UNDERSTANDING LIGHT LEVELS FOR ORCHID GROWING

Both Natural and Artificial Setups

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AGENDA

1. Introduction to light: natural and artificial
2. The various definitions of light for growing plants: energy and intensity
   i. Lumens, PAR and PPFD
3. Light levels for low, medium, and high light orchids
4. Measuring light levels in your growing spaces
5. Types of artificial lighting
6. Setting up artificial light sources
7. Thoughts for more adventurous lighting strategies

KEY REFERENCES

Let There be Light! By Kelly McCracken in Orchids: The Bulletin of the American Orchid Society Volume 90 No 7-11, 2021.

- Part 1: An Introduction to PAR and PPFD: Why You should Forget Lumens. P. 520 (July 2021)
- Part 2: Target PPFD for Orchids and Tropical Plants p. 596 (August 2021)
- Part 3: Measuring Artificial Light Without a Quantum PAR Meter p. 676 (September 2021)
- Part 4: Setting up your Led Lights – How High, How Far Apart and How Many You Need p. 758 (October 2021)
- Part 5: Spectrum and Photoperiod p. 840 (November 2021)

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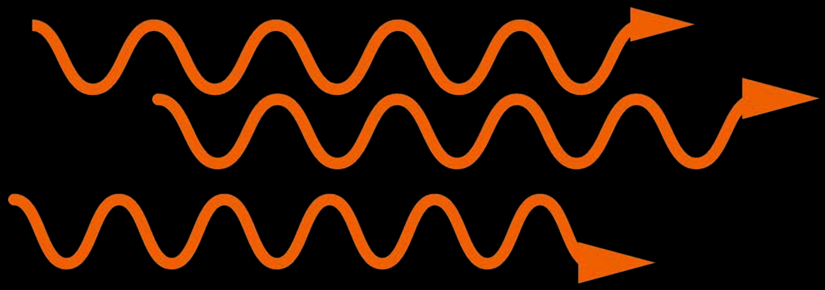
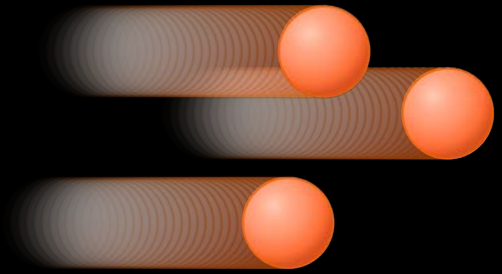
LIGHT

Light is a form of radiation.

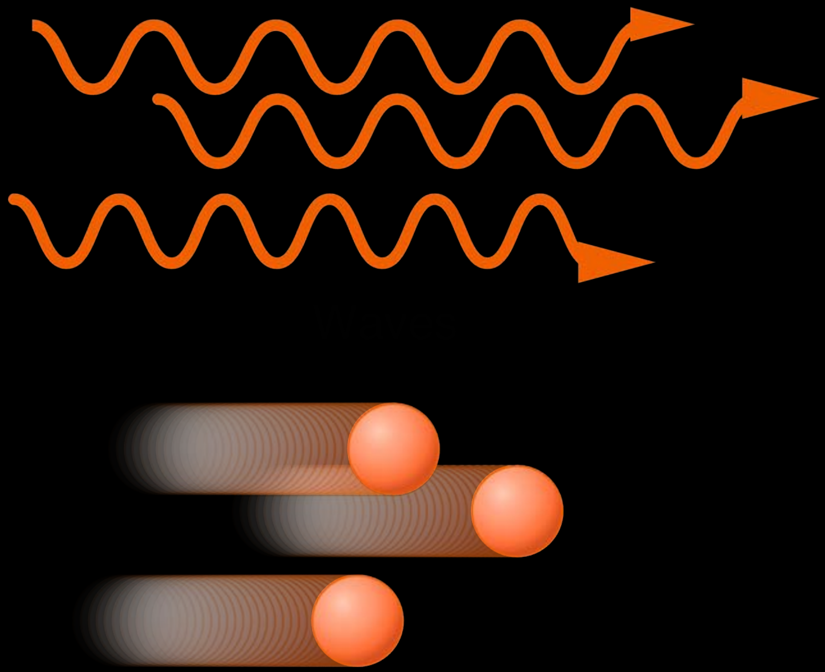
It can be thought of as a stream of packets (particles, called **photons**) of energy that also behave like a wave.





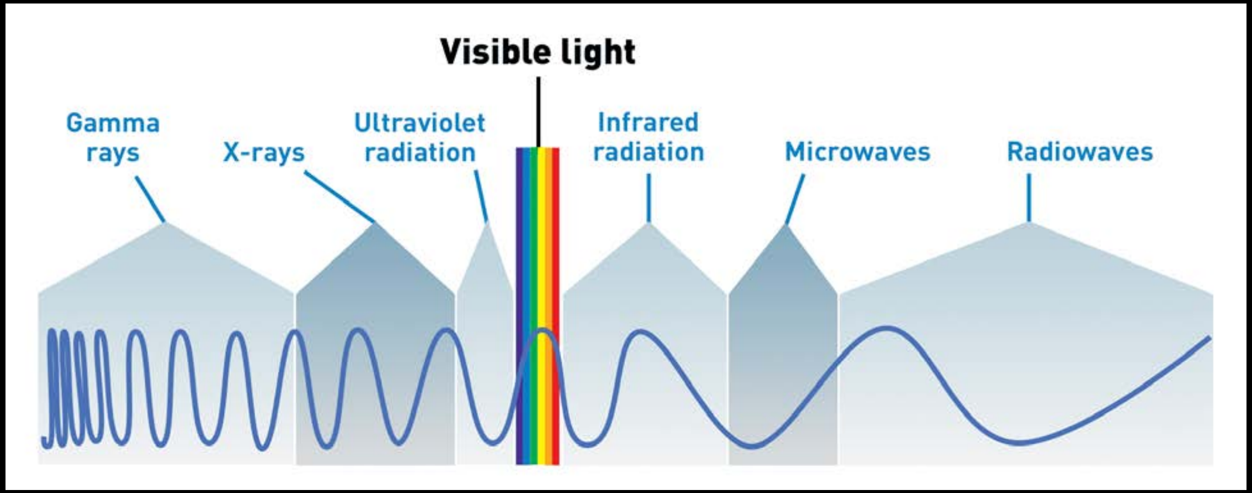
LIGHT

The energy that light delivers is dependent on its **wavelength** (colour) and **intensity** (brightness).



Light delivers energy to plants.

LIGHT

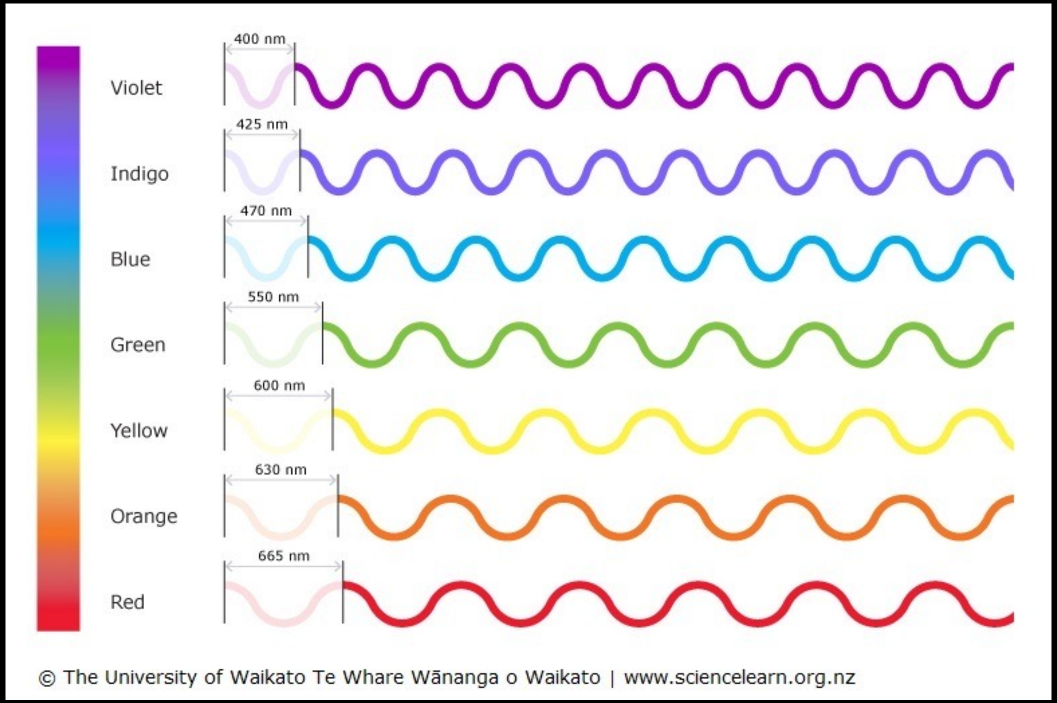


The **wavelength** tells us how much energy each photon can deliver. Shorter (bluer) wavelengths mean more energy per photon.

The **intensity** tells us how much total energy is delivered per unit of time per unit area.

Intensity = power / area

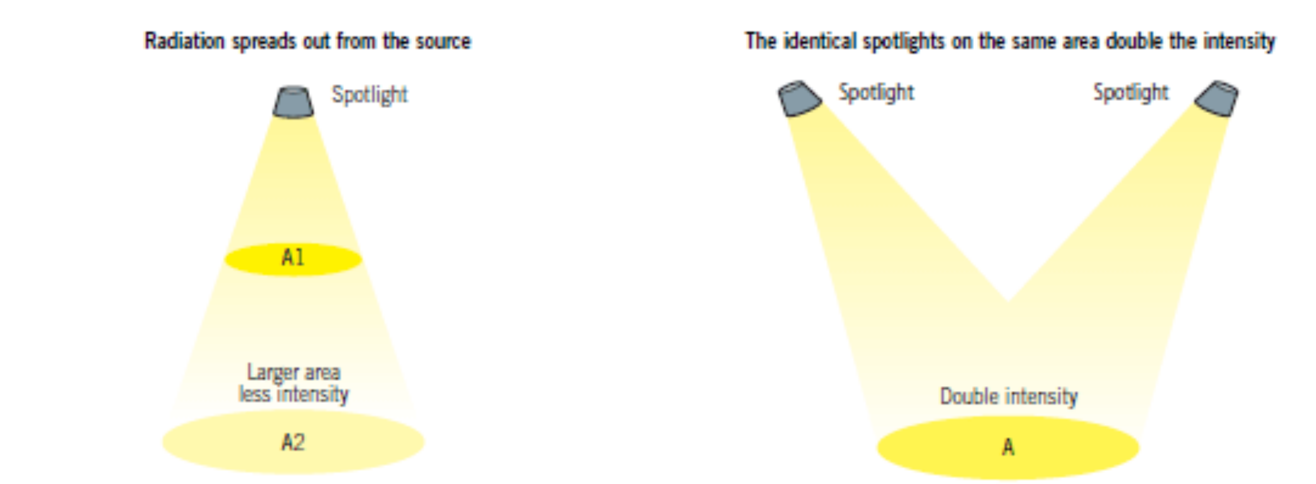
Where **Power = energy / time**



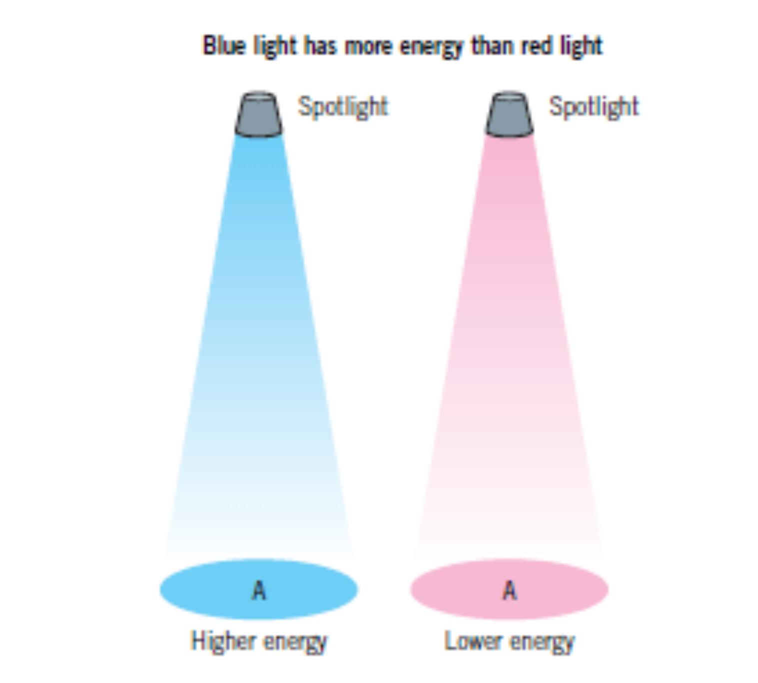
LIGHT

Intensity is dependent on the power **P** of the sources (bulbs) and how far away (distance, **d**) you are from that source.

The energy delivered also depends on the colour of the light sources.



$$I \sim \frac{P}{d^2}$$

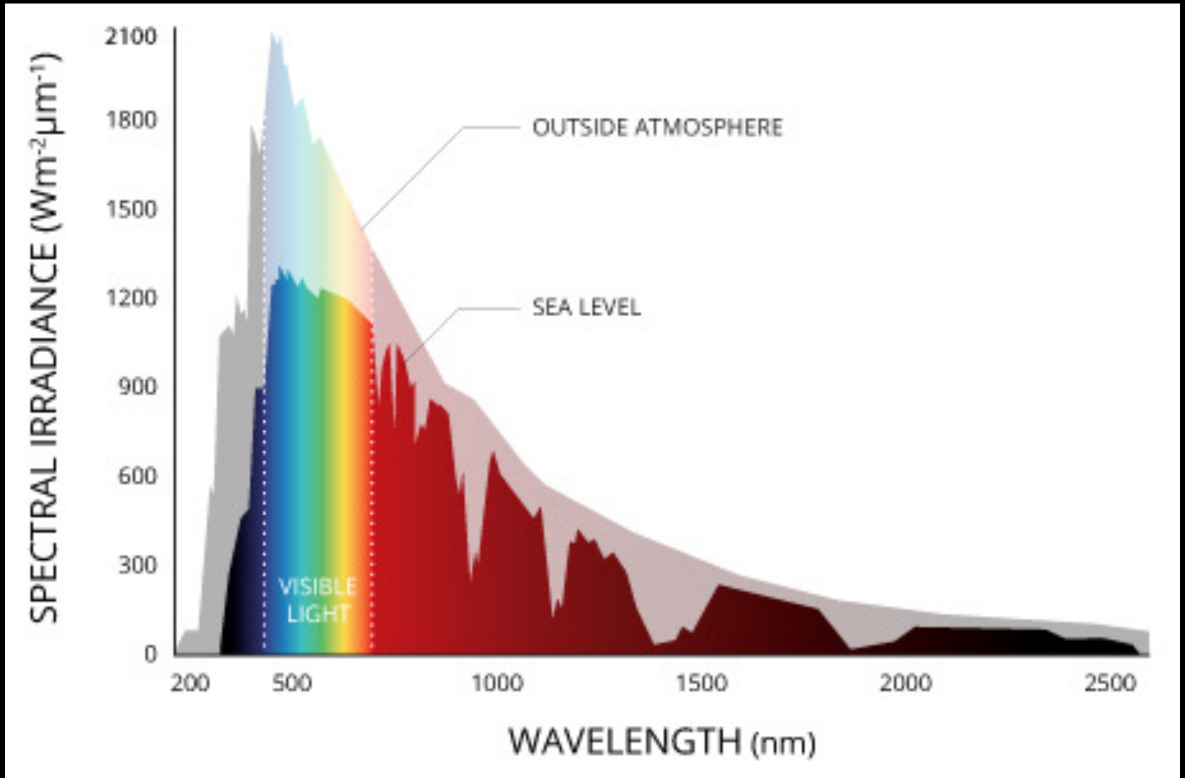


SUNLIGHT

Light from the sun spans a large range of wavelengths (energy). The part that is visible is only a narrow part of that range.

The radiation is generated from the atoms in the Sun’s atmosphere via nuclear fusion.

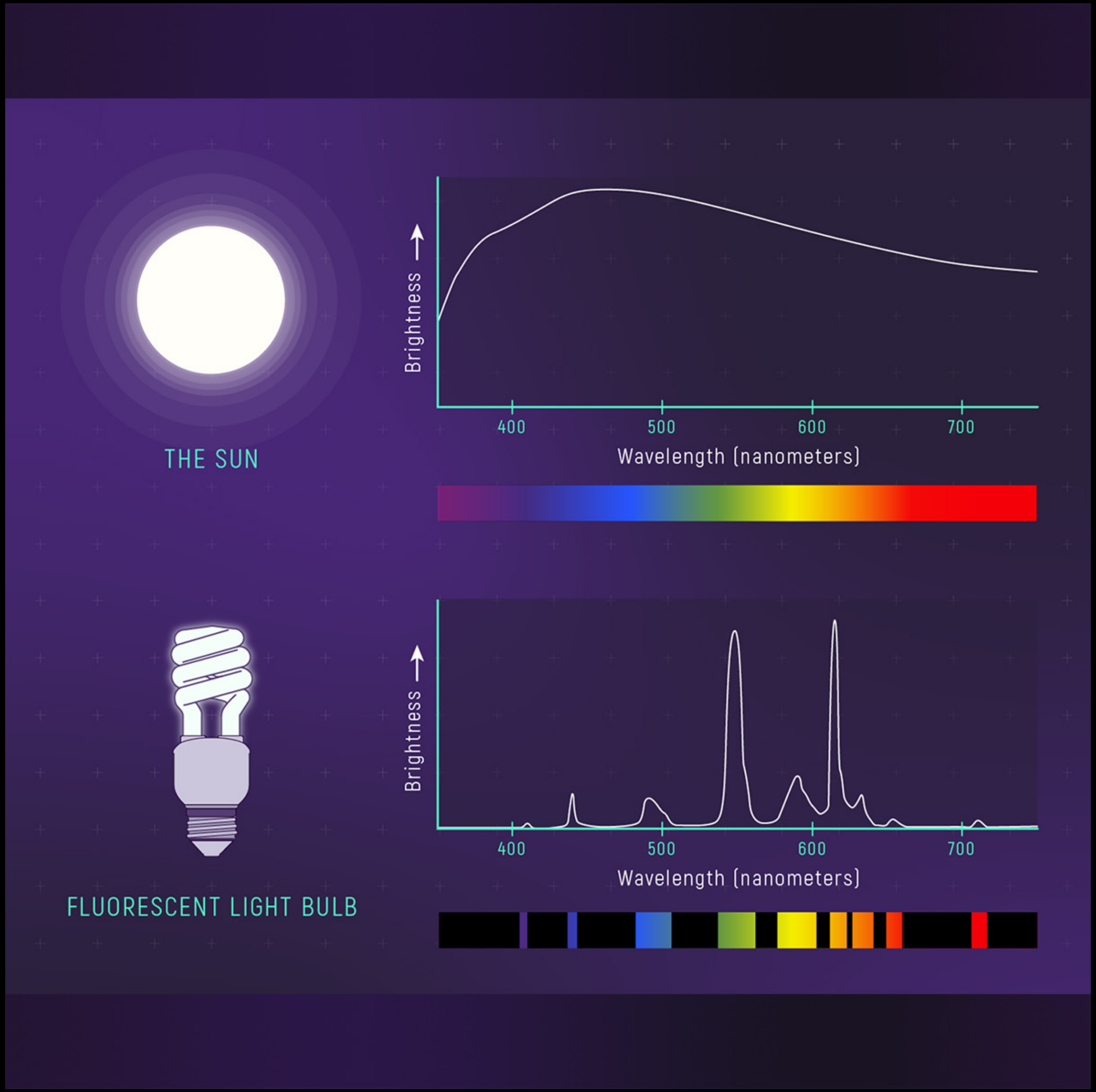
Atoms and molecules in Earth’s atmosphere absorb some of this radiation (thankfully!). The rest is available to us and the plants.



ARTIFICIAL LIGHT

Artificial bulbs generate light by using electricity rather than nuclear fusion like the Sun.

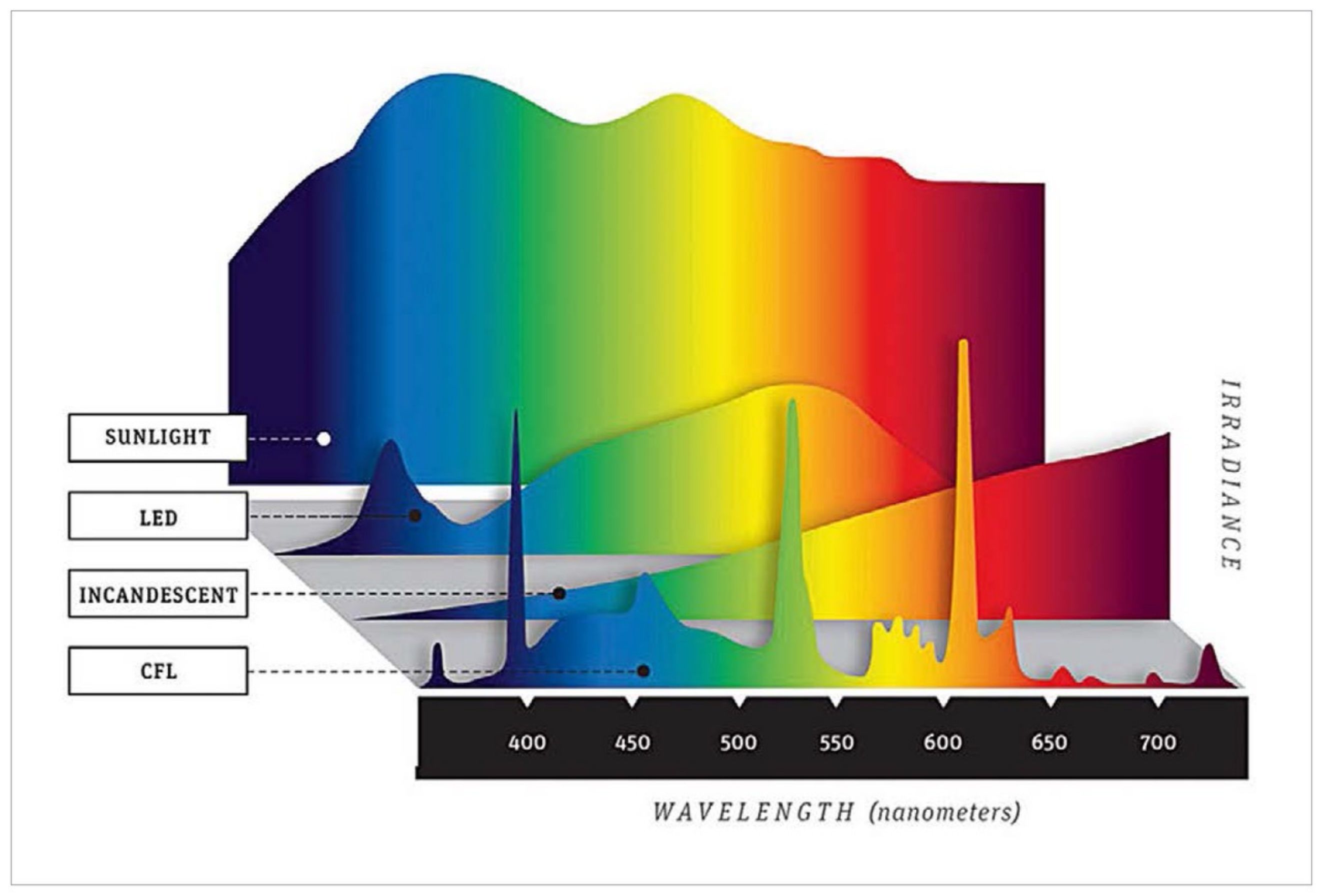
Fluorescent bulbs contain specific elements which emit a characteristic wavelength of light.



ARTIFICIAL LIGHT

There are different bulb types available and they generate light in different ways.

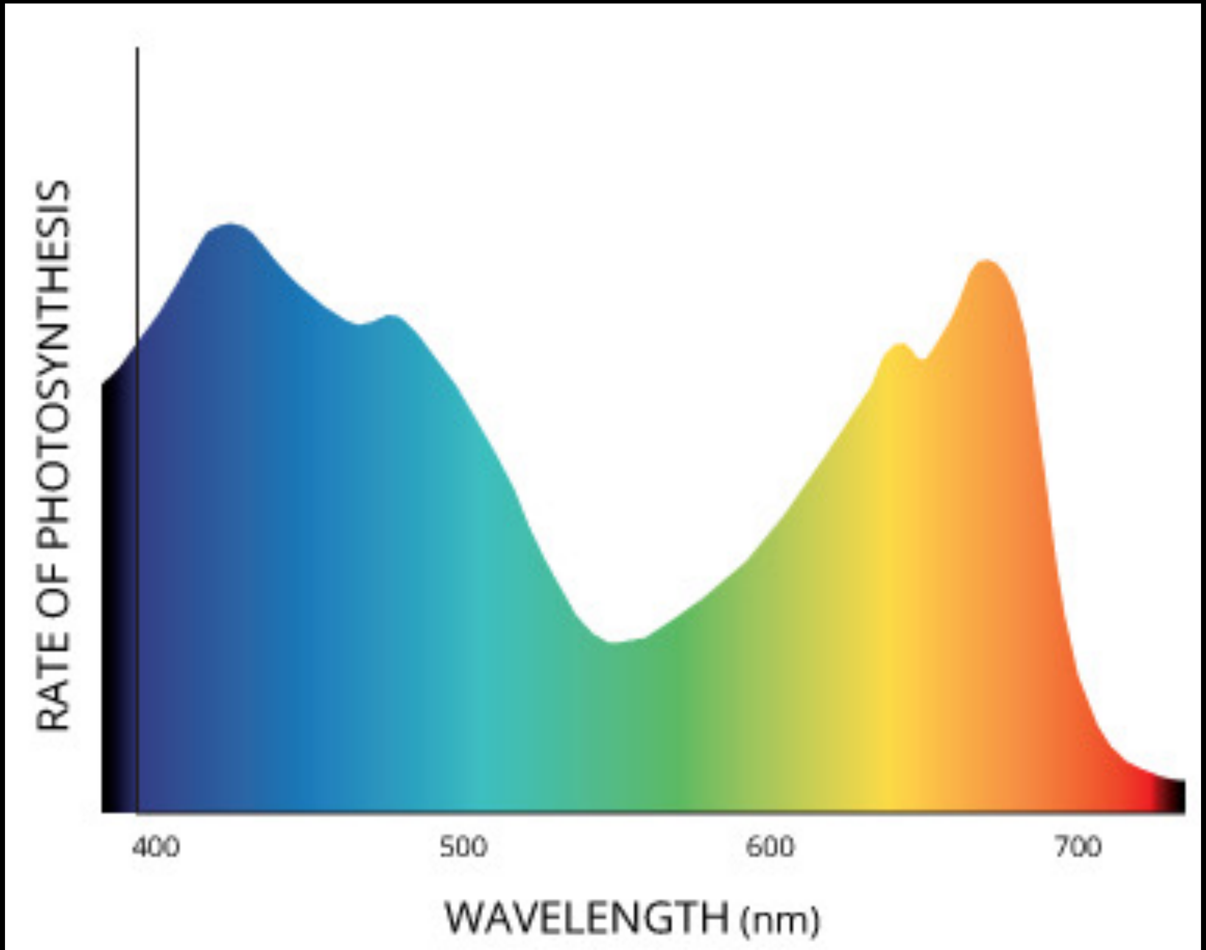
- Incandescence (from heat)
- LEDs (electroluminescence)
- CFLs (fluorescence)
- Glow sticks (chemical reaction)



WHAT PLANTS WANT

Plants have evolved to use certain wavelengths (energy) of light.

Leaves absorb some wavelengths and reflect others (e.g., green).



LIGHT – IN SUMMARY

- Light can be thought of as particles (photons) that behave also like waves.
- We need to know what energy those photons have (wavelength or colour of light) and their intensity (how many photons are falling onto the plant per unit time).
- Intensity depends on the power emitted from the source (e.g., number/type of **bulbs**) and **how far away** the surface (plant) is from the bulb.
- Plants have evolved to use visible light that comes from the Sun
- Artificial light sources try to reproduce – to varying degrees – visible light.

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DEFINITIONS OF INTENSITY

- We need to have an easy definition of "how much light is falling on my plant?"
- The goal is to provide the plant the total power it needs: the energy (wavelengths) it can use, at the right intensity.

LUMENS

Lumen:

*the SI unit of luminous flux, equal to the amount of **light emitted per second** in a unit solid angle of **one steradian** from a uniform source of one **candela**.*

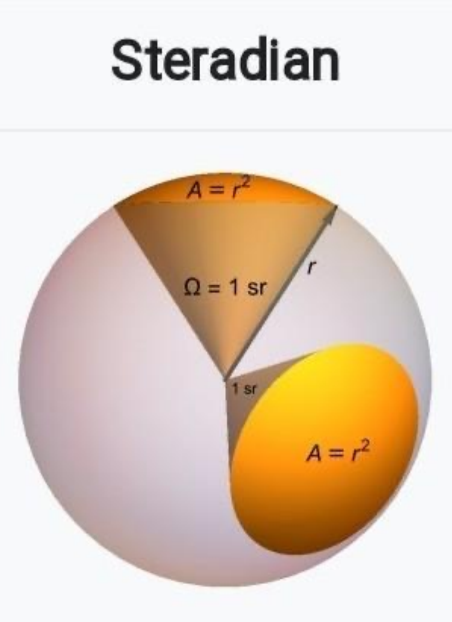
Candela:

One candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 × 10^{12} Hz and that has a radiant intensity in that direction of 1/683 watt per steradian.

(approximately equal to the light from one common wax candle)

One 25W CFL bulb emits ~ 1700 lumens.

A sphere has a total of 4π = 12.6 sr (steradians).



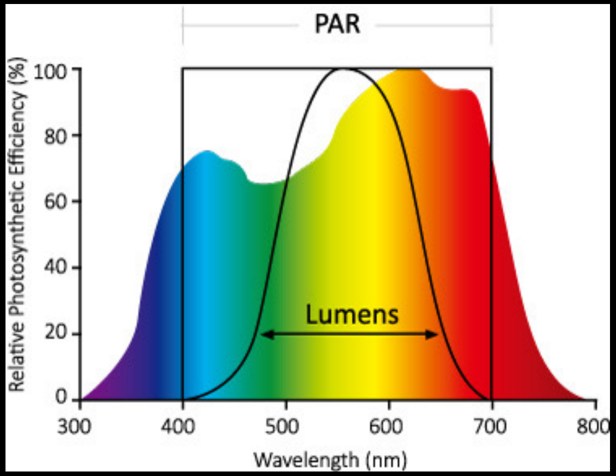
Lumens are relevant to human vision (like light bulbs).

For growth, plants don't care what the human eye sees! We want to use a different measure of the quantity of light.

DEFINITIONS OF LIGHT QUANTITY

PAR

- **Photosynthetically Active Radiation**
- Range of wavelengths below, falling on the plant (in PPFD, right):



PPFD

- **Photosynthetic Photon Flux Density**
- This is the unit of measure for PAR.
- Plants actually use the PPFD we give them (not true with lumens).
- It's measured in µmol m^{-2} s^{-1}

(# of photons hitting a unit area, per second)

(Aside: 1 mol is defined as the number of atoms in 12 grams of carbon-12)

PPFD

- In practical terms, all we really care about for plant growth is PPFD.
- The goal for the rest of this talk is to discuss:
  - What value of PPFD you need for a given plant,
  - How to measure the PPFD in your space, and
  - How to adjust light levels in your growing space to achieve a desired PPFD.

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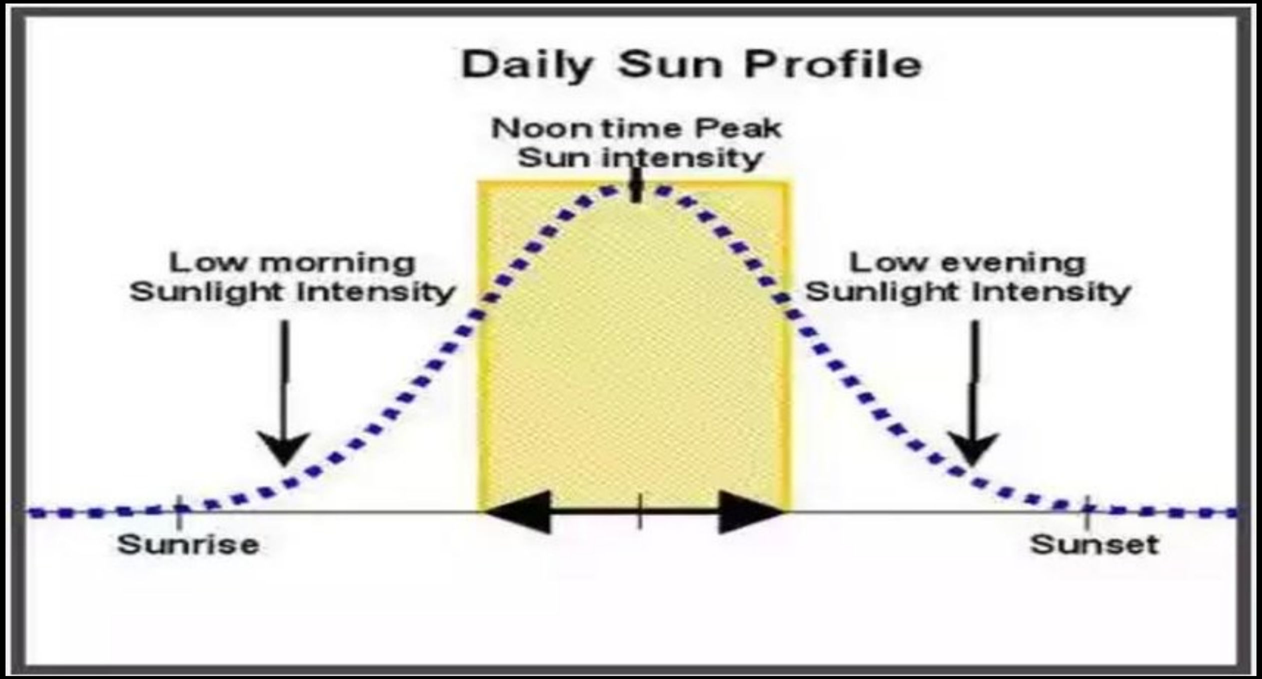
KEY FACTORS TO THINK ABOUT

Total energy delivered, averaged over the spectrum, per unit time (PPFD)

Total time the lights are on per day.

For real sunlight, intensity changes during the day and throughout the year.

Always 12hr days at the equator.



PPFD FOR SPECIFIC ORCHID TYPES

Category	Low Light Plants	Medium Light Plants	High Light Plants
PPFD range ($\mu mol\ m^{-2}\ s^{-1}$) **[12hr cycle]**	40 – 60	100 – 150	200 – 250
Examples	Phalaenopsis, jewel orchids, some paphiopedilums (also begonias, African violets)	Oncidiums, phragmipediums, some dendrobiums	Cattleyas, brassavolas

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COMPLICATED SOLUTION: QUANTUM PAR METERS

Calibrated – outputs PPFD directly.

Measures the full spectrum of PAR.

$800+

EASY SOLUTION: PHOTOGRAPHIC LIGHT METERS

Easier to find, less expensive (probably already available to you).

Less accurate? Probably good enough. (Are phones calibrated?)

Ultimately, the proof is in the flowers.

$300 - $800

EXPOSURE LIGHT METER CONVERSION f/8 @ ISO 100

Shutter Reading	EV	Lux (ignore)	PPFD (Sun) (lux x 0.017)	PPFD (FS LED/fluor) (lux x 0.014)
1/20 s	10.3	3152	53	44
1/40 s	11.3	6303	107	88
1/60 s	11.9	9554	161	132
1/80 s	12.3	12607	214	176
1/125 s	13	20480	348	287
1/160 s	13.3	25214	429	352

Convert EV/shutter to lux: https://toolstud.io/photo/light.php

BACK TO: PPFD FOR SPECIFIC ORCHID TYPES – EXPOSURE CONVERSION

Category	Low Light Plants	Medium Light Plants	High Light Plants
PPFD range ($\mu mol\ m^{-2}\ s^{-1}$)	40 – 60	100 – 150	200 – 250
Photography exposure reading (shutter, at f/8, ISO 100)	1/20 s – 1/30 s	1/60 s	1/100 s
Examples	Phalaenopsis, jewel orchids, some paphiopedilums (also begonias, African violets)	Oncidiums, phragmipediums, some dendrobiums	Cattleyas, brassavolas

EXPOSURE LIGHT METER CONVERSION
Comparison of phone with PAR meter

Reading	Photone App (PPFD)	PAR Meter (PPFD)	App overestimates by:
1	114	93	23%
2	287	207	39%
3	282	200	41%

Table derived from Orchids magazine articles.

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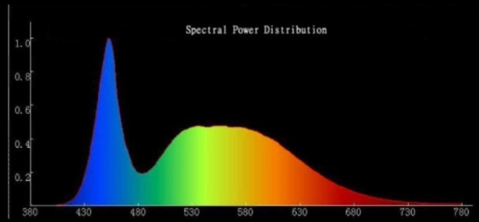
BASIC TYPES OF ARTIFICIAL LIGHTS

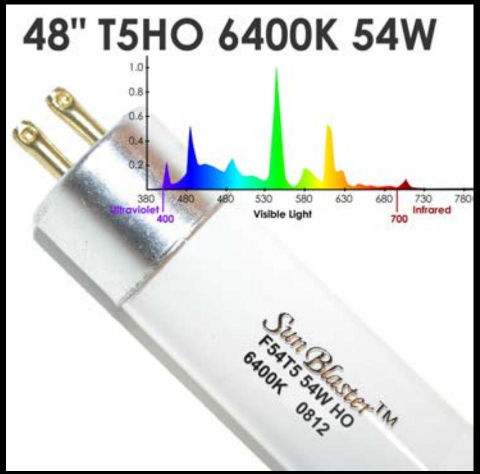
LED

- 48W (4')
- 50,000 hours
- $175
- Electricity cost per year:
  - $33
- Bulb cost per year:
  - $15



FLUORESCENT

- 54W (4')
- 10,000 hours
- $70
- Electricity cost per year:
  - $37 ($44, adj. for efficiency*)
- Bulb cost per year:
  - $31



*Note: The fluorescent bulbs here have ~20%+ less PPFD light output than the LEDs per watt.
Assume: On 12hr/day, current 2023 Saskatoon city electricity rates.

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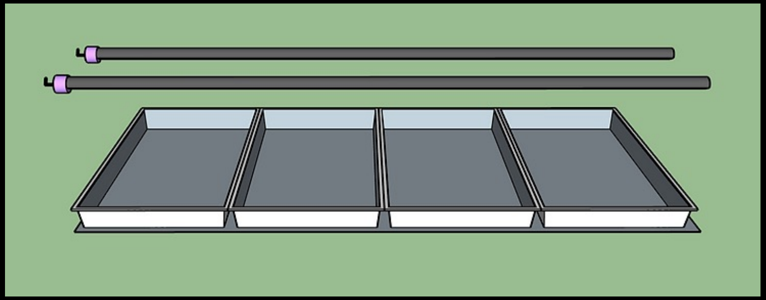
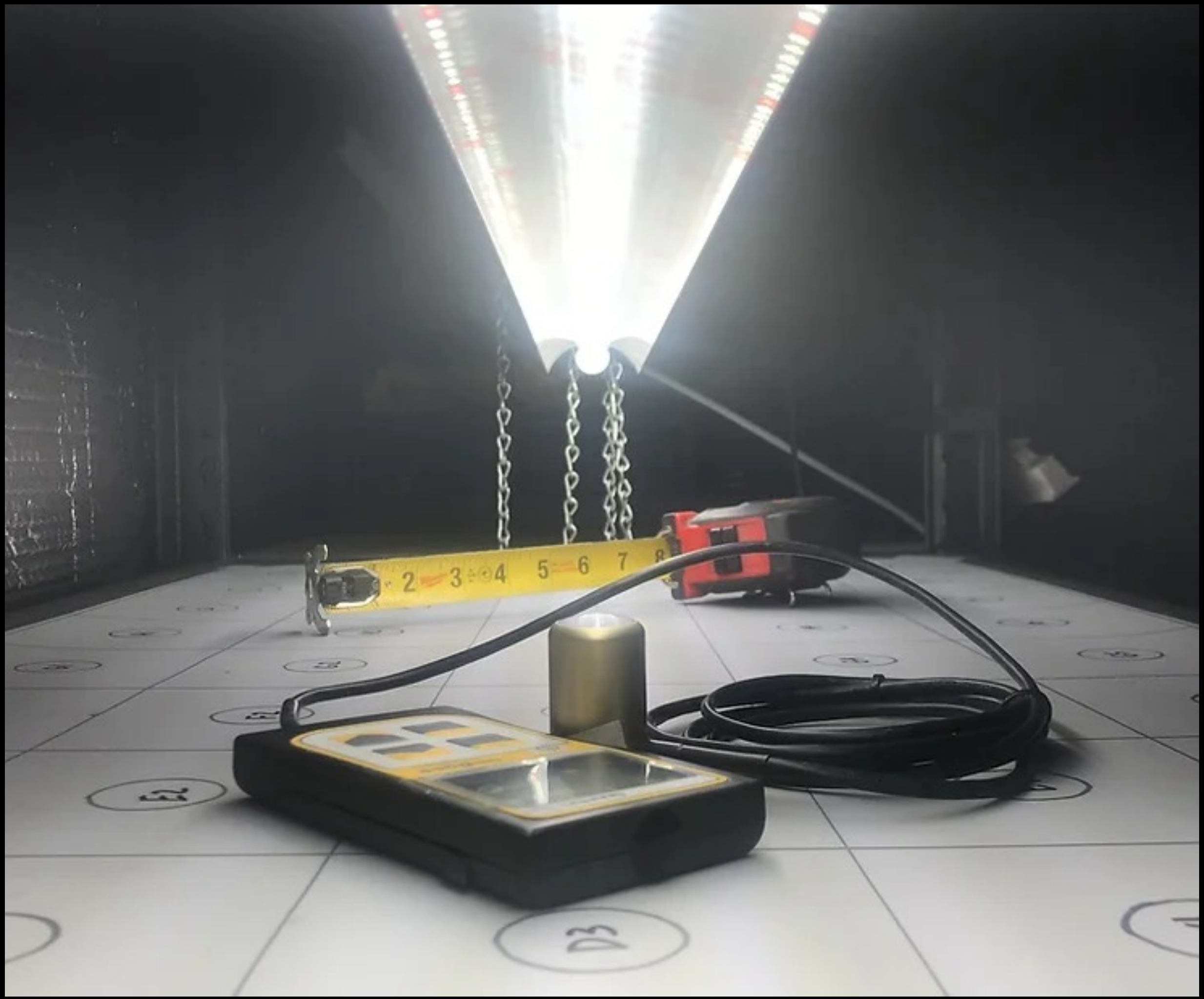
BASIC SETUP IDEAS FOR ARTIFICIAL LIGHTING

ARRANGING LIGHTS AND PPFD MAPPING

Experiment by vegetableacademy.com

- Sunblaster 4' LED
- 20" x 48" grid
- Measured PPFD with a full spectrum sensor <u>**6"**</u> **below light (vertical)**
- Mapped the PPFD distribution based on where plants would be placed.





ARRANGING LIGHTS AND PPFD MAPPING
SINGLE LED BULB

Single LED Grow Light Data

SB = SunBlaster AG = Active Grow

The tables below show test results when single lights were suspended down the centre of the data collection surface at a height of 6 inches above the light sensor. A colour gradient has been added to the test data to help you visualize the difference in light intensity over the test area.

Gradient Colour Scale of PPFD Readings (µmol m-2 s-1)							
0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400

Test: 1 x SB LED light suspended 6" above sensor	
Highest PPFD Reading (µmol m-2 s-1) =	201
Average PPFD Reading (µmol m-2 s-1) =	113
Standard Deviation =	52
16 hour DLI (mol m-2 d-1) =	7
24 hour DLI (mol m-2 d-1) =	10

	A	B	C	D	E	F	G	H	I	J	K
1	41	56	63	65	66	62	62	68	65	61	46
2	93	129	143	145	146	144	150	150	143	137	99
3	125	183	197	196	199	201	200	200	196	185	135
4	89	130	141	144	147	149	144	142	138	124	91
5	38	54	61	64	68	65	62	62	56	50	37

ARRANGING LIGHTS AND PPFD MAPPING DOUBLE LED BULB

Double LED Grow Light Data

SB = SunBlaster AG = Active Grow

The tables below show test results when two lights were spaced 8 inches apart over the data collection surface and hung at a height of 6 inches above the light sensor. A colour gradient has been added to the test data to help you visualize the difference in light intensity over the test area.

Gradient Colour Scale of PPFD Readings (µmol m-2 s-1)							
0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400

Test: 2 x SB LED lights 8" apart and 6" above sensor	
Highest PPFD Reading (µmol m-2 s-1) =	328
Average PPFD Reading (µmol m-2 s-1) =	296
Standard Deviation =	38
16 hour DLI (mol m-2 d-1) =	17
24 hour DLI (mol m-2 d-1) =	26

	A	B	C	D	E	F	G	H	I	J	K
1	119	154	168	173	177	178	177	181	166	153	119
2	222	290	312	318	323	325	324	319	311	287	222
3	222	288	312	320	328	322	328	316	308	286	220
4	225	291	313	320	324	325	323	317	310	286	219
5	120	155	168	180	177	178	177	174	166	152	118

AN EXAMPLE

2x Sunblaster 4' LED lights at
back of shelf 19" above surface

Brassavolas
1/80 s

Cattleya types
1/100 s

Phal
1/30 s

Cat shield

SUMMARY – ARTIFICIAL LIGHT SETUP RECOMMENDATIONS

- Use a full spectrum LED source – multiple bulbs as needed. Time ~12hrs on/off cycle.
- Suspend the light(s) at a height to achieve desired light level at the plant(s).
- Think about vertical as well as horizontal (lateral) distance from the light(s).
- Don't worry too much about the exact light level – adjust as the plant responds.

For natural light:

- Consider daytime and yearly changes in light levels.
- Use sheer curtains, other plants, etc., to modulate light levels.

Ultimately, you have more control with artificial light.

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OTHER LIGHTING PROPERTIES THAT (MIGHT) AFFECT YOUR PLANTS

Fancy timing

- Dimmers or additional bulbs on a different timer to mimic daytime or even seasonal changes. Where does your plant naturally live?
- There are timers with app connectivity…
- This is rather complicated if you have a variety of plants!

Fancy setup/measurement

- Combine LED and natural light to mimic natural changes in light levels.
- Take readings throughout the day and year near a window and plot the light levels.

CAVEATS

The plants

- Does your plant really care if you give it a PPFD of 125 or 150?
- Does your plant really care about seasonal variation in light timing?

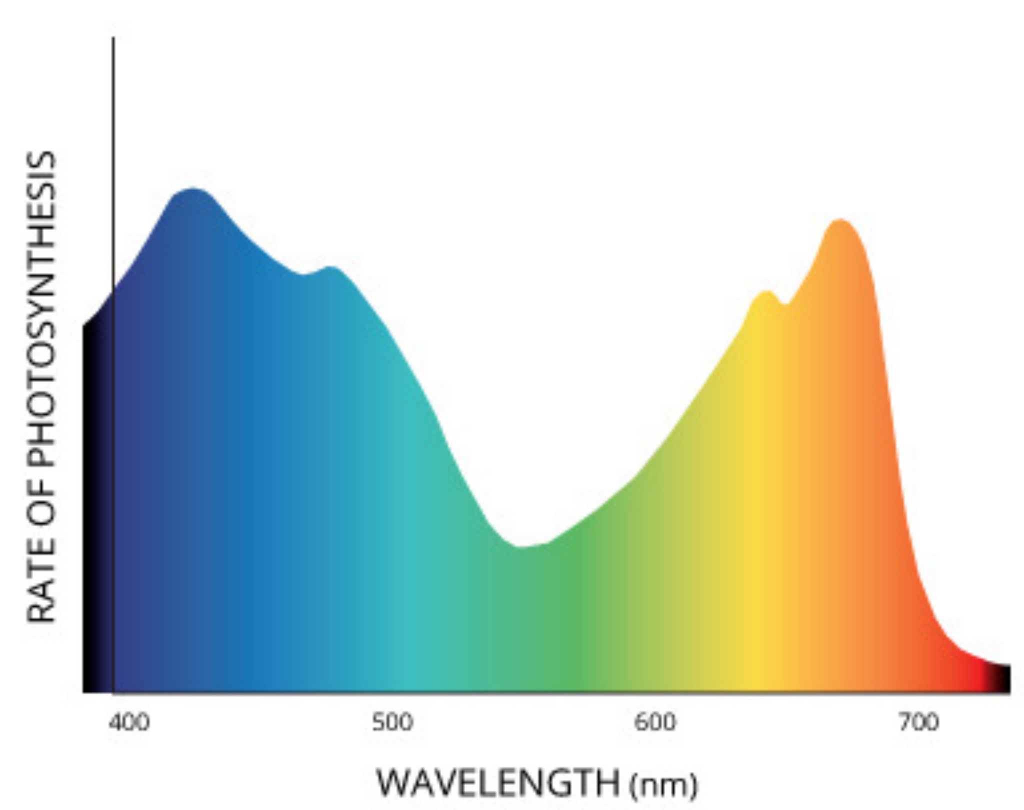
The light

- Natural light is not just subject to seasonal variation, but also the weather.

RECOMMENDATIONS

- Use full spectrum **LED lights** suspended in an adjustable way (e.g. ratcheting pulleys).
- Take some readings with a meter/camera **at f/8 and ISO 100** and look for:
  - **1/30 s for phals, low light plants**
  - **1/60 s for medium light plants**
  - **1/100 s for cattleyas and high light plants**
- Don't worry too much about the exact details… watch for how your plants respond and make adjustments.

EXTRAS



CALCULATING YOUR OWN SPECTRAL CONVERSION FACTOR

The equation

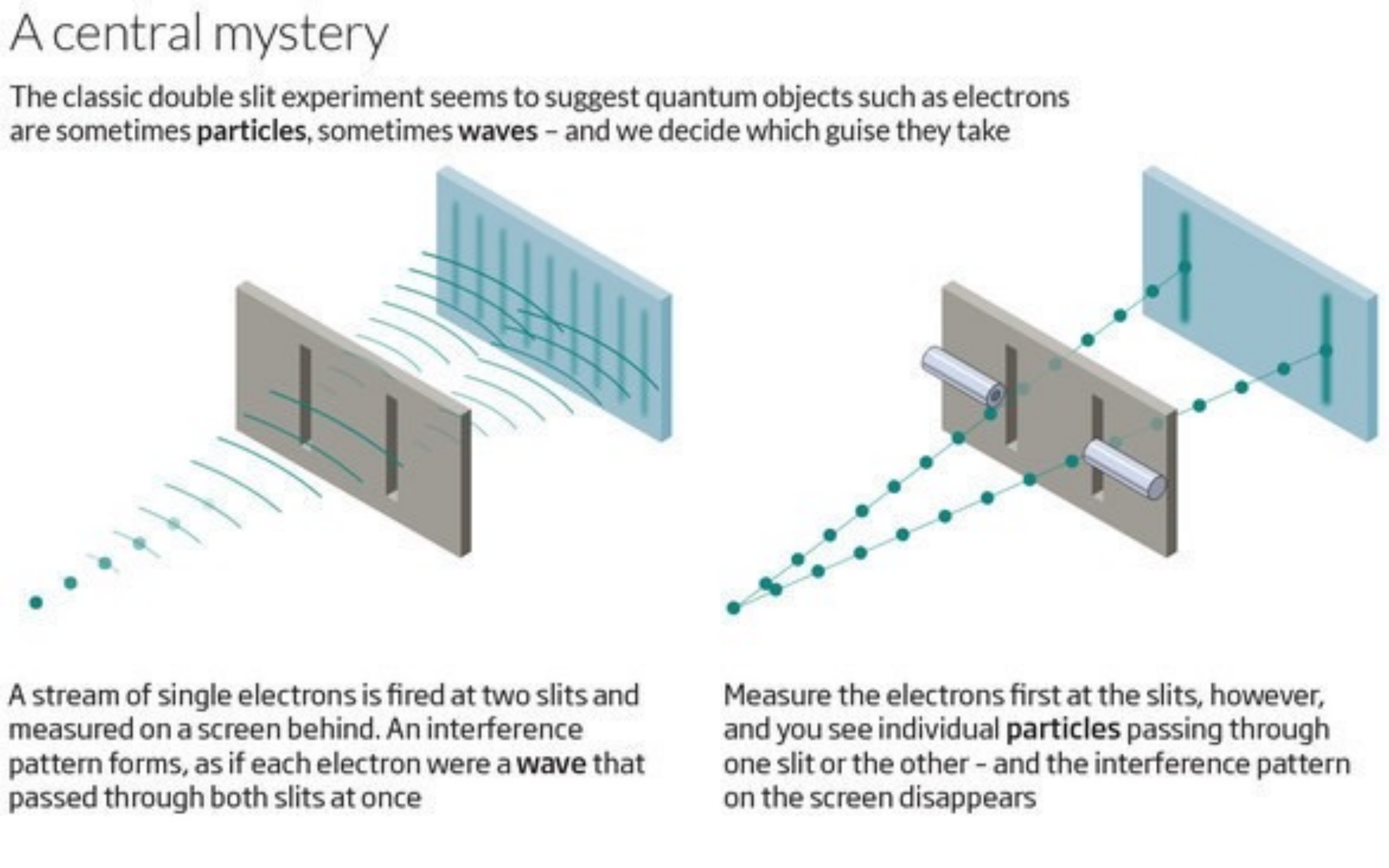
$$\frac{\int_{\lambda=400nm}^{\lambda=700nm} f(\lambda)\frac{\lambda}{hc}\frac{10^6}{N_A}d\lambda}{\int_0^\infty f(\lambda)V(\lambda)Kd\lambda}$$

Gives PPDF per lux (0.014 for LED)

Variables

- λ = wavelength
- $f(\lambda)$ = light intensity (W/m^2) from blub
- Constants h (Planck), c (speed of light), N_A, (Avogadro's #)
- K = 683 lumens per Watt
- $V(\lambda)$ = efficiency function
  - From UCL Colour and Vision Research Lab – use linear energy function (http://www.cvrl.org/)

PARTICLE AND WAVE BEHAVVIOUR: THE DOUBLE SLIT EXPERIMENT



IMAGES AND OTHER SOURCES

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