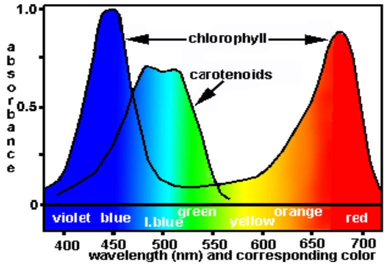
INDA-GRO
"Sunlight in a Box"™
INDUCTION GROW LIGHTS

Measuring Plant Lighting

There are a number of ways to measure indoor plant lighting levels. As such, there remains considerable debate as to which method provides the gardener with the best information in determining if the light source is providing the ideal wavelengths and intensities to optimize plant response. While the debate swirls it ultimately will always come down to our plant's response to those spectrums and intensities.

We recognize that the complexities of understanding and choosing which technology, or lamp, is best suited for gardening with indoor artificial lighting can be confusing. We publish our lamp's output data in a format that you may not be familiar with, but we believe it offers the gardener a better opportunity to determine how much energy a lamp emits between 400-700 nm relative to generally accepted photosynthetic absorption regions.

As you can see by this Net Action Absorption Chart, what is believed to be the areas of greatest importance for a lamp's energy to meet peak chlorophyll absorption points would be in the Vegetative Regions (Ultraviolet-Blue) and Flowering Regions (Red-Far Red). Less energy is required of the Carotenoid region (Green-Yellow) but as you can see there is still need for the lamp to emit within this region.



Grow lamp manufacturers produce Spectral Distribution Graphs for their lamps that graphically depict where the lamp will output wavelengths and in what intensities those wavelengths will emit. This works well in allowing the consumer to determine the lamps spectral output characteristics. The gardener can then decide if that particular lamp would work best for the type of plant being grown, specific growth cycles or if the spectrum is broad enough to take the plants from a vegetative thru a flowering state utilizing a single lamp.

In determining the proper lamp to purchase, the gardener will sometimes mistakenly rely on numerically driven data such as a comparison of lumen output, lumen/watt, kelvin, lux, and µmole ratings to name a few. For plant lighting comparisons, each of these values will at best give incomplete information and at its worse, will provide you with information that is mostly irrelevant to what your plants actually require from the lamp.

A more informed approach relies on a review of the manufacturer's spectral distribution graph. Once installed, the gardener will still want to measure light intensity to have complete lamp performance data. These types of field intensity measurements are usually made with a modestly priced PAR meter which has been calibrated to the sun and not the artificial light source being measured. Which leads us to why we do not publish our lamp output data based on:

- **Lumens, Lumens/Watt, Lux or Foot Candles** -These are all measurement terms that by definition use light meters which reference intensities adjusted to the human photopic luminosity function. They have little bearing on how a plant will respond to the intensities being emitted in visual regions.

- **Kelvin** – This is another human visual standard that references how the light appears overall to the eye with 555 nm being peak visual sensitivity and 510/610nm being ½ peak visual sensitivity. As higher Kelvin value imply, more blue to red ratio and lower Kelvin values would indicate a greater red to blue ratio. Basing your grow lamp decision based on how much visual red or blue a lamp emits is not a good means of determining if that lamp is meeting the actual absorbance regions.

- **µMole** – This value is attained by using a PAR meter which is a better meter for reading plant intensity values in that it is not correcting for human photopic luminosity function, like a meter reading lumens, lux or footcandles will do, it still has some of its own issues. The problem with relying too heavily on a µMole value is that it is based on the total light intensity in the 400-700 nm range and does not account for the spectral points within that range. This issue is further complicated by the fact that PAR meters actually measure light intensity (not actual photon counts), it must assume a spectral distribution to actually assign a uMol/M^{2}-S value. This assumed spectral distribution for a PAR meter will normally be natural sunlight, but for artificial light, with a different spectral distribution, errors will occur. For example, shorter wavelength photons have more energy than longer wavelength photons; a 420 nm photon has 1.5 times the energy of a 630 nm photon. If a particular light source was very heavy in the violet and blue region the PAR meter, based on its calibration, would likely yield a higher uMol/M^{2}-S based on its sunlight calibration assuming that some of that additional light energy from the blue must be red.

Not having a weighted µMole value is also problematic when dealing with narrow spectrum technologies such as LED panels. Manufacturers will often advertise high intensities of 2000 µMoles @ 24" from the source. While that reading might very well be in a peak absorption region, it could easily be a reading in a green-yellow region, or of such narrow bandwidth, that its output is of little value to the plants overall or regional net action absorption requirements. It is for these reasons a complete determination of the lamps output should include reference to the manufacturers spectral distribution graph as well as the amount of energy being expended in the three PAR absorbance regions.

As manufacturers, we need to publish artificial lighting data in a metric that will enable the gardener to have a numerical value which describes the lamps value in both plant spectrums and intensities. A single number, such as lamp lumen output, does not provide the gardener with meaningful data. We believe that by providing the gardener values which take into account lamp energy efficiencies, within photosynthetically active absorbance regions, it allows them to make a more informed decision when purchasing lamps for their garden.

Since no lamp technology is 100% efficient in turning electrical energy into light we have to take these conversion efficiencies into account. As such we publish our lamps values after applying the conversion efficiencies in the three plant absorbance regions as a **Watts/Region** value:

(V) Vegetative 400-520 nanometers

(C) Carotenoid 520-610 nanometers

(F) Flowering 610-700 nanometers

Pro-420-PAR:	Watts/Region (V) 45.8, (C) 25.3, (F) 44.5
Pro-420-PAR with Pontoon:	Watts/Region (V) 45.8, (C) 25.4, (F) 56.7
Pro-200-PAR:	Watts/Region (V) 21.1, (C) 11.6, (F) 20.5
Pro-100-PAR:	Watts/Region (V) 9.7, (C) 5.4, (F) 9.4

Questions and Answers:

1. Does knowing the V-C-F values of the lamps output eliminate the need for the lamp manufacturers Spectral Distribution Graphs?

   The V-C-F values represent the total watts being consumed within these 3 regions. It does not replace a Spectral Distribution Graph which enables the grower to determine precise spectrums within these regions where the majority of the energy is being consumed.

2. Does knowing the V-C-F value eliminate the need for field measurements of lighting intensities?

   The grower would be advised to continue using a quantum PAR meter for initial lamp intensity output at set determined distances from the lamp to meet proper crop Photosynthetic Photon Flux Densities (PPFD) and enable the grower to monitor intensity depreciation at the beginning of each crop cycle.

3. Can you explain how V-C-F values are achieved?

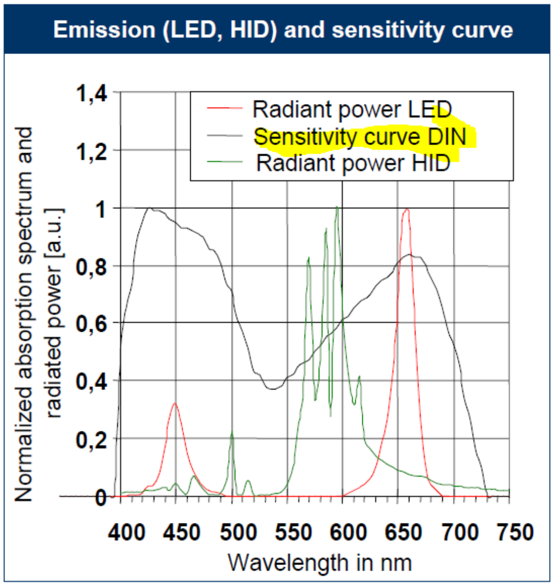
   This process relies on knowing the spectral distribution of the lamp and how much energy it consumes at each individual wavelength and adding that together to show the watts consumed within that region. The manufacturer must have the equipment to take spectral distribution measurements from within that limited V-C-F bandwidth and then publish it in a watts/region format.

4. If I only have a standard light meter that measures Lux, Lumens and Foot Candles can I use that meter to test intensities between my crop cycles?

   While we still recommend a quantum meter a typical photographic type of meter (photometer) will measure intensities loses in the Visible/Carotenoid (C) region of the 520-610 regions spectrum. The relative intensity losses within the (V) and (F) regions would be fairly proportional to the losses in the (C) region.

5. I've not seen other manufactures adopt this approach to publishing their lamps output. Are there other methods that would give the grower enough information to compare lamp outputs?

   Part of the problem is that lighting manufactures do not have a generally accepted industry standard plant absorbance sensitivity curve that manufacturers can point their lamps output data relative to that curve. The problem has been identifying a meaningful curve that is broad enough to cover a majority of plant species net absorption regions. Many manufacturers will refer to the German DIN Standard 5031-10 but this has not been accepted as, nor should it be, a hard and fast standard for all plant species.



6. If two manufacturers have posted identical V-C-F values can a gardener presume the results will be the same?

   The short answer is no. But this answer also depends on the previous answer where specific plant sensitivity curves would ultimately tell which lamp is emitting within the peak absorption ranges that are ideal for that particular plants photosynthetic processes. Watts/Region is a way to determine how much energy the lamp is emitting within that region. Since each region is broad enough that specific wavelengths within those regions may be drawing most of the energy plant response can vary with identical V-C-F values as a result of spectral differences within the regions. It is entirely possible that when comparing two lamps with identical V-C-F values that one lamp will outperform the other.

   Think of it this way; you can go into two separate restaurants and order lasagna. Both chefs will have the same or similar ingredients to get to the final dish. Both dishes have the same calories but one dish may be substantially better tasting and better for you. Plants will react the same way when 'fed' light where wavelengths within the watts/region are different between the two lamps.

7. Do reflector or fixture designs enter into the Watts/Region values?

   They do not. As in the previous two answers when comparing identical or even higher values, other considerations would be actual spectral distribution within the three regions. Beyond that other factors to consider would be:

   - How much heat a lamp/ballast combination contribute to the grow room
   - Light being emitted outside of 400-700nm
   - Intensities at the canopy (PPFD)
   - Spectral distribution within each region
   - Fixture design as thermal management
   - Reflector design and quality
   - Lamp size and shape
   - Consistency of spectral mix from the lamp(s) to the canopy

8. If I know the lamps V-C-F values what should be considered when interpreting a lamps output based on its spectral distribution?

   When you have the V-C-F value you are interpreting the amount of energy under the **height and width** of the data points shown within these graphs. For example a graph showing a high peak thin sliver intensity at a specific wavelength may not contribute as much to a plants development as a lower peak wider spectrum. To illustrate this point we would refer you to the DIN 5031-10 where you can see the radiant power differences between HID and LED relative to the plants sensitivity curve.

   Ideally one should consider lamps spectral output characteristics in terms of its ability to show:

   - Some baseline broad spectrum coverage between 400-700nm
   - Lamp to Plant efficiencies: Higher intensities in the known high PAR absorption regions
   - Broad enough spectrums within the plants PAR absorption regions

   Armed with this information one should also consider the importance of lamp lifespan, i.e. replacement costs and spectral stability as the lamp ages to maintain repeatable crop production.

V-C-F Plant Light Specification Technique

Definitions of each of the 5 specification techniques

1. **Radiant PAR Wattage:** The actual light power produced in the PAR region.
2. **PPF:** Photosynthetic Photon Flux expressed in uMol/S is the actual number of photons produced per second in the PAR region.
3. **Photopic Lumen:** Nearly useless for plant lighting, but it is so commonly used we felt it important just to show how misleading it can be when compared to the other valuations. Lumens are light power values for human vision expressed in units which have been corrected to the CIE accepted conversions per the photopic luminosity function for the specified wavelength bandwidths. While Lumens are commonly specified for plant lights, this specification should never be used in making a decision on plant lighting as it is a strict reference to how humans see light.
4. **Yield PPF:** The light power values within the PAR region shown in uMol/S which have been adjusted to the DIN standard 5031-10 sensitivity curve.
5. **Yield PAR Watts to DIN 5031-10:** These values are actual radiant watts adjusted to the DIN Standard 5031-10 absorption sensitivity. While the Radiant PAR Watt is an indicator of actual light power produced in the PAR region, the Yield PAR Watt is an indicator of what the plant should be able to actually absorb under ideal conditions.

Definitions of the various parameters used for the 5 specification techniques

- **Absolute Values:** These are the actual values for the lamp wattage rating shown for each of the 5 defined categories.
- **400-520 (V):** These are the absolute values for the Vegetative (V) region (400 to 520 nm) only.
- **520-610 (C):** These are the absolute values for the Carotenoid (C) region (520 to 610 nm) only.
- **610-700 (F):** These are the absolute values for the Flowering (F) region (610 to 700 nm) only.
- **Total 400-700**: These are the absolute values for the Total PAR region (400 to 700 nm) only.
- **Efficiencies:** These are the Total values factored on a per Watt consumed basis. This value generally represents an overall efficiency rating for each lamp technology for each of the 5 types of measurements and can be compared one to one since they have all been adjusted for consumed wattage.
- **Percentages:** These are the percentage breakout of each of the 3 regions V, C, and F to the Total. The values can be used to make one to one comparisons of the different lamp technologies for each of the 5 measurement techniques.

Notes:

1. Both CMH and Plasma have a degree of intensity that is emitted outside of the defined PAR region of 400 to 700 nm. This does result in lower values in the PAR region. This is just an explanation should there be any curiosity of these lower values, but they are valid.
2. Since LED lamp designs can vary widely we chose a lamp that represented the fairly typical of the Blue/Red combinations seen.

Technical Comparisons

Radiant Wattage	Consumed Watts	Absolute Values			Total 400-700	Radiant Efficiency	Percentages		
		400-520	520-610	610-700			400-520	520-610	610-700
HPS Digital 1000 watts	1100	18.6	173.8	110.5	302.9	0.275	6	57	36
HPS Digital 600 watts	660	12.3	114.7	72.9	199.9	0.303	6	57	36
M/H Digital 4000K 1000 watts	1100	76.5	155.0	35.5	267.0	0.243	29	58	13
M/H Digital 4000K 400 watts	440	25.2	51.2	11.7	88.1	0.200	29	58	13
CMH Magnetic 4000K 400 watts	480	29.0	34.4	28.1	91.5	0.191	32	38	31
PLASMA 300 watts	300	26.5	22.6	16.6	65.7	0.219	40	34	25
T5-HO 6500K 54 watts	58	5.6	5.9	1.7	13.2	0.228	43	44	13
T5-HO 2800K 54 watts	58	1.8	6.3	4.1	12.2	0.210	15	52	33
LED - LG650 650 watts	650	69.5	19.1	149.3	238.0	0.366	29	8	63
EFDL IG-Pro-420 420 watts	425	45.8	25.3	44.5	115.6	0.272	40	22	38
EFDL IG-420/Pontoon 460 watts	460	45.8	25.4	56.7	127.9	0.278	36	20	44

PPF (uMol/S)	Consumed Watts	Absolute Values			Total 400-700	uMol/S per Watt	Percentages		
		400-520	520-610	610-700			400-520	520-610	610-700
HPS Digital 1000 watts	1100	72	848	587	1506.3	1.37	5	56	39
HPS Digital 600 watts	660	47	560	387	994.0	1.51	5	56	39
M/H Digital 4000K 1000 watts	1100	302	738	192	1230.9	1.12	24	60	16
M/H Digital 4000K 400 watts	440	99	243	63	406.0	0.92	24	60	16
CMH Magnetic 4000K 400 watts	480	112	163	152	428	0.89	26	38	36
PLASMA 300 watts	300	103	107	90	300.0	1.00	34	36	30
T5-HO 6500K 54 watts	58	21	28	9	58.0	1.00	37	47	16
T5-HO 2800K 54 watts	58	7	30	21	58.0	1.00	12	52	37
LED-LG650 650 watts	650	258	91	821	1170.4	1.80	22	8	70
EFDL IG Pro-420 420 watts	425	174	122	237	533.0	1.25	33	23	44
EFDL IG-420/Pontoon 460 watts	460	174	122	303	599.0	1.30	29	20	51

Photopic Lumen	Consumed Watts	Absolute Values			Total 400-700	Lumen per Watt	Percentages		
		400-520	520-610	610-700			400-520	520-610	610-700
HPS Digital 1000 watts	1100	1722	93578	19992	115291.8	104.8	1	81	17
HPS Digital 600 watts	660	1137	61761	13195	76093.0	115.0	1	81	17
M/H Digital 4000K 1000 watts	1100	10934	91634	4802	107369.4	97.6	10	85	4
M/H Digital 4000K 400 watts	440	3608	30239	1585	35432.0	81.0	10	85	4
CMH Magnetic 4000K 400 watts	480	3187	19568	3235	25990.0	54.1	12	75	12
PLASMA 300 watts	300	3026	13079	1917	18022.0	60.1	17	73	11
T5-HO 6500K 54 watts	58	472	3520	378	4370.0	75.0	11	81	9
T5-HO 2800K HO 54 watts	58	131	3620	892	4644.0	80.0	3	78	19
LED-LG650 650 watts	650	3004	10889	9245	23137.4	35.6	13	47	40
EFDL IG-Pro-420 420 watts	425	3518	13751	7999	25268.0	59.0	14	54	32
EFDL IG-420/Pontoon 460 watts	460	3518	13790	8768	26076.0	57.0	13	53	34

Yield PPF (uMol/S) Based on DIN 5031-10 Sensitivity Curve	Consumed Watts	Absolute Values			Total 400-700	YPPF per Watt	Percentages		
		400-520	520-610	610-700			400-520	520-610	610-700
HPS Digital 1000 watts	1100	59	460	424	943.0	0.860	6	49	45
HPS Digital 600 watts	660	39	304	280	622.0	0.940	6	49	45
M/H Digital 4000K 1000 watts	1100	228	362	139	729.0	0.660	31	50	19
M/H Digital 4000K 400 watts	440	75	119	46	241.0	0.550	31	50	19
CMH Magnetic 4000K 400 watt	480	90	80	112	282.0	0.587	32	28	40
PLASMA 300 watts	300	82	52	66	200.0	0.670	41	26	33
T5-HO 6500K 54 watts	58	18	13	6	37.0	0.630	49	34	17
T5-HO 2800K 54 watts	58	5	15	15	35.0	0.600	15	42	43
LED-LG650 650 watts	650	237	46	652	935.0	1.440	25	5	70
EFDL IG-Pro-420 420 watts	425	143	63	171	377.0	0.890	38	17	45
EFDL IG-420/Pontoon 460 watts	460	143	63	225	431.0	0.940	33	15	52

Yield PAR Watts Based on DIN 5031-10 Sensitivity Curve	Consumed Watts	Absolute Values			Total 400-700	PAR Watt Efficiency	Percentages		
		400-520	520-610	610-700			400-520	520-610	610-700
HPS Digital 1000 watts	1100	15.5	93.9	79.7	189.0	0.172	8	50	42
HPS Digital 600 watts	660	10.2	62.0	52.6	125.0	0.190	8	50	42
M/H Digital 4000K 1000 watts	1100	58.4	75.6	25.8	159.8	0.145	37	47	16
M/H Digital 4000K 400 watts	440	19.3	24.9	8.5	53.0	0.120	37	47	16
CMH Magnetic 4000K 400 watt	440	23.4	16.8	20.6	61	0.127	39	28	34
PLASMA 300 watts	300	21.3	10.9	12.2	44.5	0.148	48	25	28
T5-HO 6500K 54 watts	58	4.7	2.7	1.2	8.6	0.150	55	31	14
T5-HO 2800K 54 watts	58	1.4	3.0	2.9	7.3	0.130	19	42	39
LED-LG650 650 watts	650	64.1	9.5	118.6	192.1	0.296	33	5	62
EFDL IG-Pro-420 420 watts	425	38.1	12.9	32.3	83.0	0.200	46	15	39
EFDL IG-420/Pontoon 460 watts	460	38.1	13.0	42.1	93.0	0.200	41	14	45

Summary Conclusions

In developing this document we used manufacturer data that was available at the time of this publication from a variety of manufacturer's websites. Nothing in this document is meant to construe that we are suggesting that any one technology is better than the other. Our interest in developing this document was to simply present another way of viewing how artificial plant lighting can be presented in a way that does not confuse the gardener with information and values that may be mostly irrelevant when it comes to selecting the best lamp for their needs.

We are not saying that the reporting methods we've suggested here cannot be improved upon. For example V-C-F is not meant to imply that a lamp which emits predominantly in the C-F regions would be the most beneficial to a flowering plant that might develop even better with a higher percentage of V.

We believe that as manufacturers it is our responsibility to be environmentally conscious while looking to continuously expand upon all available technologies which serve to enhance crop production, increase quality and bring a greater overall value to the indoor garden.

Equations used for the Calculation of the V-C-F values

The ideal method of achieving these values would be to integrate the various equations across the spectral region that is generally considered the PAR region, 400 to 700 nm. Since these lamps spectral distribution outputs do not follow any workable mathematical functions, the best method to approximate the Integral is with a Summation equation across the PAR region. The more points used the better the accuracy of the summation function. Since 400 to 700 nm represents a nice spread of 300 points at 1 nm increments this was the obvious choice of increment and is enough points to assure some degree of good accuracy. Essentially using the Summation process all the math is performed on each 1 nm sliver and then the results of each sliver are added together for the final result. The subscript $_{\text{HPS}}$ is used to indicate those functions that are specific to a unique light source. Equations 1 through 5 below are the actual equations that our V-C-F values are based.

$$1. \, Radiant\ Watts_{HPS} = \int_{\lambda=400}^{700} RW_{HPS}(\lambda) \approx \sum_{\lambda=400}^{700} RW_{HPS}(\lambda)$$

$$2. \; PPF_{HPS} = \int_{\lambda=400}^{700} RW_{HPS}(\lambda) \times MPW(\lambda) \approx \sum_{\lambda=400}^{700} RW_{HPS}(\lambda) \times MPW(\lambda)$$

$$\begin{aligned} 3. \; Lumen_{HPS} &= \int_{\lambda=400}^{700} RW_{HPS}(\lambda) \times PLF(\lambda) \times 683\, Lumen/Watt \\ &\approx \sum_{\lambda=400}^{700} RW_{HPS}(\lambda) \times PLF(\lambda) \times 683\, Lumen/Watt \end{aligned}$$

$$4. \; Yield\ PPF_{HPS} = \int_{\lambda=400}^{700} PPF_{HPS}(\lambda) \times DAS(\lambda) \approx \sum_{\lambda=400}^{700} PPF_{HPS}(\lambda) \times DAS(\lambda)$$

$$5. \; Yield\ PAR\ Watt_{HPS} = \int_{\lambda=400}^{700} RW_{HPS}(\lambda) \times DAS(\lambda) \approx \sum_{\lambda=400}^{700} RW_{HPS}(\lambda) \times DAS(\lambda)$$

The last set of equations shows the 3 individual V-C-F regions as integrals and summations for the total 400 to 700 nm range.

$$\int_{\lambda=400}^{700} f(y) = \int_{\lambda=400}^{520} f(y) + \int_{\lambda=520}^{610} f(y) + \int_{\lambda=610}^{700} f(y) \approx$$

$$\sum_{\lambda=400}^{700} f(y) = \sum_{\lambda=400}^{520} f(y) + \sum_{\lambda=521}^{610} f(y) + \sum_{\lambda=611}^{700} f(y)$$

Definitions of Terms:

RW(λ) is the Radiant Watt function as a function of **λ (Wavelength)** for the light source.

PPF(λ) is the Photosynthetic Photon Flux function as a function of λ for the light source.

MPW(λ) is the photon uMol/S per Watt function as a function of λ.

PLF(λ) is the Photopic Luminosity Function as a function of λ.

DAS(λ) is the DIN 5031-10 Absorption Sensitivity function as a function of λ.

The MPW(λ) function is the conversion of light intensity in Watts to the quantity of photons in µMol/S as a function of wavelength (λ). The derivation of the equations is shown in our analysis "The Planck Relation". This is nothing new, just a conversion of the Planck Relation equation to the terms we are more used to working with for lighting:

Wavelength in nm

Photons in µMol/S

Light Intensity in radiant watts

Converting Photon μMol/S count and intensity in Watts: The Planck Relation

$E = hc/\lambda$

E = Energy per Photon(λ)

$h = 6.62606957 \times 10^{-34}$ J-S (Planck's Constant)

$c = 2.99792458 \times 10^{8}$ M/S (Speed of Light)

λ = photon wavelength

We ultimately want to derive an equation that will relate light intensity Wattage to photon flux quantity in μMo/S as a function of wavelength λ.

$\text{Photon}_{\mu\text{Mol}}\ \text{Power}(\lambda_{nm})\ \text{Watts} = hc \times \text{Mol} \times 10^{-6}/\lambda_{nm} \times 10^{-9}\ \text{M-S}$

Where:

$\text{Mol} = 6.0221413 \times 10^{23}$

$\times 10^{-6}$ Converts photon quantity in Mol to μMol

$\times 10^{-9}$ Converts wavelength in M to nM

For equations going forward: Photon flux quantities are expressed in μMol/S and λ in nm.

$\text{Photon}_{\mu\text{Mol}}\ \text{Power}(\lambda)\ \text{Watts} = 6.62606957 \times 10^{-34}\ \text{J-S} \times 2.99792458 \times 10^{8}\ \text{M/S} \times 6.0221413 \times 10^{23} \times 10^{-6}/\lambda_{nm} \times 10^{-9}\ \text{M-S}$

$= 119.626566/\lambda_{nm}$ J/S, J/S = Joules/S = Watts, Power = 119.626566 W-nm / λ_{nm} nm

Conversion Formulas: Enter wavelength in <u>nm</u>, Power in <u>Watts</u>, and PPF in <u>μMol/S</u>

$\text{Photon}_{\mu\text{Mol}}\ \text{Power}(\lambda)\ (\text{Watts}) = 119.626566/\lambda_{nm} \times \mu\text{Mol/S}$

$\text{Photon}_{\mu\text{Mol}}(\lambda)\ \text{Flux Quantity}\ (\mu\text{Mol/S}) = .00835935 \times \lambda_{nm} \times \text{Watts}$