

### Converting dBm to mW

Optical power is commonly expressed in mW or dBm. The dBm unit is defined as the ratio in dB (decibel) of the measured optical power to a reference value of 1 mW.

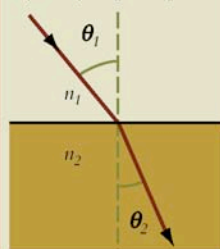
$$\text{dBm} = 10 \log \left( \frac{\text{Optical Power}}{1 \text{ mW}} \right)$$

For a quick reference, use the following table.

Optical Power (dBm)	Optical Power (mW)
15	31.6
14	25.1
13	20.0
12	15.8
11	12.6
10	10.0
9	7.9
8	6.3
7	5.0
6	4.0
5	3.2
4	2.5
3	2.0
2	1.6
1	1.3
0	1.0
-1	0.79
-2	0.63
-3	0.50
-4	0.40
-5	0.32
-6	0.25
-7	0.20
-8	0.16
-9	0.13
-10	0.10
-11	0.08
-12	0.06
-13	0.05
-14	0.04
-15	0.03

### Snell's Law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$



### International System of Units (SI) Prefixes

Factor	Name	Symbol
10 <sup>21</sup>	zetta	Z
10 <sup>18</sup>	exa	E
10 <sup>15</sup>	peta	P
10 <sup>12</sup>	tera	T
10 <sup>9</sup>	giga	G
10 <sup>6</sup>	mega	M
10 <sup>3</sup>	kilo	k
10 <sup>2</sup>	hecto	h
10 <sup>-2</sup>	centi	c
10 <sup>-3</sup>	milli	m
10 <sup>-6</sup>	micro	μ
10 <sup>-9</sup>	nano	n
10 <sup>-12</sup>	pico	p
10 <sup>-15</sup>	femto	f
10 <sup>-18</sup>	atto	a
10 <sup>-21</sup>	zepto	z
10 <sup>-24</sup>	yocto	y

### Brewster's Angle

The angle where only s-polarized light is reflected

$$\theta_{\text{Brewster}} = \arctan \left( \frac{n_{\text{transmitted medium}}}{n_{\text{incident medium}}} \right)$$

### Total Internal Reflection Angle

$$\theta_{\text{TIR}} > \arcsin \left( \frac{n_{\text{transmitted medium}}}{n_{\text{incident medium}}} \right)$$

where  $n_{\text{transmitted medium}} < n_{\text{incident medium}}$  is required for total internal reflection.

### Etalon Formulas

Two parameters completely specify an etalon: the free spectral range (FSR) and the finesse (F). The FSR is the spacing (usually given in frequency) between transmission peaks. The finesse is the ratio of the free spectral range to the full width at half maximum (FWHM) of the transmission peak and is directly related to the reflectivity of the surface R.

$$\text{FSR} = \frac{c}{2nL}$$

$$F = \frac{\text{FSR}}{\text{FWHM}} = \frac{\pi \sqrt{R}}{1-R}$$

c is the speed of light, n is the index of refraction of the etalon, and L is the thickness of the etalon.

At high finesse values (where R is very close to 100% or 1),

$$R \approx 1 - \frac{\pi}{F}$$

Finesse	Reflectivity
2	24%
4	47%
6	60%
8	68%
10	73%
15	81%
20	85%



### Physical Constants

- h=Planck's constant=6.626 x 10<sup>-27</sup> erg•s = 6.626 x 10<sup>-34</sup> J•s=4.5 x 10<sup>-15</sup> eV•s
- ħ=h/2π=Dirac's constant=1.054 x 10<sup>-27</sup> erg•s = 1.054 x 10<sup>-34</sup> J•s
- k=Boltzmann's constant = 1.380 x 10<sup>-16</sup> erg/K = 8.62 x 10<sup>-5</sup> eV/K=1.380 x 10<sup>-23</sup> J/K
- kT=25.9 meV at room temperature = 6.7 meV at liquid-nitrogen temperature (77 K) = 0.36 meV at liquid-helium temperature (4.2 K)
- c=velocity of light in vacuum=2.998 x 10<sup>8</sup> m/s (Note: the exact value is 2.99792458 x 10<sup>8</sup> m/s)
- e=electron charge=1.602 x 10<sup>-19</sup> coulombs = 4.803 x 10<sup>-10</sup> esu
- N<sub>0</sub>=Avogadro's number = 6.023 x 10<sup>23</sup> molecules/g-mole
- α<sub>0</sub>=ħ<sup>2</sup>/4πm<sub>e</sub><sup>2</sup>=first Bohr radius=5.292 x 10<sup>-11</sup> m
- ε<sub>0</sub>=permittivity constant=8.854 x 10<sup>-12</sup> F/m
- μ<sub>0</sub>=permeability constant=1.257 x 10<sup>-6</sup> H/m
- m<sub>e</sub>=electron rest mass=9.109 x 10<sup>-31</sup> kg
- m<sub>p</sub>=proton rest mass=1.672 x 10<sup>-27</sup> kg
- # of seconds in a year~π x 10<sup>7</sup>

### Focusing Gaussian Beams

A Gaussian beam spreads as follows,

$$\omega^2(x) = \omega_0^2 \left[ 1 + \left( \frac{\lambda x}{\omega_0^2} \right)^2 \right]$$

where ω(x) is the 1/e<sup>2</sup> radius, λ is the wavelength, and x is the distance from the beam waist ω<sub>0</sub> where x=0. A rule of thumb for choosing a lens is

$$f = \frac{dD\pi}{4\lambda}$$

where f is the lens focal length, d is the beam diameter at the focus, D is the 1/e<sup>2</sup> diameter of the collimated beam.

### Wave Vector, Frequency, Wavelength & Wavenumbers

- k=wave vector
- ν=frequency
- ω=angular frequency = 2πν
- λ=wavelength
- λ<sub>0</sub>=wavelength in vacuum
- n=refractive index

$$k = \frac{2\pi}{\lambda} = \frac{2\pi n}{\lambda_0}$$

$$= \frac{2\pi n \nu}{c} = \frac{n\omega}{c}$$

$$\nu = \frac{c}{\lambda_0} = \frac{c}{n\lambda}$$

$$= \frac{kc}{2\pi n} = \frac{\omega}{2\pi}$$

$$\lambda = \frac{c}{n\nu} = \frac{\lambda_0}{n}$$

$$= \frac{2\pi}{k} = \frac{2\pi c}{n\omega}$$

$$\Delta\lambda = \frac{c \cdot \Delta\nu}{\nu^2} = \frac{\lambda^2 \cdot \Delta\nu}{c}$$

An easy number to remember is a 1-pm linewidth is approximately 125 MHz at 1550 nm.

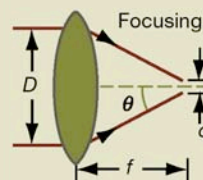
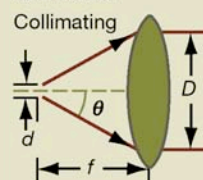
$$\text{Wavenumber (cm}^{-1}\text{)} = \frac{10^7}{\lambda \text{ (nm)}}$$

$$\text{Electron Volts (eV)} = \frac{1242}{\lambda \text{ (nm)}}$$

### Numerical Aperture

$$f/\# = \frac{f}{D} \approx \frac{1}{2NA}$$

$$NA = n \sin \theta$$



### Common Material Properties

Material	Refractive Index, n	ΔFSR*	Thermal Expansion Coefficient (α)	Thermo-Optic Coefficient (β or dn/dT)
Air	1.000	0.0 MHz	0.0 ppm/°C	1.0 ppm/°C
Fused Silica	1.444	13.1 MHz	0.55 ppm/°C	6.57 ppm/°C
Silicon	3.477	198.1 MHz	3.25 ppm/°C	160 ppm/°C
LASFN9	1.813	9.4 MHz	7.4 ppm/°C	1.3 ppm/°C

\*Change in FSR due to dispersive effects as measured from 1510 to 1570 nm for a 50-GHz etalon

Wavelength (in vacuum)	Frequency	Electron Volts	Wavenumber
1561.42 nm	192.00 THz	0.80 eV	6,404.43 cm <sup>-1</sup>
1550 nm	193.41 THz	0.80 eV	6,451.61 cm <sup>-1</sup>
1320 nm	227.12 THz	0.94 eV	7,575.76 cm <sup>-1</sup>
1064 nm	281.76 THz	1.17 eV	9,398.50 cm <sup>-1</sup>
980 nm	305.91 THz	1.27 eV	10,204.08 cm <sup>-1</sup>
780 nm	384.35 THz	1.59 eV	12,820.51 cm <sup>-1</sup>
632.8 nm	473.76 THz	1.96 eV	15,802.78 cm <sup>-1</sup>
350 nm	856.55 THz	3.55 eV	28,571.43 cm <sup>-1</sup>