ROLYN OPTICS COMPANY

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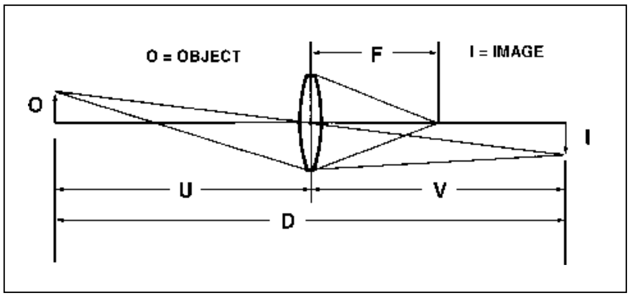
A FEW OF THE MOST COMMON OPTICAL FORMULAE USED IN EVERYDAY WORK ARE LISTED BELOW. WE HOPE YOU WILL FIND THEM USEFUL IN YOUR OPTICAL WORK.



OPTICAL FORMULAE

Five variables U, V, D, M, and F define the system in first order analysis. Each of the following three pairs of variables fixes the system, U&V, D&M or M&F. Select the pair most important to your application to fix your system.

F = Focal Length

$\frac{1}{F} = \frac{1}{U} + \frac{1}{V}$ $\quad F = \frac{U \times M}{M + 1}$ $\quad F = \frac{U}{R + 1}$

$F = \frac{D \times R}{(R + 1)^2}$ $\quad F = \frac{U \times V}{D}$ $\quad F = \frac{D \times M}{(M + 1)^2}$

D = Distance from Object to Image

$D = F(M + \frac{1}{M} + 2)$ $\quad D = F(R + \frac{1}{R} + 2)$

$D = \frac{F(M + 1)^2}{M}$ $\quad D = \frac{F(R + 1)^2}{R}$

U = Distance from Lens to Object

$U = \frac{V}{M}$ $\quad U = \frac{D}{M + 1}$

$U = \frac{R \times D}{R + 1}$ $\quad U = \frac{F \times V}{V - F}$

V = Distance from Lens to Image

$V = U \times M$ $\quad V = \frac{F}{R} + F$

$V = \frac{U}{R}$ $\quad V = (F \times M) + F$

M = Magnification

$M = \frac{V}{U}$ $\quad M = \frac{F}{U - F}$ $\quad M = \frac{V - F}{F}$

R = Reduction

$R = \frac{U}{V}$ $\quad R = \frac{U - F}{F}$ $\quad R = \frac{F}{V - F}$

LENS PAIRS

The following formulae may be used to combine lenses in pairs to obtain focal lengths other than those listed. In this manner one can demonstrate principles much more easily and economically than by fabricating special focal lengths for prototypes. Of course we can also quote on your special requirements at any time you so desire.

$$\frac{1}{FC} = \frac{1}{F1} + \frac{1}{F2} - \frac{d}{F1 \times F2}$$

or:

$$FC = \frac{F1 \times F2}{F1 + F2 - d}$$

and:

$$d = (F1 + F2) - \frac{F1 \times F2}{FC}$$

where: FC = focal length of combination
F1 = focal length of first lens
F2 = focal length of second lens
d = distance between principle planes of the two lenses.

These paraxial equations are first order relationships and as such are only approximations. They are sufficiently accurate however for the vast majority of situations. The degree of sophistication required to make the transition from thin lens to thick lens analysis is beyond the scope of this catalog and is readily available in the literature.

Listed below are various other bits of information and definitions which are frequently encountered and are offered here in an effort to avoid an unnecessary trip to the bookshelf.

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GLASS PLATES

When glass plates, filters or prisms are introduced into a converging beam of light the focus shift must be taken into consideration. The focus shift is computed as follows:

$$\text{delta } f = \left(\frac{N_2 - N_1}{N_2}\right) t$$

where: N_1 = index of the medium surrounding the glass plate (usually air; $N_1 = 1.0$)
N_2 = index of the glass plate
t = thickness of the glass plate

By rule of thumb then the image is further from the lens by t/3 when a flat plate is inserted in the beam.

EFFECTIVE FOCAL LENGTH - E.F.L.

This is defined as the distance between the second principal point and the second focal point with parallel incident light. All focal lengths referred to in this catalog are effective focal lengths unless otherwise stated.

RELATIVE APERTURE = f#

The f number of a lens is defined as the ratio of the effective focal length of the lens divided by the diameter or clear aperture of the lens. It is a measure of the amount of illumination which can pass through the lens. It is expressed as:

$$f\# = \frac{\text{E.F.L.}}{\text{Diameter}}$$

$$f\# = \frac{1}{2\ \text{N.A.}}$$

where: N.A. = numerical aperture

$$\text{N.A.} = n \sin ø$$

where: n = index of refraction of the medium between the object and objective (of a microscope) usually air (n = 1.0)
ø = the half angle of the cone of light entering the objective

DIOPTER

The diopter is the unit of power of a lens which is most used in the ophthalmic branch of the optical industry. It is defined as the reciprocal of the lens focal length stated in meters. It is computed as follows:

$$D = \frac{1}{\text{E.F.L (in meters)}}$$

And since power is additive

$$D = D1 + D2$$

where: D1 = dioptric power of the first lens
D2 = dioptric power of the second lens
D = dioptric power of the combination

SURFACE DIOPTER - DS

This is the quantity measured with diopter gauges. The measurement can be converted to the surface radius as follows:

$$R = \frac{(N-1)}{DS} \times 1000$$

where: N = index of the glass
R = radius in mm
DS = surface diopter

PRISM DIOPTER

A prism diopter power of 1.0 indicates a beam deviation of 10mm at a distance of 1 meter.

1 prism diopter = .573° beam deviation

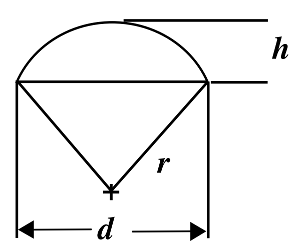
MILLIDIOPTER - MD

$$MD = \frac{1}{\text{E.F.L. (in kilometers)}}$$

SAGITTA FORMULA

$$h = r - \frac{1}{2}\sqrt{4r^2 - d^2}$$

Where:
h=sagitta
r=lens surface radius
d=lens diameter



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BEAM DEVIATION ANGLE - D

$$D = A(n - 1)$$

where: A = glass wedge angle
n = glass index
D = beam deviation angle

LENSMAKERS EQUATION

$$ø = \frac{1}{f} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where: ø = power
f = effective focal length
R_1 = first radius
R_2 = second radius
n = index of glass

when thickness (t) is considered this becomes:

$$ø = \frac{1}{f} = (n - 1)\left[\frac{1}{R_1} - \frac{1}{R_1} + \frac{t(n - 1)}{R_1 R_2 n}\right]$$

REFLECTION LOSS AT MEDIA INTERFACE

$$R = \frac{(n' - n)^2}{(n' + n)^2}$$

where: R = reflection from surface
n' = index of first medium
n = index of second medium

TYPICAL REFLECTION LOSSES PER FACE UNCOATED

Crown glass ≈ 4%
Flint glass ≈ 7%
Quartz ≈ 3.5%

M_gF_2 COATED

Crown glass ≈ 1.5%
Flint glass ≈ 0.5%
Quartz ≈ 2%

BROAD BAND MULTILAYER DIELECTRIC COATED

Crown glass ≈ 0.3%
Flint glass ≈ 0.5%
Quartz ≈ 0.3%

MAGNIFYING POWER - MP

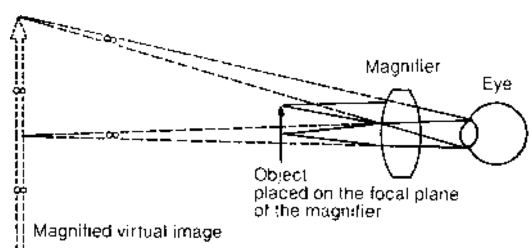
The normal magnifying power of a lens is found by dividing the focal length of the lens (in millimeters) into 254mm or the focal length (in inches) into 10 inches.

BUT:

Magnifying Power Changes with Conditions of Use

The term M.P. is often used without precise explanation. It is different from the "magnification" of the image, i.e. the physical quantity defined as the ratio of the lateral length of the image of a small object formed by an optical system (including a magnifier) to that of the object itself. The M.P. refers to the combination of a magnifier (or a compound microscope) and an observing eye. It is defined as the ratio of the view angle of the magnified virtual image of a small object to that of the same object viewed with the naked eye at a 250mm (ca. 10") distance from it, which is approximately equal to the ratio of the length of the image formed on the retina of the eye in each respective case. Thus if the M.P. of a magnifier is 7 x, the lateral length of the image viewed through it is about 7 times that of the same object seen with the naked eye at a distance of 250mm. In this case, the area is magnified about 49 times.

The M.P. of a magnifier is not constant, but varies continuously within a certain range with changes in distance between the magnifier and the eye, as well as with changes in the working distance. So its value is indefinite as long as the condition of use is not specified.



The value of the M.P. of a magnifier engraved on its barrel or listed in catalogues is the so-called "normal M.P." which is the M.P. under the condition that the object under inspection is placed on the "focal plane in the object space" of the magnifier. In this case, the rays of light emitted from each point of the object become parallel with each other after passing through the magnifier, as is shown in Fig. 1, and hence the virtual image of the object is formed at infinite distance from the eye with an infinitely large length. Hence the value of the "magnification" of the image is infinite, but the M.P. in this case, or the normal M.P. of the magnifier takes a finite value, and is given exactly by the formula being independent of the distance between the magnifier and the eye.

$$\text{normal M.P.} = \frac{250\text{(mm)}}{\text{focal length (mm) of magnifier}}$$

OPTICAL DENSITY

The density of a filter or other element is the log to the base 10 of the reciprocal of its transmittance, not including reflection losses.

$$D = \log \frac{1}{T} \quad \text{or} \quad T = 10^{-D}$$

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*B270 GLASS TRANSMISSION

Spectral transmission for an optical path of 10 mm *including* reflection loss.

For the determination of the internal transmission factor in the mean range of the visible spectrum, the spectral transmission has to be divided by the reflection factor R = 0.92.

The measuring uncertainty of the spectral transmission shown in the following table is approximately ± 0.003.

**similar to Hoya C12, no Schott equivalent*

λ in nm	d = 10 mm τ	λ in nm	d = 10 mm τ
303	0,001	625	0,910
313	0,039	650	0,912
328	0,323	675	0,911
334	0,545	700	0,912
340	0,630	750	0,914
350	0,765	800	0,916
360	0,837	900	0,908
370	0,868	1000	0,908
380	0,869	1100	0,907
390	0,887	1200	0,910
400	0,898	1300	0,910
425	0,900	1400	0,912
450	0,902	1500	0,912
475	0,905	1600	0,913
500	0,908	1700	0,912
525	0,910	1800	9,903
550	0,911	1900	0,888
575	0,914	2000	0,870
600	0,912		

CONVERSION FACTORS

1 millimeter = 0.03937 inches
1 micron = 0.00003937 inches
1 inch = 25.4 millimeters
0.001 inch = approx. 25 microns
0.0001 inch = approx. 2.5 microns
1 arc second = 0.000005 inches/inch
1 arc second = 4.848137 microradians
1 arc minute = 0.000291 inches/inch
1 arc minute = 0.290888 milliradians
1 radian = 57.29578 degrees
1 microradian = 1 microinch/inch = 1 micron/meter
1 degree = 0.017453 radians
546.1nm = 0.0000215 inches
Quarter wave = 0.000005 inch
Tenth wave = 0.000002 inch

1 gram = 0.03527 ounces	1 gram = 15.4321 grains
1 ounce = 28.3527 grams	1 gm/cm^3 = 0.036 lb/inch^3
1 grain = 0.0648 grams	1 lb/inch^3 = 27.68 gm/cm^3

OPTICAL PROPERTIES:

Refractive indices at 20°C	
n_e (λ = 546 nm)	1.5251
n_d (λ = 588 nm)	1.5230
Stress-optical coefficient c (λ = 555 nm)	2.70 · 1.02 · 10^{-12}m^2/N

THERMAL PROPERTIES:

Mean linear thermal coefficient of expansion α (20 – 300°C) =	95 · 10^{-7}/1K
Transformation point	521°C
Softening point ($10^{7.6}$ d Pas)	708°C
Working point (10^4 d Pas)	1006°C

CHEMICAL PROPERTIES:

Hydrolytic class as per DIN 12111	3
$Na_2$0-donation in μg/g glass as per DIN 12111	170

MECHANICAL PROPERTIES:

Density in g/cm^3 at 23°C	2.55