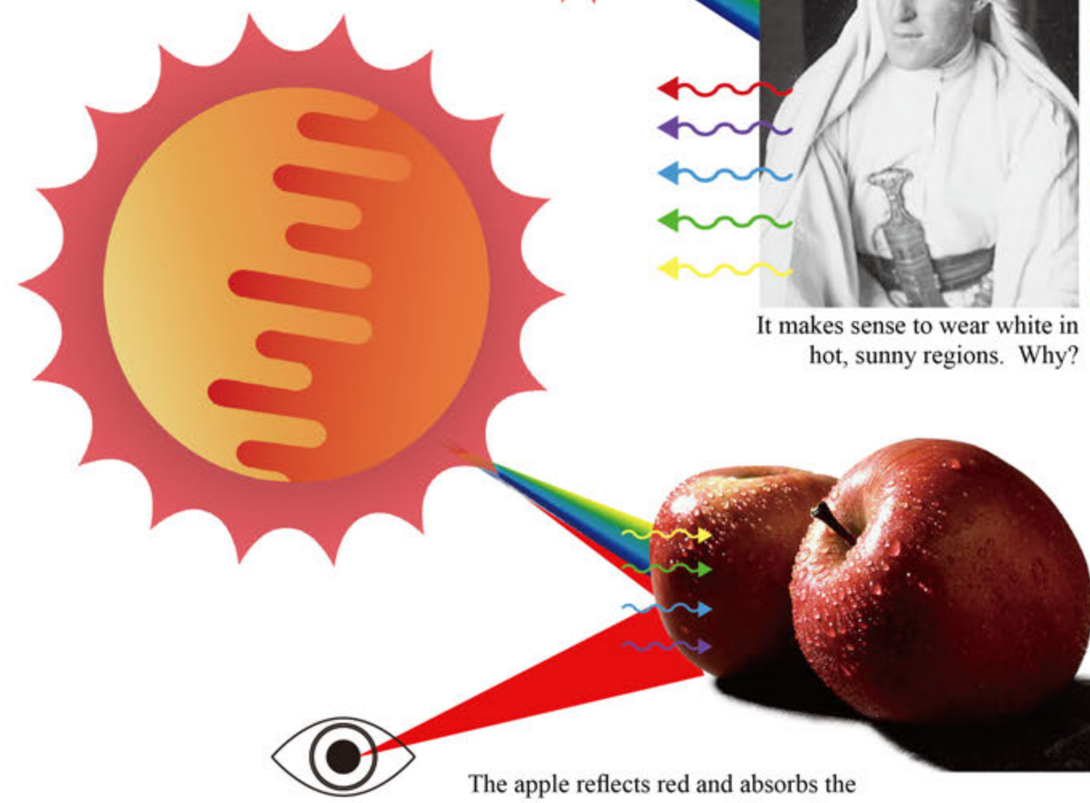


It makes sense to wear white in hot, sunny regions. Why?

TE Lawrence - Lawrence of Arabia



The apple reflects red and absorbs the rest of the colors.

Black absorbs all light and makes the cat warm.

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Color Wheel-Mixing Colors

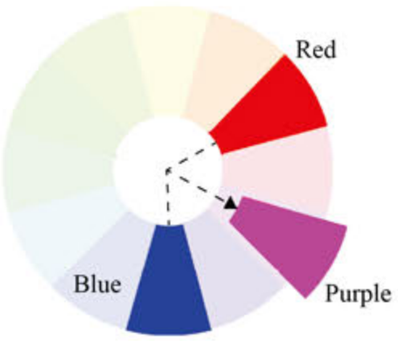
So, we know that white light is made up of different colors as Newton discovered. He also conceptualized the first color wheel. This color wheel has evolved over time and has come to show us how colors interact and mix with each other to form new colors.

The concept of primary colors was derived from the color wheel, identifying a few basic colors that could make up all of the other colors. For computers, they use red, blue and green. From these 3 colors you can make all of the colors that you can see on your screen. All of the colors in the RGB color wheel can be made with just those 3 colors. Red + blue make the Secondary color purple. Secondary + Primary colors make Tertiary colors and so on. Red + green + blue make white (in the middle). Also opposite colors such as blue + yellow also can make white (sound familiar? hint LED light + Fluorescent Light).

Good Readings

www.colormatters.com

RGB color wheel



blue+red=purple (magenta)

Primary Colors
red+green+blue=white

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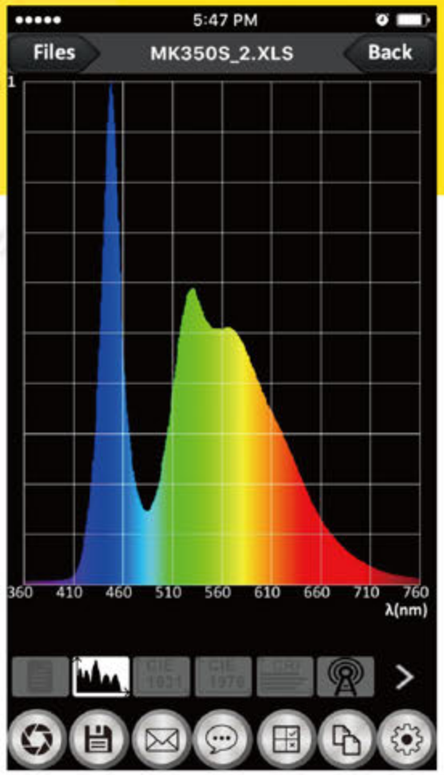
OK, so we can mix two or three colors of equal amounts to get a resulting color. The diagram on the right is another way of showing a mixture of colors - it is from a white light source. However, light is not just two or three separate colors, but a continuum of colors all connected together into what we call a spectrum (like a rainbow). There is another element and that is the amount of a certain wavelength or the intensity or brightness (y-axis). Notice that there is a green and an orange spike - this shows that the orange and green waves coming from this light are brighter (more intense) than the other colors. This type of diagram is called a color spectrum.

Opposite colors make white
(blue-yellow)



TELL ME MORE

Additive vs. Subtractive

We use these two terms to describe how to mix colors. The additive method is used with light - you add different colored lights together to make your desired color. Subtractive method is used with surfaces where you start with a light and use a surface to absorb (subtract) from the light and reflect the remaining colors to form the new color. RGB is additive and CMYK is subtractive.

Spectrum - a continuum of colors, like the rainbow

Spectral Colors - all the colors visible to humans

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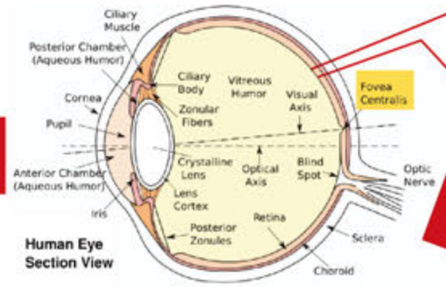
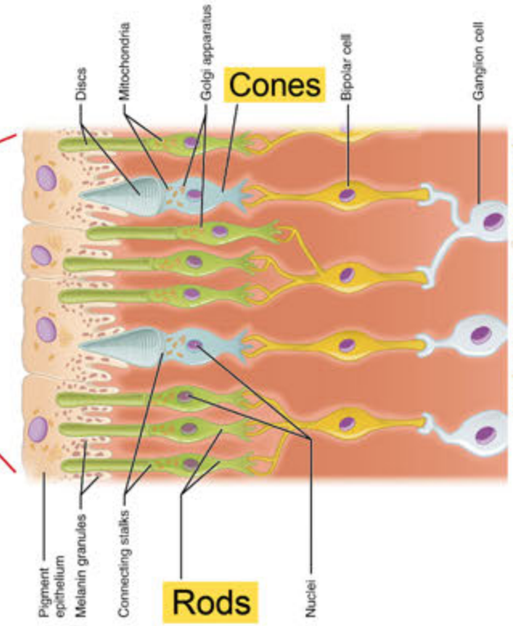
Rods & Cones

Our colors are inherently a human experience





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Patrick J. Lynch, Medical Illustrator; C. Carl Jaffe MD - CC-BY-2.5 Generic

OpenStax College - CC-BY-3.0 Unported

Color

As we mentioned, light waves can enter our eyes. In the back of our eye is the retina - the retina has photo-receptor cells (cells that can receive and act on light waves) - These photo-receptors are called

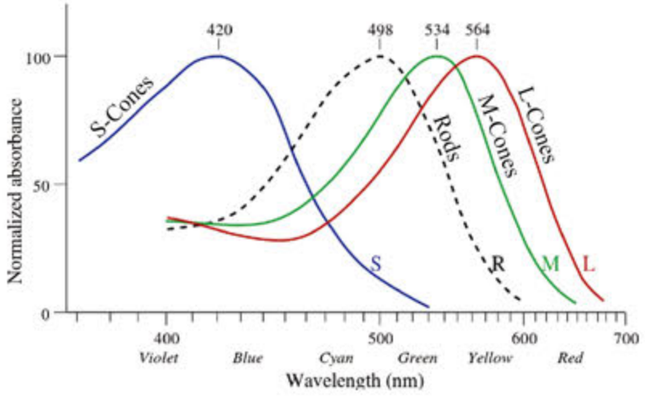
Rods (night) - Scotopic Vision
Cones (day) - Photopic Vision

These Rods and Cones process light and send impulses through the Optic Nerve to our brain, which form an image IN OUR MINDS.

The Rods are used in low light conditions and do not visualize colors well. The Cones however, are used in sunlight or lighted conditions and can process colors more effectively. Cones are mostly concentrated in the Fovea, a small depression in the Retina.

There are 3 types of cones that were first thought to process red, green and blue wavelengths and mix them together to form all colors, conveniently just like our RGB color wheel - but that was too good to be true. A more apt and recent naming convention is S, M, L cones because each cone processes a range of Small, Medium and Large wavelengths - however, they are sometimes still habitually referred to as red, blue and green cones.

These cones actually overlap each other when processing color from light (see below). It's even more complicated the further down the processing you go, as we shall see.

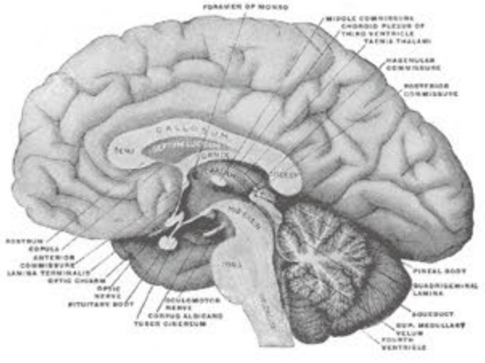


Optic Nerve

Optic Nerve

Watch a Video

http://www.youtube.com/watch?v=V73k_0KuUJo
http://www.youtube.com/watch?v=UXIfzc1UH-g



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Color

TELL ME MORE

Photometry is the science of measuring light

Spectrophotometry - measurement of flux and spectral distribution.

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Measuring Light

Superman Eyes

A light meter helps you see what you can't normally see with your own eyes.

Why measure light?

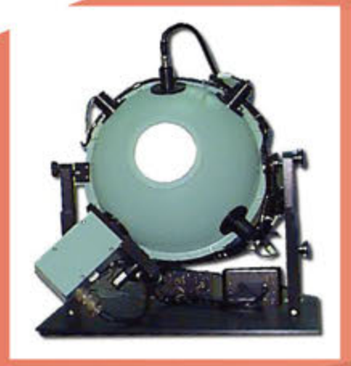
A light bulb's light quality can vary significantly and people are discovering that it can influence us emotionally, physically and even economically. Light affects the way we work, the way we feel and even the way we sleep and wake.

However, these aspects of light that affect our lives are not easily seen by the human eye and we need a measuring device to help us see things that we can't normally see.

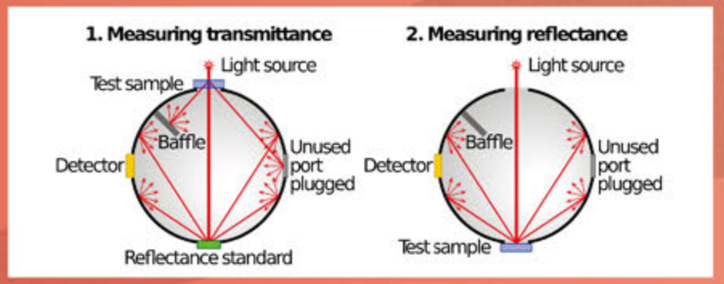
Also, as humans, our eyes are not all the same and the colors we see may be slightly different or even quite different than how others see them. We can use a light meter to help us agree on colors.

Traditional light measurement equipment is expensive, immobile, complicated and requires inordinate setup time including the manpower needed to run just one test on a single light source. The main part is called an Integrating Sphere and it is still the most sophisticated equipment for measuring light. The idea of the inner sphere is to provide a controlled environment for uniformly scattering light and accurately measuring the results.

The MK350 device is also a light measuring device. Although it admittedly cannot compare with the integrating sphere in terms of a controlled and pristine environment, the MK350 has shown remarkable light measurement accuracy in open space environments and it's practical uses and economic advantages make it nothing short a revolutionary advancement in light measurement devices.



By Electro Optical Indistries Uploaded by The Lamb of God at en.wikipedia - CC-BY-SA-3.0



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Using Temperature to measure light color?

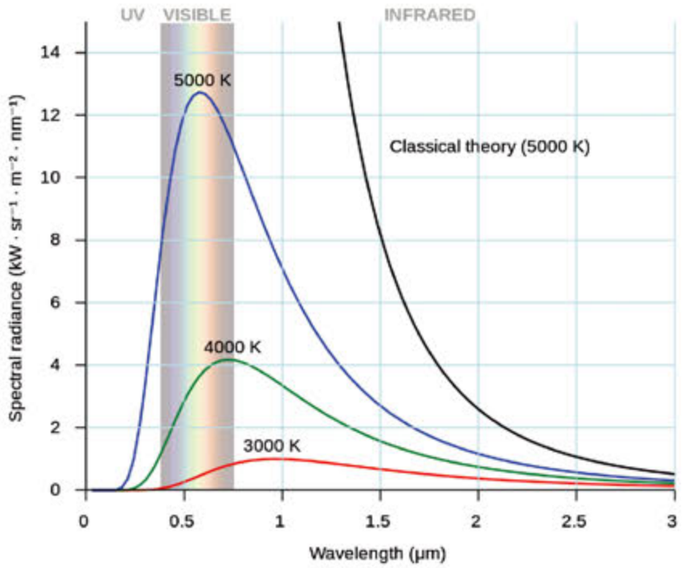
Color Temperatures and Black Body Radiators

You may find it strange that white light color can be specified by a temperature - a bulb may have a Color Temperature of 2700 Kelvins - but there is a close relationship between temperature and light.

When you heat up an object like an iron horseshoe, it begins to slowly glow red, and then turn yellow, and then white and finally blue. The cooler the temperature the more red; the hotter the temperature the more blue (opposite of what we might think). This relationship is important because it's a way to objectively measure color - this relationship was explained by Max Planck in his famous Planck's Law. An LED bulb's Color Temperature (CT) is 3000K, means that when you turn on the bulb, its light has the same color as an iron horseshoe (for example) heated to 3000K.

Of course, the amount of heat to make something glow red-yellow-blue-white will vary somewhat on the matter being used (e.g. horseshoe). So a theoretically, ideal matter was conceived called the Black Body - a perfect absorber, absorbing 100% of light and thus making it a perfect emitter of heat radiation. Nothing is really a perfect absorber, but many objects that radiate light using heat come close - the Sun, a candle, an incandescent light. Color Temperature is only applicable to lights and in lighting design it helps us to gauge how cool or warm we want our environment to look.

Generally, Color Temperatures (CT) around 5,300K are called cool colors (bluish white), while lower color temperatures around 3,300 K are called warm colors (yellow to red). It is said that people in hot tropical regions prefer buying bulbs with CT over 5,000K (to make it feel a like a cooler bluish environment), while people in cooler northern or southern regions prefer bulbs with CT below 3000K (warmer-reddish looking colors).



Warm Light
Around 3300K or below

Neutral Light
Around 3300K~5300K

Cool Light
Around 5300K or above

By "Hi-Res Images of Chemical Elements" Creative Commons Attribution 3.0 Unported

Incandescent Lights are based on heat as we learned and are natural Black Body Radiators and so Color Temperature can be specified quite accurately. CFLs and LEDs are based on Mercury Gas/Phosphor and Semiconductors and so the CT can only be approximated within a certain range - these ranges are called the Correlated Color Temperatures, which can be notoriously misleading (we'll explain why later).

How does a device measure light?

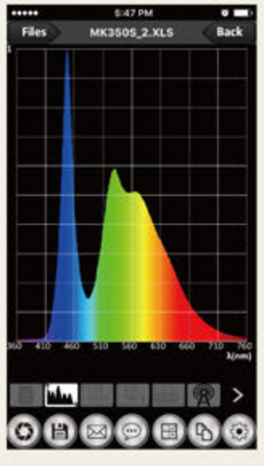
By the numbers.

How does a machine know what colors to display on a screen?

So, we've seen how to use temperature as a reference for measuring color. However, it's only a theoretical model (Black Body), used to measure white light and it is very imprecise with CFL and LED lighting. So there must be another way of measuring light.

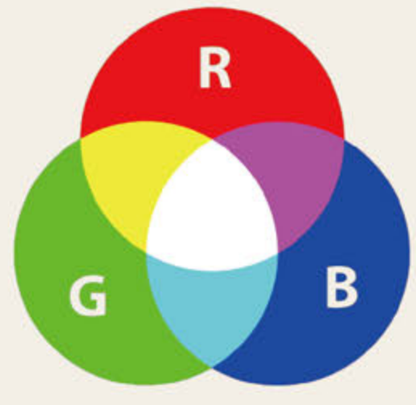
Let's take another look at "Color". Color, as we see it, is inherently a human experience - blue skies, red apples, green trees form as images in our brains. A device has no way to sense "blue", as much as it cannot sense "sadness", because "blue" and "sadness" are inherently human experiences.

Devices, however, can measure in numbers - take your scale for instance, which measures in kilograms or pounds. Light is the same - a light meter device can measure light by its numbers - i.e. wavelength, frequency and intensity. We can use these num bers to relate waves to our visual colors and an easy way to do this is to use the primary colors of red-blue-green, conveniently similar to our S, M and L cones. In other words, we can teach our device to use RGB to relate "our" colors to wavelengths.



Waves? What waves?

M.Minderhoud at nl.wikipedia - GFDL, CC-BY-SA 3.0 Unported



Yellow, what is yellow?

Measuring Ligh

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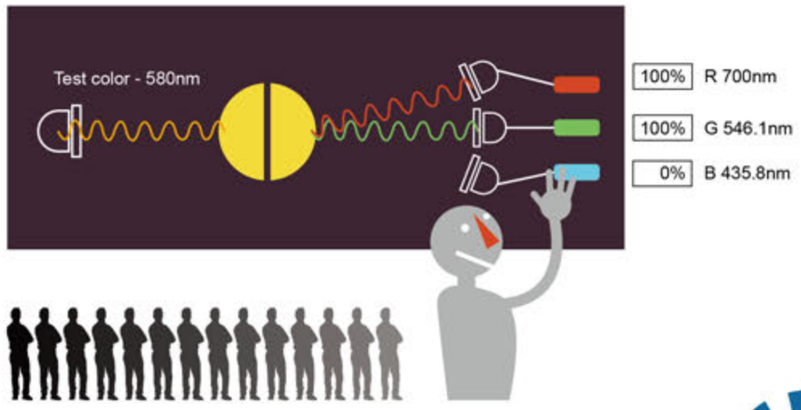
Matching wavelengths to colors *The Matching Function*

Step 1

First, we need to take a light with a certain wavelength, and then have a tester adjust intensity values of red, blue and green lights to match the test color to relate the wavelength to human color perception. This gives us 3 values (RGB) to represent each color wavelength that we want to test. However, since we all see colors a little differently, we need to include many testers, record their data and then take an average.



These tests were real experiments performed in 1926 by William David Wright and John Guild.

λ	r	g	b
380	0.0272	-0.0115	0.9843
385	0.0268	-0.0114	0.9846
390	0.0263	-0.0114	0.9851
395	0.0256	-0.0113	0.9857
400	0.0247	-0.0112	0.9865
405	0.0237	-0.0111	0.9874
410	0.0225	-0.0109	0.9884
415	0.0207	-0.0104	0.9897
420	0.0181	-0.0094	0.9913
425	0.0142	-0.0076	0.9934
430	0.0088	-0.0048	0.9960
435	0.0012	-0.0007	0.9995
440	-0.0084	0.0048	1.0036
445	[illegible]213	[illegible]	1.0093
[illegible]	[illegible]	[illegible]	[illegible]172

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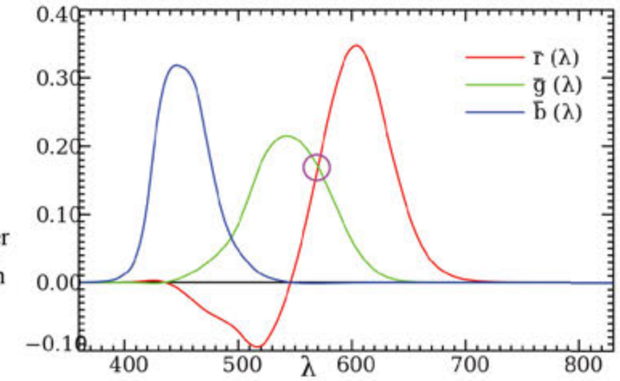
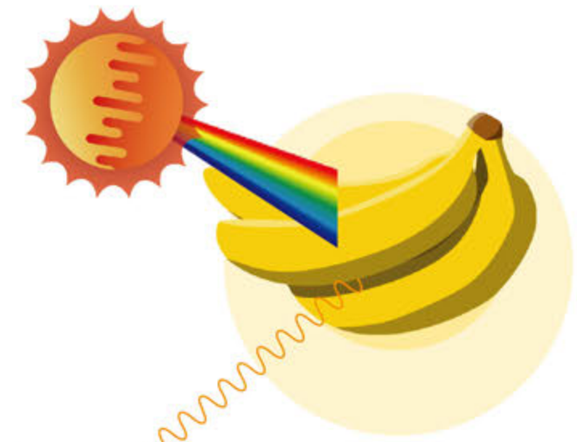
Step 2

Take the data, which is in sets of 3 RGB values per wavelength and graph it on a 2D plane - this graph makes the connection between wavelengths and RGB values that humans perceive. For a Wavelength of 580 (yellow), we see that equal parts of Red and Green are used (circle on graph).



Step 3

Oh, that's yellow!



This device can use the matching data we just created. When it encounters a wavelength of 580 nm, it can adjust its RGB screen lights and display the proper color on its screen.

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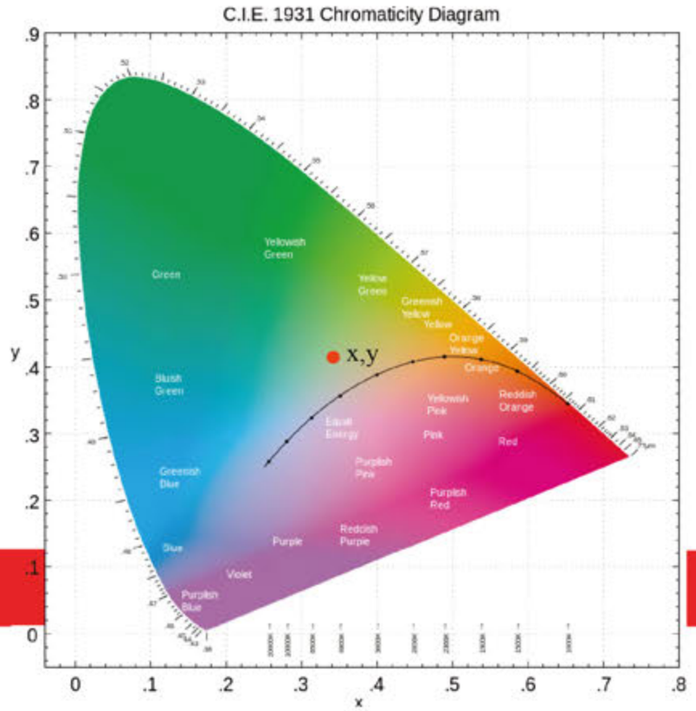
The Chromaticity Diagram

Identifying, Specifying and Comparing Light

OK, we've taught our light meter to recognize colors. Now, it would be nice to be able to take a measurement of any light source and then identify it, specify it and perhaps compare it to other lights.

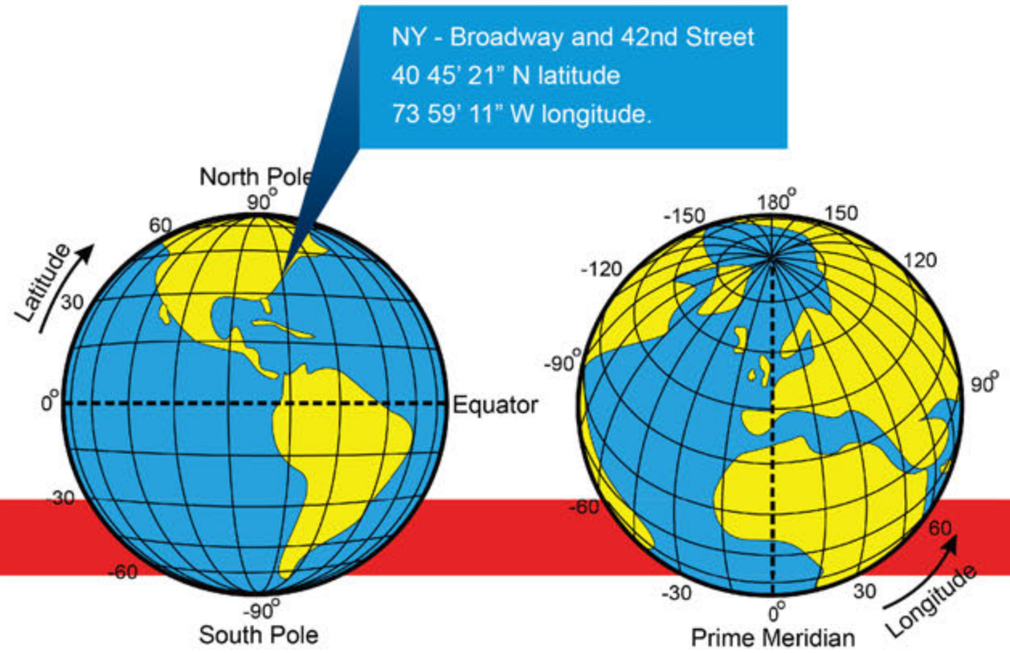
We do this with a color map called the Chromaticity Diagram (Chroma is the Greek word for color) and it' an important part of a light meter. It's like a map of our globe - if you know the Longitude and Latitude, you can identify any place on Earth. Similarly, if you know your x,y color coordinates, you can find where your light color lies compared to all the other colors we can see - and by the way, the colors contained within the map are all of the colors humans can visualize and this map is called Chromaticity Diagram.

Measuring your light source identifies where your light lies in the map of x,y coordinates.



Fuzzypeg at en.wikipedia, derived from Paulschou at en.wikipedia - CC-BY-SA-3.0

It's Like



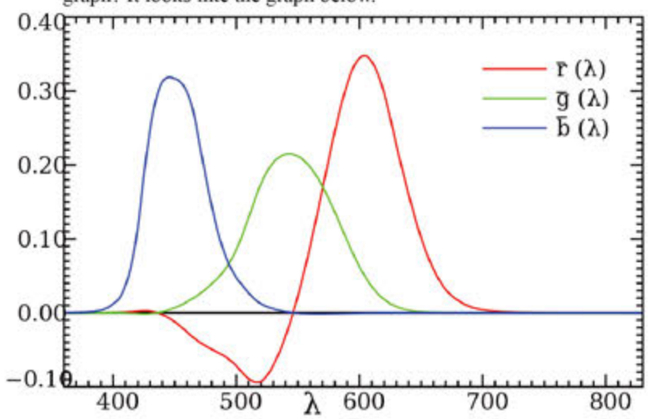
How the Chromaticity Diagram Came About

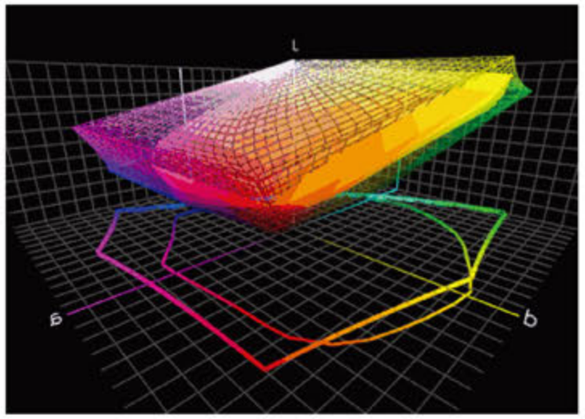
How do we come up with these x,y coordinates and the map? Well, it's a long story with lots of math, but we'll try to keep it simple. This Chromaticity Diagram was conceived in 1931 by the International Commission on Illumination or more commonly referred to by its French acronym CIE or the Commission Internationale de l'Eclairage.

It was designed to map the entire human visible spectrum - it gives us a standardized, easy, visual tool to specify, identify and compare colors. Do you remember our RGB test values from before? We plotted them on a 2D graph as shown (top right). Now what we want to do is put those same RGB values on a 3D graph. Each wavelength's RGB data were mapped as a point in 3D-Space which produced the diagram on the right, a beautiful but not very useful map. So the CIE folks did some fancy work to make a 2D map, from a 3D map.

λ	r	g	b
380	0.0272	-0.0115	0.9843
385	0.0268	-0.0114	0.9846
390	0.0263	-0.0114	0.9851
395	0.0256	-0.0113	0.9857
400	0.0247	-0.0112	0.9865
405	0.0237	-0.0111	0.9874
410	0.0225	-0.0109	0.9884
415	0.0207	-0.0104	0.9897
420	0.0181	-0.0094	0.9913
425	0.0142	-0.0076	0.9934
430	0.0088	-0.0048	0.9960
435	0.0012	-0.0007	0.9995
440	-0.0084	0.0048	1.0036
445	[illegible]	[illegible]	1.0093
[illegible]	[illegible]	[illegible]	[illegible]

Remember when the three RGB test values are plotted on a 2D graph? It looks like the graph below.





If you plotted all of the RGB test values onto a 3D graph, then you would get this. It's hard to use a 3D map for color identification because your color might lie in the middle.

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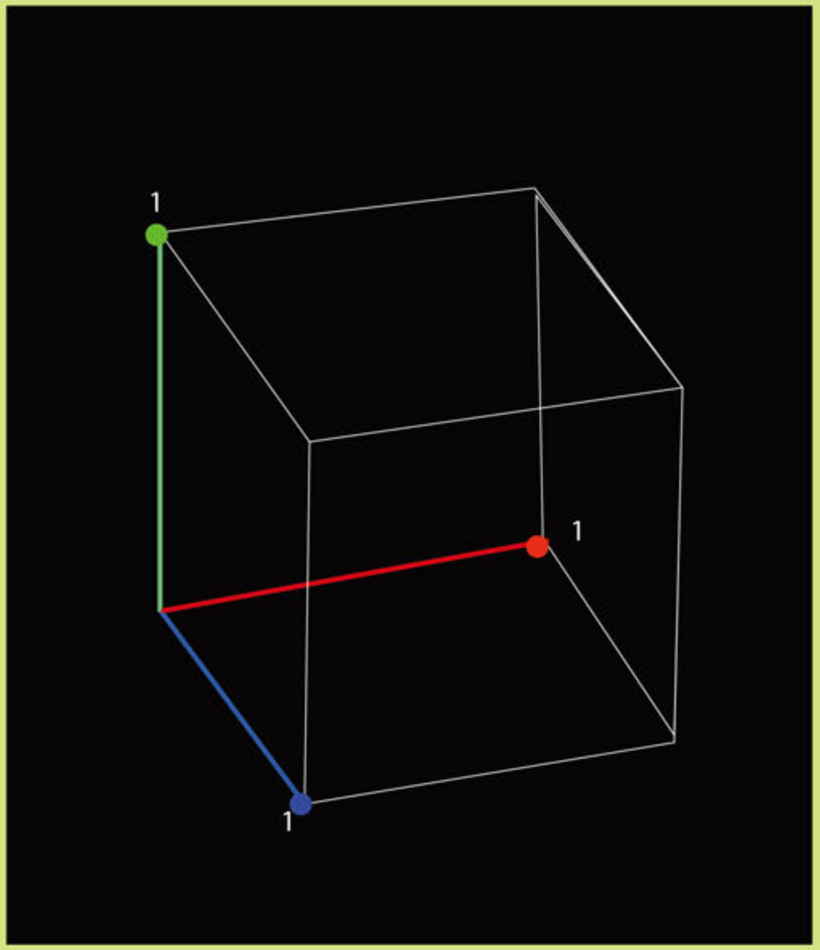
1

Let's first draw a 3D space. Each axis represents one of the primary colors of Red, Blue and Green. The ends of each axis represent the highest intensity from the each RGB test data set, which we will show as 1.



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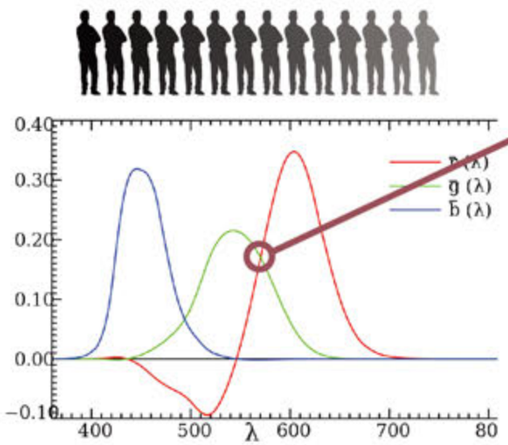
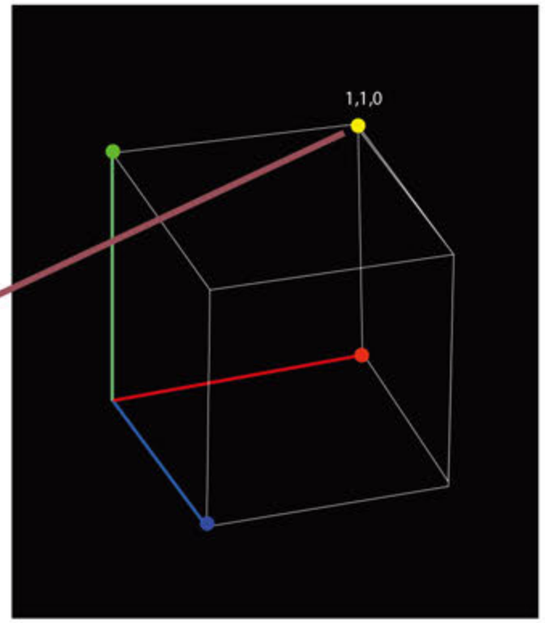
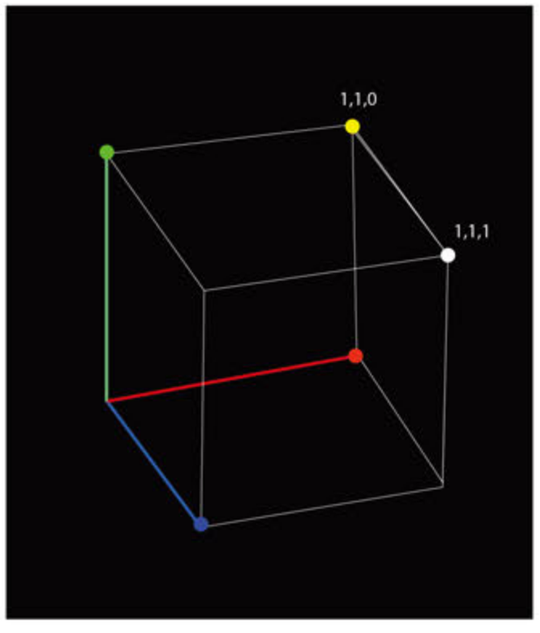
2

Now let's plot our yellow wavelength (580 nm), which is full red, full green and no blue (1,1,0)







3

Let's take our "White", which is a combination of 100% Red, 100% Green and 100% Blue and plot that. Imagine doing this for all our RGB points for each wavelength.

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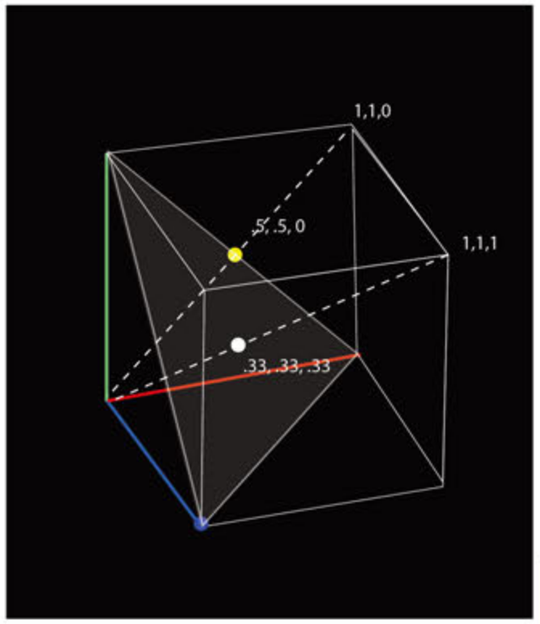
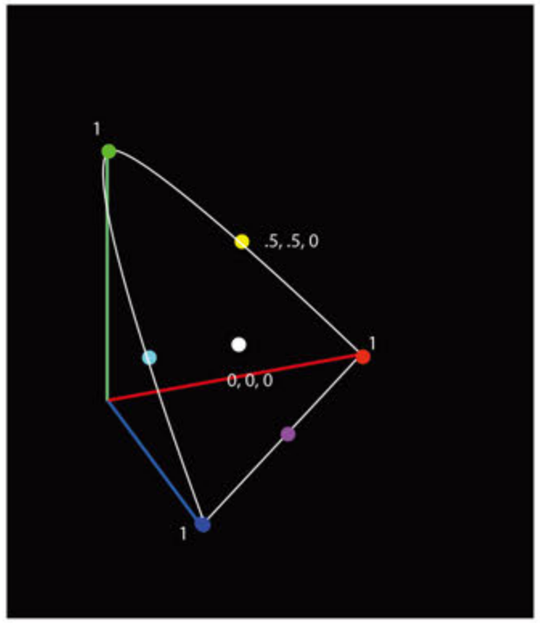
4

Next (this is the magical part), make a triangle by connecting 3 three points that each represent 100% intensity at each primary color (RGB) - this is a plane called the Unit Plane - if you take a single point on the plane and add up the three associated data values, they will always add up to 1. If you draw a line between each RGB point that we plotted (in step 3) and the origin (0,0,0), it intersects our Unit Plane and creates a new point. This point represents the same proportions as the original point and so it is essentially the same color.





5

Now imagine all the wavelength RGB points mapped to the Unit plane - what will you get? A horse-shaped Chromaticity Diagram!

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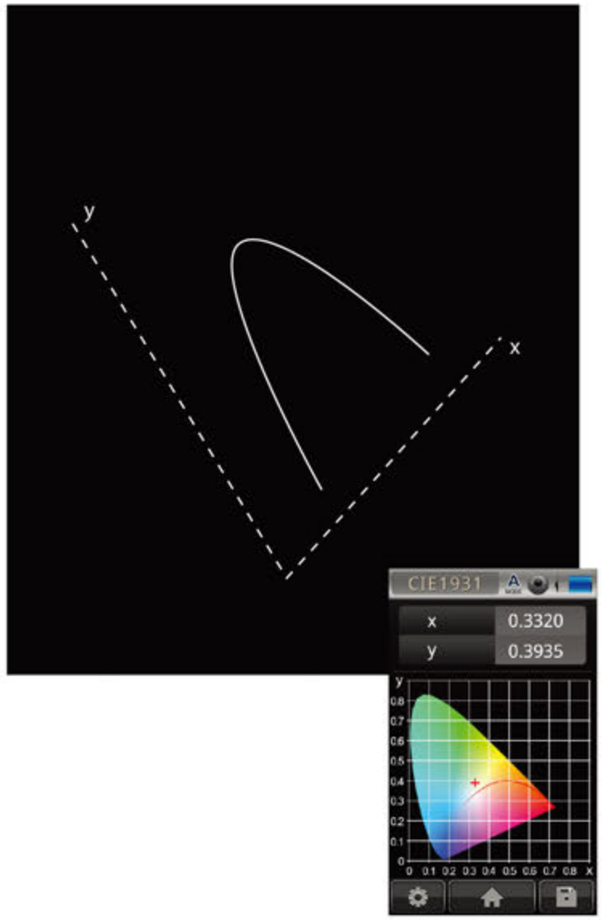
Measuring Ligh

6 Since our Unit Plane is a 2D plane, we can now assign it an x,y axis. This is where the horse-shoe shaped CIE Chromaticity Diagram comes from.



Take Home

1. The horseshoe shaped diagram is a "map" all of the colors that human beings can visualize.
2. If you measure a light source, it can give you an x,y coordinate which tells you where in our map your light color resides.
3. The x,y coordinates are derived from data from the original 1926 RGB Human Experiments. They represent RGB data values that have been mathematically condensed from 3D to a 2D plane because it is much easier to work with.

Watch a Video

http://www.youtube.com/watch?v=82ItpxqPP4I

Play

http://www.biyee.net/color-science/cie-chromaticity-diagram/

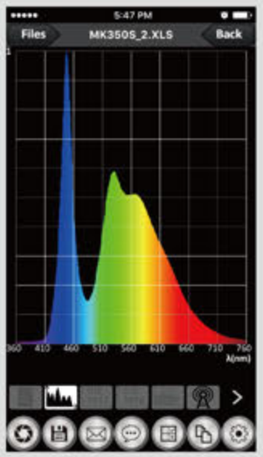
NOTE

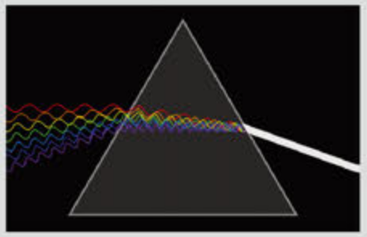
The previous explanation is a conceptual description of the creation of the Chromaticity Diagram. For additional information see Appendix I.

Wavelength Intensity

Now we know that a device like an MK350 can capture a single light source and separate it into its different component wavelengths. Each component wavelength inside the light could have different quantities of "intensity", which influence the color. This is represented by the Color Spectrum (below-left) also provided by the MK350 devices. It shows the different wavelengths and their respective intensities. In this example, we can see that reddish colors at about 610 nm are dominant and will cause the white light to appear perhaps reddish - however, you must really take all the colors and mix them together to really know if your light is more reddish, greenish or bluish - and that is what the x,y point on the Chromaticity Diagram can tell you. Chromaticity Diagrams show you color; the Color Spectrum shows you the intensities of all the wavelengths that, when mixed together, make up that color.

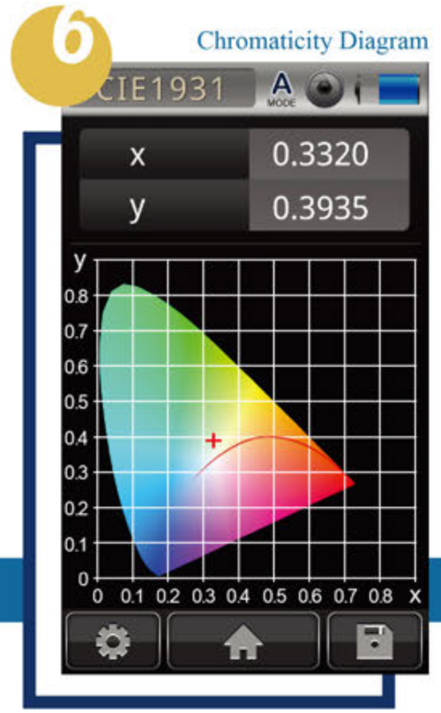
Color Spectrum





How does a light meter determine x,y?

1. A light meter captures light
2. Separates the light into distinct wavelengths
3. Sends each wavelength data through the Color Matching function to figure out how humans see these wavelengths in terms of Reds, Greens and Blues.
4. For each wavelength, it then "mathematically" plots the RGB values for all those wavelengths in 3D space and "mathematically" normalizes it to 2D (Unit Plane or x,y plane).
5. It takes all those points and adds them together to arrive at a single x,y coordinate.
6. Finally it plots it on the Chromaticity Diagram!



Take home - The CIE 1931 Chromaticity Diagram is ...

- a way to objectively specify, identify and compare light sources
- derived from Human Data Experiments (1926)
- derived from RGB, a convenient model for mixing colors; it is convenient because it is like our 3 Cones which are loosely based on RGB.
- used to map x,y coordinates that represent a light's chromaticity (color) among all the colors humans can see and agree on (standardize colors)
- used by a light meter like the MK350 - it captures light and goes through all the necessary steps to arrive at an x,y coordinate for a light source
- all the colors visible to the human eye

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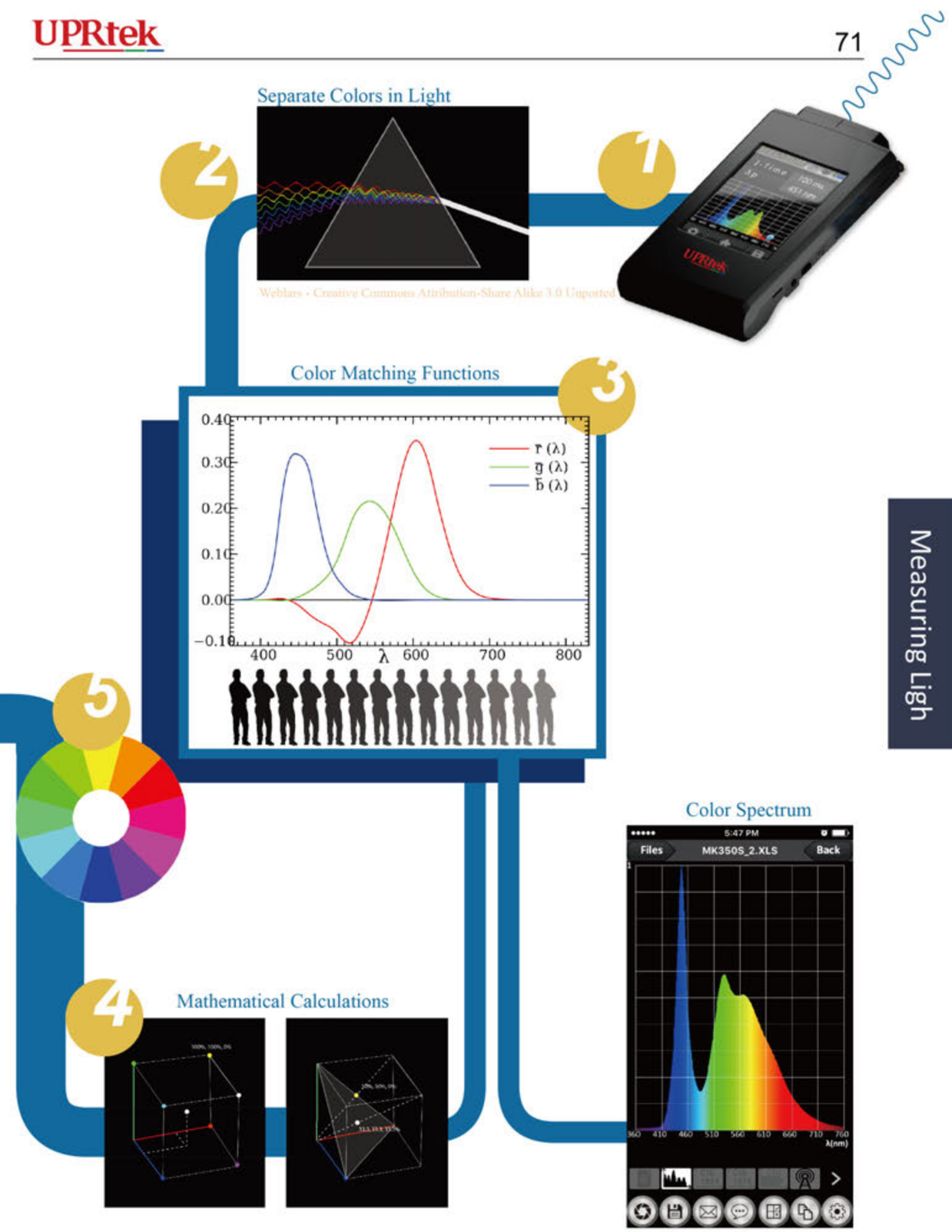

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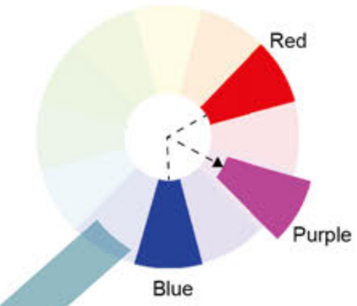
Color wheel and the Chromaticity Diagram

RGB color wheel

Remember our original color wheel? Our Chromaticity Diagram has characteristics that are similar in some ways. Like mixing and matching colors to make new colors.



Opposite colors make white (blue-yellow)

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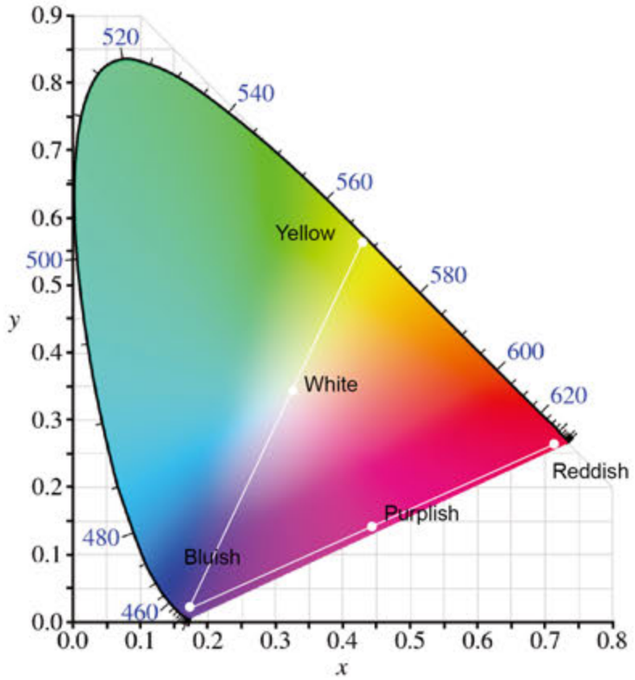
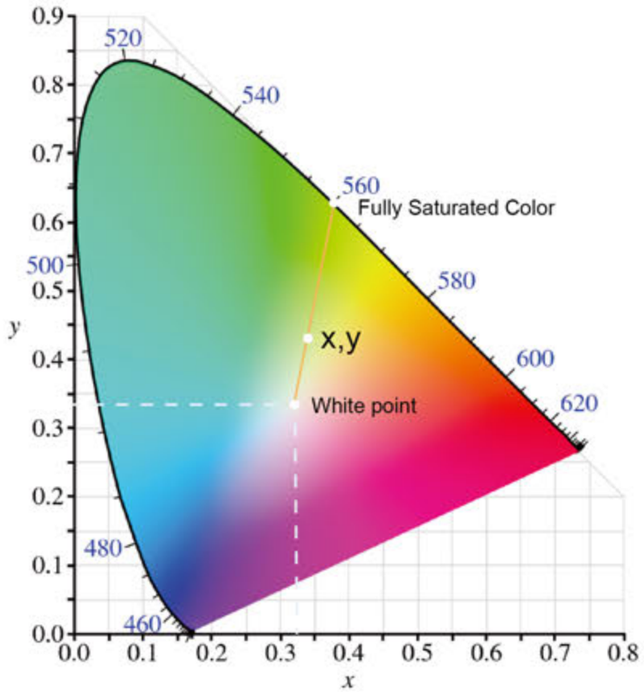


In our Chromaticity Diagram, you can mix n' play like our color wheel. If you take a point that is red and you connect it to a blue point, the midpoint will be purple. Similarly, mixing blue and yellow gives you whitish color - however these midpoints will not generally be accurate because of distortions in the diagram.

Somewhere close to the middle of the gamut there is a white point, which is at .33 and .33. This is an important reference point.



If your color is at x,y and you drew a line from the white point to the outer edge, you will arrive at a fully saturated color, or the "dominant wavelength" (e.g. 560) - it's like taking your x,y color and taking all of the white out of it.

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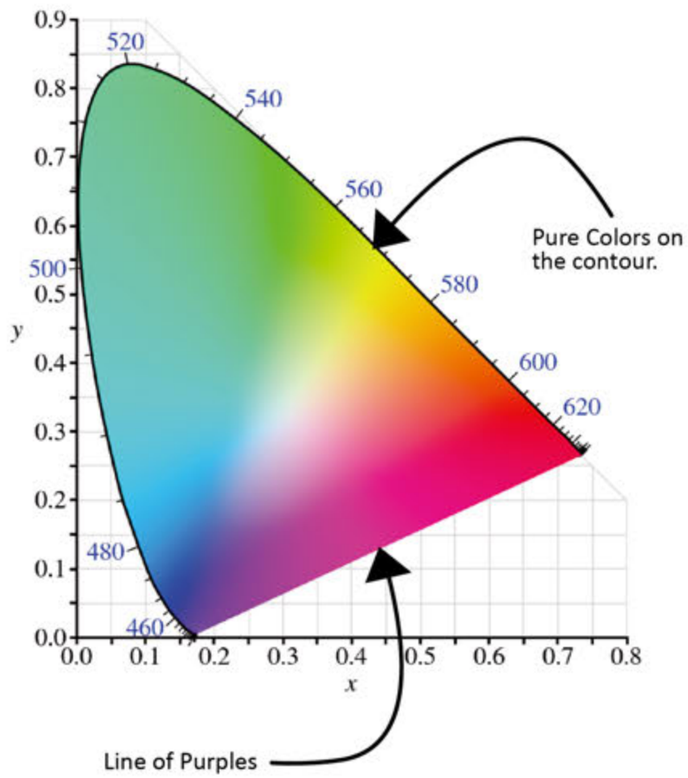
All of the dominant wavelengths on the outer contour and are also all the monochromatic (pure) colors that can be represented by one wavelength and are also all the colors split up by our prism (all the rainbow colors).

At the bottom of the "horseshoe" is a straight line. It is called the "Line of purples". These are real colors that we can see but with one exception - they are not pure colors, meaning a single wavelength cannot represent any color on that line (unlike 700 nm wavelength that represents pure red); you need to mix two or more colors to produce them.



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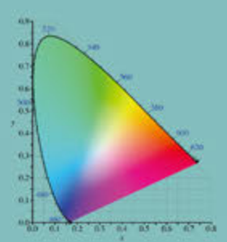
Measuring Ligh

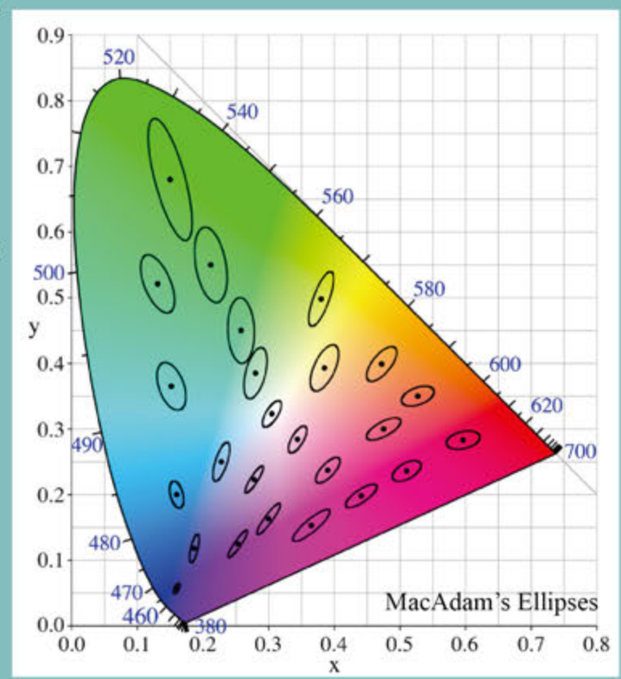
CIE 1931 to CIE 1976

Better but still not perfect

The CIE 1931 was the original Chromaticity Diagram followed by, CIE 1960 and CIE1976, which were improvements to their respective predecessor - but change doesn't always come easy - CIE 1931, is still in widely used. The most recent CIE 1976 version boasts improvements that more accurately matches our visual perception compared to the CIE 1931 diagram.

All the colors in the CIE 1931 diagram are supposed to be distinguishable colors. Experiments by Kodak researcher David L. MacAdam along with Deane B. Judd and Gunter Wyszecki provided empirical evidence that CIE 1931 represented a distorted view of how humans see colors. Basically, the ellipses in the MacAdam's Ellipse diagram show areas where there is no discernible difference in color according to test subjects. The CIE 1976 Chromaticity Diagram improved on these distortions but was admittedly still not perfect.





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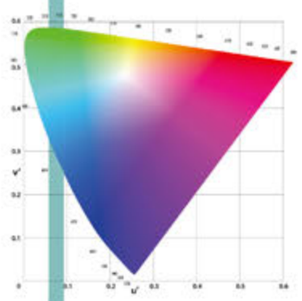
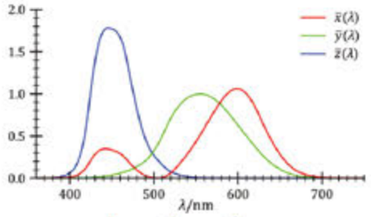
CIE 1976 is better suited to human visual perception because it incorporates MacAdam's Ellipses and more closely parallels how our cones work, using a new paradigm called the Opponent Theory.

CIE 1976 specification actually includes two versions; the CIELAB and CIELUV. They both take into account the distortions revealed by the MacAdam's Ellipses. Furthermore, these also take into account more recent revelations in how our 3 cones really process colors (see below). Like CIE 1931, CIELUV and CIELAB have x,y coordinates, but use u,v and a,b respectively



Another advantage to CIELAB and CIELUV is that they have a larger color space and are device independent - what does this mean? It means that you can choose a logo color and not have to worry about CMYK, RGB, sRGB, Adobe RGB, Pantone - the devices will adapt to CIELAB. However, change comes slow and this is why lots of devices are still stuck on CIE 1931, not wanting to comply with CIELAB.

The difference between CIELAB and CIELUV is usage. CIELAB is recommended to be used for subtractive processes used in printers, while CIELUV is recommended for use with additive processes like displays (monitors).

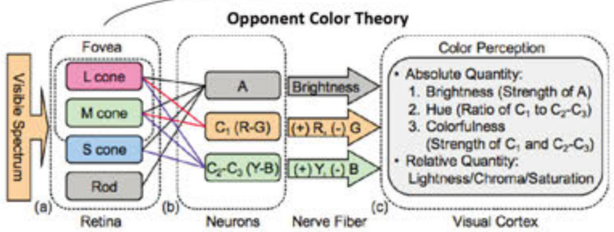


Our knowledge of how our cones work has evolved.

1800s

1931

1976



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MK350 Series - Things you should know

The MK350 Series are UPRtek's precision Spectroradiometers (i.e. light meters) including the Advanced, Basic and Compact models. They are differentiated by functionality, usage and size.

The Advanced model has a very wide range of features and measurement capabilities, and can cover most portable applications from basic measurements to specialty analysis, comparison and administration.

Both the Basic and Compact models provide the user with a quick snapshot and basic measurement information. The Compact model only has a small visual screen but is conveniently pocket-sized. Both of these products were given a tremendous boost with the ability to connect to the uSpectrum PC software and the Smart Phone Apps. Additionally, the Compact model was recently upgraded with a new feature called Flicker sensor.

Advanced MK350S

Basic MK350N

Basic MK350N PLUS

Compact MK350D

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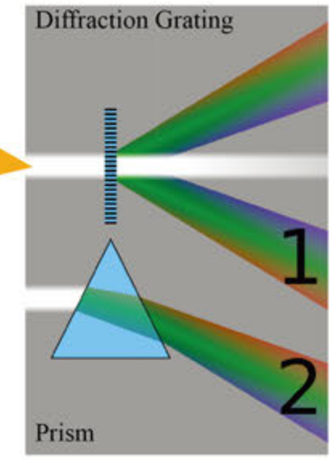
Specialty Terms

The MK350 User Manuals will explain most of the features and functions, which we will skip here (you should read the User Manuals at some point). In this section we'll look at some of the special terms and functionality that were not covered in depth in the User Manual.

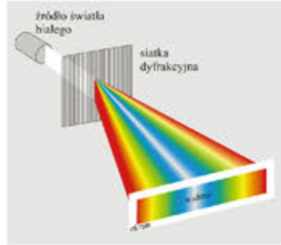
MK350N Plus

MK350N Plus was upgraded from the 1st generation handheld spectrometer MK350N.
It has built-in Flicker sensor detector to guard your health.
Additional Data Browser Mode allows you to manage data easily.

Diffraction Grating



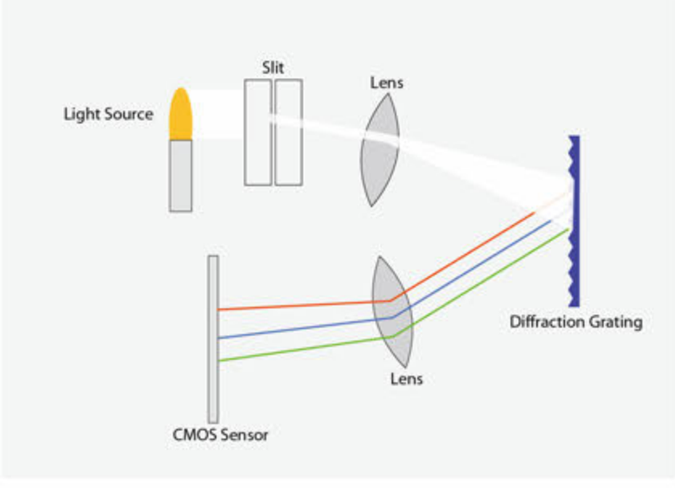
Cinglee - CC-BY-SA-3.0



MPastermak - CC-BY-SA-3.0

We've already talked about how a meter device can capture a white light and derive an x,y coordinate for our chromaticity diagram.

In that discussion we used a prism to separate the colors in white light - but actually, in our MK350 devices, we have what is called a diffraction grating that does the same thing but more efficiently and effectively.



The simplified explanation is that light is received through a small slit which transmits and reflects off lenses and the diffraction grating to finally reach the CMOS sensor which is the device that actually senses the dispersed light waves to be recorded as wavelength and intensity data.

Watch a Video

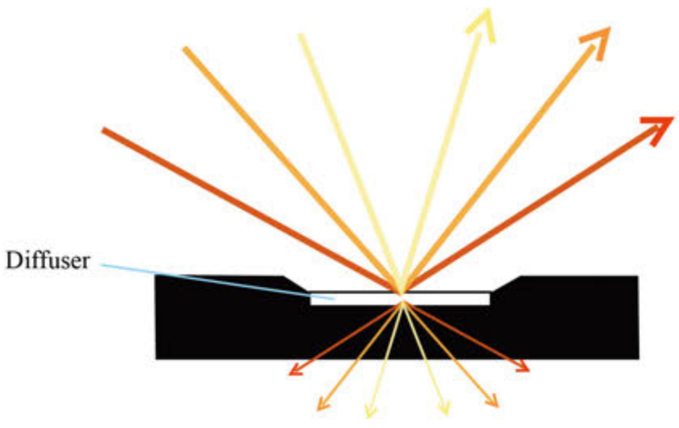
http://www.youtube.com/watch?v=pxC6F7bK8CU

Cosine Correction

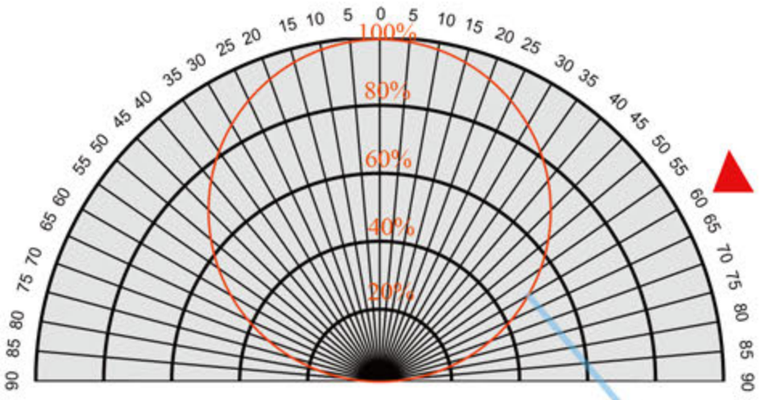
Another term you will run into is Cosine Correction. It is associated with measuring illuminance or how much light brightens a certain area - it is measured in LUX which is lumens per sq. meter. A lumen is a unit of measure that represents an "amount" of visible light.

First, you must know that light coming in at an angle will influence the brightness or LUX. A light shining from directly above will shine brighter than a light coming in at an oblique angle. In fact there is a direct correlation between the angle of the light and amount of brightness - this was explained by Johann Heinrich Lambert in 1760.

Measuring light intensity on a flat light meter lens is not so straight forward, especially when trying to measure light coming in at angles and then accurately recording the brightness according to the Lambert's laws - you need to make adjustments or innaccuracies will occur. These adjustment are called Cosine Correction and there is a chart (next page), which is a guide to measuring brightness according to Lambert's laws.. The MK350 (as with most light meters) uses a Diffuser or Cosine Diffuser that "diffuses" the light to arrive at a more appropriate calculation of LUX. Diffusers are physically apparant on certain meters where you can see a white opaque material just under the lens. However, no diffuser is 100% accurate and you can only attempt to arrive at ideal corrections for light arriving at angles.



Ideally, Cosine Correction for oblique (angular) light should follow the graph shown below. For example, a light hitting our surface at 60 degrees should register radiant intensity in the meter at around 50%. As the angle becomes less oblique, the intensity should increase according the circular orange line in the graph below. A Diffuser is installed in MK350 devices to get as close to the ideal pattern (orange circle) as possible.



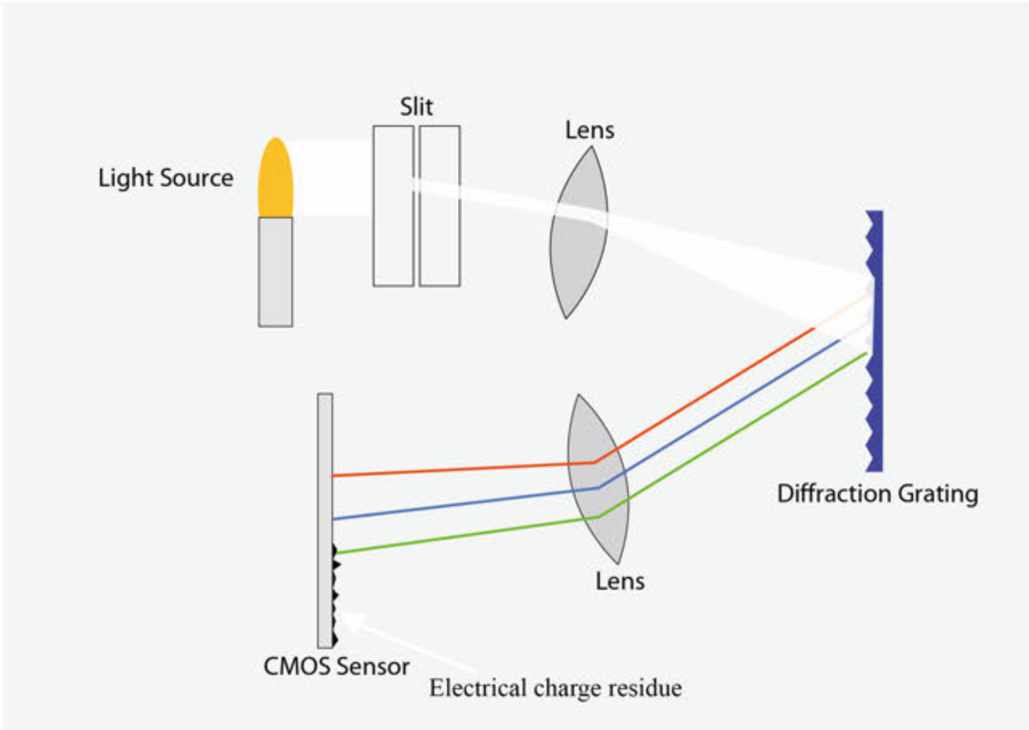
Light coming in at 60 degrees should result in about 50% of it's original intensity. Cosine 60 degrees = .5 or 50%

TELL ME MORE

Cosine is a mathematical function used to calculate and specify the characteristics (length & angles) of triangles (Trigonometry). The orange circle in the graph above was described by Johann Heinrich Lambert in 1760 and is called "Lambert's Cosine Law". Basically, it shows how light intensity changes as the angle of the light changes.

Dark Calibration

Dark Calibration is an optional operation in all of the MK350 devices. The devices will always ask if you want to perform a Dark Calibration each time you turn on the device. While the device is in operation, you can also, through the "Options" menu, manually execute a Dark Calibration. What is Dark Calibration used for? Basically, an electrical residue or "charge" accumulates on the CMOS sensor and may interfere with accurate measurements. This charge builds up when the temperatures you are operating in changes significantly. The other situation is when you move from lighter to darker environments or vice versa. Also, it is a good time to perform a Dark Calibration anytime you are experiencing some anomalies in measurements. The MK350 devices always ask if you want to perform a Dark Calibration when powering on your device because it is just good practice to do so.



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MK350 Series

Can the MK350 measure Fluorescent?

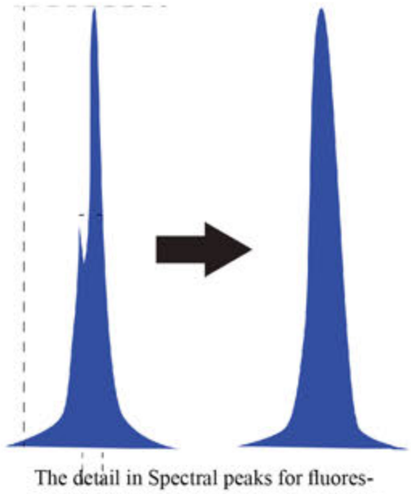
For all intents and purposes, yes it can. However, there is one aspect of Fluorescent Lights to be aware of. The color spectrum is NOT a conveniently fixed set of individual wavelengths to measure, but a continuum of wavelengths (like a rainbow). It's impossible and impractical for any light meter to carve up the spectrum into infinitely small wavelengths. So, it carves up the spectrum into sections and then does some averaging to come up with a continuum color spectrum to display on the screen.

However, everything within the width of the carved section is averaged and details within are smoothed out. For LEDs and Incandescents, it isn't a problem - but for Fluorescent Lights, the individual peaks are so thin, the device may not have the resolution to catch all the details within.

This is the case with the MK350 and Fluorescent Lights. The resolution of the MK350 is 12nm - this means that 2 or more peaks that fall within 12nm will be smoothed out. Fluorescent Lights have peaks that can fall well within 12nm - and so they are all smoothed. So what we can determine from the MK350 and Fluorescent Light is a general wavelength spectrum shape only.

Half Bandwidth

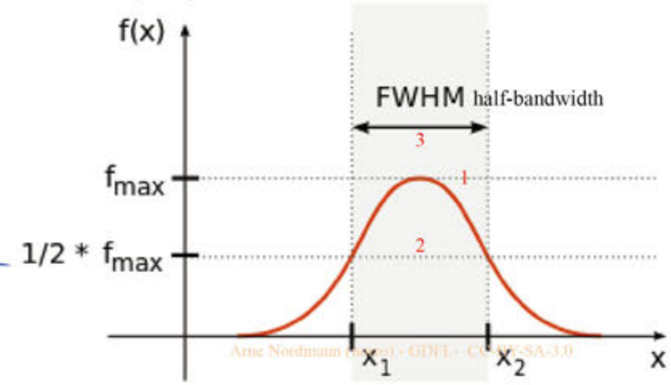
To the right is the uSpectrum software, which can display the half-bandwidth (Show Peak On). The half-bandwidth is calculated by taking the λp (peak wave height)$_1$ and dividing it by 2 - next, at that 1/2 height, draw a vertical line across the wave$_2$ - the thickness of the wavelength at that height is called the half-bandwidth$_3$. The half-bandwidth for the peak shown in the diagram (right) is 14nm. However, since this is a Fluorescent Light, there may be several sub-peaks within the 14 nm peak that were smoothed out.

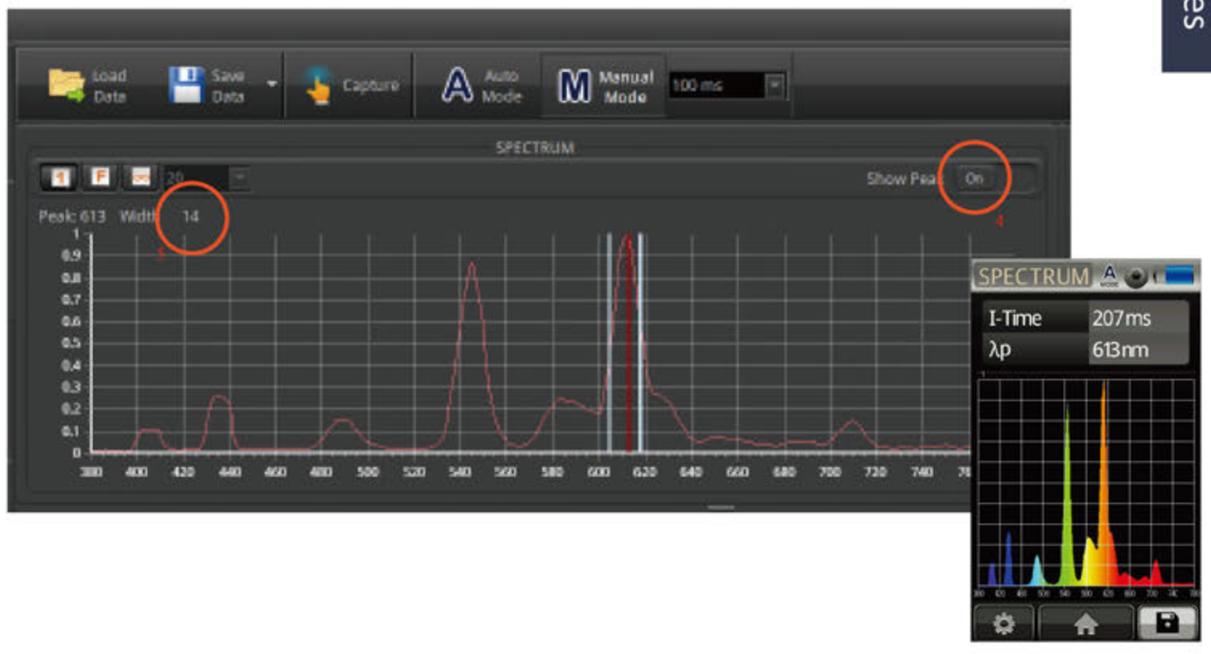


The detail in Spectral peaks for fluorescent lights may be too fine and could be smoothed out by the Mk350.

On the uSpectrum screen, you have to turn "Show Peak" On$_4$ - after a capture, the half-bandwidth will display in the upper left corner$_5$. Any detail within 12 nm sections of the span will be smoothed out (averaged).

Half bandwidth is used by LED manufacturers to measure the thickness of the peaks, to try to measure color consistency - too fat or too slim will obviously alter color quality.



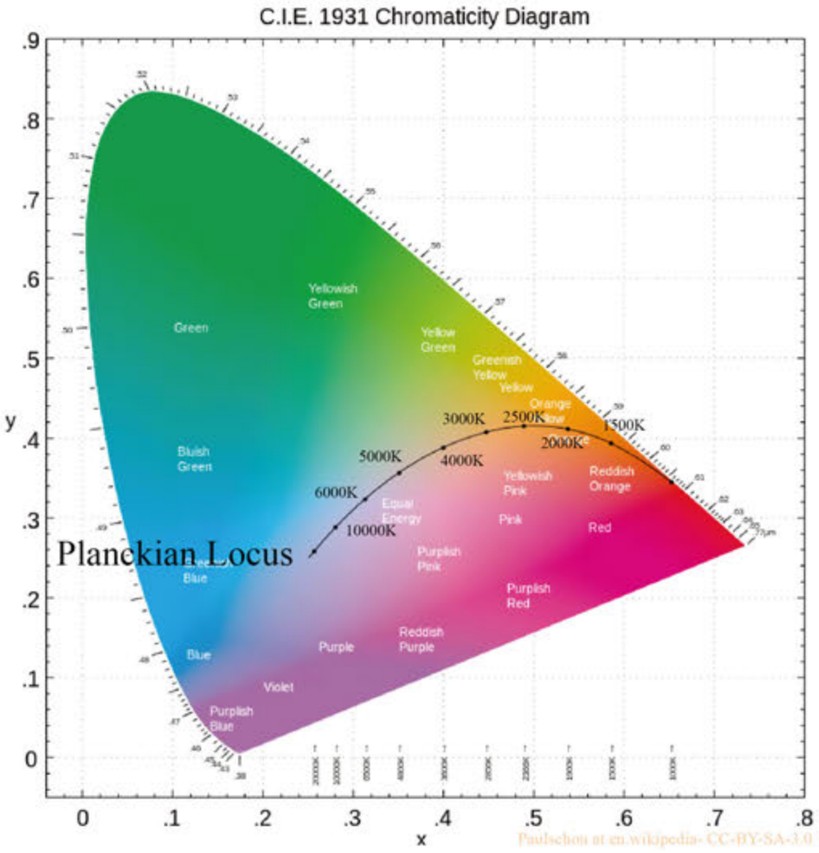


Planckian Locus

Previously, we discussed Black Body Radiators - basically, it is an object that heats up and emits different wavelengths of light (color) as the temperature rises - these colors are identified as Color Temperatures in Kelvin and are indicated on the Chromaticity Diagram below as the black curved line, otherwise known as the Planckian Locus. Generally, the Color Temperature (CT) for light bulbs tells designers whether the light emits a warm feeling (inclined to reds) or cool feeling (inclined to blues).

Warm Feeling 2500K

Cool Feeling 5600K



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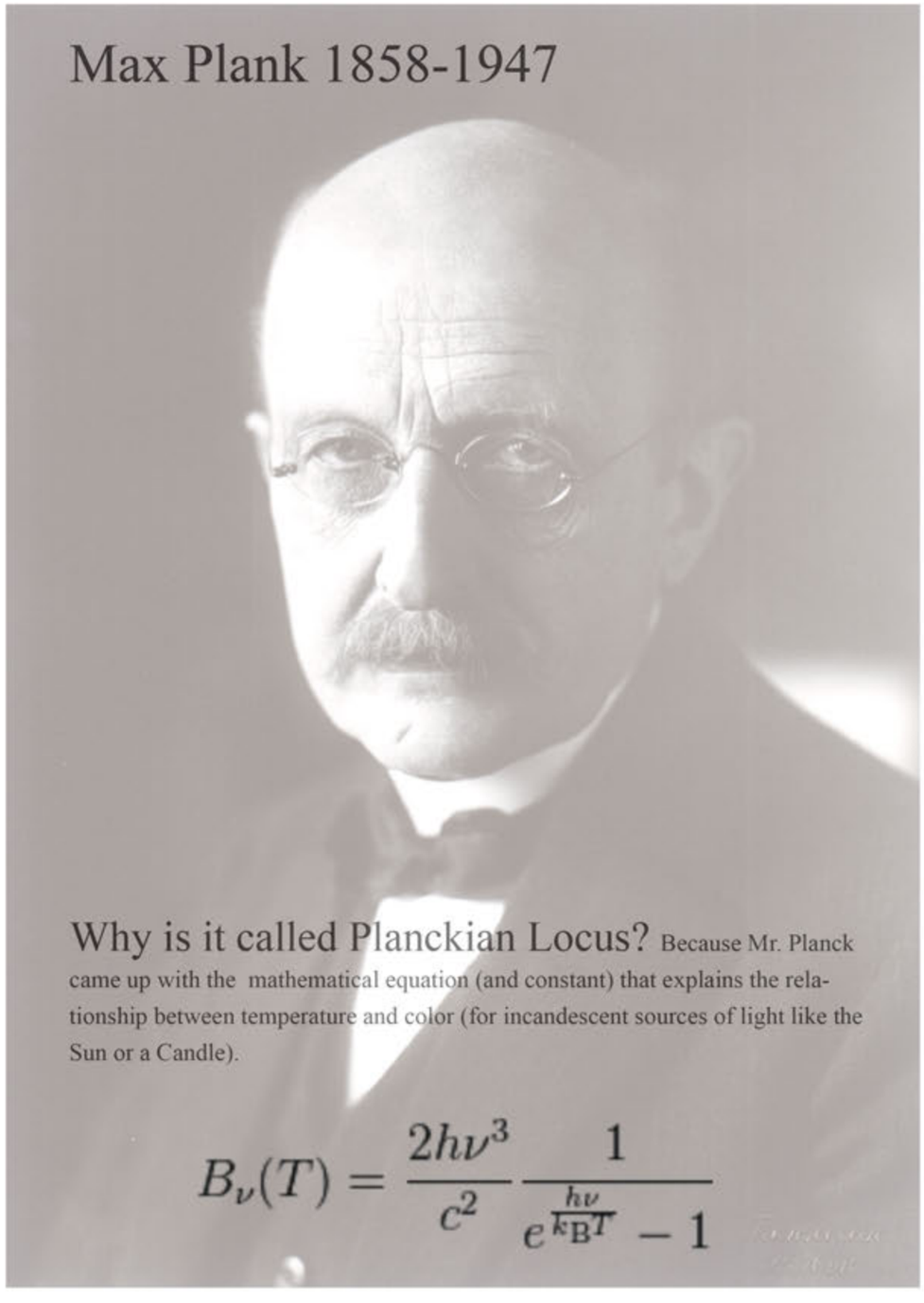

Why is it called Planckian Locus? Because Mr. Planck came up with the mathematical equation (and constant) that explains the relationship between temperature and color (for incandescent sources of light like the Sun or a Candle).

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{k_B T}} - 1}$$

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Rundown of Unit Measurements

This section lists the various unit measurements and the page number where an explanation can be found or a direct explanation.

MK350S ▲

MK350N PLUS ▲

MK350D ▲

Unit Msr.	MK350S	MK350N PLUS	MK350D	Explanation
CRI (Ra)	✓	✓	✓	Color Rendering Index, is a quantitative measure of the ability of a light source to reveal the colors of various objects.
CCT	✓	✓	✓	Correlated Color Temperature, is the color temperature of a black-body radiator which to human color perception most closely matches the light from the lamp.
LUX	✓	✓	✓	Lux, is the SI unit of illuminance and luminous emittance, measuring luminous flux per unit area. Normally use in photopic vision.
LUX-Scotopic	✓a	✓a	✓a	Lux value using scotopic vision.
λp	✓	✓	✓	The peak of wavelength. is the wavelength with the maximum power.
λp Value (Lamdba PV)	✓	✓a	✓a	The peak power value in the peak of wavelength.
λd	✓	✓		The dominant wavelength, is way of describing polychromatic light mixtures in terms of the monochromatic light that evokes an identical perception of hue. The wavelength of the monochromatic light is the dominant wavelength.
I-Time	✓	✓	✓a	Integration time (like exposure time)
Purity	✓	✓		Testing and Calibrating LED-based screens and monitors p126
R1-R8	✓	✓	✓a	Lighting Store Display p 130
R9	✓	✓	✓	Lighting Store Display p 130
R10-R15	✓	✓	✓a	Lighting Store Display p 130
x	✓	✓	✓	Part of the Chromaticity Explanation p62
y	✓	✓	✓	Part of the Chromaticity Explanation p62
u'	✓	✓	✓	Similar to x coordinate but for CIE 1976 (p77)
v'	✓	✓	✓	Similar to y coordinate but for CIE 1976 (p77)
Duv	✓	✓		Lighting Designers p108
Δx	✓	✓		Lighting Designers p108
Δy	✓	✓		Lighting Designers p108
Δu'	✓	✓		Lighting Designers p108
Δv'	✓	✓		Lighting Designers p108
PPF	✓			Explained on p99
PPF-UV	✓			Explained on p99
PPF-B	✓			Explained on p99
PPF-G	✓			Explained on p99
PPF-R	✓			Explained on p99
PPF-NIR	✓			Explained on p99
fc	✓	✓	✓	Foot Candle- Similar to LUX but is used mostly in the US. 1fc= 10.764 lux
Flicker %		✓	✓	Measuring Flicker p116
CQS	✓	✓		Color Quality Scale, is a quantitative measure of the ability of a light source to reproduce colors of illuminated objects.
SP-ratio	✓	✓		Scotopic and Photopic Ratio, is the rario of light in scotopic vision and photopic vision.
GAI	✓			Gamut Area Index, in an attempt to improve over the flaws found in the CRI. A higher GAI equates to greater saturation or vividness of object colors.
TLCI	✓	✓		Television Lighting Consistency Index, have been developed to replace the human observer with a camera observer. Similar to the CRI, the metric measures quality of a light source as it would appear on camera.
X	✓	✓		CIE 1931 color space
Y	✓	✓		CIE 1931 color space
Z	✓	✓		CIE 1931 color space

a - Requires uSpectrum Software

MK350 Series

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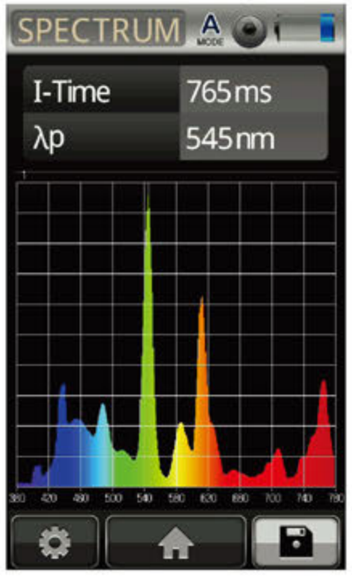
Recognizing different wavelength spectra

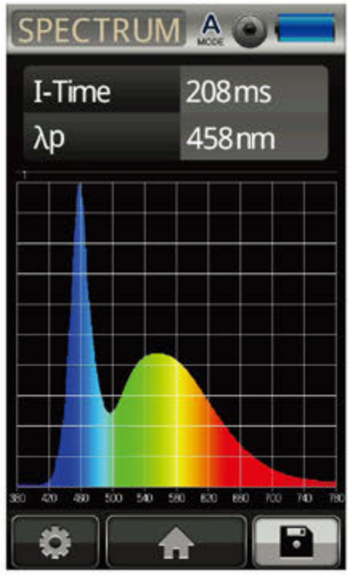
These are the different color spectrums that you should get to know ...

Fluorescent Light



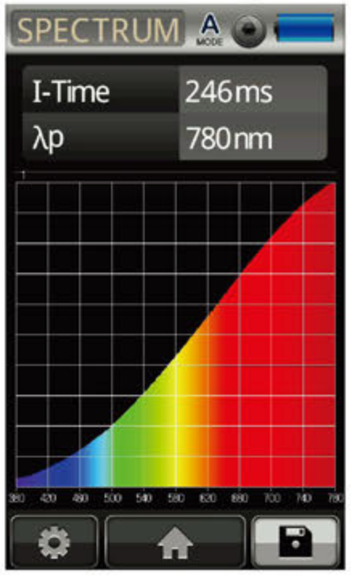
Fluorescent Lights have this distinctive jagged continuum. Notice the small amount of UV radiation (under 400nm) - it's presumably from the UV radiation emanating from the Mercury vapor.

LED Light



The important LED characteristic to understand is that there are two peaks. The first peak represents the bluish light from the semiconductor. The green-yellow-red peak indicates the colors emanating from the yellow phosphor layer.

Incandescent Light



This is from an Incandescent bulb. This continuum of color wavelengths is indicative of a Black Body radiator. Notice how it leans more towards the red colors - that is what makes incandescent lights feel "warmer". As you increase the temperature of a Black Body Radiator, the color should change from reds to more blues (see Sun Light on next page).

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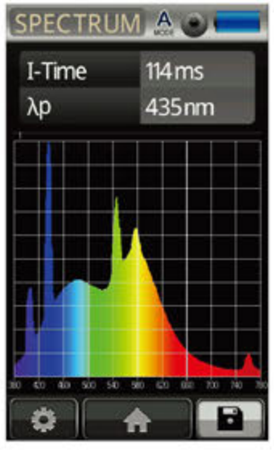
Sun Light

Sunlight is the gold standard for light. Notice that it has the most even continuum of colors, which means it renders all colors very vividly. Also notice the relatively high amounts of UV radiation (< 400 nm) which is harmful to the eyes and skin.



Can you guess where this was captured? Hint - notice the jagged peaks, but also notice the distinctive blue peak and green-yellow-orange peaks.

Taken between LED and Fluorescent Lights.

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MK350

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Applications

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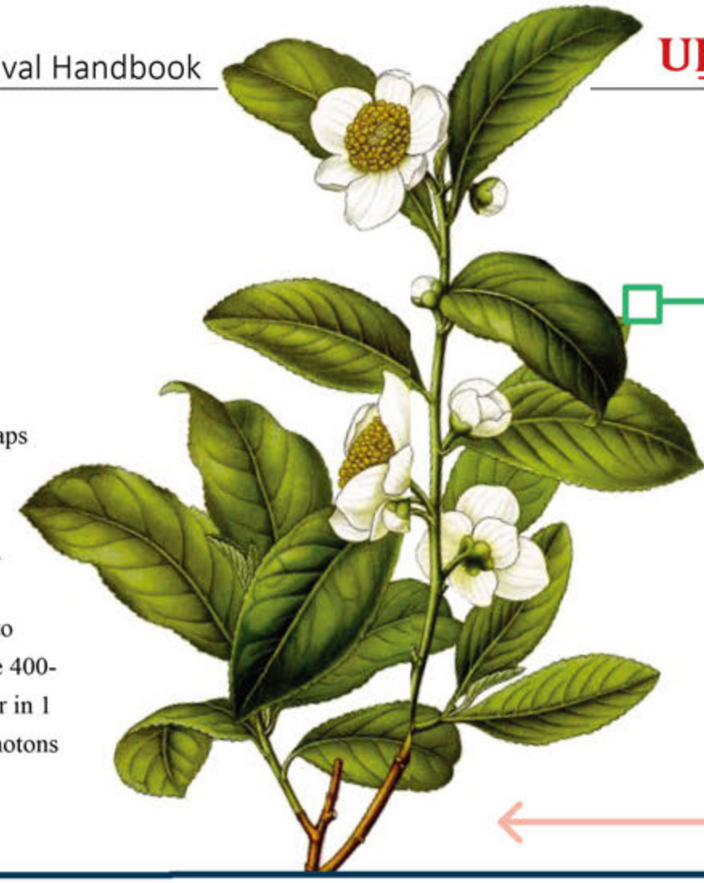
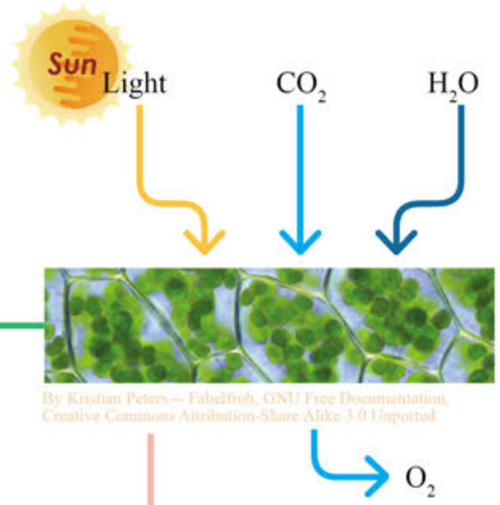
Light and Agriculture

Indoor Agriculture has been increasingly gaining interest as a means for plant-assisted growth using artificial light. This has ramifications for supplemental food production during winter months, especially in regions with short-days and reduced sunlight. This technology also has the commercial potential for ornamental plants as well and even perhaps for growing plants 24 hours / day.

Plant assisted growth using artificial light uses wavelengths described as PAR (photosynthetically active radiation). It is measured in PPF (Photosynthetic Photo Flux), which is the amount of light in the 400-700 nm range that falls on a square meter in 1 second: µmol m-2 s-1 (micromoles of photons per meter squared per second).





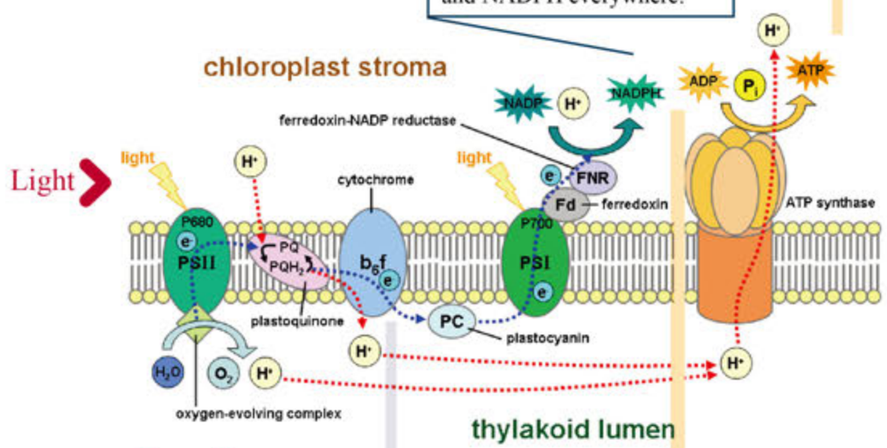
Plants use Sunlight, Carbon Dioxide and Water to make sugars used to fuel the plant's activities (e.g. growth, germination) - this is called Photosynthesis. This process can be simplified into 2 steps - Light Reactions and the Calvin Cycle (sometimes called Photosystem II & Photosystem I).

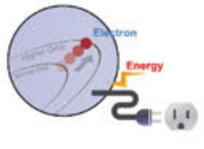
Applications

Photosynthesis

1 Light Reactions

ATP and NADPH are very important energy stores (like batteries) that can be used for many processes. In fact, the human body also uses ATP and NADPH everywhere.

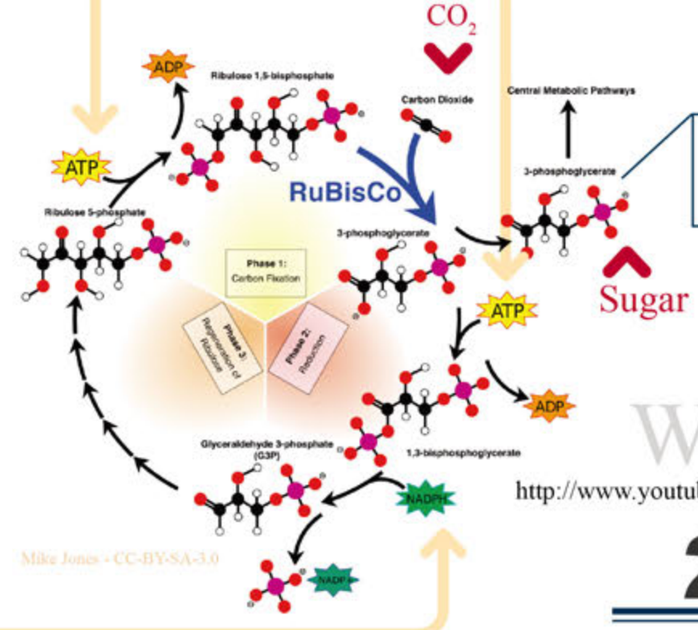




H_2O O_2

Electrons are the key

Electrons are the key



Sugars are used for growth, germination, flowering etc.

Watch a Vi

http://www.youtube.com/watch?v=g78utcLQrJ4

2 Calvin Cycle

Applications

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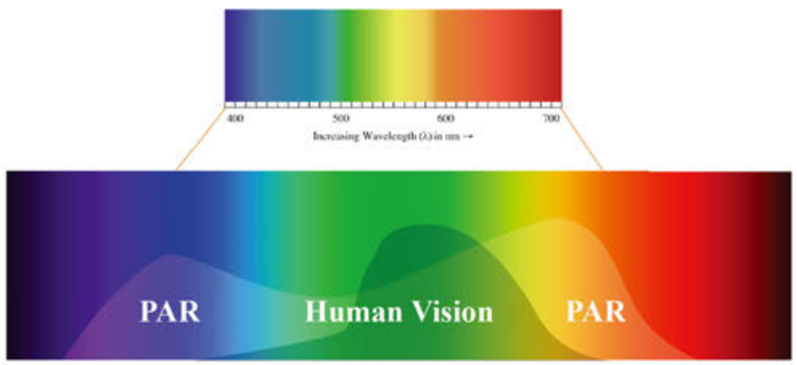
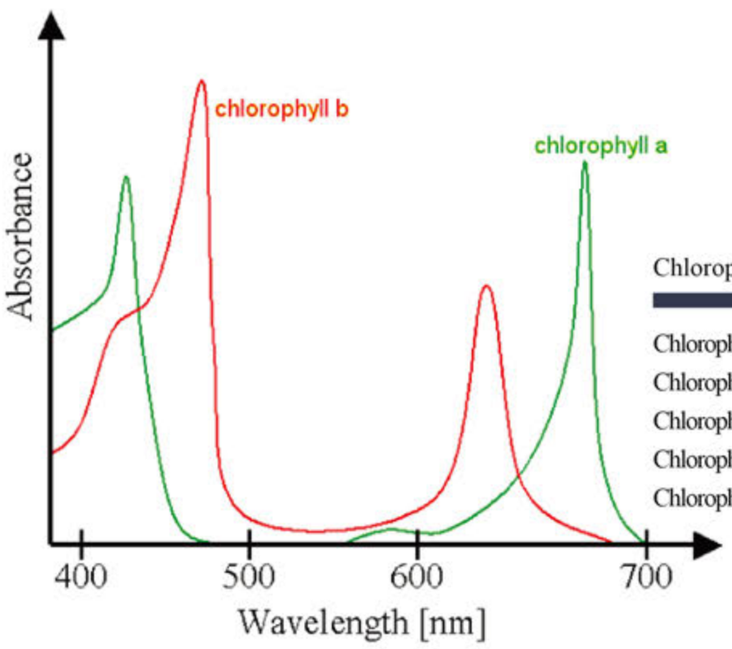
Measuring PAR

Plants photosynthesize at wider range of wavelengths than what we can see, mostly at the red and blue ends of the color spectrum and less in the greens. However, not all plants synthesize in the same way - different plants need different wavelengths of light and even the same plant will require different wavelengths depending on its development phase.

Chloroplasts are a subunit within a plant cell and contain Chlorophyll - different plants have different types of chlorophyll and thus respond to different wavelengths of light. The MK350S can measure PPF at different ranges of wavelengths to determine if certain plants are receiving the appropriate amounts of light at the right colors.





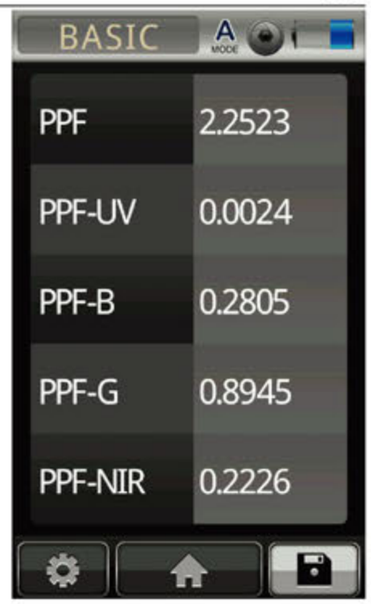
Chlorophyll Peak Sensitivities

Chlorophyll a -430 nm and 664 nm;
Chlorophyll b - 460 nm and 647 nm;
Chlorophyll c1 - 442 nm and 630 nm;
Chlorophyll c2 - 444 nm and 630 nm;
Chlorophyll d - 401 nm, 455 nm and 696 nm

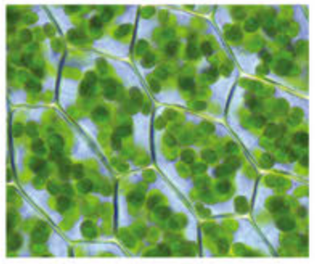
Ausbalz - GFDL - CC-BY-SA-3.0

The Advanced MK350S can measure PPF (photosynthetic photo flux)

PPF (full spectrum 400~700 nm)
PPF-R (Red 600-699 nm)
PPF-G (Green 500~599)
PPF-B (Blue 400-499)
PPF-NIR (near infra red 700~780)
PPF-UV (ultraviolet 380~400)



PAR sensors are also used outdoors for agriculture or forestation to measure the amount and quality of sunlight reaching vegetation, which could be affected by cloud cover, forest canopy cover, building shade or pollution.



Why are most plants green?

Because the molecular structure is such that it reflects green colors.

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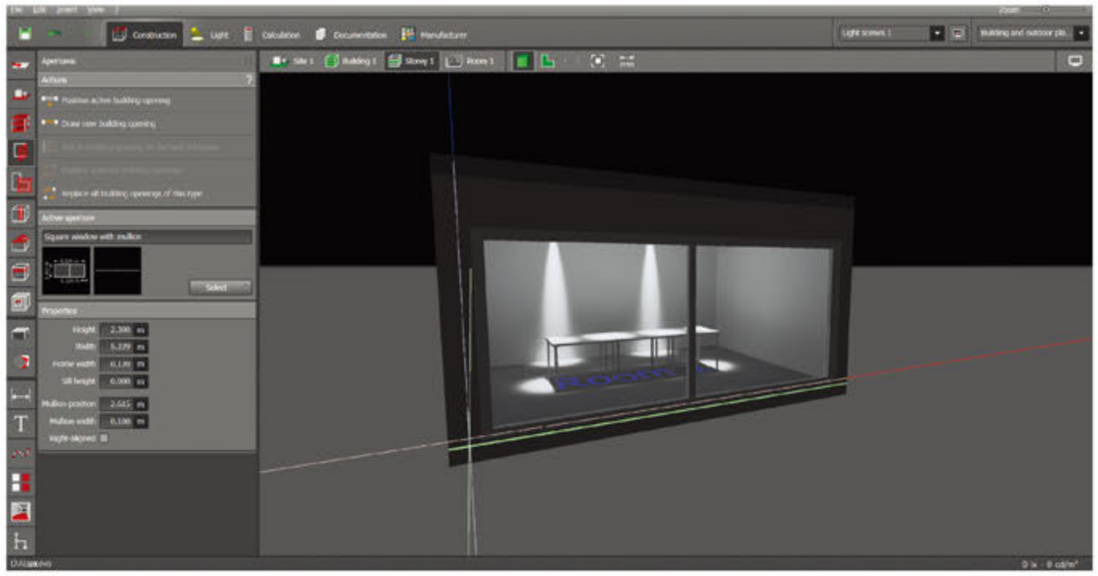
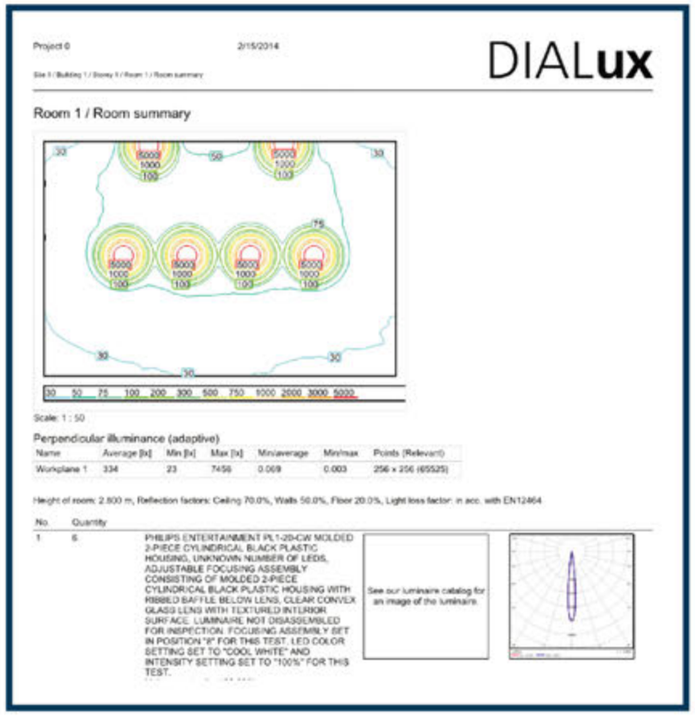
Dialux

Lighting Designers



Dialux is 3D software used by Lighting Designers to help plan luminaire lighting for almost any situation including building lighting, home lighting, street lighting. The designer receives an AutoCad premises layout from a client, which can be imported into Dialux as a floor-plan - from there, the designer can reconstruct the entire client environment complete with colors, windows, walls, ceilings, roof, doors and furniture. Finally, the designer is able to select a set of simulation luminaires, which are ready to install simulation light bulbs from vendors all around the world. In order to do this, the vendor must have an IES file to download - these files contain light specifications about their lighting products. Finally, luminaires are installed and light simulation can be evaluated. From here designers check brightness or LUX, which is lumens per sq. meter. A lumen is a unit of measure that represents an "amount" of visible light. The Dialux software produces reports that show LUX levels in every room, on floors, tables and walls.



Bulb Selector

Lighting Vendor Selector

Furniture Selector

Tennen-Gas - CC-BY-SA-3.0

Luminaires

A Luminaire is sometimes called a Light Fixture and is a complete lighting unit that consists of one or more bulbs and everything else needed for end-user installation - encasement, sockets, connectors, reflectors, and power sources.

Applications

Software simulations and reports are one thing, but actual implementation and results are another matter. Once all the real lighting has been installed, other than visual, there is no quantitative way to show the client that your lighting installation meets original specifications. This is important, because sometimes it's necessary to meet regulations for public spaces, such as libraries and schools. The lighting designer uses the MK350 to show clients that, in fact, LUX levels on tables, walls and workspaces do meet regulations.

Lighting regulations for public spaces is sometimes mandated and sometimes just guidelines, but no matter, most developed countries are beginning to pay attention to the importance of proper, appropriate illumination and light color.

You can find many guidelines on the Internet from different organizations, but the "word" is that most of them are very similar. Some of these organizations include:

US - OSHA (Occupational Safety and Hazard Association)
UK - HSE (Health and Safety Executive)
EU - CEN (European Committee for Standardization)

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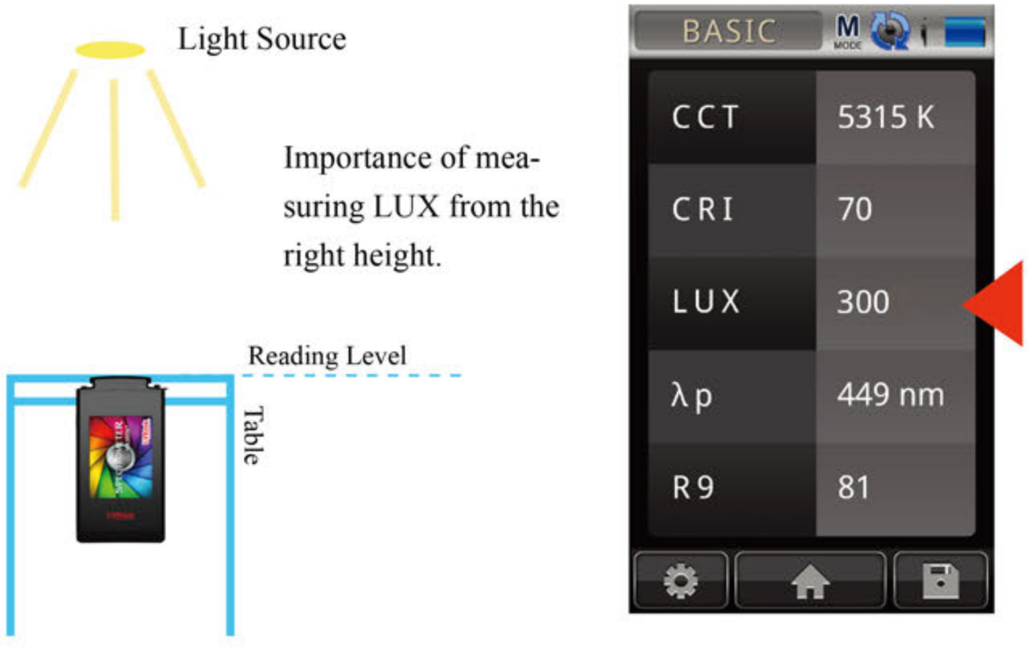
category	Illuminance Level (lux)	typical areas of application
General Lighting for rooms and areas not frequently used and /or used for casual or simple visual tasks	20	Minimum service illuminance in exterior circulation areas, outdoor stores, stockyards
	50	Exterior walkways and platforms
	70	Boiler house
	100	Transformer yards, furnace room etc.
	150	Circulation areas in industry, stores and stock rooms.
General lighting for interiors	200	Minmum service illuminance on the task
	300	Medium bench & machine work, general process in chemical and food industries, casual reading and filing activities.
	450	Hangers, inspection, drawing offices, fine bench and machine assembly, color work, critical drawing tasks.
	1500	Very fine bench and machine work, instrument & small precision mechanism assembly; electronic components, gauging & inspection of small intricate parts (may be partly provided by local task lighting)
Additional localized lighting for visually exacting tasks	3000	Minutely detailed and precise work, e.g very small parts of instruments, watch making, engraving.

When the Lighting Designer is using the MK350 to validate LUX for a library client, he/she positions the device at just the height of the table, which is where you will normally be placing a book. The height is important because even a short difference in distance of 33 cm can make a difference of 30-40 LUX.



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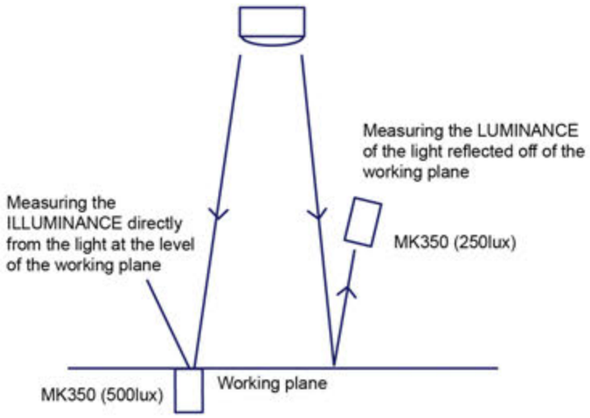
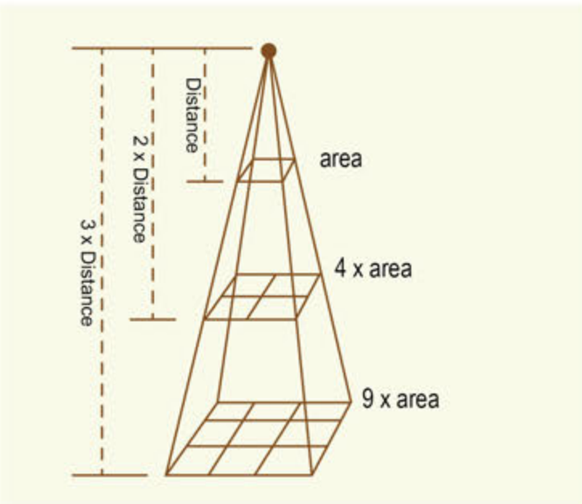
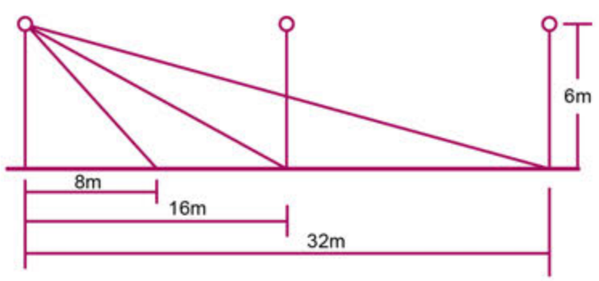


Here are some other simple things that you should know. There is "Illuminance" which was the light we just measured with the library example - it is measured in LUX. Then there is "Luminance", where you measure LUX that is reflected off the table surface. Of course, Luminance also depends on the surface material - a black table top would show a lower LUX than a white table top.



In measuring Illuminance, if you move the light source farther from the table top, the area of illumination naturally increases - this increase is proportional to the square of the distance. At the same time the LUX also is reduced proportionally (at "2d", LUX is 1/4 of what it is at "d", at "3d" LUX is 1/9 of what it is at "d").



As you move farther away laterally from the center of the light, the LUX also diminishes in proportion to distance. These are some of the items to consider in lighting design.

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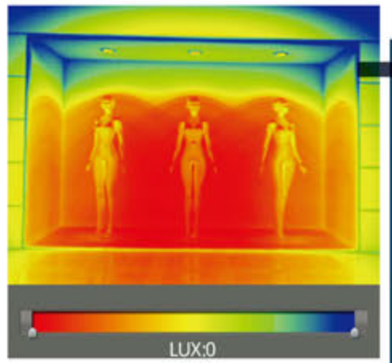
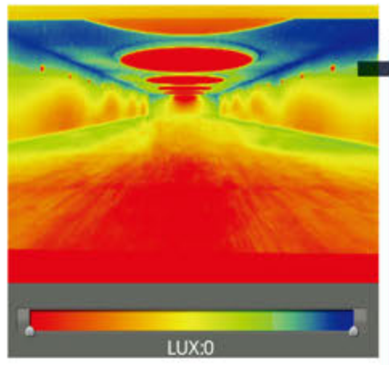


Objective Luminance
Lighting Designers use the MK350S LuxG view to get a more objective view of where luminance is and where adjustments are necessary. The red areas indicate intense light which, in this LuxG image, falls mostly on the floor and background.



Uniformity
LuxG view also allows a lighting designer to gauge the even-ness or uniformity of light, which is hard to otherwise do with the distraction of objects, colors and textures.

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Cool vs Warm – Color Temperature

Lighting designers are telling us that most of their clients are not familiar with the Color Temperature. However, they do understand the concepts of warm and cool environments. With Incandescent lights, the color temperature is used by designers to determine ranges for Warm, Neutral and Cool as shown below.

Warm Light
3300K or below

Neutral Light
Around 3300K to 5300K

Cool Light
5300K or above

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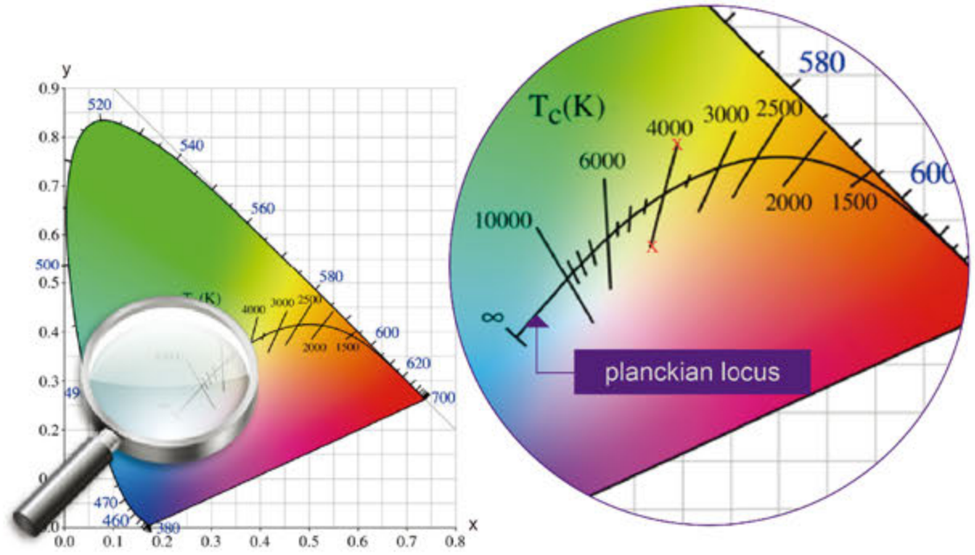
Correlated Color Temperature

Remember that color temperature is based on a theoretical model called a Black Body Radiator (heat to make light) and the Sun and Incandescent Lights are fairly accurate representations of that because they use heat to emit light. However, as we know, LED and Fluorescent lights are based on semiconductors and mercury/phosphors respectively, so a Black Body Color Temperature really makes little sense.

However, a Correlated Color Temperature was devised to estimate a color temperature for LEDs and Fluorescents. However, this correlation can only give a broad range estimate. Remember that the Planckian locus is the theoretical Black Body Color Temperatures on our Chromaticity Diagram. The slash marks acrros this locus (shown below) indicate the Correlated Color Temperature ranges for Fluorescents and LEDs. In other words, an LED spec'ed for a CCT of 4000 could be a yellow-green to yellow-blue-orange or anything in between. Therefore, the CCT can be ambiguous for estimating the warmth or coolness of light for a designer.



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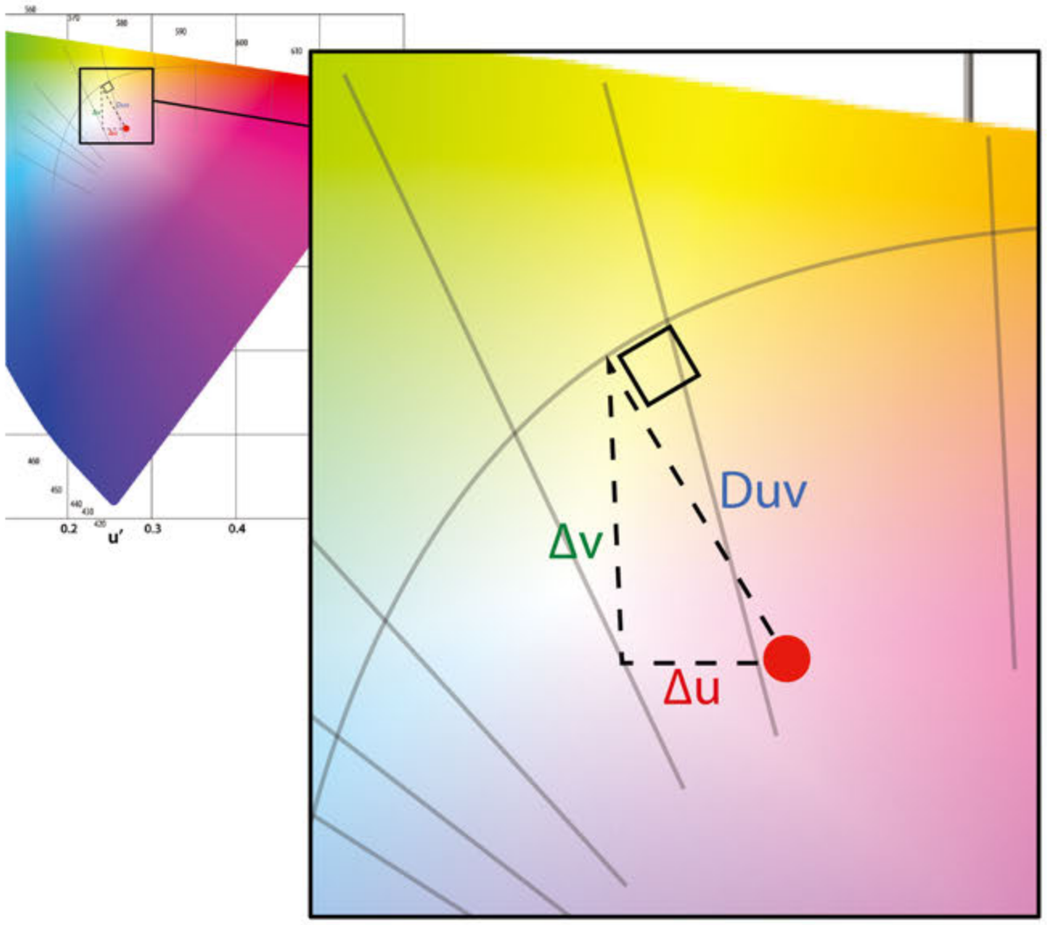
That's why we have Duv Δu Δv Δy Δx

For CFLs and LEDs, there are other unit measures that the **MK350S** provides to help the designer estimate "warmth" or "coolness". Let's say your light falls on the point marked with a red dot (below) - first of all, the closer the red dot is to the Planck's locus (blue dot), the more true the CCT is for determining the "warmth/cooling" feel of the light. This difference is called the Duv (or Delta uv) for CIE 1976 diagram. More specifically you can get the Delta u (Δu) and Delta v (Δv).



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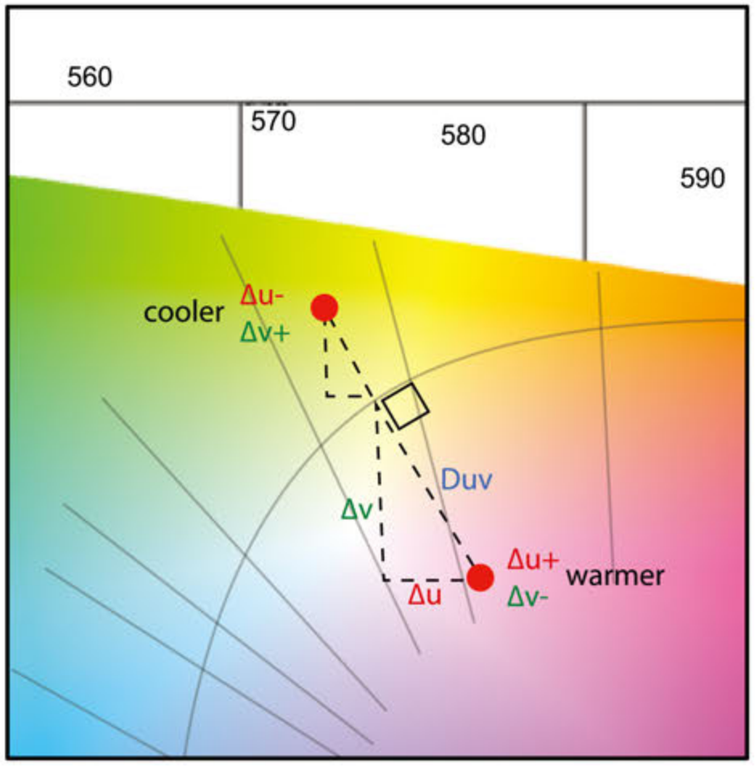
So how does this help you determine real "coolness (blue)" or "warmth" (red)? It depends on which side of the Planckian locus you are on, and the positive and negative values of Δu and Δv give you this indication. In general, a positive Δu and negative Δv leans more towards the warm colors, and a negative Δu and positive Δv pushes the color towards the cooler colors.



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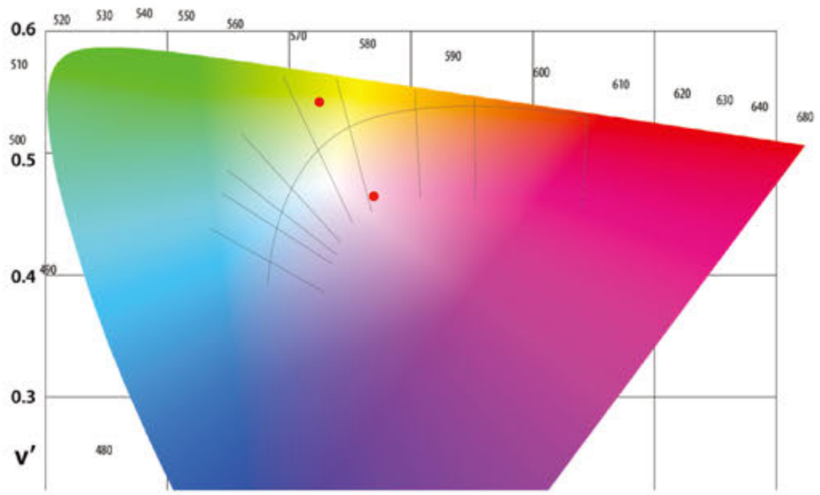
Applications

Why not just look at the Chroma Diagram?

Why not just look at the coordinates on the Chromaticity Diagram? - you can quickly see where the colors are inclined to (warm or cool) - so you don't really need Δu and Δv right?



Strength in Numbers

For a lighting designer, it may be enough to look at the Chromaticity Diagram. However, there are advantages to working with numbers like Δu and Δv, particularly when you are working with lots of data. With a list of Δu and Δv values, you can observe trends and deviations much more clearly than you can by looking at a diagram. Furthermore you can take these numbers and calculate useful statistical data, such as averages, means, and standard deviations.

DATA

State

ambdaD	Duv	deltax	deltay	deltau	deltav	Purity	fc	CRI	R1	R2
583	0.00000	0.00673	0.01227	-0.00114	0.00559	0.7	13.4	81.9	98	93
583	0.00000	0.00676	0.01239	-0.00116	0.00564	0.7	13.9	81.8	98	92
583	0.00000	0.00667	0.01218	-0.00114	0.00555	0.7	12.3	82.0	98	93
583	0.00000	0.00683	0.01236	-0.00111	0.00564	0.7	12.4	81.9	98	93
583	0.00000	0.00678	0.01237	-0.00114	0.00564	0.7	13.4	81.9	98	93

From data window of MK350 uSpectrum PC Software

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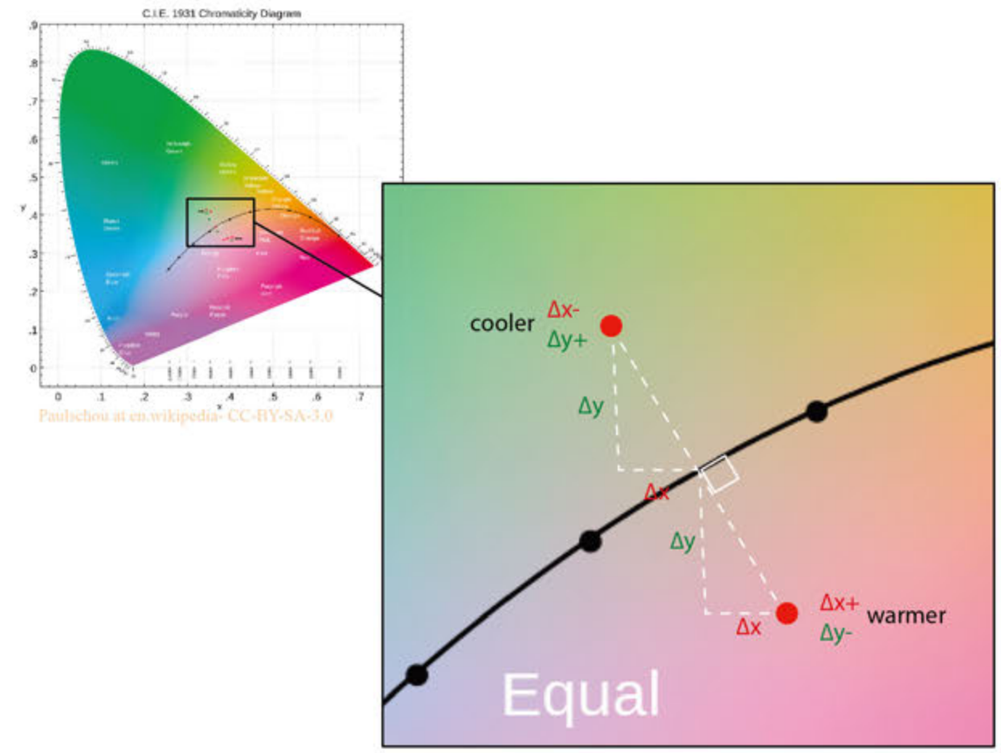
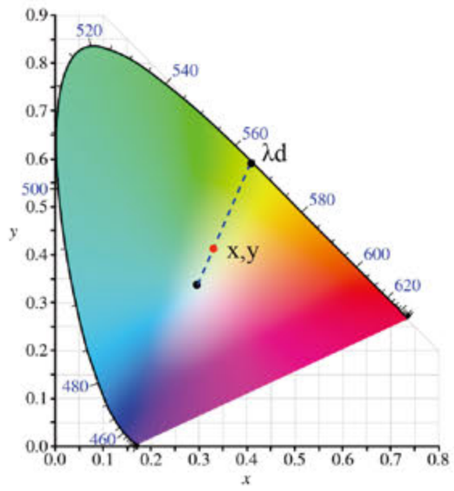
The CIE 1931 also has delta values but they are in terms of delta x and y (Δx and Δy)



Still another way of determining "Cool" or "Warm" is by running a line from the white point (.33, .33) through your x,y coordinate - where it hits the outer contour is where the dominant wavelength (λd) is and from that wavelength you can get a sense of "cool or warm". The MK350S can display λd, without all of the fuss of figuring it out yourself.



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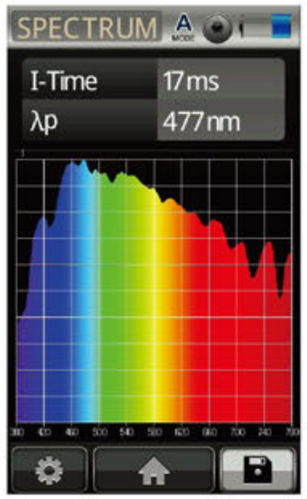
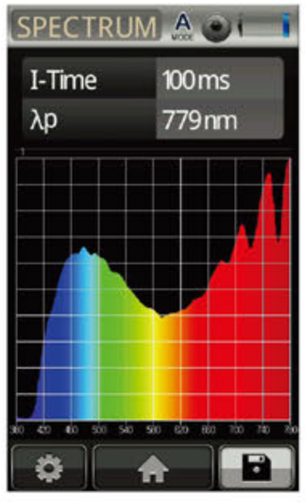
Measuring UV light (radiation)

UV light or more accurately UV radiation is harmful to the eyes and skin. There many products that offer UV Protection including sunglasses, windows, and sunscreen. The danger in sun glasses is that if they are not properly UV protected, your eyes will open wider because the intensity of the sun is mitigated by the colored glass - however, at the same time, it will allow more UV light to enter your eyes, without protecting your eyes.

You can use the MK350 devices to test sunglasses. From the two MK350 captures on the right, you can see the dramatic reduction of UV region (380-400) when using properly coated UV protected Sunglasses. We should note that UV protection is not only offered in sun glasses but can be coated onto clear glasses as well.



MK350 pointed at Sun



MK350 pointed at Sun through Sunglasses

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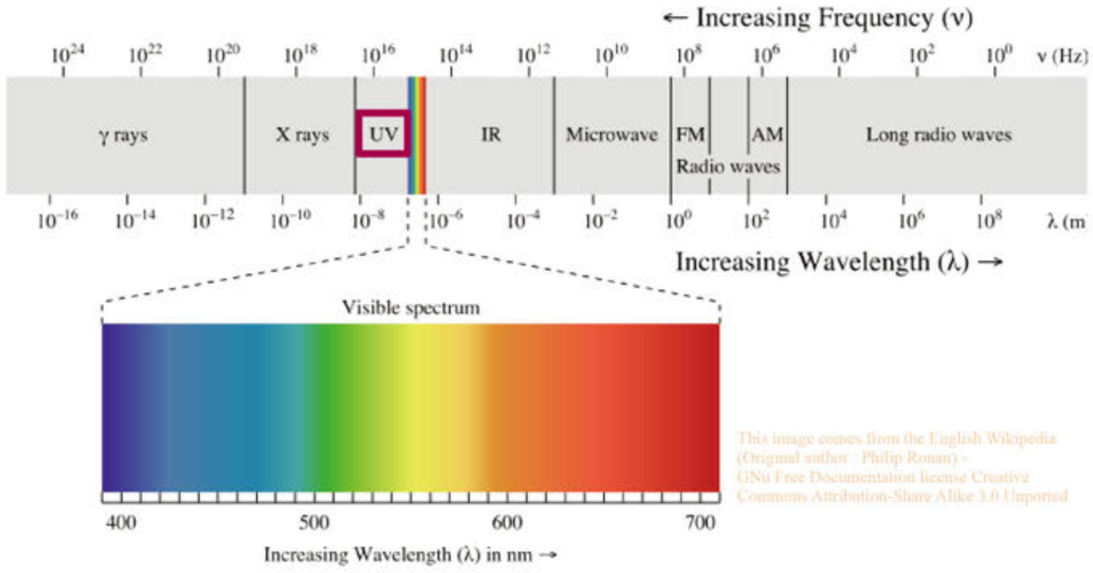
Light Health and Safety

CFL UV light

If you remember, Fluorescent Lights use UV radiation to excite the phosphor coating inside the tube. Most of the harmful UV light is absorbed by the phosphor (UVC), but a small amount of UV light in the higher UV region can be seen (UVA 380-400) by the MK350.



This image comes from the English Wikipedia (Original author : Philip Ronan) - GNu Free Documentation license Creative Commons Attribution-Share Alike 3.0 Unported

See article below

http://ee.ret.gov.au/energy-efficiency/lighting/incandescent-light-bulbs-phase-out/health-questions/minimising-uv-light-exposure-artificial-lighting

Note:

The range of UV Light is actually 10 nm to 400 nm, but the MK350 only can measure down to 380 nm - and so it only measures only the very top end of UV radiation. Suntan lotion protects against harmful UVB radiation whose wavelengths are 280 to 315, which are too low for the MK350 to detect. All this is to say MK350 cannot speak to UV protection devices under 380 nm.

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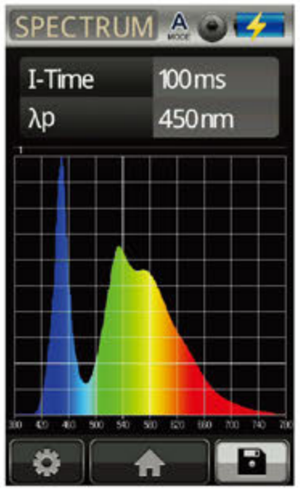
Applications

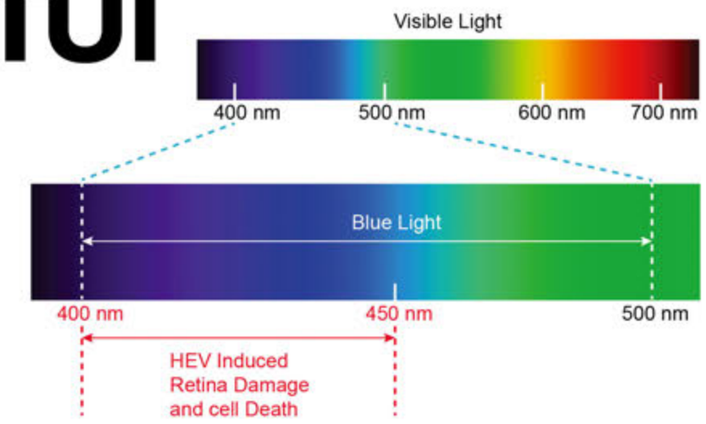
Much has been discussed about harmful "Blue Light", which refers to the visible blue region from 400nm - 450nm (shorter wavelength region of blue). It is also referred to HEV (Harmful Energy Visible) light and is under suspicion of causing cell damage in the retina and Age-related Macular Degeneration (AMD). Also, post-cataract surgery patients are more exposed to HEV since part of the lens, which yellows with age, is removed and can no longer effectively absorb the HEV blue light (yellow is blue's complement).

Exposure to HEV at night is also mentioned in suppressing Melatonin suppression (sleep hormone) causing sleep disorders by disrupting our circadian (24 hr) rhythms. Anything that is designed around LEDs, TVs, Computer Monitors, Light Bulbs all have the potential of exposing you to HEV light. The MK350 can easily reveal HEV on the color spectrum.

http://www.visionmonday.com/business/labs/article/protecting-eyes-from-bad-blue-light-vm-090913



Measuring Harmful Blue Light



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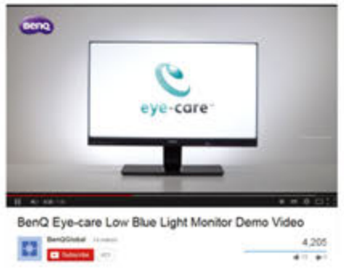
Applications

LED monitors, turn down the blue

The image below was taken with MK350S using the uSpectrum PC software. MK350 shows a significant reduction in HEV intensity simply by turning down the blue color tones in the monitor's color adjustment panel. The monitor may appear distractingly yellowish at first, but your eyes will quickly get accustomed to it.



Blue Light filtering products include Sunglasses that block out some of the HEV light. There is a computer monitor screen filter and even a low blue-light monitor.

http://www.youtube.com/watch?v=B8JrVESRcJk

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Measuring Flicker

Flicker is the problem certain lights have, exhibiting a subtle pulsating or strobing effect, most of the time barely noticeable by the human eye - however, more organizations are paying attention to flicker because it is being implicated in triggering a host of health related issues such as **epilepsy attacks, migraines, fatigue, reduced visual task performance, distraction and visual impairment.**

The source of this problem is the power current, particularly a conflict with the mains (from the outlet) and the power supply (of the light). Dimmers also induce or increase flicker. All lights running on AC power have this problem to a certain degree - Fluorescent lights had long been most criticized for high flicker before more recent advances . Now LEDs are also beginning to exhibit the same symptoms. LEDs further complicate the issue with their changing power needs that come with temperature fluctuations.

LEDs should be equipped with what is called an LED driver - it sits between the power supply of the light and the light itself. It's main function is to regulate or maintain a constant voltage to the LED - a well designed driver will adequately mitigate the problems of flicker. If an LED is equipped with components for other types of lights (e.g. transformers), this will also cause flicker problems.

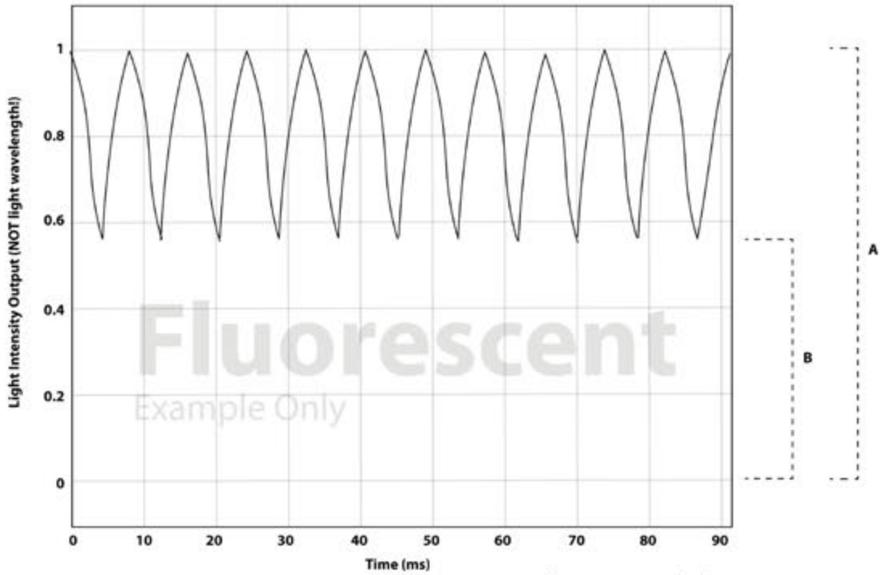
The MK350D is able to accurately measure flicker percentage from 1~100%. 0% is a pure uninterrupted continuum of light (no flicker). 100% is when there are complete breaks or 0 light anytime in the wave.

Dimmer

Busch-Jaeger - CC-BY-SA-3.0

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/poplawski_dimming_lightfair2012.pdf

MK350D

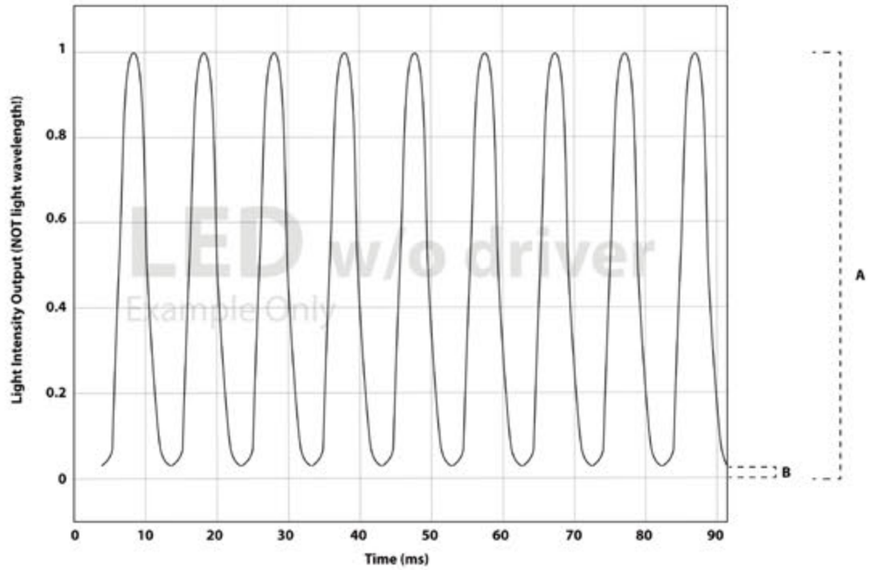


A-B/A+B = 29% Flicker
1-0.55/1+0.55=0.29

Calculating Percentage of Flicker

(these waves are NOT light color waves, but light intensity waves)

A-B/A+B = 96.1% Flicker
1-0.02/1+0.02=0.961



A good **LED driver** adequately regulates power fluctuations and manages LED power needs, reducing flicker.

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State and Light Energy agencies are already beginning to address this serious problem with draft regulations in progress (as of this writing 2/2014). The Russian government, after reviewing exhaustive studies, has implemented a ban on LED devices with high flicker rates.

Organizations such as Energy Star, IEC, IEEE, EPA are all considering Flicker standards at the time of this writing (02/2014).

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Lighting Road & Traffic

Measuring LED Degradation

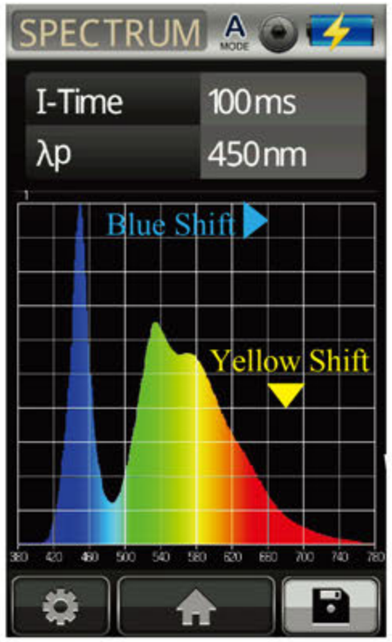
Yes it's true that LEDs can last up to 50,000 hours and this means over 11 years of night time service from LED street lamps. However, total lifetime and useful lifetime are two completely different things for LED lights. LED light quality inherently degrades in color and luminescence over time and when its "useful life" as a street light is over, there can be no compromise - they must be replaced. The challenge is how to monitor and maintain those LED street lights, especially if they are located in rural, even desolate highway areas. This is where the MK350 devices are especially important in practicality and convenience. Not only are they very portable, these devices can auto capture and log data over time, which could be very convenient for equi-spaced street lighting.

CimitryG - CC-BY-SA-3.0

LED degradation is due to heat that passes through the LED, and we know that heat can adversely affect materials (e.g. incandescent filaments). When LED light quality degrades, you can assess where the problem lies by looking at the color spectrum - most LEDs have a Blue peak and a Yellow peak - the Blue is due to the light emitted from the semiconductor - the yellow is the light emitted from the Fluorescent film (together they make a white light). When there is degradation, what we see in these spectrums are a red-shift, where the blue peak moves to the right toward the red - it is a probable indication that the semiconductor material is changing. It was also mentioned that the yellow Fluorescent can also degrade, shifting downwards in the spectrum (losing intensity).

This degradation is also a very serious concern for LED traffic lights where color is tantamount to driver safety. Another issue is weather - high temperature climates can also exacerbate degradation. Yet another issue is that, as difficult as it is to predict LED color, it is as difficult to predict LED degradation. These are all reasons that a portable LED light meter like the MK350 devices for field observations are indispensable tools.

A few ways to alleviate heat related degradation issues is to make sure you obtain good materials for your semiconductor dies and also implement well designed heat sinks to dissipate heat efficiently.



A Wintery LED Issue

Tiverton UK - CC-BY-SA-2.0

Conversely, LED street lamps and traffic lights have a heat problem in the Winter too. But it is the lack of heat that is the issue - LEDs give off heat but much less heat than both Incandescents and Fluorescents - and this leads to snow and ice build-up on street lights.

In this case, heating circuitry must be built into the luminaires to supplement heat to melt snow and ice. In certain regions of the world, there are very wide swings in hot-cold temperatures and both heat dissipation and heating circuitry must be built into the LED street light/traffic light luminaire.

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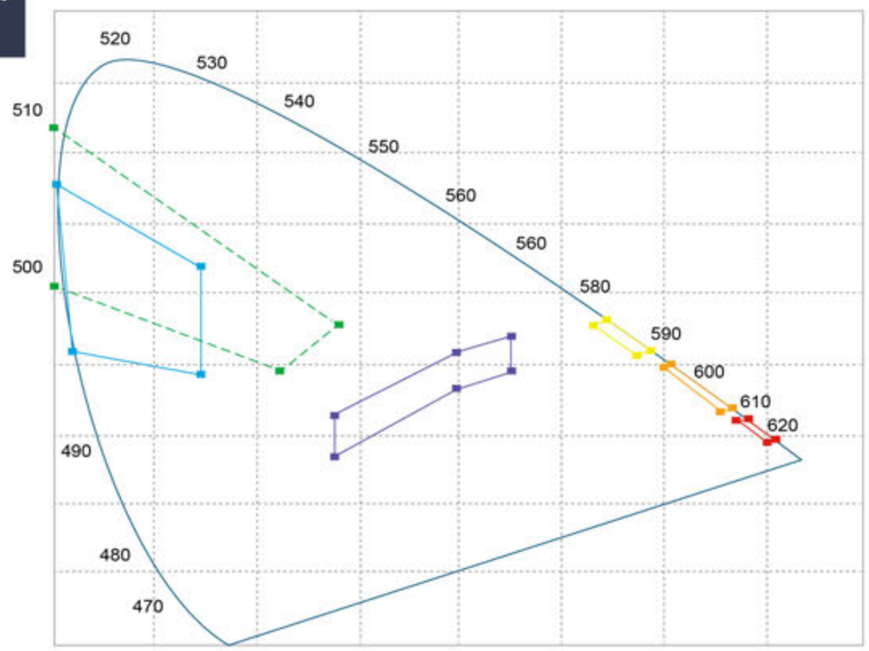
Measuring Traffic Lights

In most developed countries, it is critical to maintain proper color quality for traffic lights . Traffic lights using LEDs must be carefully monitored as gradual shifts in color over time could result in significant issues in color perception as daylight changes (due to time-of-day,) cloud cover and air pollution.

In the US, the ITE (Institute of Traffic Engineers) sets strict guidelines and regulations for color compliance.

Below is a sample Color Space with Bin markings for traffic light color guidelines. The MK350S has Bin Rating tools to help assist these organizations in procuring appropriate colored lighting.



Measuring Light in Hospitals

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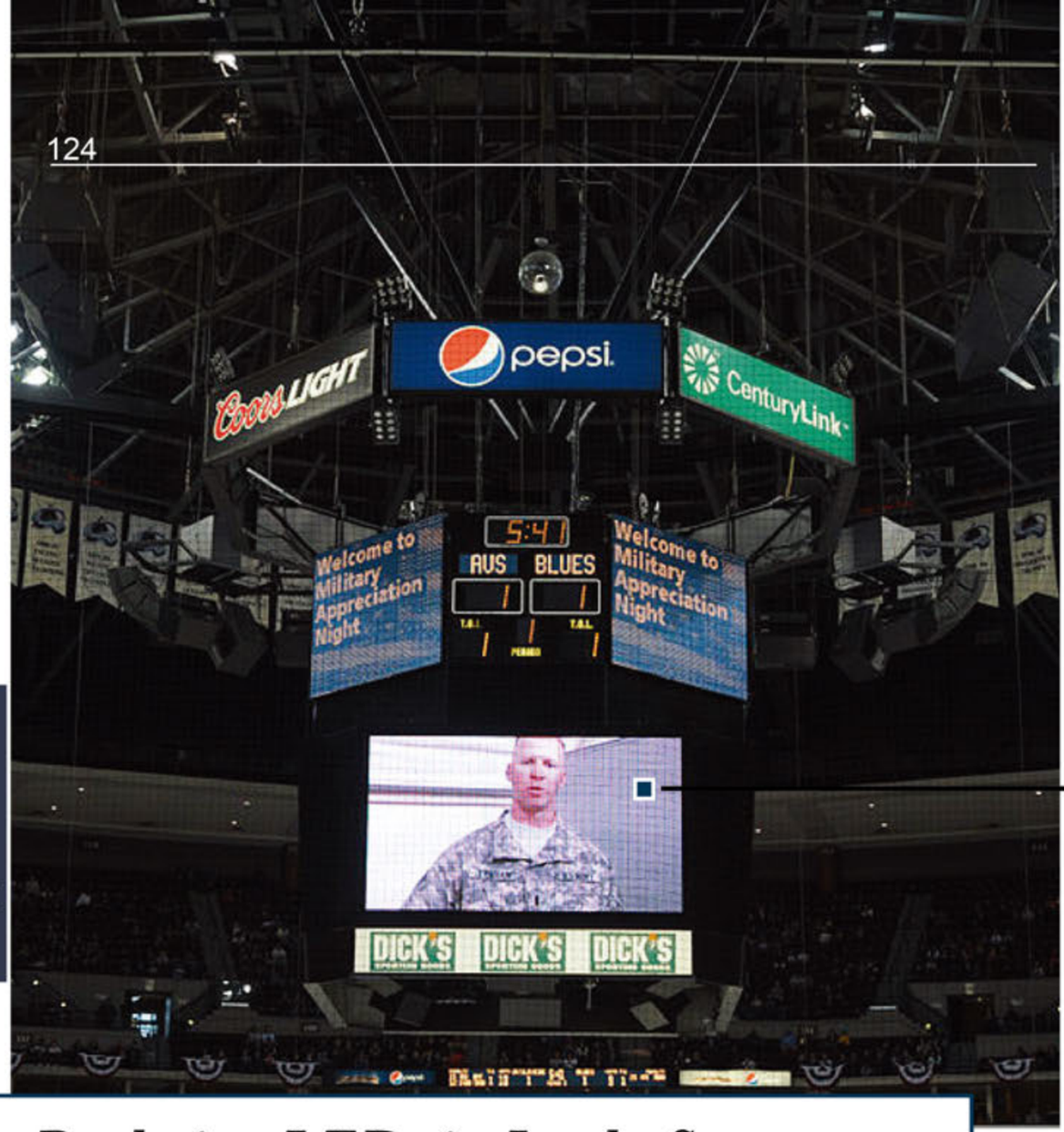
It is important in pharmaceutical environments to make sure high LED CRI (color rendering) can render pill, tablet and label colors appropriately to reduce mishandling and problems in pill identification. For the same reason, it is important for senior and elderly homes to account for good CRI lighting. In other areas of a hospital, LEDs are preferred because of long-life - changing bulbs frequently results in loosening of dust from the ceilings.

Surgical Lights

As LED technology has evolved with more reliable CRI, CCT and LUX specifications, there has been an increase in LED surgical lighting as a cost saving, low-maintenance option to Halogen based lights. In addition, the very low heat generated from LED lighting reduces tissue necrosis. However, when manufacturing or purchasing surgical LED lights, it is important to check CRI values, as it will determine proper color rendering for intricately visual procedures.



Replacing LEDs in Jumbo Screen

More recent Jumbo Screen / Jumbo Tron wall-sized monitors are turning to LED based display. These screens are made up of groups of Red Blue Green LED bulbs in the thousands. Each group makes up a pixel of information like on a TV.

It then uses Color Mixing strategies to vary each group of pixels to achieve the right colors in the right areas of the screen. When these LEDs begin to degrade or when they fail, they must be replaced. However, with the unpredictability in LED light color, it is necessary to pay attention to the light quality of the replacement bulb and an MK350 device is a convenient device to do to just that.

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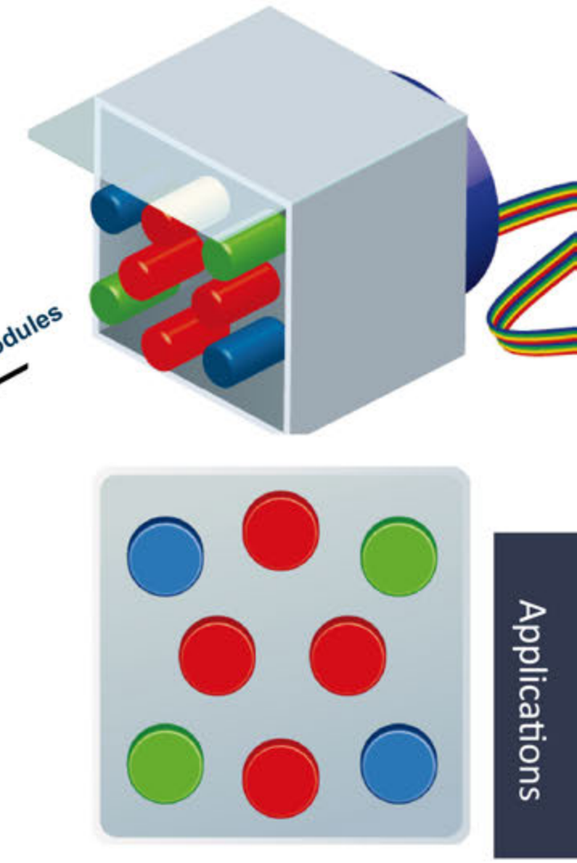

Replacement LED bulbs must match the old LEDs to ensure proper color and intensity match with the remaining LEDs and this can all be easily done with the MK350 device.

Otherwise, over time, the images on the screen will begin to show anomalies in color. On another note, you can use the MK350 to monitor degradation of LEDs as well, because this will also affect picture quality.

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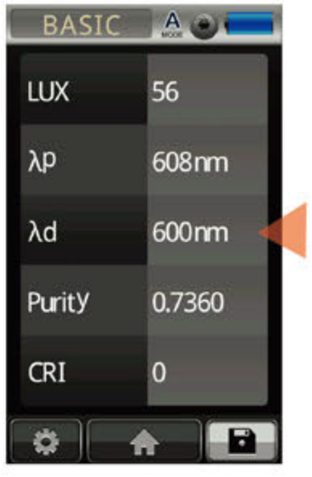
Testing and Calibrating LED Based Screens and Monitors.

Applications

Any LED based TV or Monitor manufacturer can use a light meter to test screen colors. You can even use Illustrator or Windows Paint to fill an area with a primary color and find the dominant wavelength by displaying λd on the Basic List.



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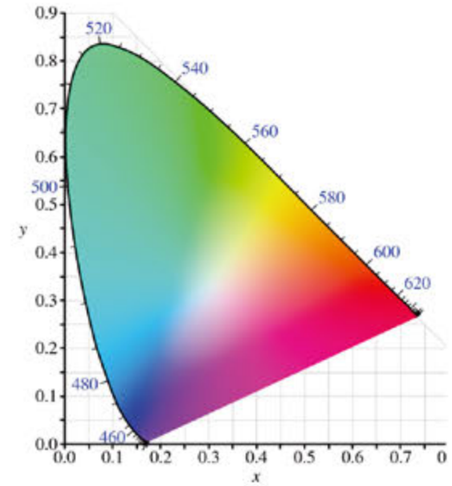

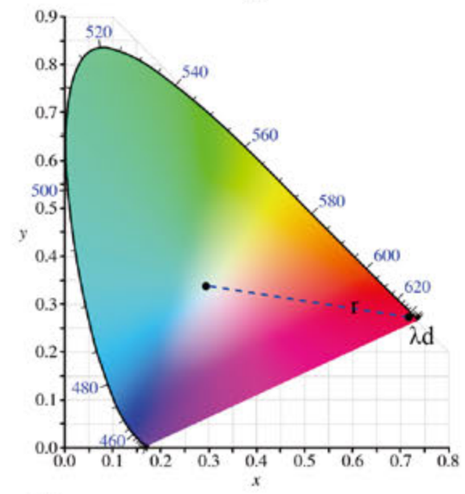

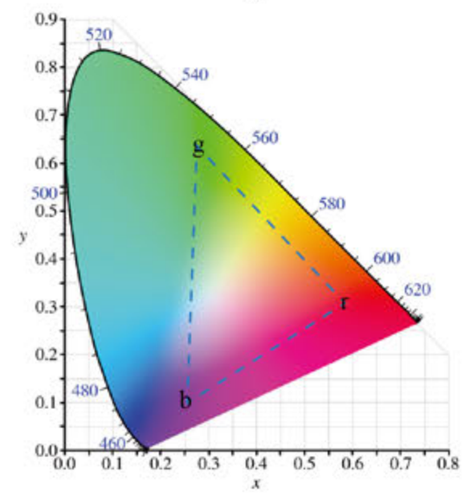

λd and Purity

You can use the MK350 to test the color range of any LED based monitor. As you know, the CIE 1931 chromaticity diagram represents all the colors that we can see. However, an LED monitor is only capable of displaying only a subset of those colors. One monitor brand might be able to display a larger portion of the area. How do you check?

First establish where the Red, Blue and Green points are for your monitor. Show a pure red color on the monitor (Windows Paint) and take your MK350 and hold it up to the screen and take a reading with the Basic List showing the dominant wavelength (λd). If you draw a line from the white point (.33, .33), and extend it to the furthest contour point, it will be λd. This should tell you how true your reds are on your monitor. (Note: your monitor should be adjusted to Normal color tones)

Second, do the same for Green and Blue and check their λd values. Then draw a line between the three points. The area within this triangle are all the colors that this monitor is capable of displaying - as you see there is alot of visible color that it will not be able to show.

Applications

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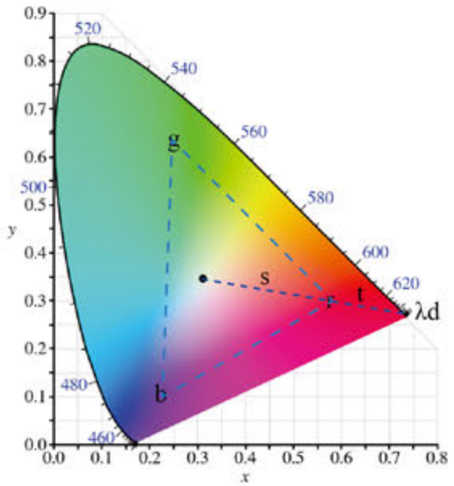
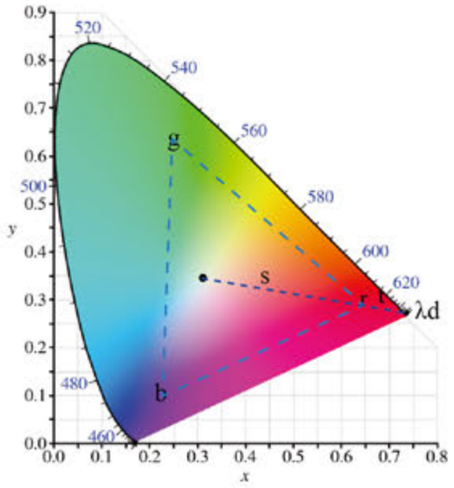


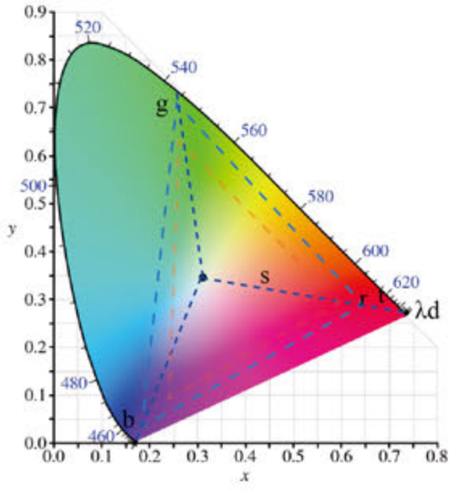
Now, let's look at another measurement. It's called "Purity". Purity is a percentage that is:

s/s+t = Purity

Purity tells us how close your color is to the outer edge which represents our pure colors.

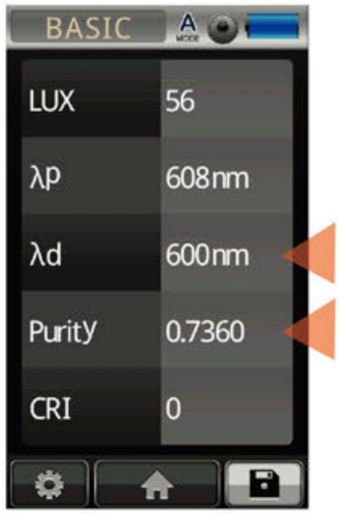


Now, let's say that the purity of the red color on another monitor is larger. What this is telling us is that the RGB triangle will be larger and thus, we are able to see more of our visible colors.

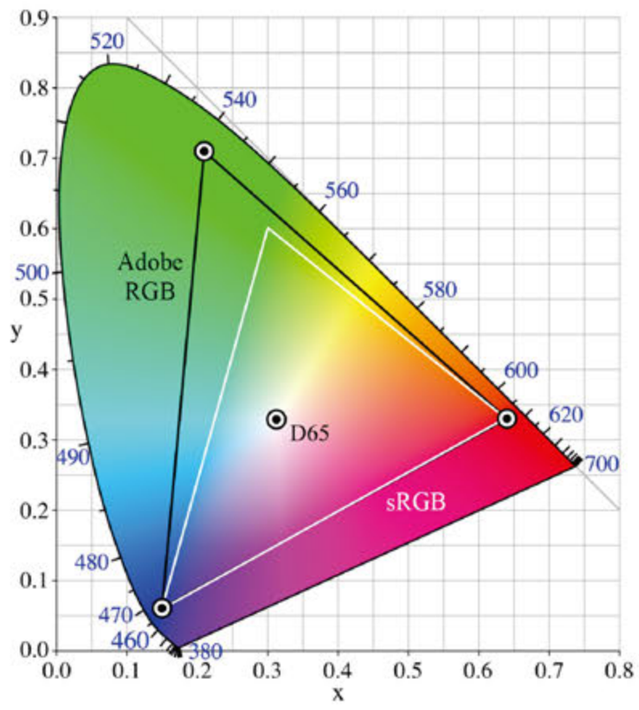


If the Purities for the greens and blues are also larger, our triangle would be larger and the monitor would be able to display even more visible colors than the other monitor.

All this is to say, the larger the purity, the better.



sRGB, AdobeRGB



Wikipedia Creative Commons Attribution-Share Alike 3.0 Mbearnstein37

If you are testing a monitor or screen device, it will probably be using a specific Color Space. With most monitors you will find that they comply with the sRGB color space. This is indicated within the white triangle (left). It means that an sRGB monitor can only display colors within it's triangle borders, which also means that there is alot of visible colors that it cannot display. You can then use your λd and Purity values to see how well your monitor's triangle fits within the sRGB triangle.

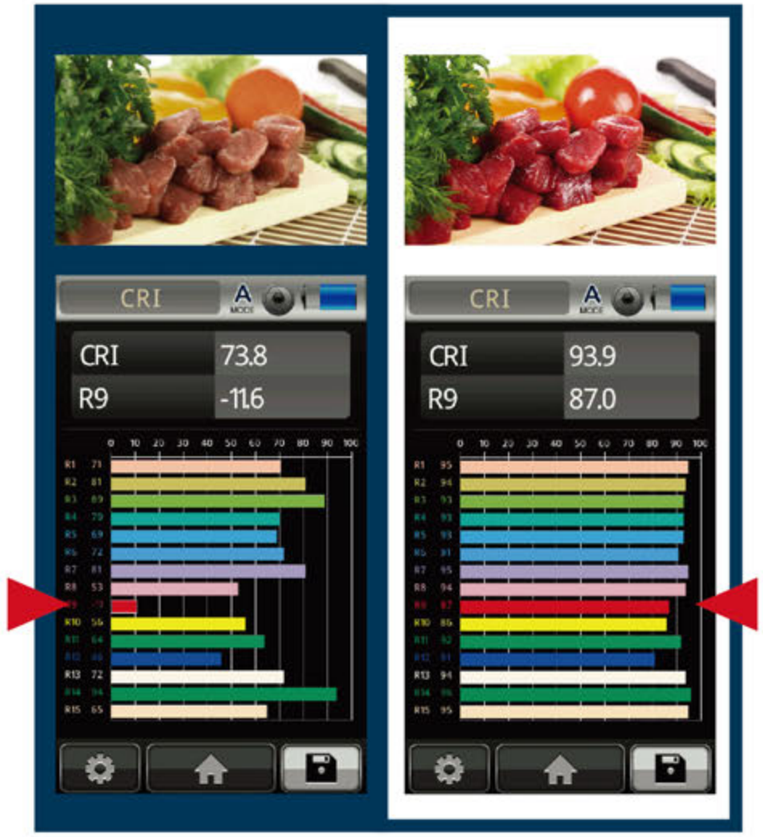
Adobe RGB is another color space that monitors and printers can use. Notice it's triangle is larger and thus can display more colors than sRGB.

Lighting Store Display

Importance of CRI

CRI (color rendering index) or the ability of a light to properly render colors, such as reds, greens, and blues, is important in store display design, especially when using LEDs and Fluorescents. The sun is the gold standard for CRI because it has a full, even spectrum of colors and gives us the vivid colors that our eyes are used to seeing - so a CRI value of 100 represents the Sun and any thing less is a measure of how close it comes to the Sun.

The CRI values are 15 color ranges, R_1-R_{15} - each range tells us how much of each color is coming from the light source. There is a general "CRI" value itself and it averages R_1-R_8 - but if your "CRI" value is 100, it could be misleading if your are looking at red, as in fresh meat. To measure the value of reds in your light you should really look at R_9. As you see from the two pictures (right) a higher R_9 value renders the red meat more red.



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Which oranges *would you buy?*

To really see startling differences in store display and CRI, see the video below at about the 25 minute 16 second mark.

http://www.youtube.com/watch?v=tfK_FF-4aDI

Watch a Video

Note that CRI for Incandescent lights are most likely to show favorable CRI (over 90) because, like the Sun, it is a Black Body Radiator and displays a similar spectrum of colors.

Note that the Basic and Compact versions do not have the CRI bar chart but can show the "CRI" value (R_1-R_8).

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Lighting Academics & Research

MK350 is being used at Universities and Colleges as an indispensible teaching tool, for understanding Light, Color and Physics. Understanding light physics is about complex mathematical functions and computations and the MK350 allows teachers to train and test students by comparing student computations with MK350 results. Thesis projects also take advantage of MK350 uSpectrum software and software developer's kit (SDK) for research.

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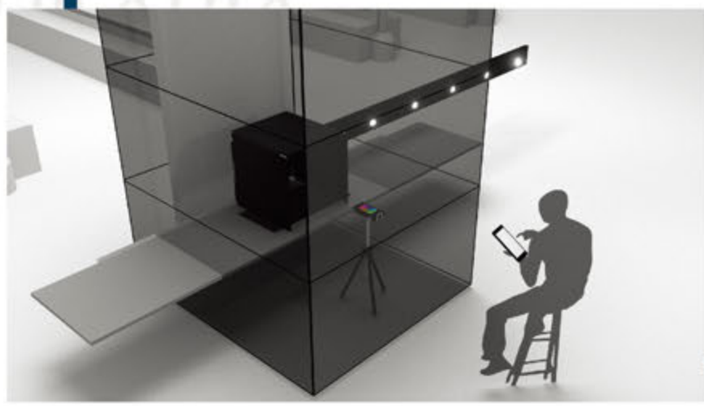

MK350's ability to capture, record and compare data is one of the great advantages for researchers gathering information for thesis projects. Wireless facilities and software developer kits make the MK350 a versatile option for assorted testing environments.

uSpectrum PC software and SDK (Systems Developer's Kit)

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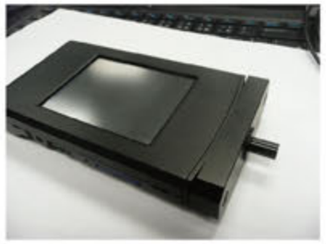
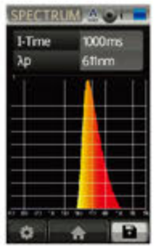
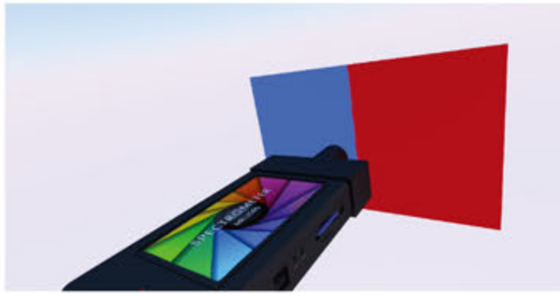
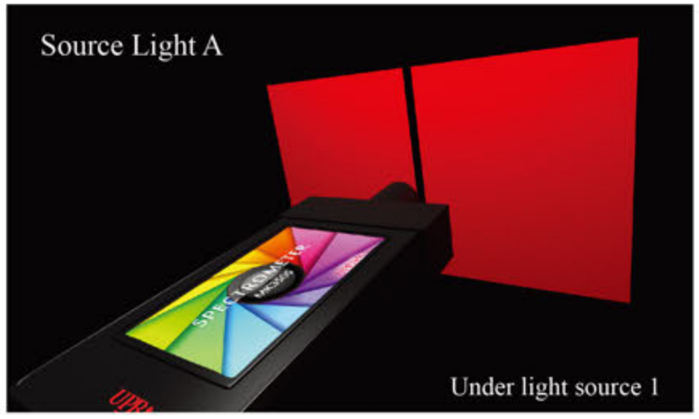


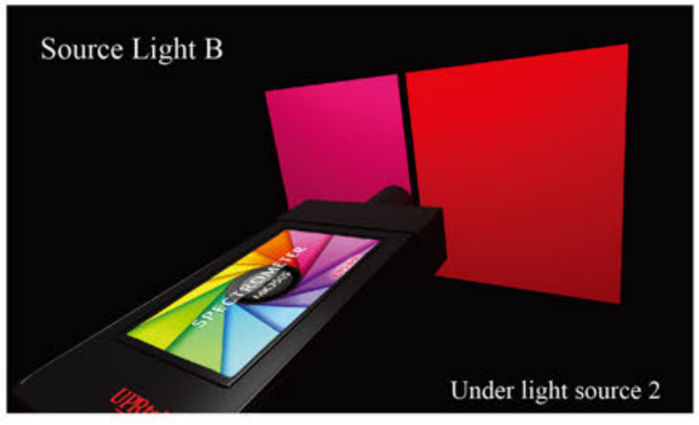


Current Research
Measuring Surface Colors

MK350 is also being researched as a viable tool for measuring surface colors (as opposed to only light source). This has many ramifications in the market for standardizing and validating color matches for printed material, fabric color, component color uniformity, logo color compliance. This also has ramifications for studying Metamerism.







Metamerism

When comparing two color patches under one light source, the colors may match - but when you try it with another light source, they fail to match. This is an optical phenomena called metamerism. A more practical example is where you pick out a shirt and pants in a department store because they have matching colors - but when you wear it outside under daylight, the colors do not match anymore. The MK350 may be able to analyze this phenomena and come to understand how light spectrum and surface reflectivity cause these problems.

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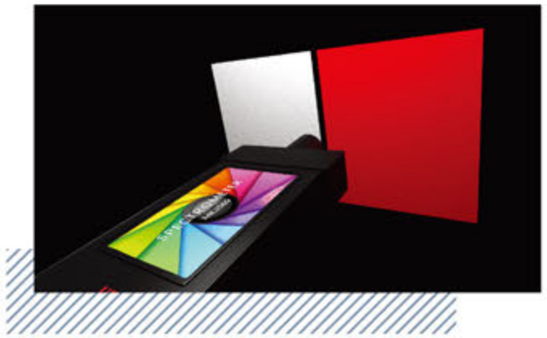
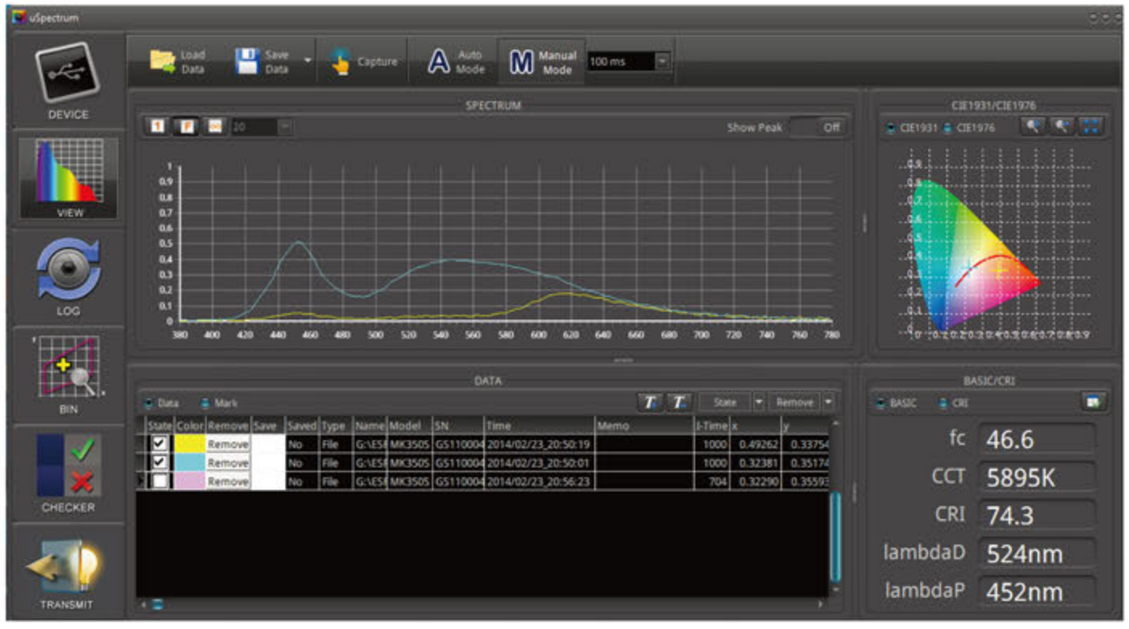
Measuring surface color varies widely with the source light. Academic Research is under way to determine if using spectrums from standard white baseline juxtaposed againt a color patch can be mathematically combined to come up with a standardized color, in spite of the type of light source.



Information is courtesy of Professor MeiJun Lo of the Shih Hsin University (Taiwan)



The above color spectrum captured a white baseline swatch (blue line) and a red test swatch (yellow line) under an LED light using a test lens tunnel accessory (see next page).

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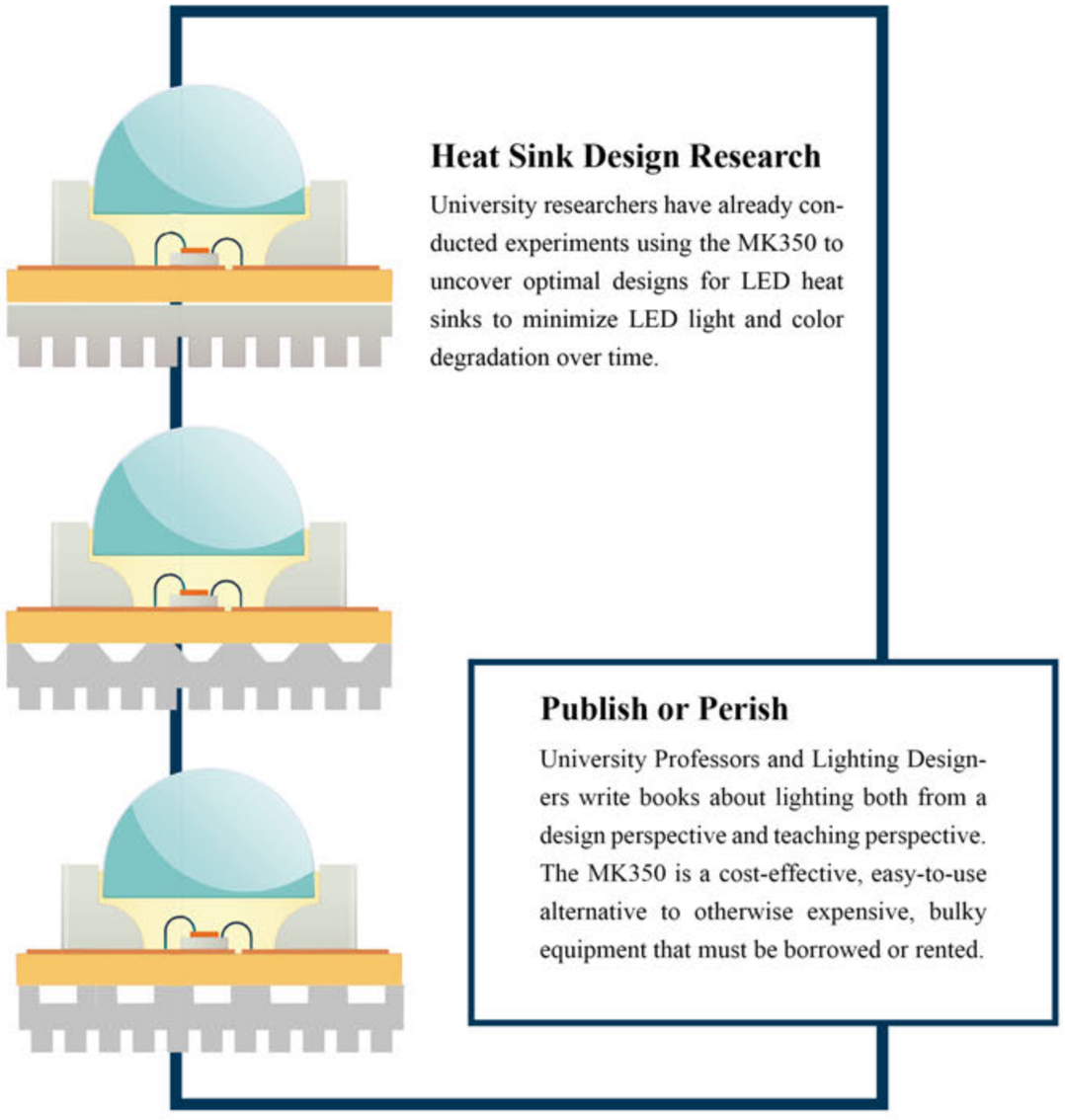
Measuring colors on a surface with an MK350 device as shown (right) will let too much peripheral light in. Because the MK350 performs Cosine Correction your results will show a spectrum closer to the dominant light source. Trying to block out the peripheral light by pressing the lens up against the surface will block out all light and will only produce results for black.

UPRtek is currently researching accessory devices as shown right to block out peripheral light while capturing only the surface area in front. However, even with this procedure, you are still at the mercy of the source light colors.

Being able to measure surface colors will help companies monitor their brand colors, especially in the outdoors, where sunlight is apt to oxidize paints/inks and fade colors over time. Many companies are especially cognizant of displaying true brand colors and will be quick to replace them when color degradation falls below standards.



Heat Sink Design Research

University researchers have already conducted experiments using the MK350 to uncover optimal designs for LED heat sinks to minimize LED light and color degradation over time.

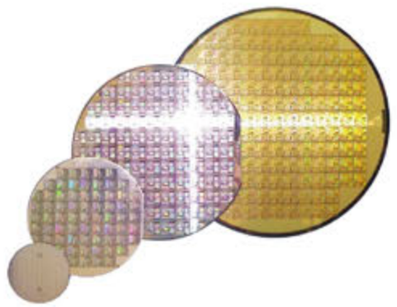
Publish or Perish

University Professors and Lighting Designers write books about lighting both from a design perspective and teaching perspective. The MK350 is a cost-effective, easy-to-use alternative to otherwise expensive, bulky equipment that must be borrowed or rented.

Performance of Light Emitting Diode on Surface Machined Heat Sink
S. Shanmugan*, D. Mutharasu, O. Zeng Yin
Nano Optoelectronics Research Laboratory, School of Physics, Universiti Sains Malaysia (USM),11800, Minden, Pulau Penang, Malaysia

LED Manufacturing Professionals

LED manufacturing professionals are people working in the three basic types of LED manufacturing companies.



The **LED Chip Manufacturer** produces semiconductor chips that come on wafers. This is an important process of mixing alloys and impurities (doping) to produce the final wafer product.

www.youtube.com/watch?v=AMgQ1-HdElM (www.microchemicals.eu)

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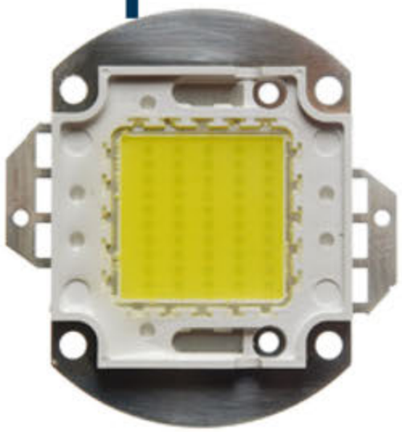

The **LED Assembly Manufacturer** receives wafers, and using mostly robotics, apply the appropriate circuitry (wiring) and cut the wafer into chips. These chips are tested for color and light properties (robotically) and at this point are classified and physically separated into bins. Then chips from one bin are mounted on a circuit board. Fluorescent film is also added. After further preparation, they are cut into individual circuit boards.

www.youtube.com/watch?v=SoCfcETd72Q (Formetcolnc)

The final process is done by **LED Bulb Manufacturers**. This includes applying the housing, power supply, driver and any other remaining wiring and componentry needed to finalize the bulb or luminaire for delivery to the end customer.

www.youtube.com/watch?v=ltqO3O8MMws (ChromaAutomation)

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Research and Development

Even though the assembly lines in all 3 types of LED manufacturing companies are equipped with robotic facilities for measuring light properties, there remains many ancillary applications where the portable MK350 devices remain an indispensable industry tool.

Research and Development in all three types of companies are using the MK350 in their test labs. Experimentation is a laborious, time consuming process taken up by collecting data, testing, comparing, and analyzing. Though these companies have sophisticated equipment (e.g. integrating spheres), the workflow for this type of preliminary research work is best served by the compact, portable MK350. It is said that margin in precision between a sphere and an MK350 is far outweighed by the immense practicality of the MK350.

The MK350 works with the uSpectrum PC software and that ultimately is the key to this type of work, providing full screen PC connectivity, with data logging, multiple item comparison, sorting and annotation - in addition, UPRtek provides dll libraries allowing companies to develop their own software to match their own testing facilities - some companies are even making customized MK350 fittings to semi-automate testing using MK350 auto-logging facilities.

Practicality vs. Precision

There are hundreds of thousands of LED components rolling off of assembly lines every minute and it is impossible to provide 100% quality-control for every single item. However, at certain points in the SOP, it is prudent to sample items periodically to ensure that processes upstream are performing as expected. This type of spot checking is easily and readily performed by the MK350. In addition, data can be easily logged for purposes of reporting and evaluating defect rates.

Quality Control

Lighting Exhibitions

All LED Bulb Companies create deep channels in the LED market through distributors, agents, wholesale and retail stores, all of whom need to compare and evaluate LED light and color quality as never before. Even end-users such as factories, libraries, museums, department stores will become more savvy about LEDs and agents must be prepared to validate LED quality offsite with a reliable, precision meter. These same meters are also proving invaluable at lighting exhibitions, allowing buyers to evaluate while sellers validate.

The big three manufacturing arms of the LED industry are not without occasional disagreements. The MK350 series is often used to settle differences in light quality between companies. In one case, an LED bulb maker used the MK350 color spectrum to reveal a flaw in the Blue peak, showing abnormal double horns, settling a dispute between semiconductor company and the assembly company.

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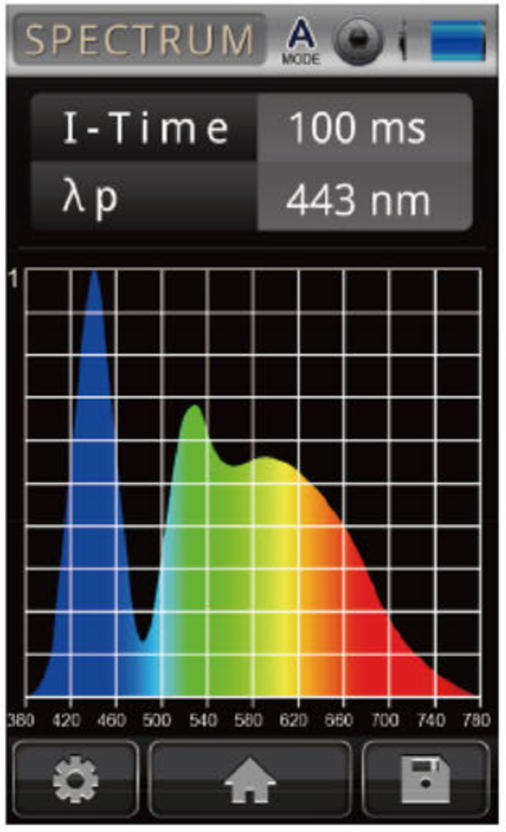

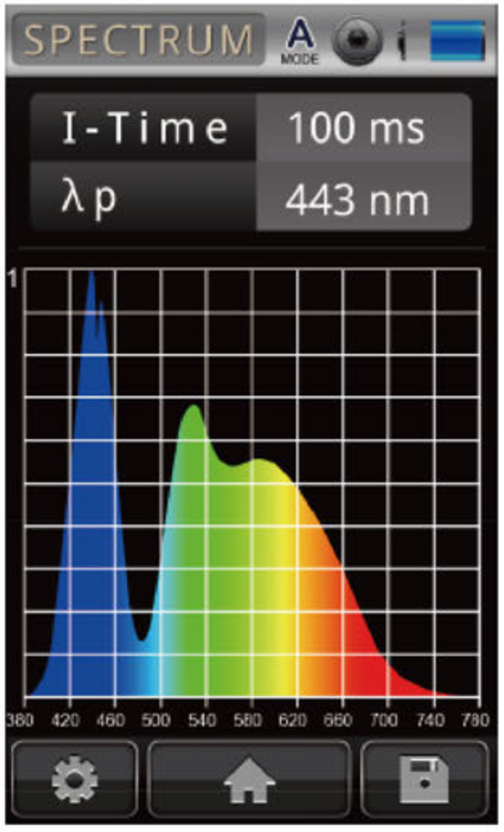

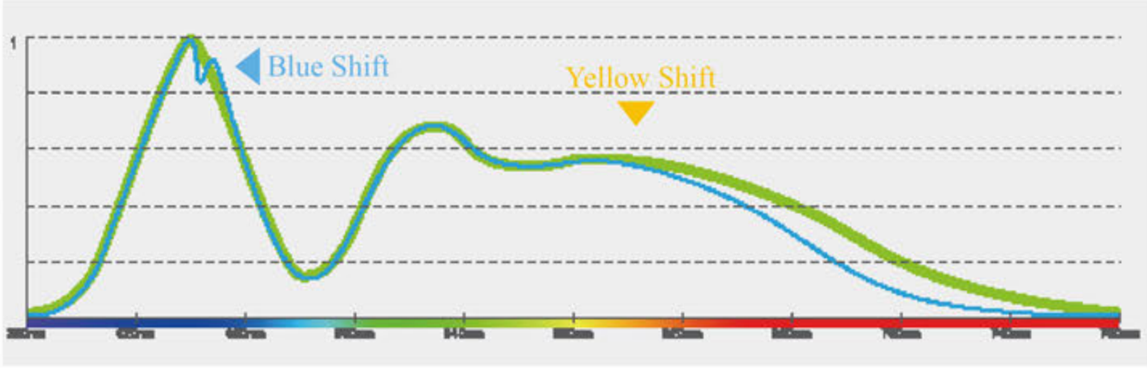

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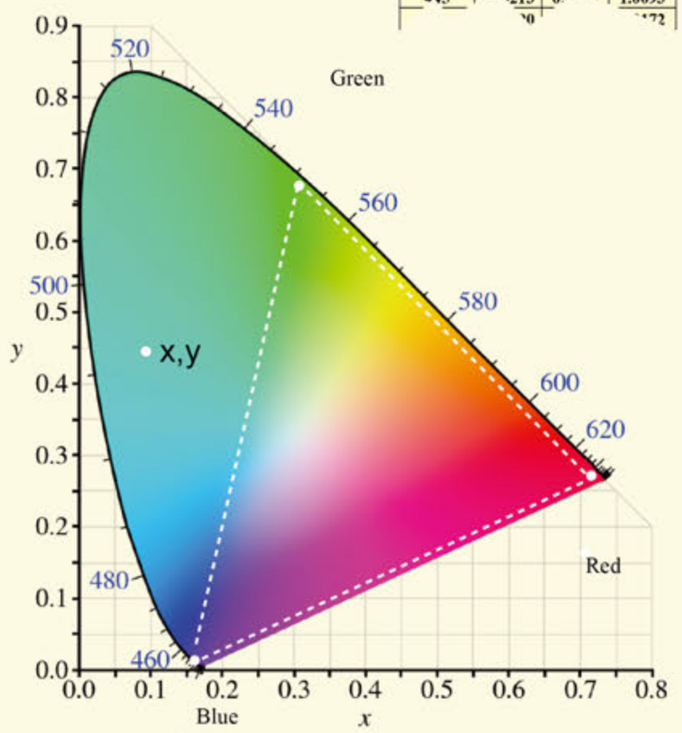
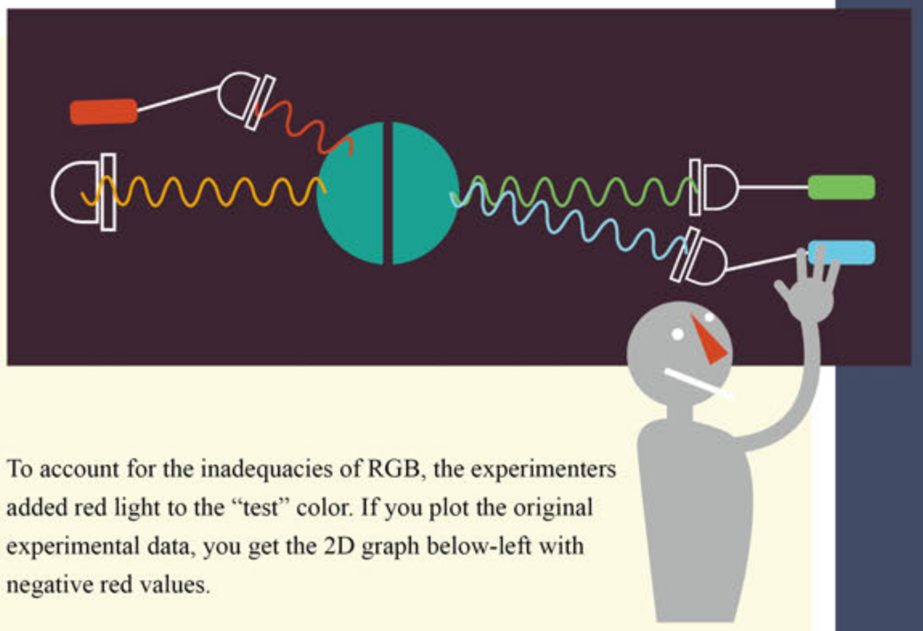
Appendix 1 - CIE 1931 In-depth

λ	r	g	b
380	0.0272	-0.0115	0.9843
385	0.0268	-0.0114	0.9846
390	0.0263	-0.0114	0.9851
395	0.0256	-0.0113	0.9857
400	0.0247	-0.0112	0.9865
405	0.0237	-0.0111	0.9874
410	0.0225	-0.0109	0.9884
415	0.0207	-0.0104	0.9897
420	0.0181	-0.0094	0.9913
425	0.0142	-0.0076	0.9934
430	0.0088	-0.0048	0.9960
435	0.0012	-0.0007	0.9995
440	-0.0084	0.0048	1.0036
445	[illegible]	[illegible]	1.0093

As convenient as a model RGB seems to be, alas, it's not perfect - RGB CANNOT reproduce all the colors we can see. Draw a triangle from our 3 pure colors of Red Blue and Green and you can see this - the area within the triangle are really all the colors RGB can simulate, which is obviously not all the colors we can see. There is a large area in the blue-green that humans can see but are not contained in the triangle. Why?

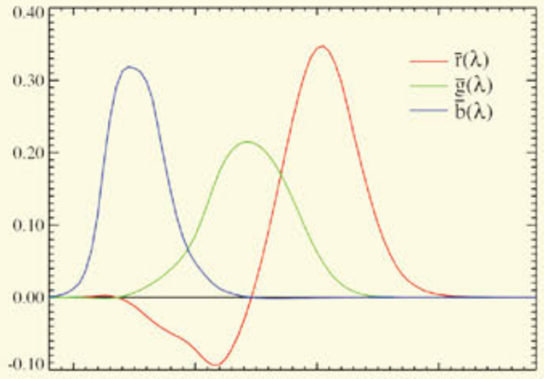
This is because the RGB additive model is not perfectly aligned with how we see colors.





To account for the inadequacies of RGB, the experimenters added red light to the "test" color. If you plot the original experimental data, you get the 2D graph below-left with negative red values.

Troublesome negative values for the Red



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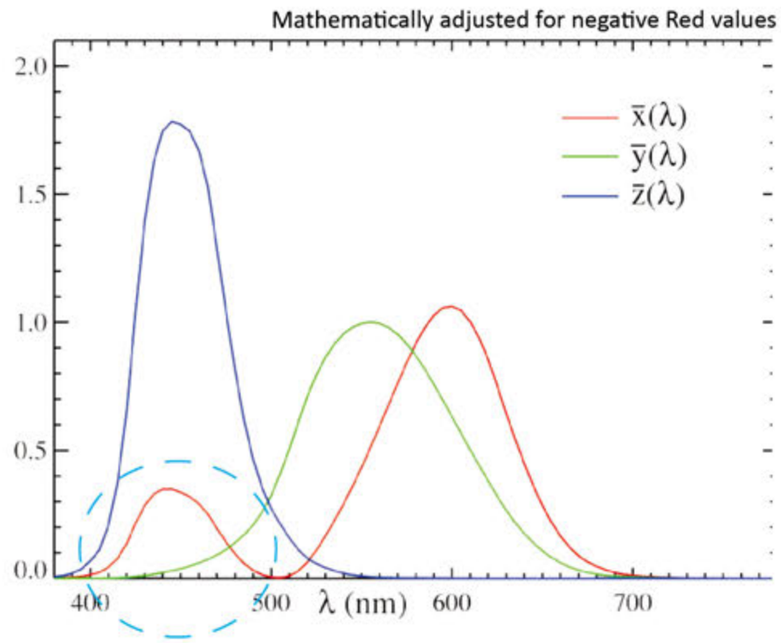
The smart people at CIE mathematically adjusted these negative values and came up with a new graph or the Color Matching Functions shown below. Notice that the red line that was below the axis (negative) now lies on top of it. Keep in mind that these new functions are still originally based on the RGB experiments.



The Color Matching Function chart data is then transformed further into what we call "X", "Y" and "Z" values (in capitals) - these values represent still another way in which humans see color, but they are still, in essence, tristimulus values derived from the original RGB human experiments. The transformation formula is shown below, using integral calculus - here we also must introduce I(λ), which is the intensity (or SPD - Spectral Power Distribution) of each of the wavelengths and λd represents the resolution or slice of each wavelength taken from the continuum (spectrum). The formula sums all the wavelength data into a single X, Y and Z data set.

$$X = \int_{380}^{780} I(\lambda)\,\bar{x}(\lambda)\,d\lambda$$
$$Y = \int_{380}^{780} I(\lambda)\,\bar{y}(\lambda)\,d\lambda$$
$$Z = \int_{380}^{780} I(\lambda)\,\bar{z}(\lambda)\,d\lambda$$

The CIE model capitalizes on this fact by defining Y as luminance. Z is quasi-equal to blue stimulation, or the S cone response, and X is a mix (a linear combination) of cone response curves chosen to be nonnegative. www.wikipedia.org - CIE 1931

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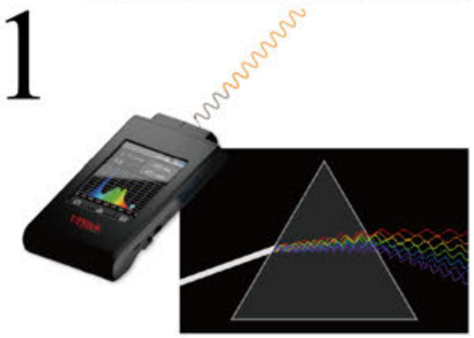
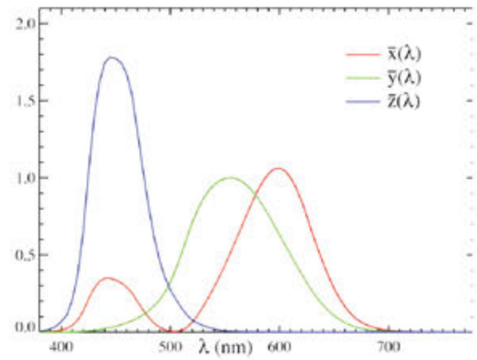
So let's go through the process again of calculating an x,y coordinate for a light source.

1) MK350 captures light and separates it into multiple wavelength data along with their intensities, 2) sends data through Color Matching Functions, 3) transforms that data into an XYZ point in 3D space (mathematically), 4) normalizes to Unit Plane (mathematically , and 5) plots it to an x,y 2D plane

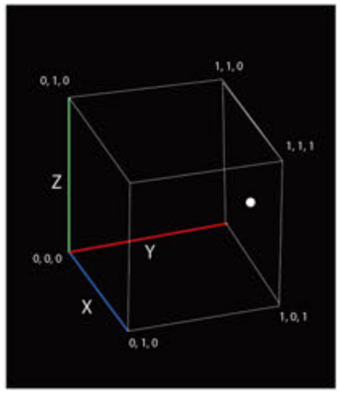
1 *Capture light, disperse wavelengths, record SPDs*



2 *Send each wavelength data through Color Matching Function*

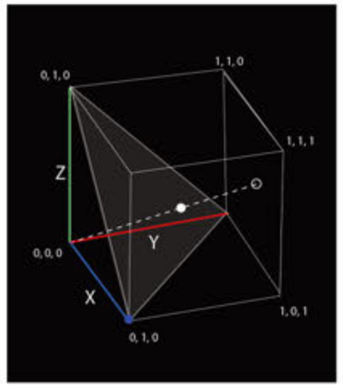


3 *Use Color Matching and SPD data to transform to a single point (represented by X, Y, Z in 3D space below).*



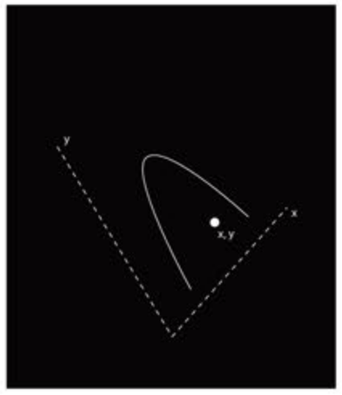
$$X = \int_{380}^{780} I(\lambda)\,\bar{x}(\lambda)\,d\lambda$$
$$Y = \int_{380}^{780} I(\lambda)\,\bar{y}(\lambda)\,d\lambda$$
$$Z = \int_{380}^{780} I(\lambda)\,\bar{z}(\lambda)\,d\lambda$$

4 *Mathematically normalize to Unit Plane (x+y+z=1).* ***Important*** *- the proportions of the 3 values have not changed so it still represents the same color.*



$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$

5 *Use the Unit Plane to make a 2D x,y coordinate system, and plot the x,y coordinates on the Color Gamut explained in the earlier sectons..*



Note that there still are some simplifications for the sake of explanation.

Artificial Lighting

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UPRtek

United Power Research Technology Corporation, an affiliate of the Phison Group, was formed in 2010, inspired to respond to declining net margins in the technology sectors.

United in the Power of elite Research Technology, the UPRtek mission is to avail inaccessible, exclusive science and technology to a broader market by reinventing them for practical use for everyday businesses as well as for individual consumers. In 2011, UPRtek released its first two brand products into the market – the UPRtek Smart Controller and the UPRtek LED Meter.

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