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Grow Light PAR Meter

Handbook by UPRtek

Grow Lights | Light Meters


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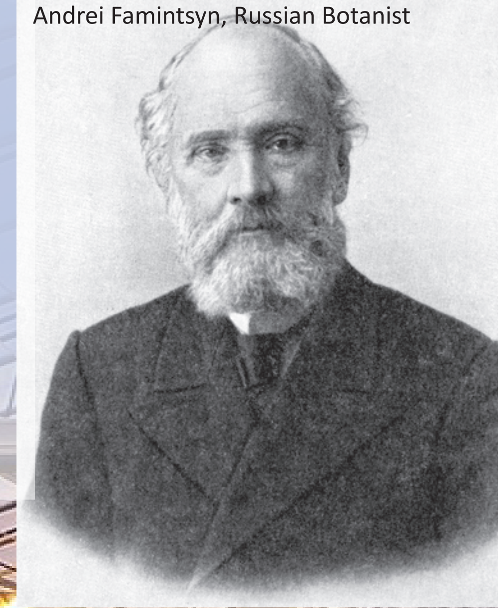
Introduction

Green Houses, Grow Lights and Light Meters Oh My!

It was always given that you needed sun, soil and water to make a seed grow into a plant. And I believed there was something magic about the sun's life giving light, that no light bulb could ever replicate. But in fact, light from a bulb is simply light, just like light from the sun. And as far back as the 1868, Andrei Famintsyn a Russian botanist discovered that, indeed, plants could demonstrate metabolic processes even under artificial light. But I dare to guess that those first few experiments produced anything but burgeoning results.

Andrei Famintsyn, Russian Botanist



Ever since, individuals and companies have been trying to uncover the secret sauce in sunlight that makes plants grow robust and healthy. And if they could replicate the Sun in plant-lights, or what we call "grow lights", it would have ramifications far reaching and globally significant.

Today's technology brings to "light" what Mr. Famintsyn didn't have access to. And we can use this technology to not only replicate the Sun's extraordinary magic, but possibly to exceed it, using the latest in light metering. And that means being able to see into light and dissect the main ingredients.

In this article we'll be discussing how "grow light" horticulture works and how a light meter is an invaluable tool to both researcher and growers.

UPRtek PG100N

Industry

Why even consider grow lights?

Image by Assimilatieverlichting CC BY-SA 3.0 Wikimedia Commons

Why even consider using artificial grow lights when there is plenty of sunlight to go around? First of all, as you know, there are areas on the planet that do not get even a sliver of sun during the winter months. And even where there is sun, winter is an inhospitable place to grow vegetation in many places. Also in certain areas, the terrain is unsuitable for agriculture, or land space is squeezed, impossible for large tracts of farmland. Even NASA is experimenting with artificial lighting and plant growth in the tight quarters or even on other planets.

Winter in many regions are inhospitable to agriculture. Image by Corey Coyle CC BY 3.0 Wikimedia Commons (with color modifications)

And that's why we have indoor horticulture and greenhouses, where you can control micro-climates perfect for growing - and this also means using grow lights. With new indoor farming technology you can also grow vertically, shelf above shelf, and floor above floor, a methodology called **Vertical Farming**. Think about the real estate saved by having a 20 floor indoor farm.

Greenhouses can provide adequate climate conditions for farming year round. Image by L T Hunter - Flickr: [1], CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=18279188

If this can be accomplished, just think of the ramifications. Fresh produce the whole year round that is local and straight off the vine. You might even be able to grow faster than traditional farming, using lights even during the night. Pest and pollutants can be more tightly controlled, and water can be more efficiently recycled and re-used than traditional farming.

Vertical Farming is a type of indoor horticulture that has shelves of plants stacked one above the other.

Image Courtesy of Taiwan HiPoint Corporation www.twhipoint.com

NASA horticulture experiments on potato plants using LED light.

So using lights for horticulture is a no-brainer, right? Actually there are still a lot of considerations. Let alone the trouble of building a greenhouse, there are also fertilizer, water, soil, seeds, lighting, heating/cooling, air flow and the costs associated therein. Even carbon footprint advantages are still under considerable debate.

Lighting for plants in vertical farming is placed underneath the floorboard of the shelf above

Image of Underground Growing Farm , London - Courtesy Valoya - www.valoya.com

The Market for Grow Lights

Some of World's largest Greenhouses are in the Netherlands

CC BY 1.0, https://commons.wikimedia.org/w/index.php?curid=130481 (with modifications)

Lettuce grown with indoor vertical farming system.
Image by Valcenteu CC BY-SA 3.0 (Wikipedia "vertical farming")

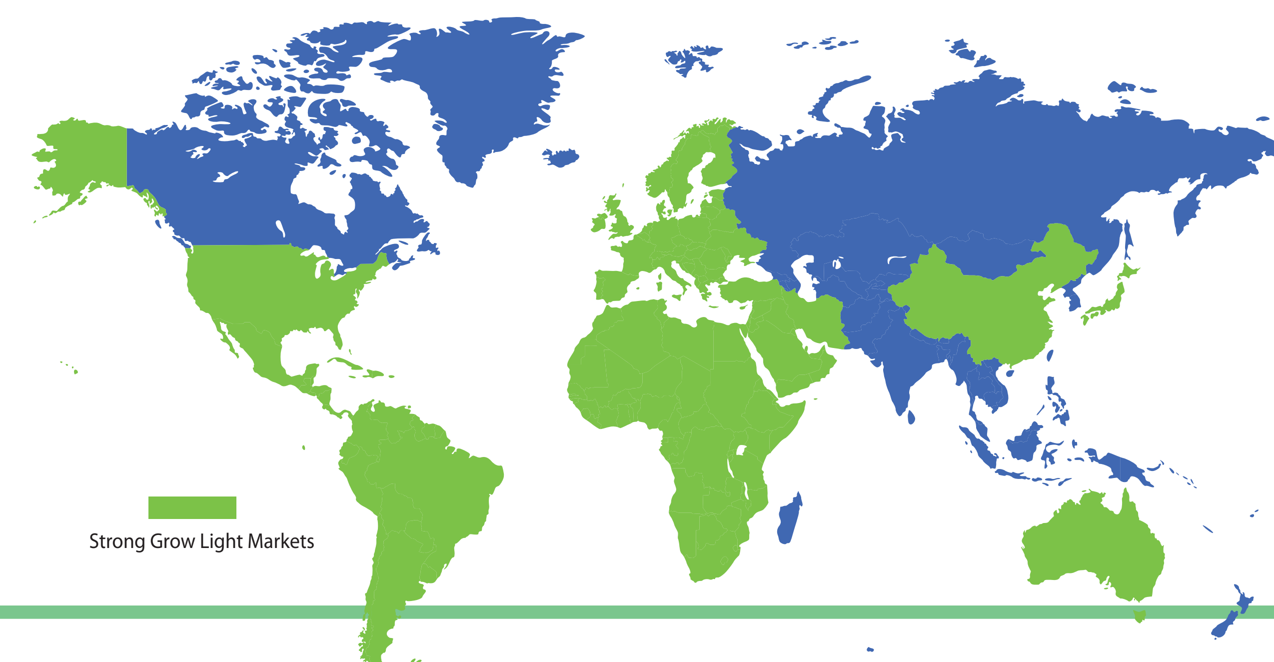
In spite of the ongoing debates surrounding the viability of indoor horticulture, there are businesses today running indoor farming operations and making a profit from it - and all indications point to a burgeoning trend. Most marketing data point to a rapid rise in use of grow lights between 2016-2022. Why? Because of improved indoor farming technology, government support, proliferation of LEDs, and the development of the CEA (Controlled Environment Agriculture) initiative, more operations are realizing the advantages of commercial greenhouses.

Although, it's still a small percentage of the total world farm produce, it's giving some regions a chance to grow where it would otherwise be difficult or impossible. Also, major light bulb makers are developing "grow light" products and are expecting a boom in indoor farming within the next 10 years.

In fact there are market studies that have grow lights reaching $4 billion by 2018 (up from $741 million in 2011).

All things considered, the potential of indoor farming is still intriguing. And who says you have to be a major farming outfit. Small independent or even personal indoor farming is becoming more and more popular.

Marketers seem to be focusing grow lights in the US, China, Europe, and Japan as the top players. Latin America, Middle East and Africa have also been mentioned frequently in other reports. Australia, Singapore has been mentioned by grow light producers. Of note in Europe, the Netherlands is taking much of the lead in greenhouse horticulture, where some of the largest greenhouses in the world occupy 10,526 hectares.

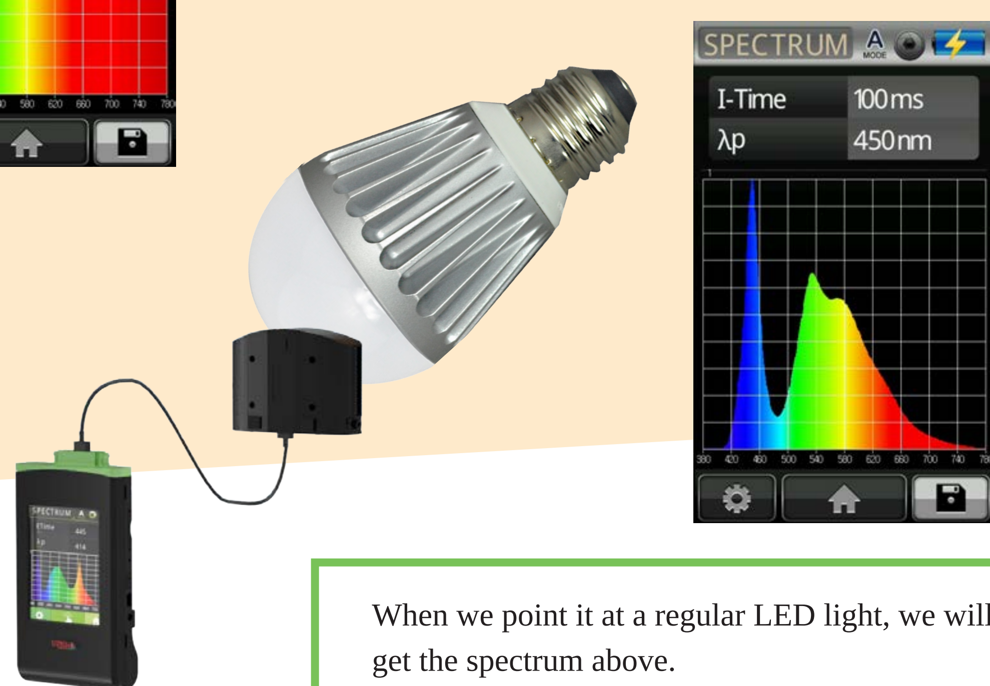


Sun v. Grow Light

What's the secret sauce in sunlight?

Image by Bigroger27509 wikimedia commons CC BY-SA 3.0

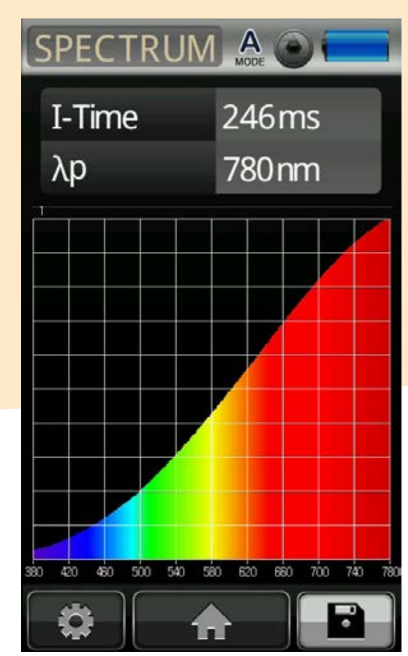
As we mentioned, light is light, no matter from the sun or from a light bulb. However, there are certain aspects that differ between the two. First, let's look at a color spectrum for Sun. We can attain this by use a light spectrometer. Point it at the sun and we get the spectrum to the left.



When we point it at a regular LED light, we will get the spectrum above.

The Sun's colors are a full spectrum of continuous rainbow colors, whereas the LED seems to be lacking in certain color areas. Some will argue, that full spectrum lights are more appropriate for plants who have evolved and adapted to sun light over millions of years - but the jury is still out on that one as we shall see.

Now let's use the spectrometer to take a brightness reading which will yield a brightness unit of measure called LUX. We can see that the Sun is generating much more brightness than the LED.



So from the start, we can see that color and brightness are the main differences. And if we could make light more like the Sun, perhaps we can achieve some results in artificial light induced plant growth. In fact, incandescent lights are said to be very much like the sun. But even though it is more of an continuous color distribution like the sun, there is still some color deficiencies. As well, one glaring problem with incandescent bulbs is that they require a lot of energy to generate enough brightness for a large greenhouse area and, of course, most of the energy is wasted through heat dissipation, not for light.

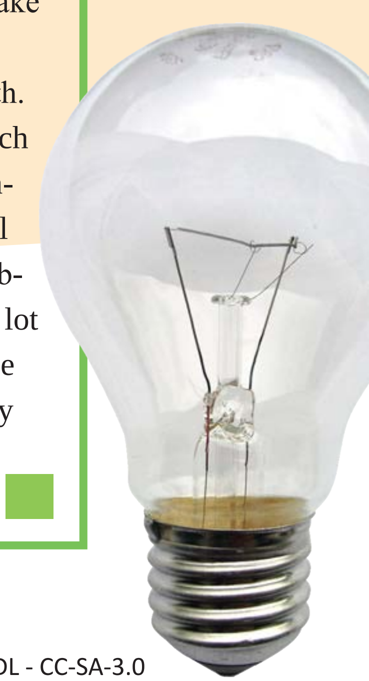


Image by KMJ, wikimedia commons - GFDL - CC-SA-3.0

Why a plant needs light

It's a basic high school science question, but let's still start with the basics and then go deeper.

Plants need light, like humans need food. Food is a vital nutrient that helps humans to grow and sustain our bodies. We eat meat or beans (protein) which become the material substance that make up our physical self (skin, hair , blood etc.). We eat things like pasta (carbs) that turn into sugars which are energy that is used as fuel used to take the proteins and grow our hair, nails, regenerate blood etc. (Disclaimer - the interplay between these nutrients is actually a little more complicated).

Similarly, plants need substance (materials) and they can get it from the soil and water. Like humans, they also need sugars as energy to transform the materials into stems, leaves, flowers and perform other metabolic processes. But plants can't eat sugar. Then where do the sugars come from? It comes from a process called photosynthesis, which uses sun light to kick off a reaction in plant cells that eventually results in sugar!

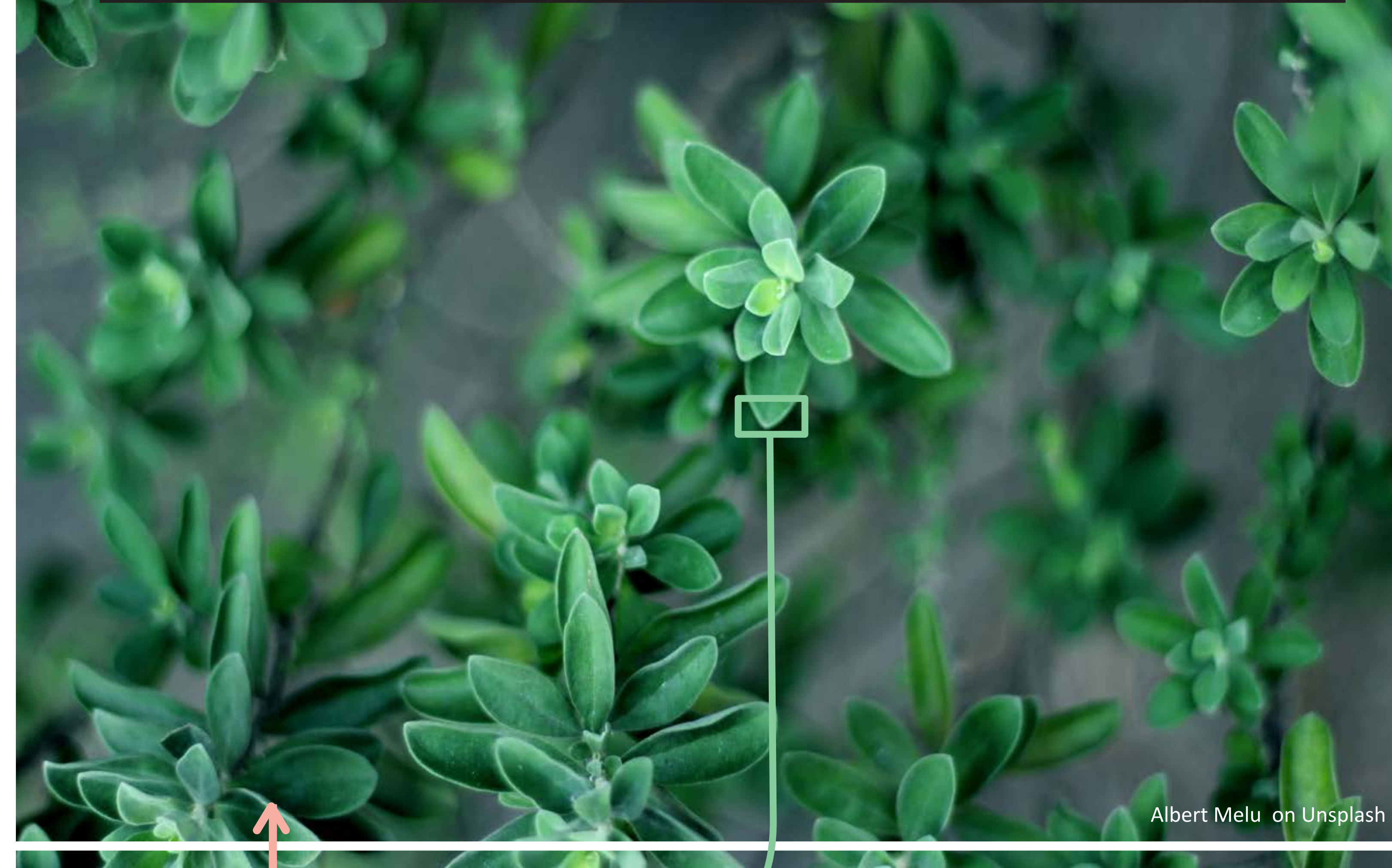
Photo By Kristian Peters -- Fabelfroh, CC BY-SA 3.0 Wikipedia

Photosynthesis

A plant is like the solar panels on your roof. A solar panel turns sunlight into usable energy (electricity). A leaf will also turn sunlight into usable energy (sugars). When light hits the leaf plant cell, there is a chemical called chlorophyll that receives this light and kicks off an electrical and chemical chain reaction that results in sugar - this process is **Photosynthesis.**

Photosynthesis is like a little factory. A factory needs input (raw materials), which goes through a production line process to arrive at a finished product. In photosynthesis, those inputs are light, CO_2 and water (H_2O). A factory will have waste material - in photosynthesis that waste material is O_2 , which is the same O_2 we breath. Finally the finished product in photosynthesis is sugar.

Image by emijrp own work, CC BY-SA 3.0 wikimedia commons, https://commons.wikimedia.org/w/index.php?curid=6776195



Albert Melu on Unsplash

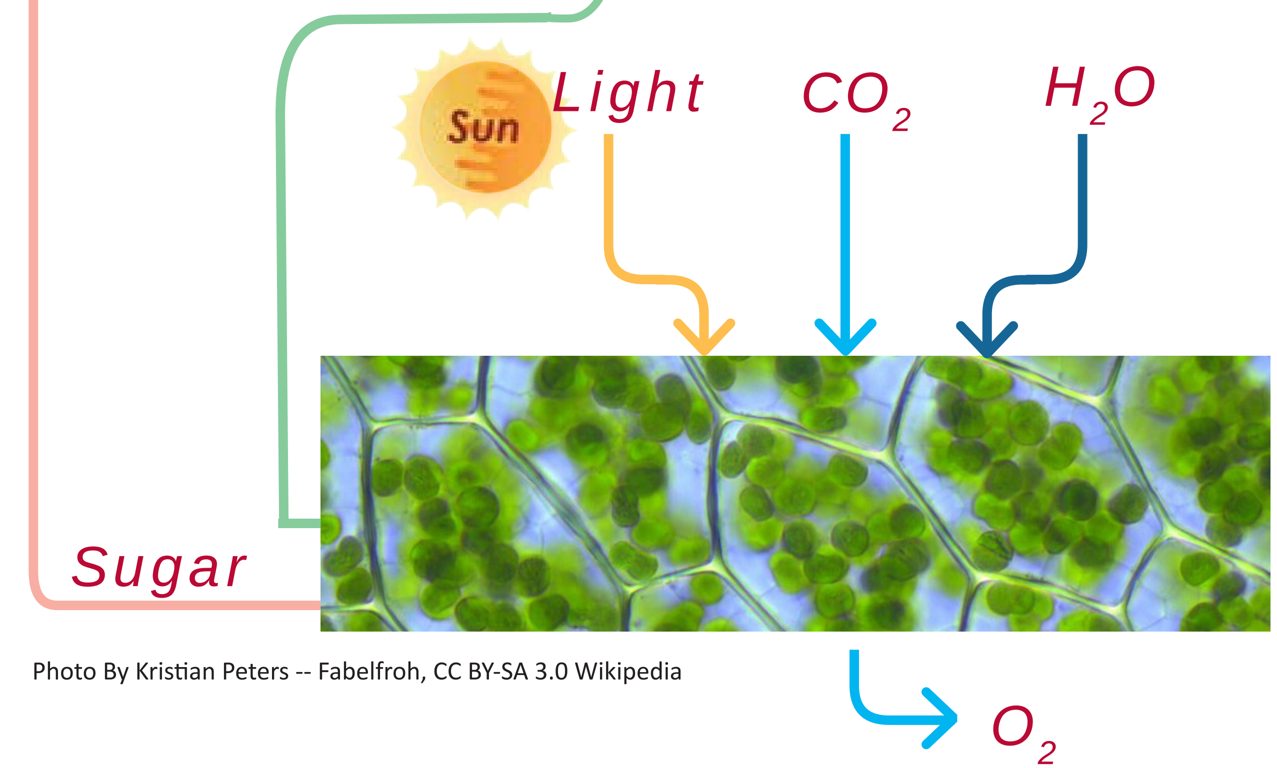


Photo By Kristian Peters -- Fabelfroh, CC BY-SA 3.0 Wikipedia

Photosynthesis in Detail

A plant leaf has plant cells (1). Within those plant cells are smaller cells called Chloroplasts (2). They are called chloroplasts because they contain the **Chlorophyll** molecule. Actually, the Chlorophyll is buried even deeper in an even smaller cell called the thylakoid (3). The Chlorophyll is called a pigment because it reflects mostly green colors and that's why we see a leaf as green. The reds and blues? They are being absorbed by the leaf as light energy that kicks off a chain reaction called photosynthesis (4).

1

Plant Cell

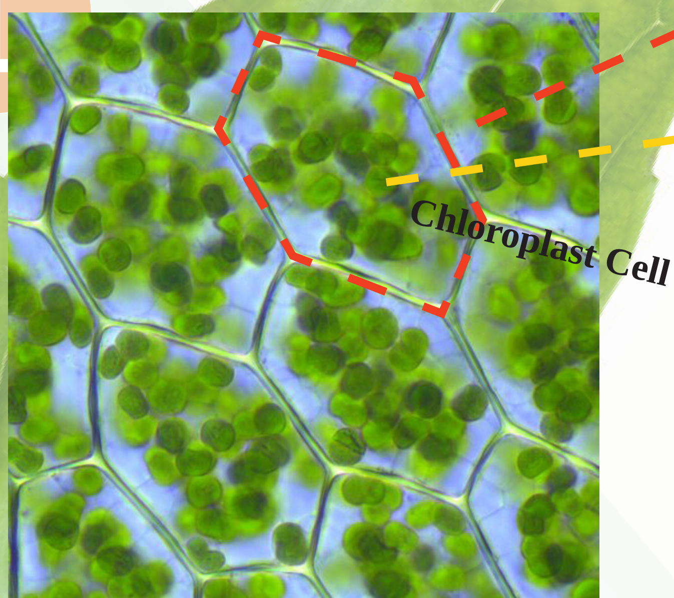
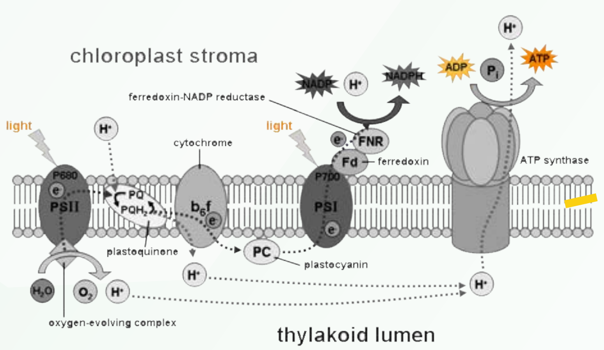
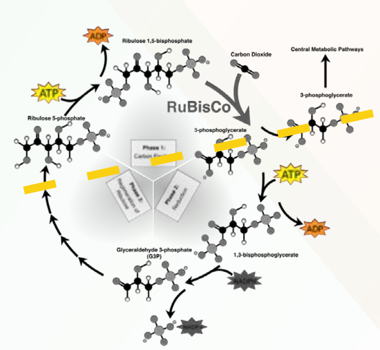


Photo By Kristian Peters -- Fabelfroh, CC BY-SA 3.0 Wikipedia

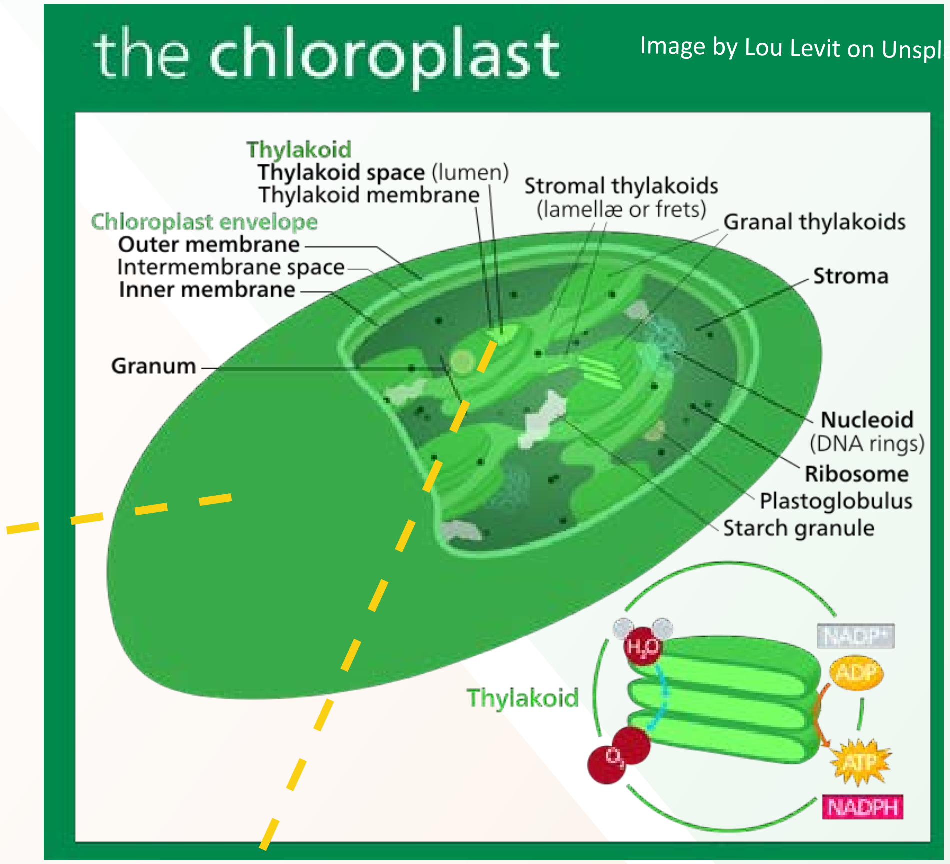
Photosynthesis is very much like a factory line. Below is the chemical reaction for photosynthesis. Don't be put off by the chemistry - it's just a factory line with inputs, processes wastes and a final product - with a little guidance, you'll be able to get the gist of what is going on. We'll go into more detail in the following pages.

4





Calvin cyclle illustration by Mike Jones - CC-BY-SA-3.0 wikimedia commons (with color modifications)



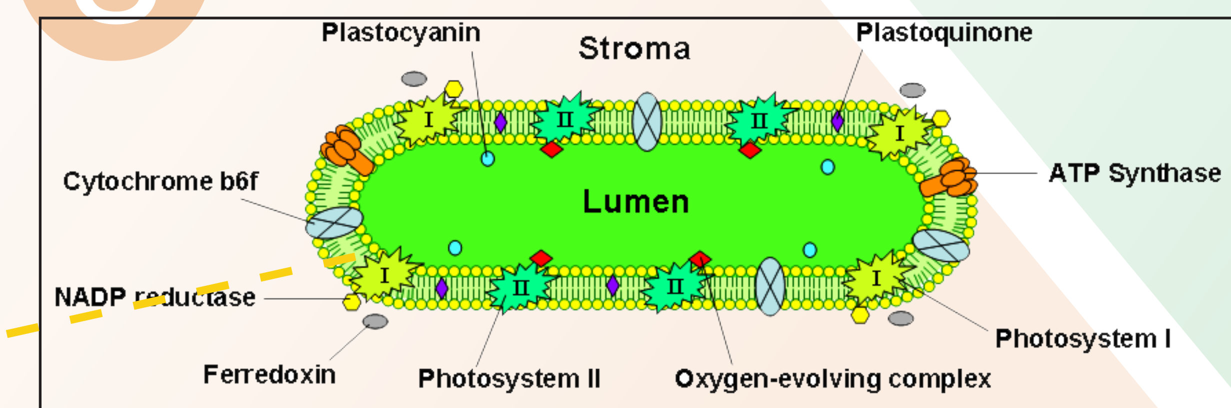
2

The **Chloroplast** is a cell within a cell (plant cell). Within the Chloroplast are stacks of smaller cells called Thylakoids.

By Kelvinsong - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=26247252

3

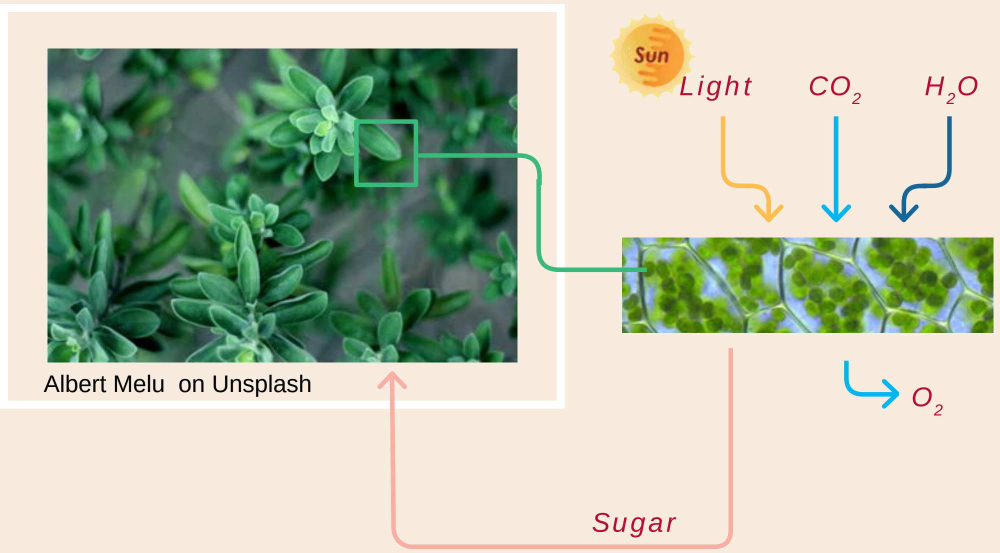
The **Thylakoid** is a cell within a cell (chloroplast) within a cell (plant cell). Ultimately, this is where chlorophyll resides, more specifically in the surface layer (membrane) of the thylakoid.



Did you know?

Photosynthesis drives all of the plants, forests, plankton and consequently animals and human beings. Did you know that the process of photosynthesis is more efficient in producing energy than coal, gas, and oil. We know how to reproduce photosynthesis in the laboratory but we are not very good at it. But if we could unravel all the secrets of natural photosynthesis, we could do away with coal, gas and oil and we could alleviate global warming altogether. Photosynthesis is the ultimate non-toxic, self sustaining green energy factory.

Digging Deeper - The Chemistry



Albert Melu on Unsplash

Do you remember this diagram? It shows you the inputs (Light, CO2 and H2O), the waste (O2) and the final product (sugar).

And if you look at the chemical representation of photosynthesis below, you can easily see all the inputs and outputs.

Everything in between is simply a factory production line.

There are two parts to photosynthesis - the first part is called the Light Reaction cycle because it's all about how light energy is first absorbed by the plant. The second part is called the Calvin cycle, which is the process that actually puts together the sugar.

In the Light Reaction stage, a photon of light hits the leaf and starts a chain reaction that uses water as input to produce ADP and NADPH, which are temporary energy stores (like batteries).

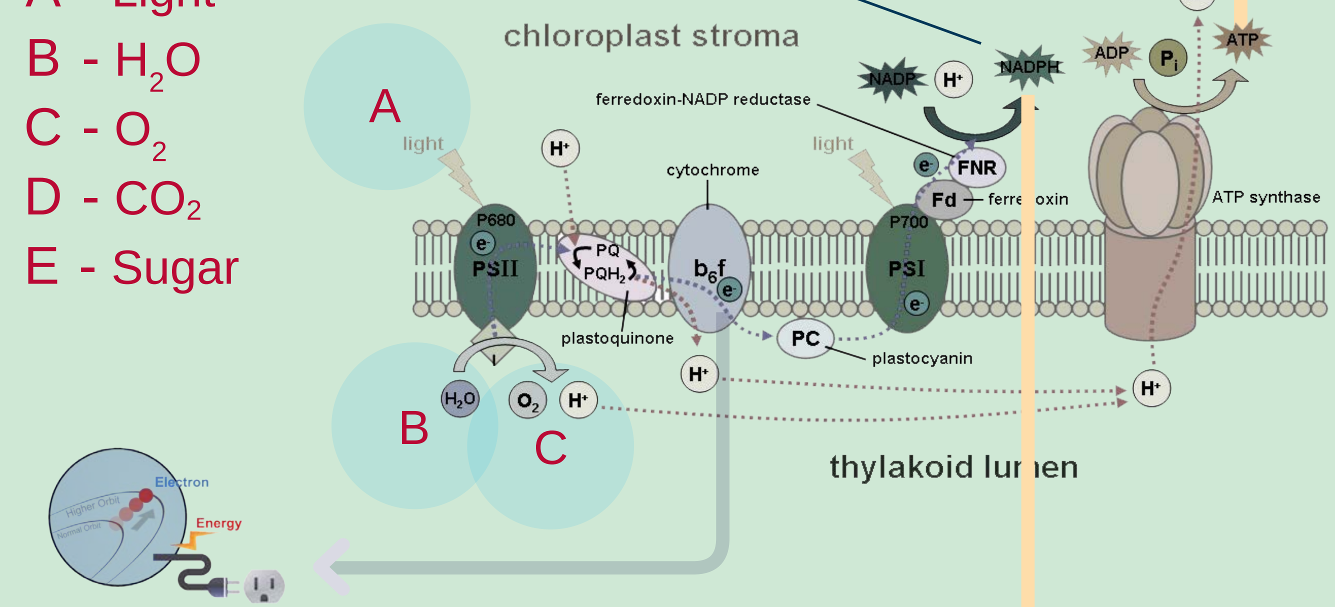
These batteries are passed on to the Calvin Cycle and there, CO2 is used as input to produce Sugar (end product). Sugars are used in plants for many things. Plants need this energy source for growth, germination, flowering, respiration etc. If you are curious what drives this whole process - it's electrons. The light ignites the process and it kicks off an electron which triggers another process, which kicks off another electron and the next process and so on. It's electron flow, not unsimilar to the electricity that is needed to run a factory.

Also, you might wonder where the Calvin Cycle takes place - it is outside of the Thylakoid cell in the interior space of the chloroplast, called the "stroma".

1 Light Reactions

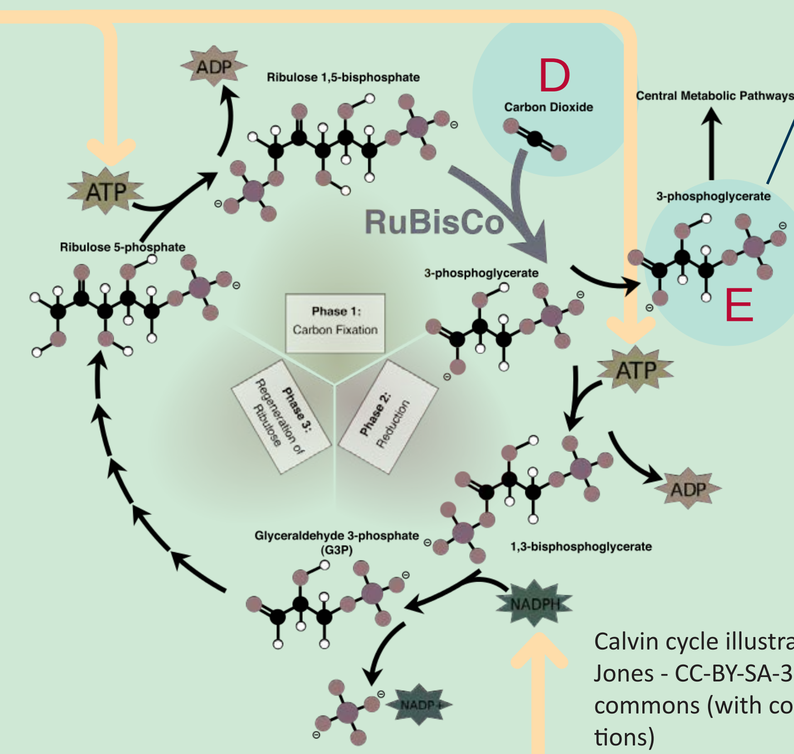
ATP and NADPH are very important energy stores (like batteries) that can be used for many processes. In fact, the human body also uses ATP and NADPH everywhere.

A - Light
B - H_2O
C - O_2
D - CO_2
E - Sugar

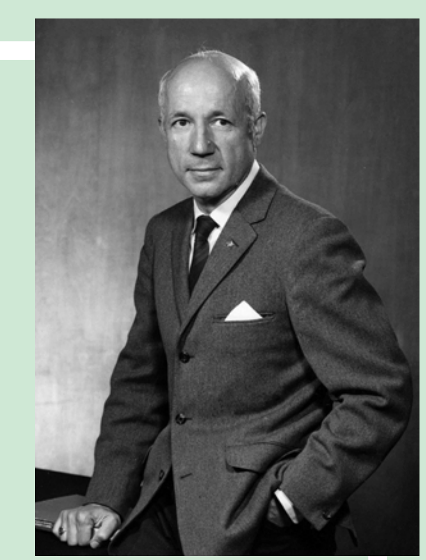


Calvin Cycle 2

Sugars are used for growth, germination, flowering etc.



Calvin cycle illustration by Mike Jones - CC-BY-SA-3.0 wikimedia commons (with color modifications)

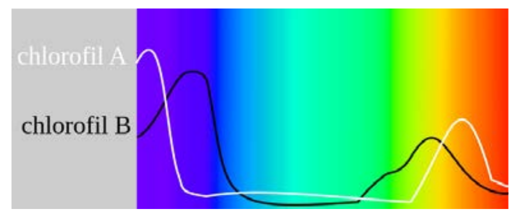


Melvin Calvin

Scott Webb on Unsplash

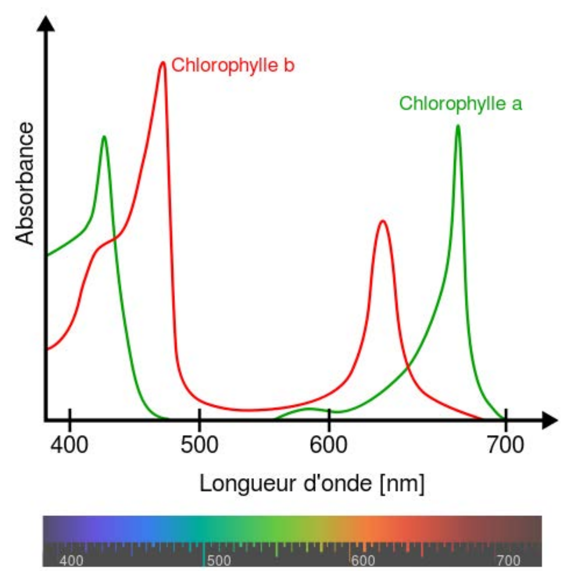
Chlorophyll and Spectrum

So we could surmise that since the plants reflect the green light, they must be using the red and blue light waves from the Sun for photosynthesis. And after thorough research and experimentation, indeed, the data shows how chlorophyll, the main light absorbing components in plants, react to light color in the way we expected (below) - in the blue and red spectra. (Chlorophyll is explained later in detail).



By Mix321 - Own work, Lewiński, Holak, Biologia dla liceum, wyd. Operon, GFDL, https://commons.wikimedia.org/w/index.php?curid=24481692

AND this is why some grow lights will look like the one on the right.



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But we must not discount green light too fast. Research has shown that even though most of the green is reflected, some of it penetrates and still can be absorbed deeper into the plant. Though still not well understood, this green light might be able to signal plant response to adapt to low light conditions (photomorphogenic response).

In effect, the majority of plants react to light mostly between 400 nm and 700 nm, commonly designated as **PAR or Photosynthetically Active Radiation**.

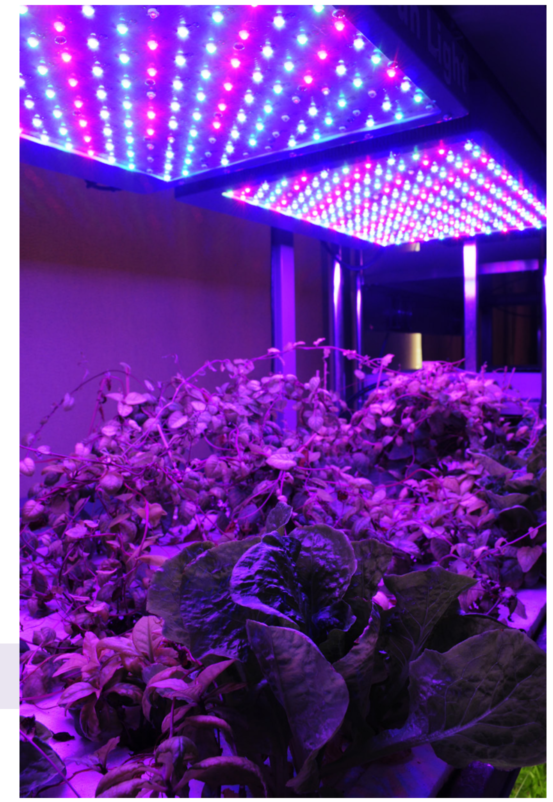
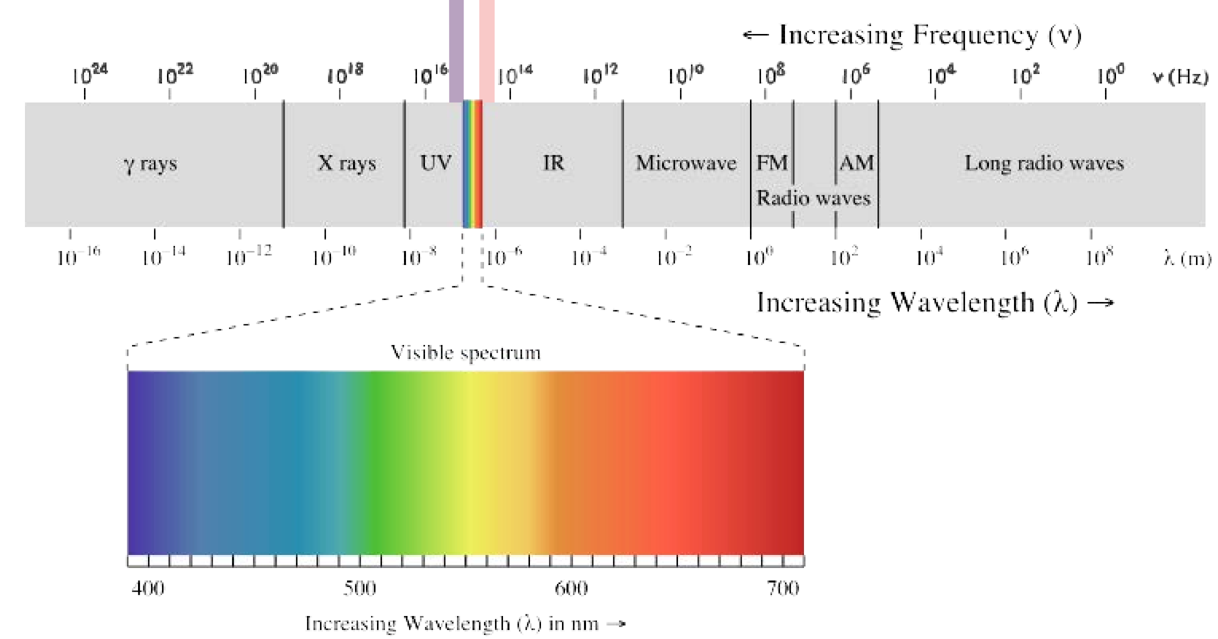


Image Courtesy of Taiwan HiPoint Corporation
www.twhipoint.com

Other colors include near-infrared or far-red, which can be exploited by cyanobacteria, purple bacteria and heliobacteria at ocean depths or stagnant ponds. Studies also show far red it plays a role in flowering in certain species (e.g. for cannabis). It also plays a role in stem elongation in low light conditions (an unwanted effect in some produce).

UV light is harmful to plants and has no beneficial use for plant growth, but has shown to affect a plant's color, taste and aroma. UV light exposure (blue light and UV-A) can also triggers protective mechanisms such as enzyme production that repair DNA sequences already damaged by UV. It also said that plants produce phenolic compounds when exposed to UV radiation - this includes antiviral, antibacterial, anti-allergic, anti-inflammatory, anti-carcinogenic and powerful antioxidants.



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Most green land plants have two main types of Chlorophyll - Chlorophyll A and Chlorophyll B. Chlorophyll A is the primary active pigment (chemical) in photosynthesis. Chlorophyll A will reside in both PSII and PS I in the diagram on the opposite page. In PSII there is another label P680 - this represents Chlorophyll A that accepts light waves up to 680 nm. This is where the production line begins and it's where electrons are passed from this stage to the next. Eventually we arrive at PSI where you see a P700, which has Chlorophyll A that best reacts to light waves greater than 680 nm up to 700 nm. In fact you might see Chlorophyll A represented as Chlorophyll A 700, Chlorophyll A 660 or Chlorophyll A 680 etc. to represent the different subcategories of Chlorophyll A.

PSI is where NADPH is created, which is one of the main energy stores, a temporary battery you might say.

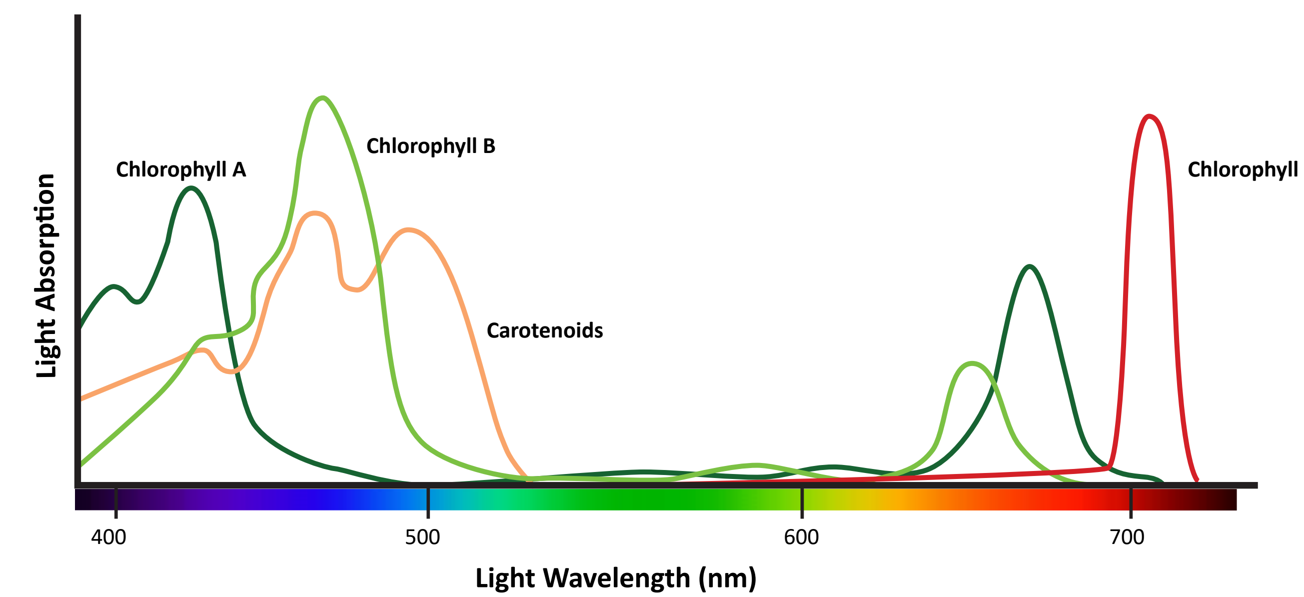
Chlorophyll B is called an accessory pigment and resides mostly in PSII. When light is low, a plant will produce more Chlorophyll B, which can then help the process by transferring even more electron energy to be used further on in the production line. In effect, in low light situations, having more Chlorophyll B, with a slightly different range of wavelength, means that together with Chlorophyll A, a plant has a larger range to collect light energy.

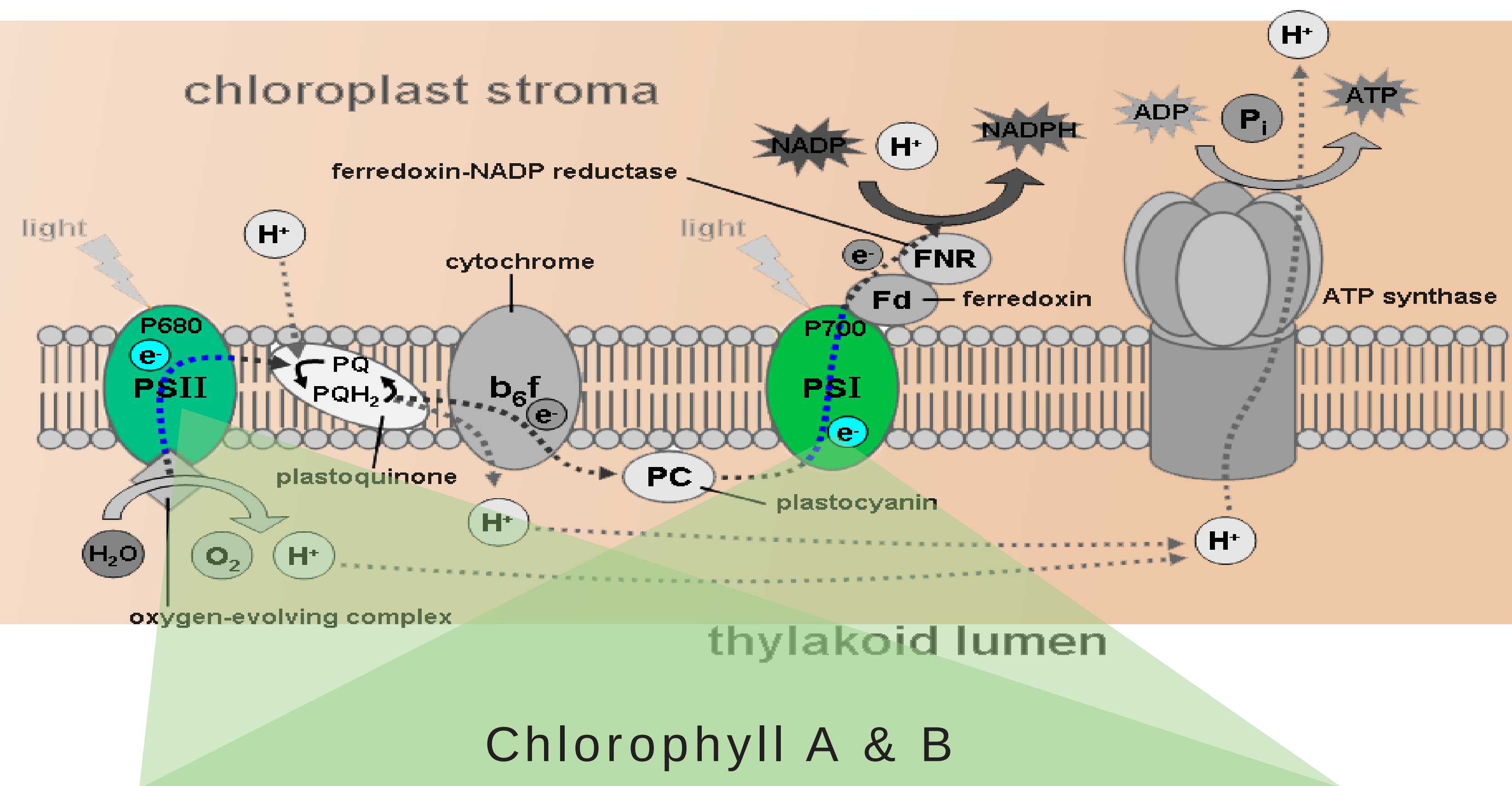
There are many other classifications of Chlorophyll other than A and B; There is C1, C2, D, F and Carotenoids used by other plants or even bacteria, or act as accessory pigments (like B).

Did you know? BioFuels from Algae are commercially available.

There are actually many more types of Chlorophyll that are found in species other than garden variety green plants - there is chlorophyll c1 (algae), Chlorophyll c2 (algae), Chlorophyll d (Cyanobacteria,) Chlorophyll f (Cyanobacteria). Of particular interest are the Chlorophylls for algae, which someday might be used commercially as biofuels to replace fossil fuels. It was first proposed by Harder and VonWitsch in 1942. Today, millions of dollars are being spent on continuing research, with a few companies already having commercially sold these biofuels as early as 2012.

Photobioreactor - By IGV Biotech - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=25767679





Chlorophyll A resides in these two places (PSII and PS1). Chlorophyll in PSII can receive light up to 680nm in wavelength, while Chlorophyll in PSI can receive light wavelength up to 700nm.

Chlorophyll B resides mostly in PSII (they also reside in PSI in smaller numbers) and is produced in more numbers when light is low, and since it's peak wavelengths are different from Chlorophyll A, it gives the plant a larger range of light-wavelength to receive light energy.

Grow Lights

Who, What, Where

Photo by petra cigale on Unsplash

Image by Assimilatieverlichting CC BY-SA 3.0 Wikimedia Commons

Image by Valcenteu CC BY-SA 3.0 (Wikipedia "vertical farming")

Let's get back to how we actually use grow lights in a practical environment. Having grow lights doesn't mean you only use lights to grow your plants. The traditional greenhouse actually has glass roofs to allow sunlight, but can use supplemental lighting during the low light winter months.

Vertical farming usually means shelves of plants are stacked one on top of the other, and the light comes from bottom of the shelf above it . "Vertical Farming" was further embellished by ecologist Dickson Despommier by proposing skyscrapers housing sustainable, vertical farming. Although a skyscraper farm has not, to this date been built, other companies are acquiring space in cavernous, abandoned warehouses and factories in urban areas for the purpose of growing local food, using local help, all without the consequences of large runoff waste water. All this being said, the jury is still out to whether this sort of farming is in fact ecologically better and cost efficient, or not.

Grow lights have also allowed hobbyist and individuals to grow plants and vegetables within their own personal space. But what about soil and nutrients they use?

Indoor farming can provide nutrients to plants either by soil or liquids. Both methods are commonly used. Soil is perhaps more bulky and must be prepared for indoor use - the soil is usually heated or doused with UV radiation to eradicate pests, mold, and bacteria.

Using liquid based nutritional supplements, called hydroponics, is perhaps more physically and spatially convenient. Additives can easily be obtained and added to the liquid mix. The runoff water can also be recycled - in fact hydroponic faming is much more water conservative, especially in low rainfall or drought condition regions. It is said that over 70% of freshwater contamination comes from traditional farming. Even another type of hydroponics is called Aquaponics, where marine animals (fish, snails, prawns, crayfish) are used as part of the irrigation system to provide nutrients (excrement contains toxic nitrites but are nitrified to nutrient nitrates).

By Narek75 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=53495399

By Oregon State University - Hydroponics, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=56922225

By ryan griffis from Urbana, USA - Growing Power, Milwaukee, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=7928080

As for pesticides with indoor horticulture, there is a great reduction in pesticide use - but just because your farm is indoors, doesn't mean that you won't have any pests, and you have still have to be vigilant.

We see a lot of leafy vegetables such as lettuce being grown indoors, but it's entirely possible to harvest fruit bearing trees, such as lemons. It may not be common, but the technology and vertical space in some of these warehouse farms can certainly accommodate. It's now simply a matter of working out the logistics and cost benefits.

It's not only foods that are being considered for indoor farming. Ornamental flowers and medicinal vegetation such as medical cannabis are also being cultivated.

Light, nutrients and water are not the only considerations. Temperature, humidity, air flow and CO_2 also must be maintained to achieve optimal growing conditions. Air flow must be consistent to prevent pockets of dry or humid micro-climates within the indoor structure.

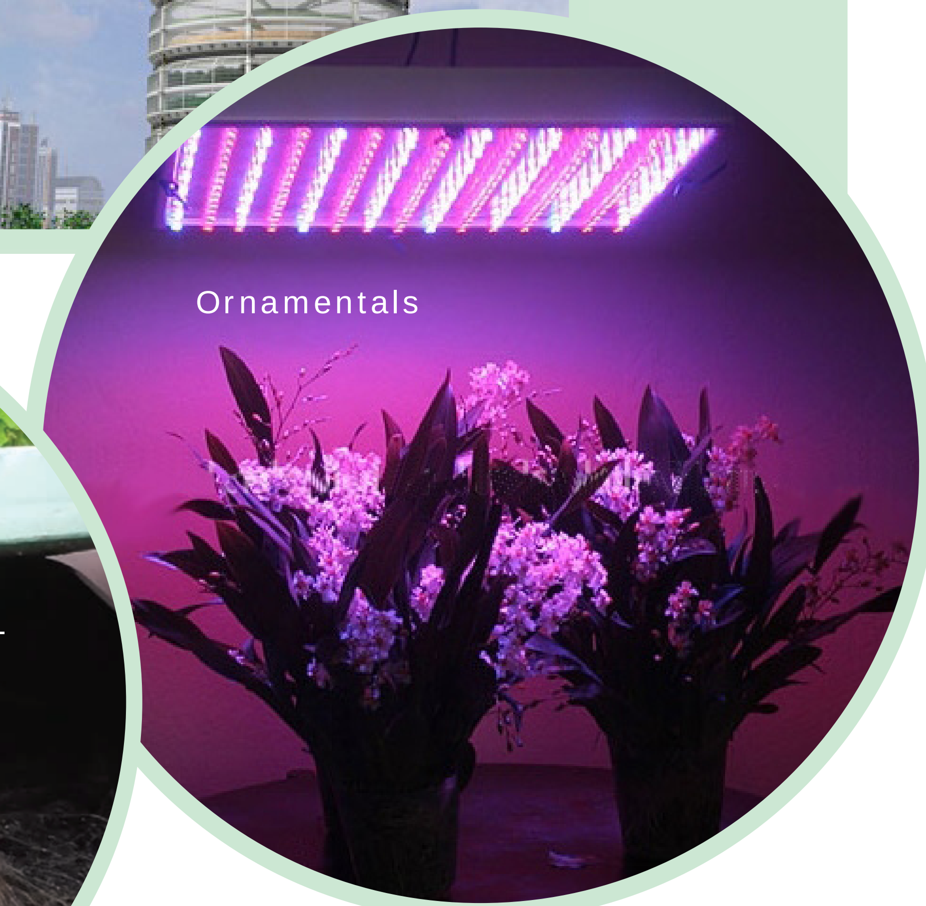
Plants breath CO_2 like we breath O_2 and since these places are enclosed structures, CO_2 levels could fall below optimal levels - many indoor farms will rent CO_2 tanks and pump CO_2 into the greenhouses.

Some companies, like HiPoint (Taiwan) build Specialized Growth Chambers to carefully monitor, control and administrate production.

By Cjacobs627 at English Wikipedia, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=6060509

Grow Chambers Courtesy of Taiwan HiPoint Corporation
www.twhipoint.com

Image courtesy of Al Gracian of albopepper.com



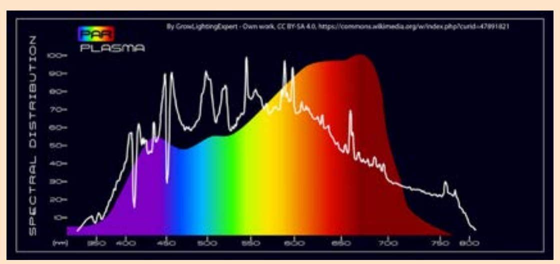
By Sunshine 117 - wikimedia commons - CC BY-SA 3.0

Types of Grow Lights

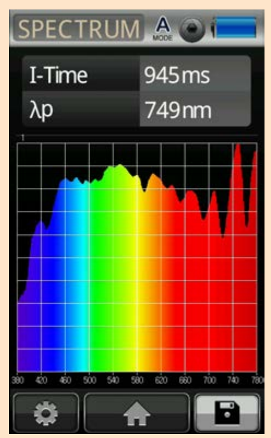
As of this writing, the most common type of grow light is NOT LED, nor is it fluorescent. It is a type of arc lamp called **HID or High Intensity Discharge Light**. Under this category there are many; Metal Halide, Ceramic Metal Halide, Combination MH and HPS (CMH, CDM), Combination MH and HPS (dual arc), High-Pressure Sodium, HEP (High -efficiency plasma). In fact in 2015, it was noted that over 98% of the grow lights were High-Pressure Sodium lights. As their namesake implies, these lights are high intensity discharge lights that also have very high lumen-per-watt efficiency (60-125 lumens/ watt for some Metal Halides). Also, some of these types of lights are said to have a color spectrum similar to the Sun.

High-Pressure Sodium Light

High Efficiency Plasma Light Spectrum

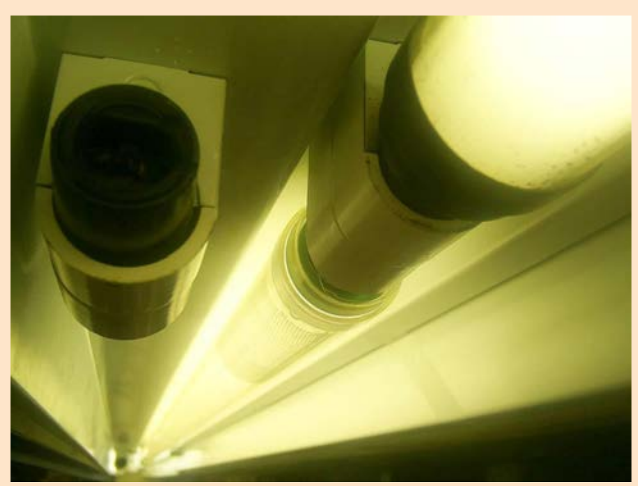


By GrowLightingExpert - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47891821



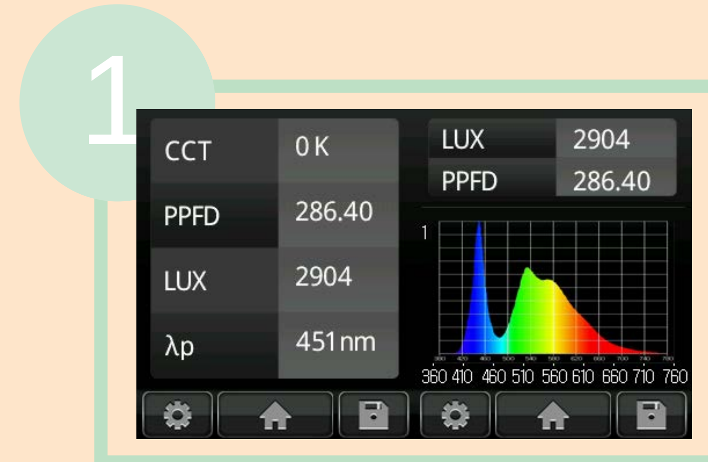
Sun Spectrum

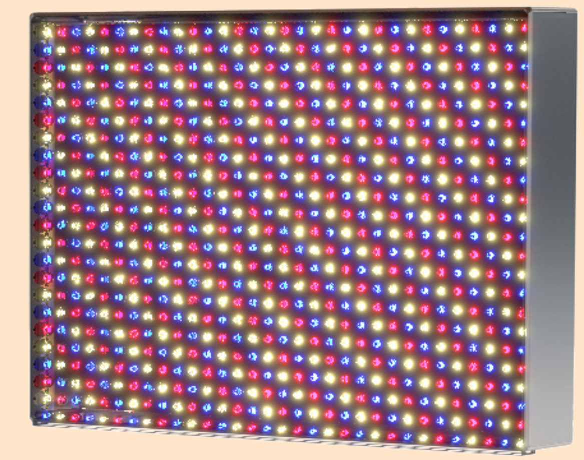
Fluorescent lights used to be the most popular as grow lights. They are relatively power efficient and although not as bright as HIDs, they can come in long tubing that can fit easily under bottoms of shelves for stacked or vertical farming - you may see these lights referred to as T5, T8, T12, where the "T" stands for the Tubular form factor. The cooler temperatures of fluorescent lights are also an advantage in stacked shelves in close quarters, reducing leaf burn and wilting, especially in leafy vegetables like lettuce. These lights also produce a more diffusing light that can be more equitably distributed over the plants. They are often associated with greener colors but can still provide warm, daylight , or blue colors. They don't provide as much light intensity, but they are often supplemented with reflectors to increase the overall light.



Fluorescent Light

What about LEDs?





Two views on Grow Lights.

There are two views on Grow Lights. One view is to provide a full spectrum of light in order to come as close as possible to that of the sun. The HID and Fluorescent lights are full spectrum lights, which can still be manufactured to be warmer or cooler, but they still contain the full colors of the rainbow.

With a single LED bulb, it is possible to focus around a single wavelength of light. And if you can do this, you can focus on precisely the wavelengths that a plant needs. This not only introduces a more controlled environment but also can reduce the wattage needed for unnecessary parts of the spectrum. For some specialized lights, the ratios of these individual colors can also be adjusted. In effect, how many wavelengths do you really need when plants peak at certain wavelengths only? But LED spectrums also do not have to be only blue and red lights. They also can be full spectrum with emphasis on the blue/red regions. Some argue, that with blue/red lights only, it's difficult to assess the true conditions of the plants when everything is looking purple.

Images below are Courtesy of Taiwan HiPoint Corporation, www.twhipoint.com

LEDS with full spectrum

LEDS with only red/blue

A couple of words about the advantages of LEDs

Other than spectrum versatility, LEDs have other advantages. Durability and Longevity - they are SSL (solid state lights) and very sturdy. They also have a relatively long life - but you should not expect an LED product to perform at its peak past the warranty period, as LED light quality will diminish over time. The cool temperatures of LED lighting is also an advantage, even more so than fluorescent lights. However, it must be said that cool LED temperatures can actually be a disadvantage in cold climates and more so because most heat from LEDs will dissipate from the back. On the other hand, having cool LEDs in warm climates is an advantage in that it cuts down on power needed to supply air conditioning to counteract otherwise heat producing light bulbs.

Still another advantage is that LEDs are inherently adaptive to small and large scale operations. They can be shaped into bulbs, strips and even panels. Furthermore, because of the driver circuit board technology, LEDs can easily be remotely controlled over a large indoor farming area.

All that being said, the optimism for LEDs is growing and many in the industry foresee an imminent shift in grow lights towards LEDs.

Image is Courtesy of Taiwan HiPoint Corporation, www.twhipoint.com

Do different types of lights really make a difference?

If ever you tried to grow plants, you must know they are very sensitive to the environment; nutrients, humidity, water, CO_2, temperature and also light. You can see, from tests performed (right) how different light types and color characteristics can really make a difference in growth and shape size. This is called photomorphogenisis or how different lights, their colors, color ratios and quantity can drive the shape of a plant. But what exactly is the perfect ratio for plants? There are no fast and easy answers as these factors vary with plant type.

Image courtesy of Al Gracian, www.albopepper.com

It must be noted that indoor farmers take great care in the shape of the produce - what looks good will sell better. Overall shape, leaf appearance can all be factored in when applying artificial lights. Additionally lights can even trigger events in a plant to regulate taste factors, like saltiness or bitterness.

What kind of lighting do plants really need?

You can shine a light on a plant 24 hours a day but that doesn't mean that it will continue to grow forever. Plants as humans operate on a circadian rhythm and both need to sleep. And as for light, too much and too little are both detrimental. A term photo inhibition refers to too much light being shone on a plant which will inhibit the photosynthetic abilities, which might manifest in shortened, stunted leaves. The wavelengths targeted for different plants can also have an impact on growth. Also different plants can respond to different wavelengths depending on it's growth phase. It's generally known that red light is better for fruiting and flowering, while blue light is better for leaf growth (vegetative phase).

That being said, Metal Halide lights can be used for the vegetative phase of the plant because they emit large amounts of blue and ultraviolet radiation. And perhaps a High Pressure Sodium (HPS) light can be used for flowering or fruiting since it's wavelengths can favor the reds. But both of these are still broad spectrum and can be used for both.

And why would you even bother to care about when a plant flowers? Ornamental indoor flower growers do care. It's an advantage to delay the plant from flowering until just before shipment. Therefore, the flowers are more fresh upon arrival. This might be done by showering the plant with red light during the pre-shipment phase. Just think of the advantages of controlling the flowering of roses up until Valentines day. Also the flowering of cannabis is important because the flower contains the primary active ingredient TCH (Tetrahydrocannabinol).

Aside from using grow lights in regions that don't get light in the winter, you can provide light to plants at night to accelerate growth. But wait - didn't I say that plants need their rest too? Yes, but it depends on the plant. Typical light schedules might look like this; 14/10 (light/dark hours), 10/14 (light/dark hours), 18/6 (light/dark hours).

Studies even show that cucumbers will take advantage of extra light - in fact, they can take on light for 22 hours straight. Whereas tomatoes will not take advantage of the same extra dosages of light.

Certain companies are also experimenting with ways to use light to alter the taste and even mineral content of vegetables - for example, the salt content of cauliflower can be reduced for certain people who are intolerant to high sodium.

FLOWER

LEAF

Alex lby on Unsplash

Highly controlled Growth Chambers, such as this one from Taiwan HiPoint Corporation, can produce amazing results using only LED lighting.

How do we know how much light a plant needs?

We know one thing - plants are very sensitive to light - too little light, too much light, too much blue, not enough far red or UV. Then how do we know how much light to give to optimize growth? From what we know, there is currently a growing trend of research, witnessed by the number of inquiries from public and private sectors reported by grow light companies.

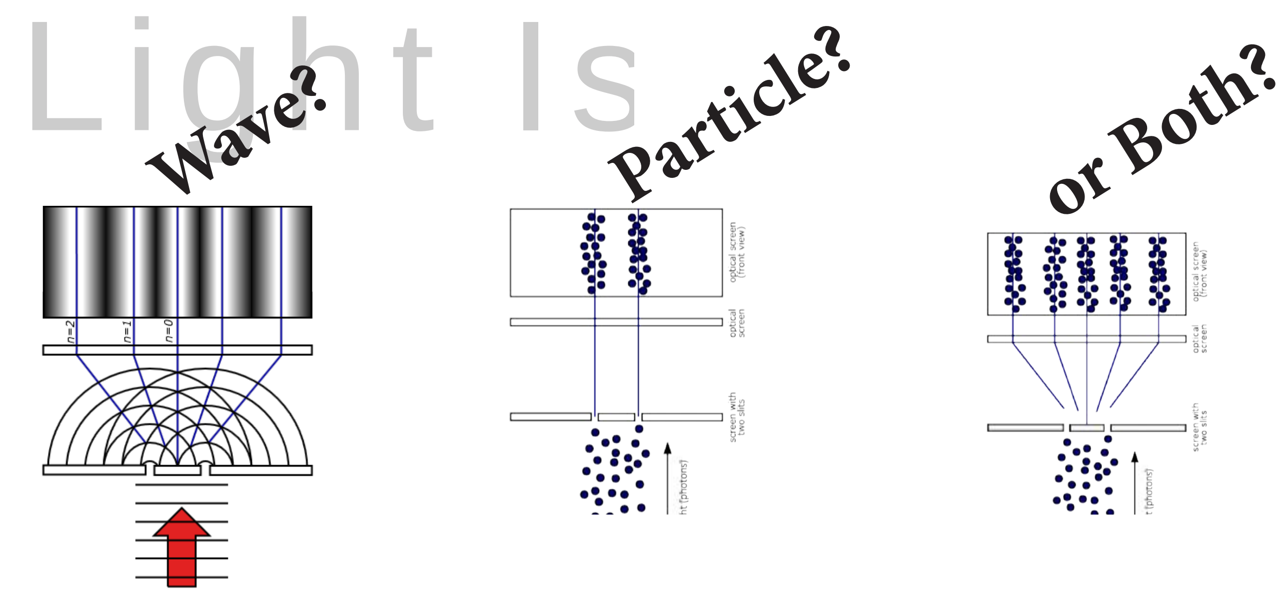
There is no simple way of developing a recipe for any particular plant based on a common formula. Right now the research is simply trial and error, but companies and academic organizations are beginning to accumulate databases with their findings.

But how do we know if plants are reacting to certain wavelengths of light - we would have to wait weeks for any sort of physical changes. Not really - in research labs, plants are grown in "clean" Growth Chambers, where they are exposed to various test lights. If they are metabolically active (photosynthesis) under the test lights, they will give off the by-product O^2. They can then measure this rise in O^2 in the chamber very accurately and within a reasonable period of time.

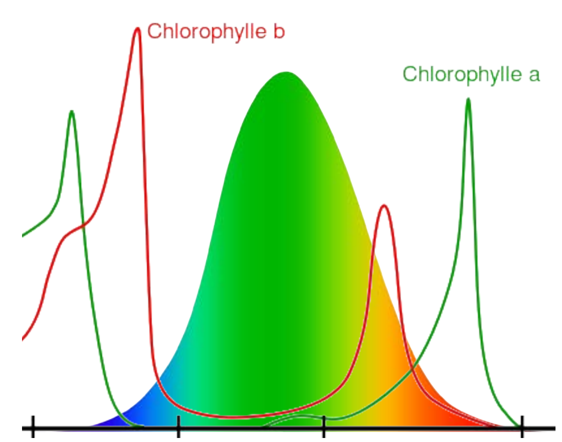
Other than the wavelength of the light, there is one other important factor. A lot of people will think that the brightness of the light in lumens or LUX will make a difference in growing plants. But in fact, both are calibrated for how humans perceive brightness, mostly in green regions (pictured to the right), which is mostly irrelevant to plants. Plants care mostly about blue and red wavelengths, and if you have an LED lamp that is registering in those colors only, it will not register as very bright in lumens. But this is misleading as the light will still be quite effective in plant growth.

What is PAR and PPFD?

So if it's not brilliance (lumens) that effects plant growth, what is it? PAR or Photosynthetically Active Radiation represents the range of light wavelengths most plants react to (400 nm to 700 nm). However, the actual unit of measurement used to quantify the amount of light is called PPFD or Photosynthetic Photon Flux Density - it's a mouthful, but let's try to break it down. First you must understand that light can be considered two very separate things. It can be considered a wave, or it can be considered a particle - this is the confounding part of Quantum Physics (see Survival Handbook for more).



Light is considered both particle and wave at the same time. When you are talking about brightness (lumens) or color, you need to consider the wave aspect of light. If you are talking about PPFD, you need to look at light as particles, and light particles are referred to as photons. With PPFD we are concerned with how many photons are falling on the leaf in a certain period of time.



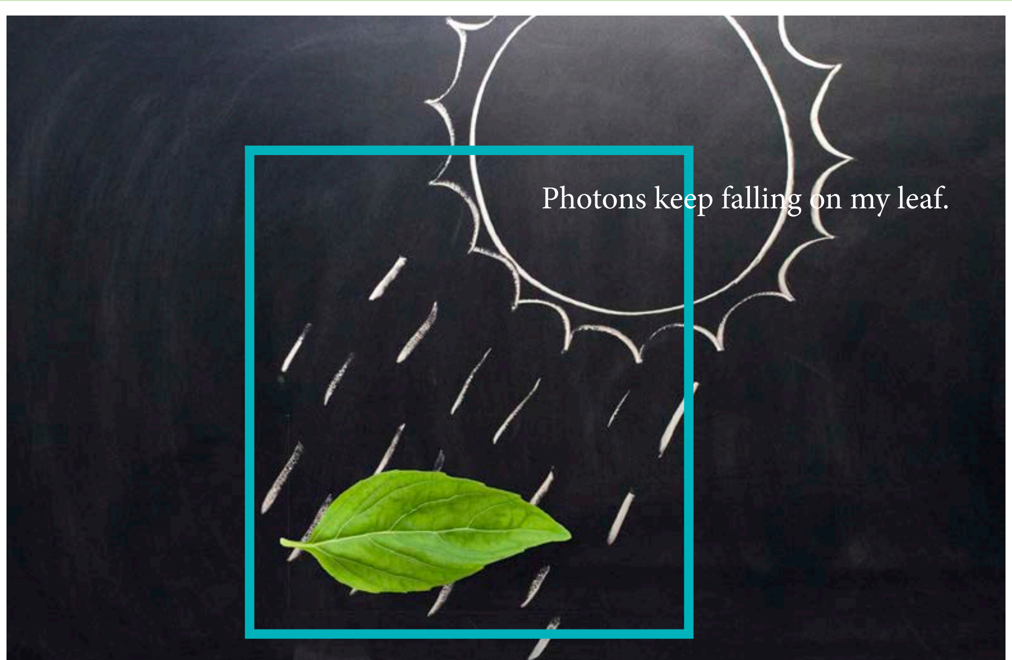
Humans sense brightness mostly in the green regions of the spectrum. Plants, sense colors in blues and reds - human brightness has no meaning to them.

Horticulture Researchers will take heed of the shape, health, length of the leaves, as well as root formation and bulk.

Image courtesy of Al Gracian of albopepper.com

Research: PPFD, light and photons

What is a photon? Imagine running across a street in the rain and wondering how wet your hair will get. It's not important what temperature the droplets are, or what color they are - you are just concerned with how many droplets will hit your head in the time you get to the other side. When you shine a light on a leaf, you can think of the photons as droplets that you have to measure. It's not the brightness of the light that's important, it's the number of photons that are striking the leaf and starting the photosynthetic reaction.



So what is PPFD?

PPFD = µmol/m^2/sec

In effect, you are measuring how many photons hit a defined area in one second. And PPFD is the unit of measure, defined by µmol/m2/s or micro-moles of photons falling on a square meter per second.

What is a µmol?

1,000,000th of a mole.

What is a mole?

A mole is just a number.

A mole represents 602,200,000,000,000,000,000,000 of some object, like atoms, or photons, or even french fries. 2 moles of french fries is ... 2 x 6.022 x 10^{23} french fries (but we usually use moles for much smaller objects).

Why do we do we use moles? To make very large numbers more manageable as you might have guessed. It's easier to say "1 mole of Copper Atoms" than it is to say "602,200,000,000,000,000,000,000 Copper Atoms". A photon of light is also a very, very small item, and counting the number of photons that hit a square area in one second will leave you with a huge number with a lot of decimal places. It's easier to take that number of photons, divide by 6.022 x 10^{23} and call it moles. But you still get a very big number, so you divide again by 1,000,000 to arrive at an even more reasonable µmol (micro-mole).

You might see this:

90 PPFD (90 micro-moles of photons per meter squared per second)

If you didn't have PPFD and "moles", you would have to write,

54,198,000,000,000,000,000,000,000,000,000 photons/m^2/sec

By the way

6.022 x 10^{23}

If you are curious where 6.022 x 10^{23} came from, there is an origin. It derives from comparing and weighing chemical elements (atomic mass & kg), with thanks to Mr. Amedeo Avogadro and others. Atoms are very very small and you need a more convenient unit of measure. Originally, 6.022 x 10^{23} comes from the total number of atoms in exactly 1g of Hydrogen, which is the first element of the periodic table.

Amadeo Avogadro

The Big Picture

To understand the importance of PPFD means to understand the particle nature of light, in effect photons. PPFD measures how many photons are falling on a leaf, determining the amount of vital photosynthesis that can take place. The more photons falling on a leaf, means a better chance the photon will strike a chlorophyll molecule to trigger a photo-synthetic event. To put it all together, we again lay out the big picture; leaf, chloroplast, thylkakoid, thylakoid membrane, and the final location, PSII (or PSI), where the chlorophyll resides and photosynthesis chain of events begins.

Plant Cell

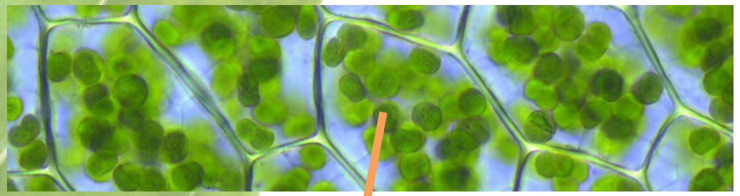
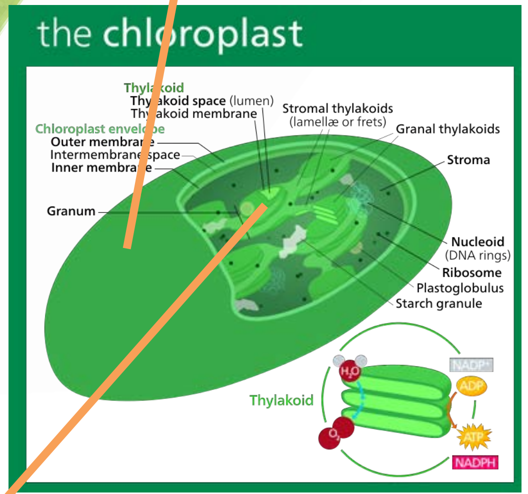


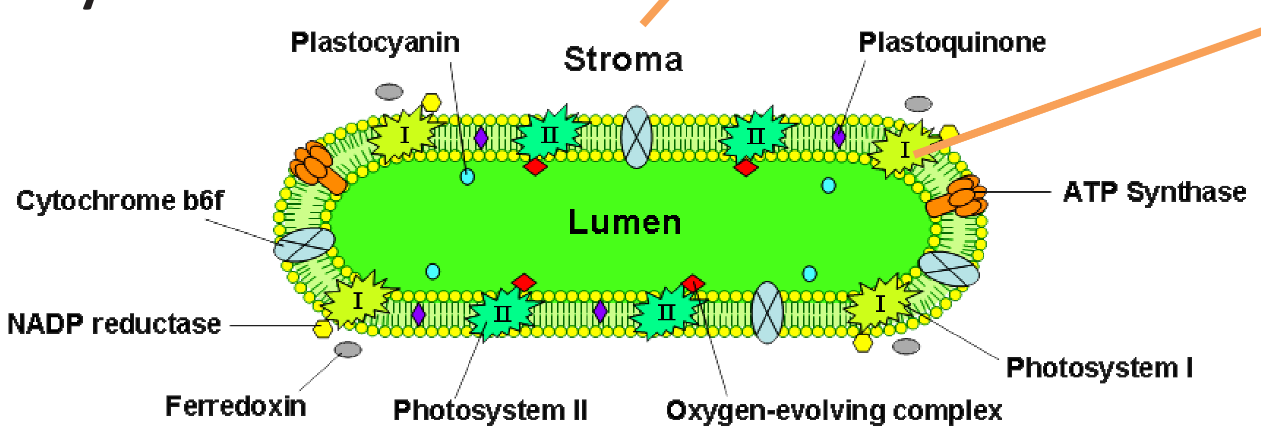
Photo By Kristian Peters Fabelfroh, CC BY-SA 3.0 Wikipedia

Chloroplast Cell

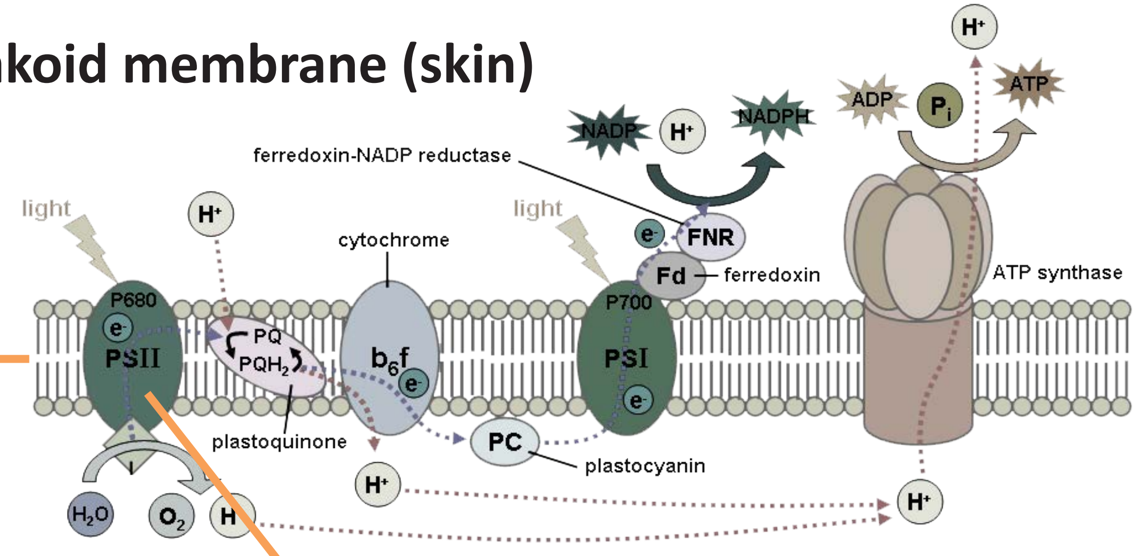


By Kelvinsong - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=26247252

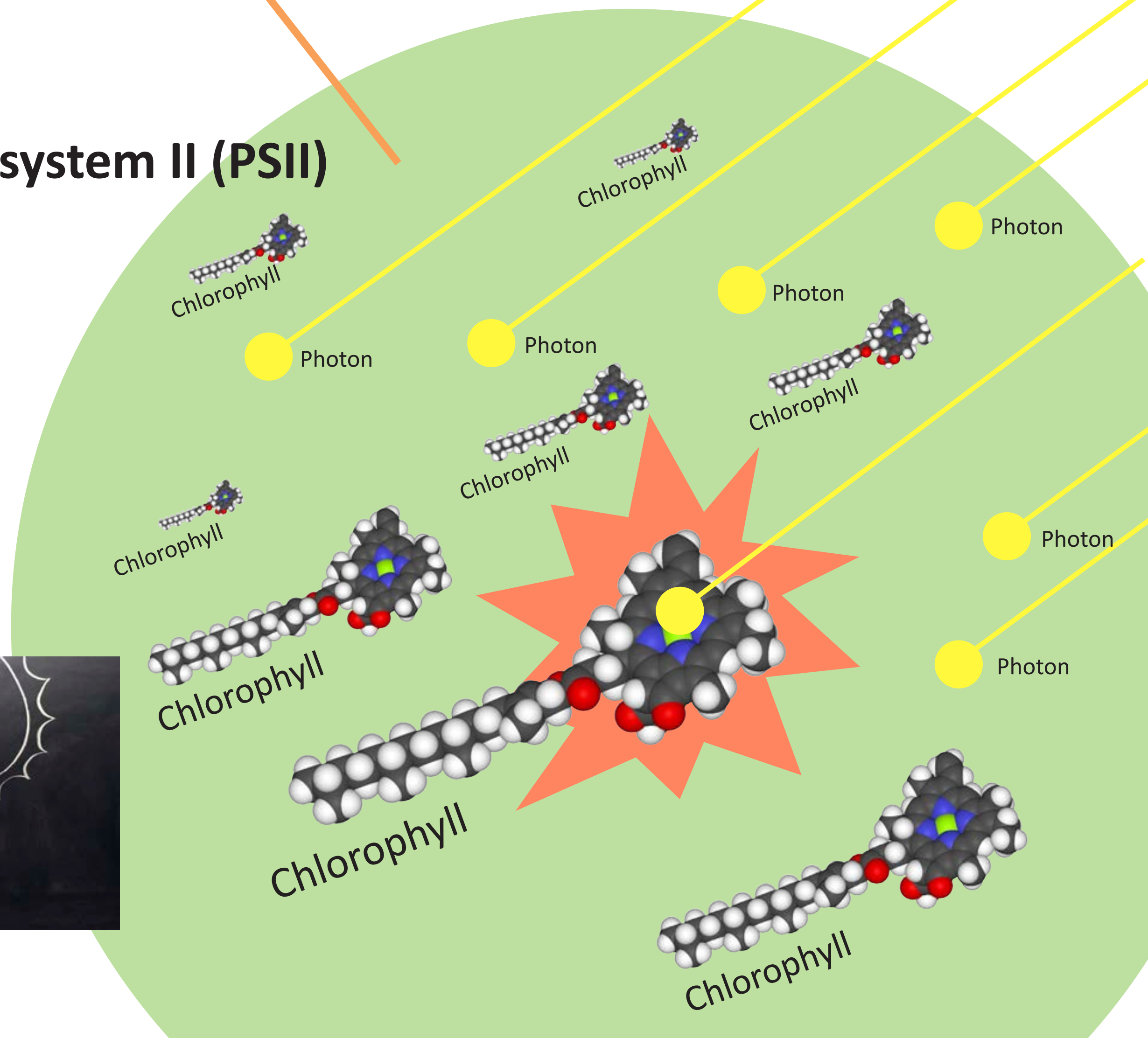
Thylakoid Cell



Thylakoid membrane (skin)



Photosystem II (PSII)



Now What? **Get a light meter Dude!**

So we learned that the wavelength of light and the number of photons that hit the plant are important factors in plant growth and shape (photomorphogenisis). We also learned that certain colors at certain phases of growth can also optimize growth during that phase. We learned that some amount of UV light can actually be useful in strengthening the plant. Once we have a recipe for growing, either obtained or tested for, you need to buy and set up your lights.

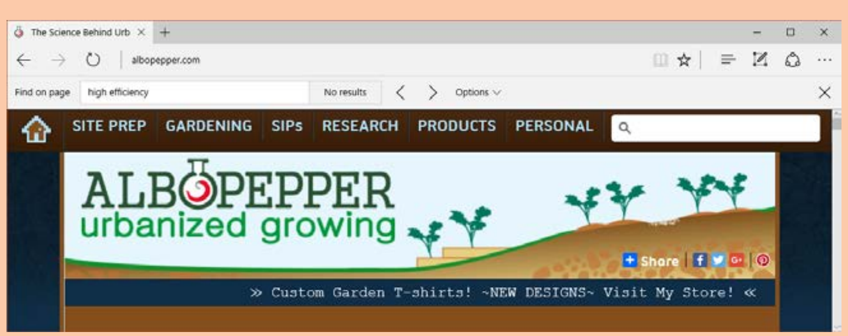
We need a light meter or a spectrometer. But for the purposes of plant grow lights, it also needs to be able to measure PPFD. The PG100N is a light-weight, mobile device designed for grow light horticulture. It's the best way to test your lights before purchase and to use during the setup your lights in a greenhouse environment, big or small.

It's also ideal for research and academics with the ability to record information onto an SD card.

UPRtek PG100N Spectrometer with PAR Meter

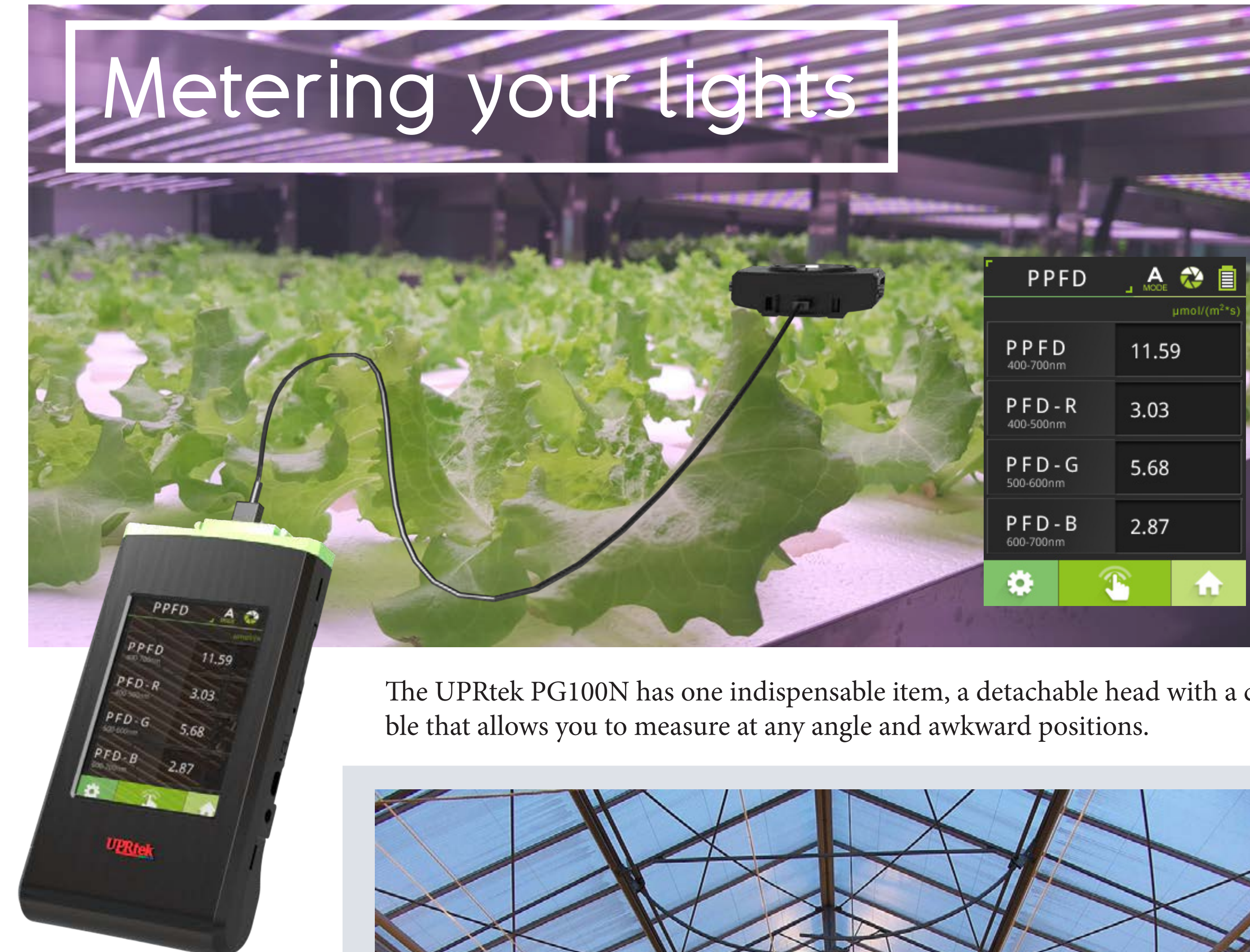
By the way: A Cottage Industry

Recent anxieties over global warming, pesticide use and dissatisfaction with the overall quality of produce has spurred on indoor farming in the public sector. And this has given rise to a cottage industry of home grown websites dedicated to providing valuable horticulture education. These websites also provide a valuable service by reviewing products, like lighting equipment, that both private consumers and companies can take advantage of before purchasing equipment. Below is one such website, albopepper.com, a popular website for horticulturists that covers a wide range of topics from water, seeding, lighting, soil, pest control, gardening methodology and more.

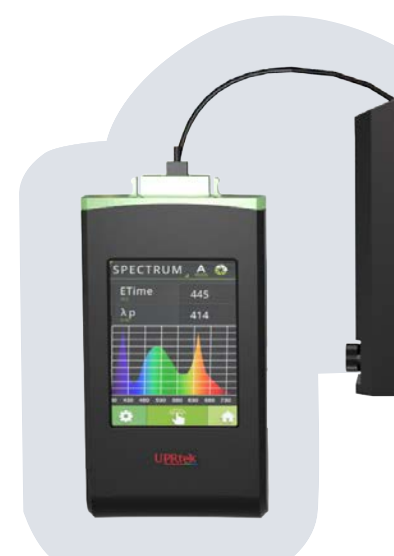


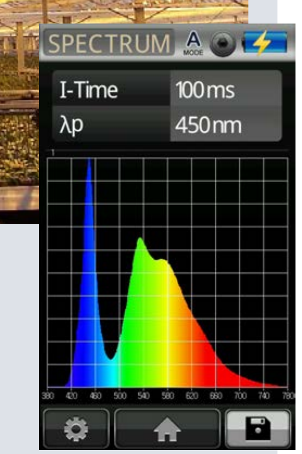
www.albopepper.com

Image below is Courtesy of Taiwan HiPoint Corporation, www.twhipoint.com



The UPRtek PG100N has one indispensable item, a detachable head with a cable that allows you to measure at any angle and awkward positions.





Portable field metering is a must for grow lights, especially in a vast spread. Collecting and storing light data is also imperative for plant growth research and development.

How do you purchase your lights? ... take your light meter with you

When you buy your lights, whether HID, Fluorescent or LED, you should check that the wavelengths you need are properly represented in the spectrum of the light. You can use the spectrometer to show the spectrum of the light. Simple enough?

But when you compare it to the active peaks for chlorophyll, you may find that the light you are considering is not conducive to photosynthesis for the type of plant you are growing. This is why you need a spectrometer, to help you find the best lighting source to promote optimal photosynthesis performance for you're particular plants.

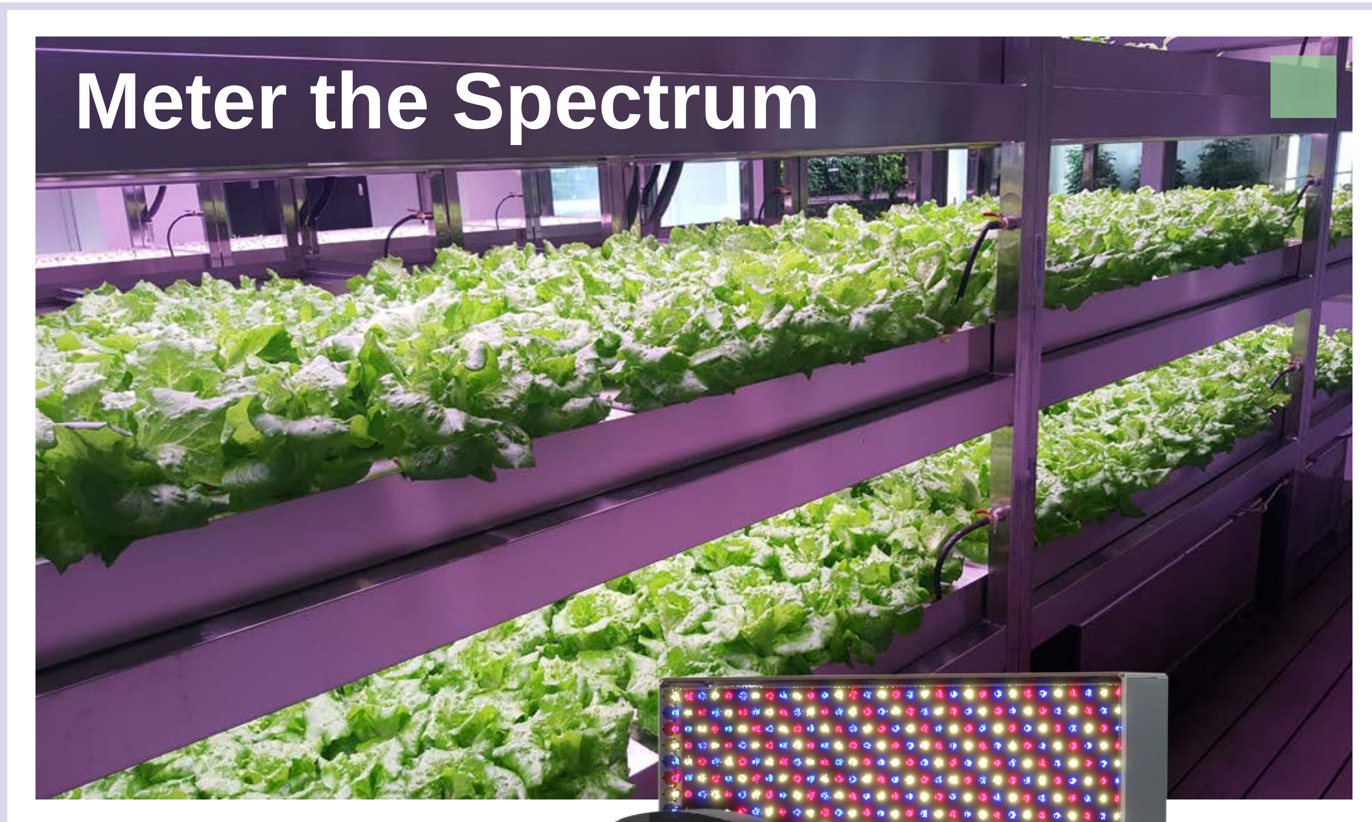


Image above is Courtesy of Taiwan HiPoint Corporation, www.twhipoint.com

How much light do your plants need?

The spectrum is about color wavelength. Now the question becomes how much? Again, do not use lumens to measure the amount of light your plants need. If you want to know how much light you need to give your plant,s you need to start with the PPFD.

A sample light recipe for lettuce may look like this:

Lettuce requires 250-280 PPFD (μmol/m2/sec) of light for 16 hours per day with 8 hours of dark time.

If you do the math, this amounts to:

7,776,000 to 9,072,000 μmol/m2/day

This is referred to as **DLI** or **Daily Light Integral** or put another way, PPF per day.

And a light with a lower PPFD (than another light) can still accommodate your required DLI if you leave the light on longer. Or if you move the light closer to the plant (without overheating it).

Alphonso Cenname on Unsplash

Example recipe for lettuce ...

- **LED distance from plant 30-50 cm**
- **Light Quantity: 250-280 PPFD**
- **16 hours light / 8 hours dark**
- **Sowing to nursery 10-14 days.**
- **Plant to harvest 28 days**

(total process is about 6 weeks)

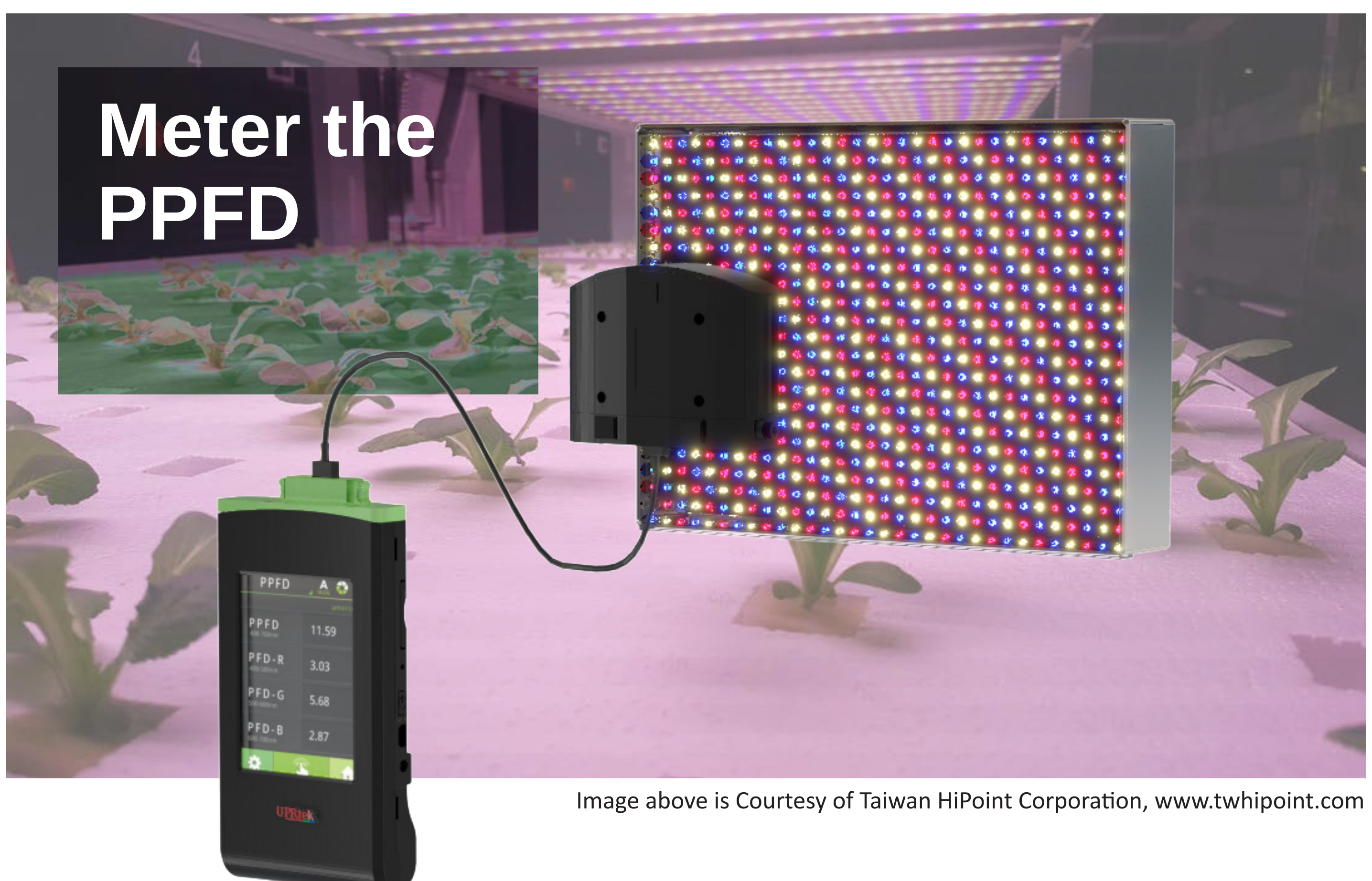


Image above is Courtesy of Taiwan HiPoint Corporation, www.twhipoint.com

Whats wrong with PPFD? YPFD

PPF and PPFD is sometimes criticized because it assumes that all photons are created equal, meaning each photon have will have the same effect on photosynthesis when it is absorbed by a plant. However, according to experiments, photons of different wavelengths, in fact, have different impact, meaning 10 red photons may have a greater impact on photosynthesis than 10 blue photons.

And this is why we can argue to reconsider the wavelength of the photon when measuring light efficacy. The **YPFD or Yield Photon Flux Density** is just the measurement to take into account the spectral characteristics (wavelength energy) of photons at different wavelengths and how they impact photosynthesis differently. It places weights or emphasis on these differences before calculating the final result. And these weights are based on empirical data collected from extensive testing.

We should note, a Quantum Sensor (photon sensor to measure PPFD) only measures photons and is unable to give you a YPFD because it cannot break down the light into discrete wavelengths. Spectral Light Meters (PG100N), as the name implies, are built to dissect the spectrum and thus is more suited for YPFD.

Another criticism of PPFD is that it assumes that all photosynthetic activity pertains to wavelengths between 400-700 nm. Where in fact, as we mentioned, plant photosynthetic efficacy goes beyond these borders (UV and Far Red) and YPFD also addresses this (360-760 nm).

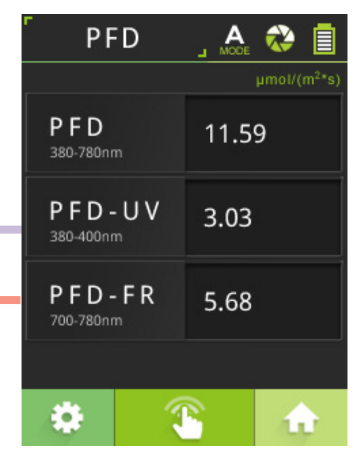
Alas, there is still much debate on PPFD vs. YPFD, and both are still said to be flawed.

(continued on next page)

Photo by chuttersnap on Unsplash

The PG100N addresses this situation differently. It can actually separate out the individual PPFD values for different wavelengths and other often overlooked wavelengths, UV and FR (far red). Remember how this is significant. Blue affects Vegetable Leaf Growth, Red is for Flowering and Fruiting, UV is for producing phenolic compounds, and FR for elongation, and flowering (for some plants). You can see what wavelengths are being administered properly and even use the information for diagnosis and remedy when your plants are not growing well.

The PG100N can see beyond the 400-700 wavelengths into UV and Far Red.



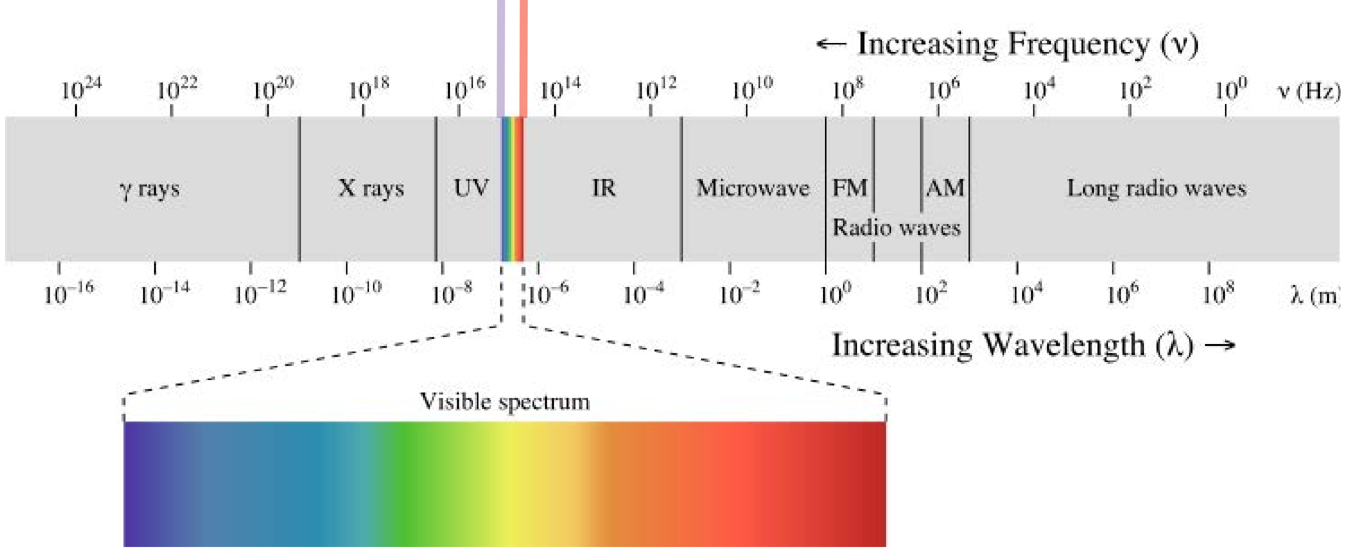
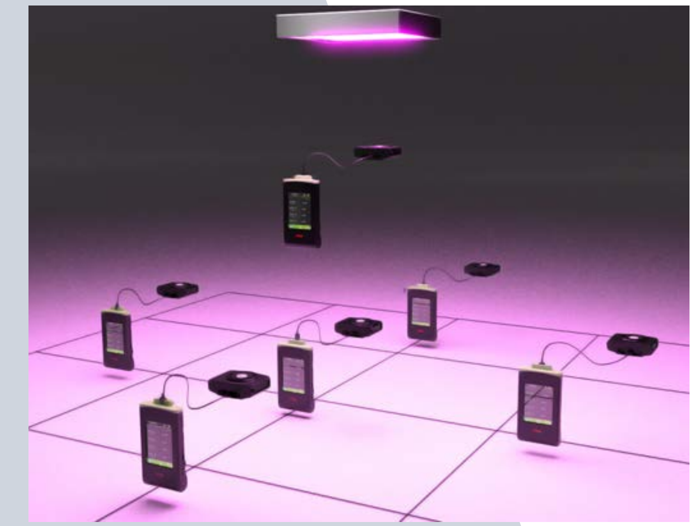


Illustration by Phillip Ronan CC BY-SA 3.0 wikimedia commons

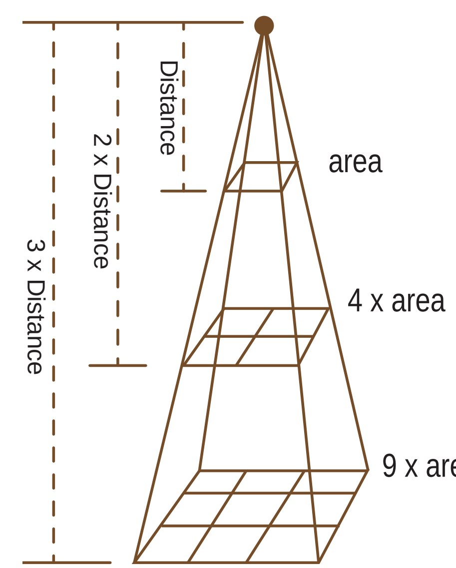
PPFD, distance from plant and spacing your lights.

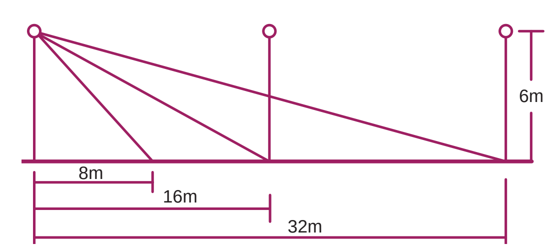


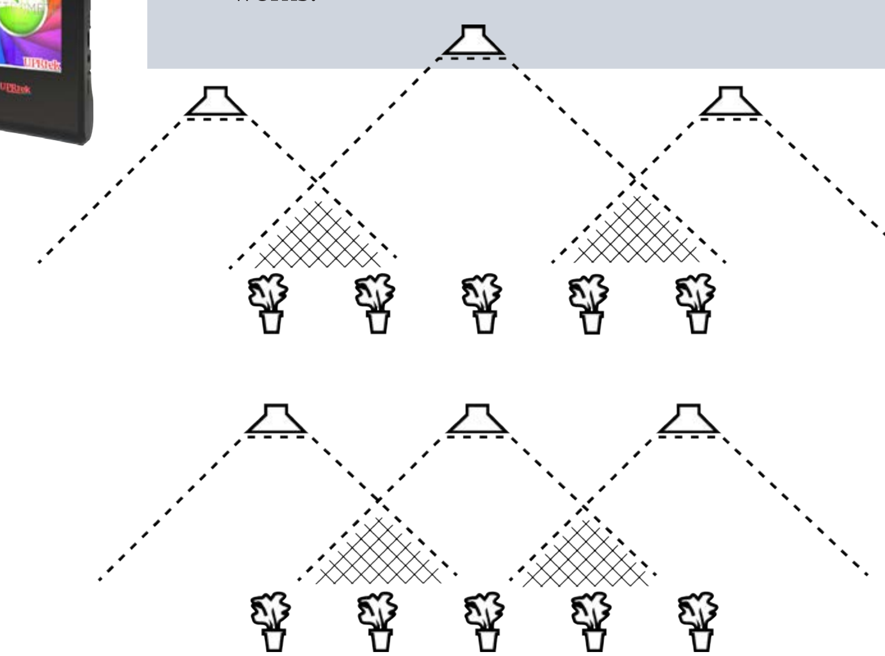
How light is distributed on a plant depends on the light, the height and distance from the plant. When you check the PPFD for a light, you should also measure not only at the center but from different heights and all sides of the light. This will help you determine how many lamps need to be placed alongside each other to maintain the DLI for all sides of the planting area. Some may also use reflectors in confined spaces to ensure equitable distribution of light and may allow you to increase your PPFD by 25-35%. When light is not equitably distributed, you may get elongation from the plants on the outer edges, a plant's natural response to reach for more light.

Also, PPFD from two lights are generally additive meaning that two lights with a PPFD of 100, will produce a PPFD of 200 if shown on the exact same area.

When you measure PPFD, if you move the light farther from the plant vertically, the photons that hit the plant decreases proportionally to the square of the distance. PPFD is reduced proportionally (at "2d", PPFD is 1/4 of what it is at "d", at "3d" PPFD is 1/9 of what it is at "d").. As you move farther away laterally from the center of the light, the PPFD also diminishes in proportion to distance. This would be very similar to the way LUX works.







Determining height and distribution of your lights for adequate PPFD light allocation can only be practically done with a portable PAR meter.

How about light efficiency in energy savings.

If you really want to measure energy efficiency you should calculate the PPF per Joule, not lumens per watt.

PPF is µmol/second and Watts are represented by Joules per second

If you take PPF µmol/s and divide by Watts which is J/sec, the "seconds" will cancel and you'll be left with **µmol/joule** and this is a more accurate measure of grow light efficiency than lumens per watt.

First you better get an accurate read on the actual Wattage. Depending on the light brand, the actual wattage can sometimes be misrepresented in the specifications. Some product testing websites will take a wattage meter and measure for themselves.

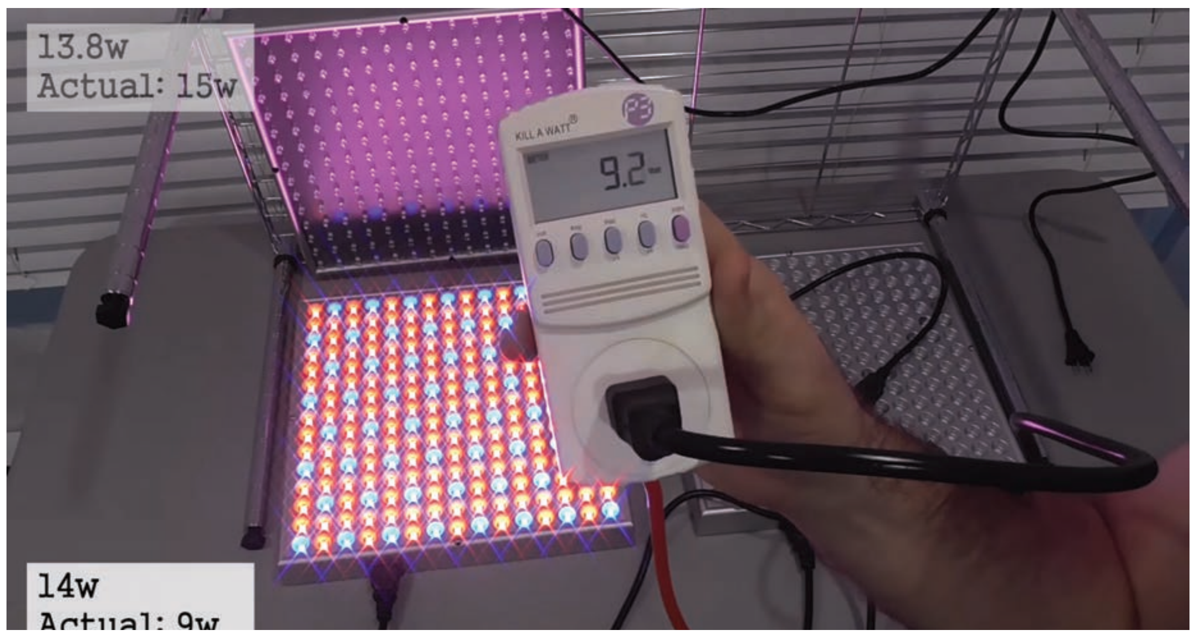
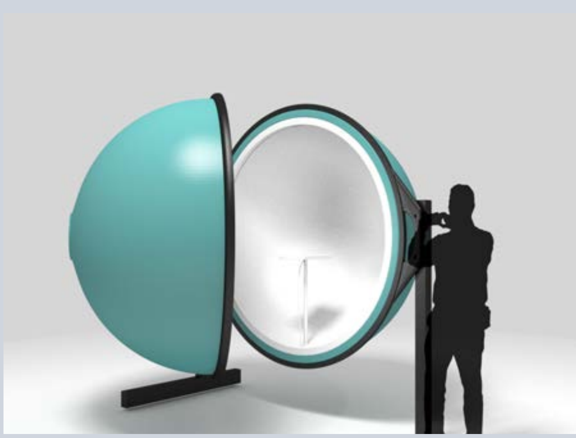


Image above is courtesy of Al Gracian of www.albopepper.com



Also, it's not certain if PPF (µmol/sec) will even be mentioned with your light fixture specifications. If they are mentioned, these measurements like lumens/watt are not always accurately represented and can be easily manipulated. So it's best to measure it yourself with a watt meter and a light meter.

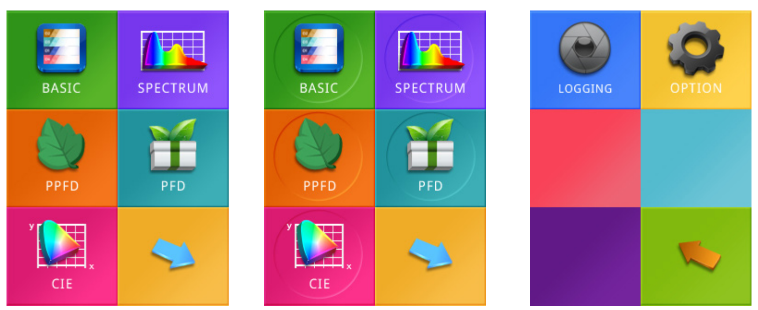
However, to get a PPF measurement, you would actually need specialized light measuring equipment called an integrating sphere, which is expensive and mostly unwieldy. You place your light in the middle, close the sphere and it calculates the total light emanating from all around the light. That is why it is not practical for any portable light meter to measure PPF. Portable light meters measure light from straight on.

However, you can use a light meter like the PG100N to measure PPFD (µmol/m²/sec), which is the same as PPF, only that it measures light on an area of 1 meter squared. So you can use PPFD to calculate energy efficiency the same way, calculating µmol/m2/sec divided by Joules/sec, leaving you with **µmol/m2/Joule**. And as long as you use this same unit measure for all your lights, it should be an objective assessment of light efficiency between different lights. The higher the number, the better.

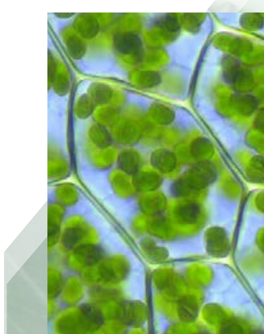
Photo by Alfonso Cenname on Unsplash

The Last Say

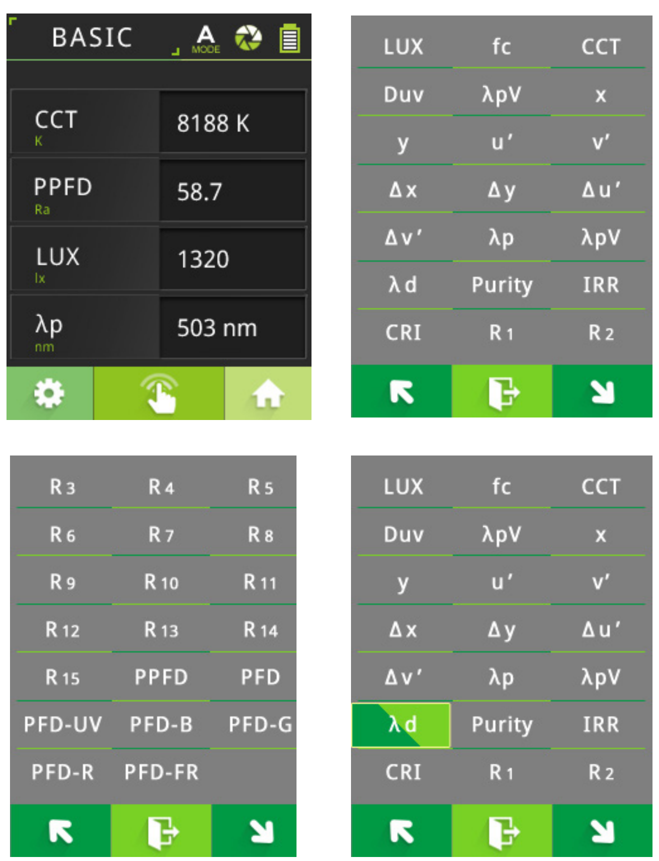
The burgeoning indoor horticulture industry has resulted in a booming market for Grow Lights. Whether augmenting sunlight or using it as the main source of light energy, the practice and proper usage of Grow Lights will have a significant impact on the appearance, taste and shape of a plant. And there is only one way to practically ensure the quality and quantity of light over a large indoor farming area and that is to use a light meter. But not all light meters are designed with grow lights in mind. The PG100N is geared specifically for grow lights with both spectral and quantitative measurements allowing growers and researchers a tool for getting their arms around the fickle nature of growing plants with artificial lights.

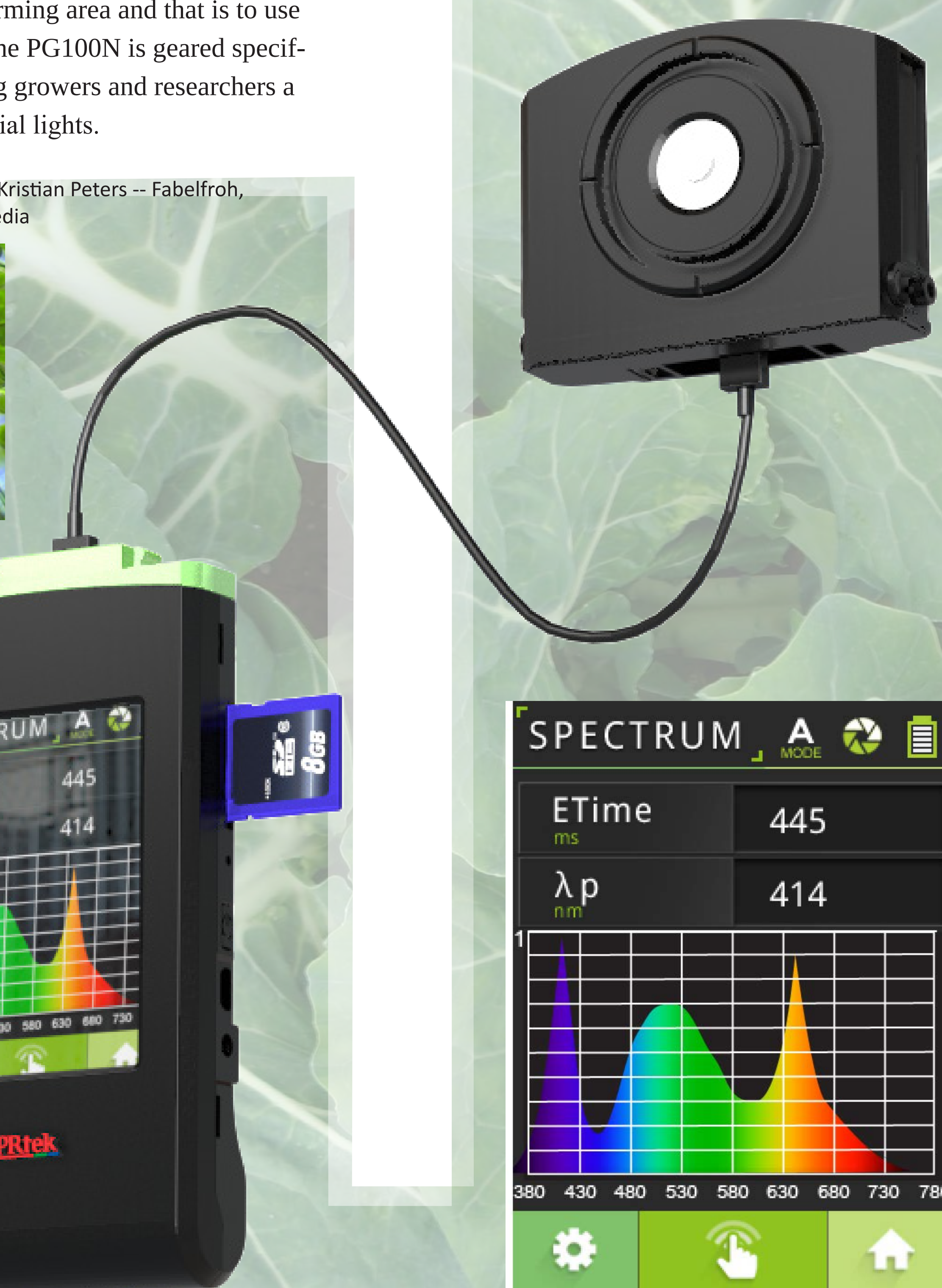


Plant Cell Photo By Kristian Peters -- Fabelfroh, CC BY-SA 3.0 Wikipedia



Complete Basic List

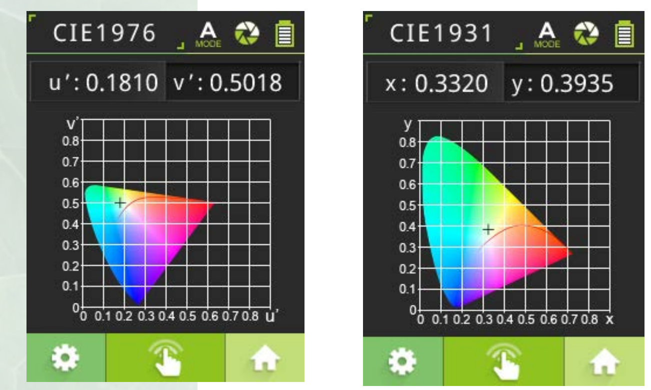




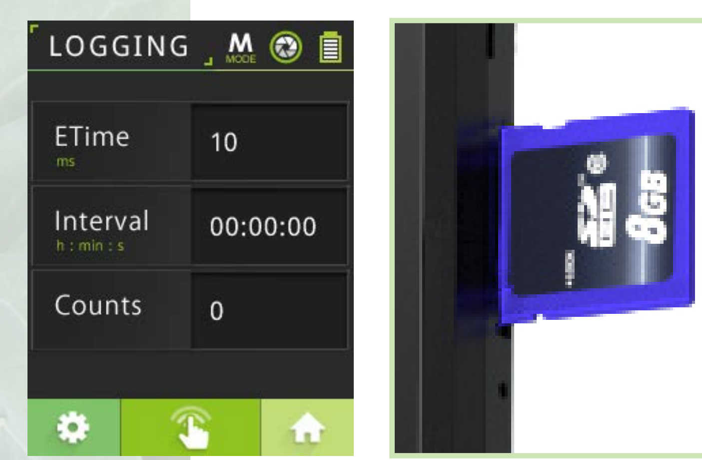
UPRtek PG100N

Separated PPFD values including UV and Far Red

Color Space 1931 & 1976



Logging and SD card



Background photo by Marta Reis on Unsplash

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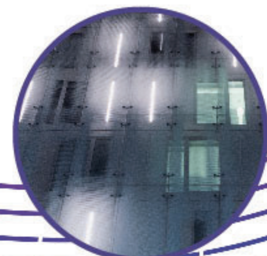
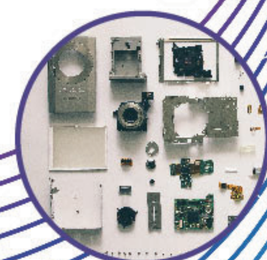
Accuracy

Quality

Professionalism



Flexibility



Integration

Execution

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