National Academy of Opticianry

Continuing Education Course

Approved by the American Board of Opticianry

Lens Power, Nominal Power, Focal Length, Sagittal Depth, Thick Lens Power

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PREFACE:

This continuing education course was prepared under the auspices of the National Academy of Opticianry and is designed to be convenient, cost effective and practical for the Optician.

The skills and knowledge required to practice the profession of Opticianry will continue to change in the future as advances in technology are applied to the eye care specialty. Higher rates of obsolescence will result in an increased tempo of change as well as knowledge to meet these changes. The National Academy of Opticianry recognizes the need to provide a Continuing Education Program for all Opticians. This course has been developed as a part of the overall program to enable Opticians to develop and improve their technical knowledge and skills in their chosen profession.

The National Academy of Opticianry

INSTRUCTIONS:

Read and study the material. After you feel that you understand the material thoroughly, take the test following the instructions given at the beginning of the test. Upon completion of the test, mail the answer sheet to the National Academy of Opticianry, 8401 Corporate Drive, Suite 605, Landover, Maryland 20785 or fax it to 301-577-3880. Be sure you complete the ABO – NCLE evaluation form on the answer sheet. Please allow two weeks for scoring and test results.

CREDITS:

The American Board of Opticianry has approved this course for one (1) Continuing Education Credit toward certification renewal. To earn this credit, you must achieve a grade of 80% or higher on the test. The Academy will notify all test takers of their score and mail the credit certificate to those who pass. You must mail the appropriate section of the credit certificate to the ABO and/or your state licensing board to renew your certification/licensure. One portion is to be retained for your records.

AUTHOR:

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INTENDED AUDIENCE:

This course is intended for opticians of all levels.

COURSE DESCRIPTION:

This course will explain lens power, nominal power, and focal length of lenses. In addition, sagittal depth and thick lens design will be presented. Understanding these basic concepts helps the ECP to understand the final form of the patient's lens.

OBJECTIVES:

At the completion of this subsection, the student should be able to:

- Calculate nominal power
- Explain base curve and tool curves
- Calculate both focal length and dioptric power
- Be able to explain the relationship between focal length and lens power
- Discuss sagittal depth of a lens surface and how to calculate thickness of a lens
- Calculate the power of a thick lens

Lens Power, Nominal Power, Focal Length,

Sagittal Depth, Thick Lens Power

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The first ophthalmic lenses that are known to have been used were converging lenses. Converging lenses are convex (plus power) with a positive focal length and diverging lenses are concave (minus power) with a negative focal length. Theoretically, when a person has a refraction, the necessary focal length is identified to focus light on the retina. When the prescription is written the focal length is not given; rather the dioptric power of the lens that matches that focal length. In addition, when one uses a lensometer (lensmeter) the focal length of a specific lens is identified. We translate that focal length to dioptric powers. A diopter is the unit of measurement for lens power. It is the reciprocal of the focal length in Meters. The total power of a lens or lens surface to bend light is referred to as its focal power.

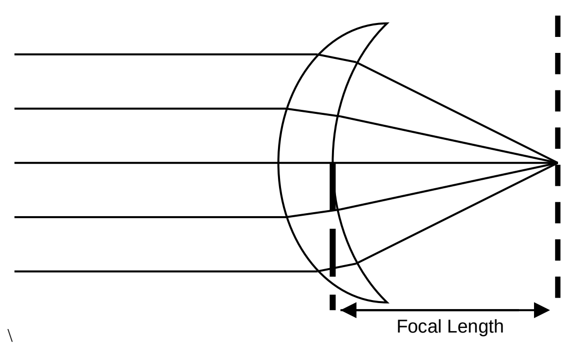
Focal Length – The Definition

Focal length is the point of convergence of light rays. In another definition, it is the distance between the back of the lens and the point focus.

The focal length of a lens is the distance at which the lens brings light to a focus.

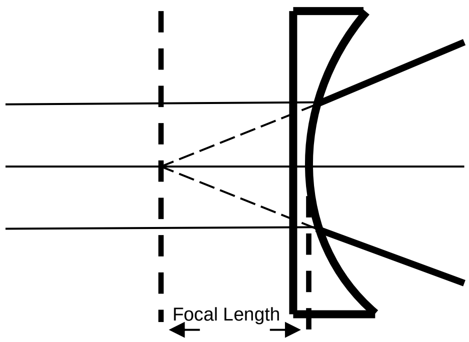
Positive Focal Length

A plus lens creates a positive focal length, meaning that light is brought to focus behind the lens (generally speaking, between the lens and the eye). The image is real. The distance from the back surface of a plus lens to the point at which the light rays are brought to a point focus the positive focal length of that lens.



Virtual Focal Length

A minus lens creates a virtual focal length, meaning that the focal point is in front of the lens. The image is virtual. The distance from the back surface of a minus lens to the point at which the light rays would reach a common point if the diverged light rays were to be drawn back through the lens is called the virtual focal length for that lens.

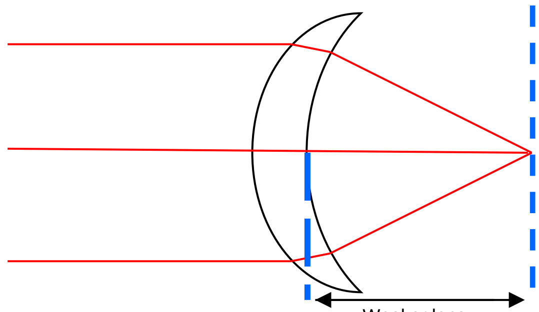


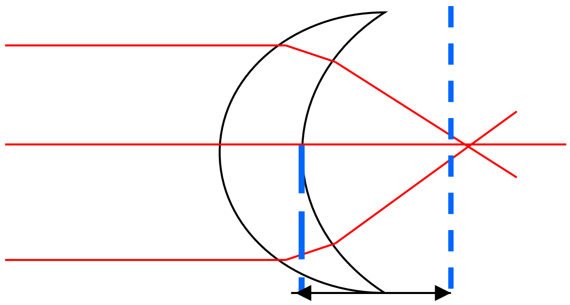
Dioptric Power of Lenses

A lens diopter is defined as the lens power that will bring light to focus at a focal distance of 1 meter.

A diopter is an optical unit of measurement, the reciprocal of the secondary focal length in meters, used to express the power of a lens. A plus one diopter lens will converge parallel rays of light to a real focus at 1 meter. A minus one diopter lens will diverge parallel rays of light to a virtual focus at 1 meter.

The dioptric power of the lens has a direct, reciprocal relationship to the focal length. Although it seems reversed, a weaker lens has a longer focal length than a stronger lens. For example, consider the information that you have learned regarding lenses/prisms thus far. The stronger the lens, the more light will be bent, so the length would be less to the point of focus. The weaker the lens/prism, the less light will be bent, so the length would be more to the point of focus. So, the stronger the dioptric power of the lens, the shorter the focal length, while the weaker the dioptric power, the longer the focal length. Other factors that influence dioptric power include thickness, radii of curvature, and index of refraction which we will cover more in-depth later.





Focal Length

The focal length in meters equals the reciprocal of the dioptric power of the lens. That means that if you know the dioptric power of the lens, to calculate the focal length, you simply divide the dioptric power into 1.

The formula is f = 1/D

– <u>In the formula:</u>

- D = Dioptric power of lens
- f = focal length in meters

Remember to adjust the formula based on mm, cm, dm, or inches. In order to convert the formula for mm, cm, dm, or inches, you may convert by the metric system or simply use the formulae below. It's important for test purposes that you remember what formula you need to use.

- f = 1/D = M = meters
- f = 10/D = dm = decimeters
- f = 100/D = cm = centimeters
- f = 1000/D = mm = millimeters
- f = 40/D (actually f = 39.37/D) = inches

Lens Power

The dioptric power of the lens equals the reciprocal of the focal length in meters. That means that if you know the focal length of the lens, to calculate the dioptric power of the lens, you simply divide the focal length into 1. Based upon the formula just presented for focal length, you simply reverse the formula.

<u>The formula is: D = 1/f</u>

- <u>In the formula</u>
  - D = Dioptric power of lens
  - f = focal length in meters

Again, remember to adjust the formula based on mm, cm, dm, or inches.

- D = 1/f = M = meters
- D = 10/f = dm = decimeters
- D = 100/f = cm = centimeters
- D = 1000/f = mm = millimeters
- D = 40/f (actually D = 39.37/f) = inches

Focal Length

Example:

What is the focal length in cm of a +2.00 lens? Remember that we need to adjust the formula for cm.

As in all optics, you will find there is more than one way to get to the same answer. Therefore, we will demonstrate two ways to find the answer. Choose the method that works best for you. Remember that we work in meters and the different formulas are simply variations on the meter.

The first method converts to centimeters AFTER finding the answer in meters. The second method converts to centimeters using the formula.

<u>*Method 1*</u>

<u>f = 1/D using the formula, remember your answer will be in meters so you will have to convert to centimeters.</u>

<u>f = 1/D</u>

<u>f = ½ or .5 meters</u>

.5 meters becomes

5 decimeters becomes
50 centimeters becomes
500 millimeters

Looking at all of the answers we have arrived at, we know we need centimeters. The answer in centimeters of a +2.00 D lens would be 50 cm.

Method 2

f = 1/D is the formula for meters, so the formula for centimeters is:

f = 100/D

therefore

f = 100/2

f = 50 cm

Dioptric Power of a Lens

Example:

D = -2.50D ((the question was asked regarding a virtual focal length; an extra notation was given (minus lens). The extra notation is not always given so remember if the question states virtual focal length, the examiner is requesting the answer as a minus power lens.))

Method 2

D = 1/f is the formula for meters.

D = 1/f

Therefore, to convert 400 mm to meters

.4 meters becomes

4 decimeters becomes
40 centimeters becomes
400 millimeters

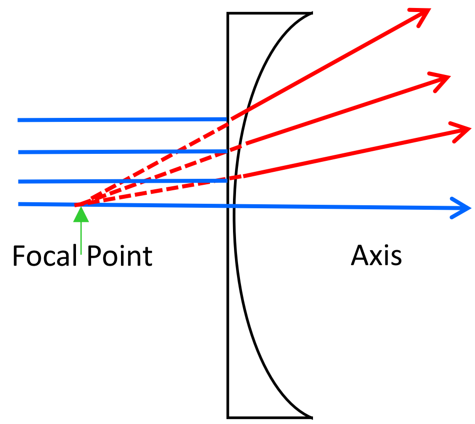
Looking at all of the answers we have arrived at, we know we need to convert millimeters to meters.

D = 1/.4

D = -2.50D (This is a minus power because it is a virtual focal length.)

Because we understand that every student comprehends in a different manner, we will present information in another format in addition to the one just discussed.

Here is a different approach to looking at focal lengths.



The lens pictured above has a virtual focal point (minus lens). The thickest part of the lens is on the edge and the thinnest part is in the center.

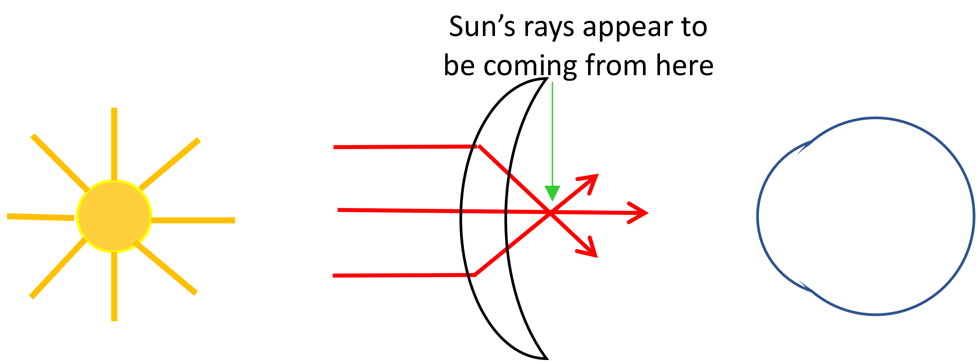
Light passing through a minus lens diverges, bends toward the base (lens edge). Light coming from a source closer than optical infinity (20 feet) is diverging. Light coming from a source at optical infinity or greater than optical infinity is considered parallel. If you look at the lens above, the light rays are diverging; therefore, the light doesn't come to a point focus behind the lens but appears to come to a point in front, thus a virtual focal point. The rays that emerge from this lens diverge from each other, instead of converging. We define divergence as negative vergence. This lens will add negative vergence to the rays entering it.

In this case, the rays emerge from the lens diverging *as if they had come from the focal point*, where in the other lens they *actually crossed at the focal point*. In a lens that adds plus vergence the focal point is *real* because the rays actually go through that point. In this case, the focal point is *virtual* because, although the rays act as if they came from the focal point, most of them never actually pass through the focal point.

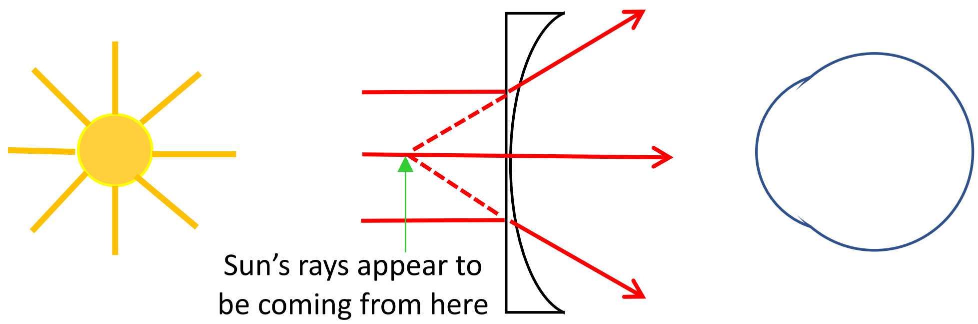
You can start a fire by placing a piece of paper at the real focal point of the lens that adds plus vergence. This lens is a plus lens. You cannot start a fire with a virtual focal point, such as we have with the minus lens, which adds minus vergence.

You have probably used the word *virtual* before. "Virtual reality" or "virtual games" are all phrases that are used to describe something that seems very real, even though it is not. Well, a virtual image from a lens that adds negative vergence still appears to be very real; it just isn't!

When you look at an object, an image is formed on the light-sensitive film (retina) in your eye, and your brain interprets the result as the object. The rays diverge from the object and are absorbed by the special light-sensitive nerve cells (rods & cones) in your eye. The processing that occurs in the nerve cells of the eye and brain interprets the object to be at the point that the rays diverged from.



When a plus lens changes the vergence of the rays that come from a distance, the result is that the eye interprets the position of the object (in this case the sun) to be at the point that the rays are diverging from. (In these drawings, the light is a long way away (beyond optical infinity), and the lens is several feet away from the eye. We are using the sun for illustration. We know that you know better than to look directly at the sun, through any lens or any other way.) **DO NOT TRY THIS AT HOME.**



When a minus lens changes the vergence of the rays that come from the distance, the result is that the eye interprets the position of the object to be at the point where the rays *appear* to be diverging from, even though the rays never actually went through that point.

Well, what about the focal length?

With the plus lens, which added plus power, we had a real focal point, and the power of the lens was 1 divided by the focal length in meters. We will now say, by definition, that the focal length of a plus lens is positive, and the power in diopters is positive.

Then the lens that adds minus vergence is a minus lens, the focal length is negative, and the power is 1 divided by the negative focal length in meters, so the power of this lens is negative.

From this moment on, whenever you specify a power for a lens, it must have a + or a - sign. If it does not have a sign it will be wrong; whether the power is right or not!

Suppose you have a lens with a virtual focal length of 1 meter. What is the lens power?

We are going to use f to represent focal length and D to represent diopters. A virtual focal length is negative, so the focal length is -1 m. $D = 1 \div f = 1 \div (-1)$, so D = -1 diopters. This is another way to write the same formula that we used previously.

$D = 1/f$ is the same formula as $D = 1 \div f$

If the virtual focal length is 0.5 m, then the power is $D = 1 \div f = 1 \div (-0.5)$, so D = -2.00 diopters.

A minus lens has a focal length of 40 cm. What is its power?

A minus lens has a negative focal length, so f = -40 cm.
The focal length must be in meters, so f = -40 cm = -0.40 m.
$D = 1 \div f = 1 \div (-0.4)$ m
D = -2.50D

Right?

What is the focal length of a -6.25D lens in mm?

D = -6.25
$f = 1 \div D = 1 \div (-6.25)$
f = -0.16 m = -160 mm. (That will be a virtual focal point in front of the lens.)

Make sure that you keep track of the minus sign and the decimal point!

We have discussed that 40 inches are almost equal to one meter. So, if you are given the focal length in inches, or if you are given the power and asked for the focal length in inches, you can use the equation $D = 40 \div f$ or $f = 40 \div D$.

In this case, the negative lens (minus lens) still has a negative focal length, and the positive lens (plus lens) still has a positive focal length.

Nominal Power of Lenses

By definition, the word nominal means in name only. That means that it is not exact, or actually, it is in name only. A real-life example of nominal would be that if you go to the lumber yard to buy 2x4's, what will you get? Lumber with dimensions of 2" by 4"? You get lumber with dimensions 1.75" x 3.50". 2x4 is the nominal dimension of the lumber, but the lumber is not, in fact, that size. So, when we are talking about the power of a lens, the nominal power will not be an exact power but will be a very close approximation.

The definition of the nominal power of a lens is the sum of the front surface and the back-surface powers.

The Nominal Power formula is:

$D_e = D_1 + D_2$

Where:
D_e = effective, vertex or lensometer power
D_1 = true power of front curve
D_2 = true power of back curve

As has been discussed previously, you may encounter varying versions of a formula. Another form of the Nominal Power formula is:

$D_N = D_1 + D_2$

Where:
D_N = effective, vertex or lensometer power
D_1 = true power of front curve
D_2 = true power of back curve

Here we have the nominal power formula for our lenses. What does this mean? Does it mean that the lens will not really be the power that we get from this formula?

That is exactly what it means!

All of the following are the variables that determine the actual power of a lens:

- The curvature of the front surface
- The curvature of the back surface
- The material the lens is made from
- The material on each side of the lens (may be the same on each side, or may be two different materials)
- The thickness of the lens
- The wavelength of the light going through the lens
- Which surface the ray of light enters first

For our purposes, knowing the nominal power of a lens will assist us in frame and lens material selection. Items 3 – 7 are higher order lens parameters that will affect the actual power of the.

The *Nominal Power* formula uses just the surface curves of the lens. Some people call this the thin lens power formula; because it assumes that the lens has no thickness, so the thickness will not affect the power of the lens. This nominal power formula is fine for lenses with a power that is less than about +4.00 D; above that the assumption that the lens thickness is negligible is no longer valid.

We used curvature and lens material index to find the power of each surface. Now we will find the lens power from the surface powers.

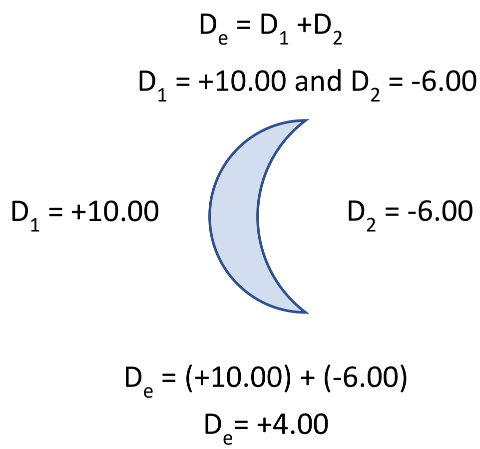
The nominal lens formula says that you can add together the powers of the front and back surfaces of the lens, and you will have the nominal power of the lens.

When we defined surfaces, we defined a concave (back) surface as having minus power and a convex (front) surface as having plus power.

Let’s look at some examples.

$D_e = D_1 + D_2$
D_e = Nominal power of lens in diopters
D_1 = Front (base) curve (power of the front surface)
D_2= Back (ocular or tool) curve/s

1. Find the nominal power (D_e) if:
    - $D_1 = +10.00$ and $D_2 = -6.00$ - see-example below
    - $D_1 = +2.00$ and $D_2 = -4.50$
    - $D_1 = +8.00$ and $D_2 = -5.75$
    - $D_1 = +1.25$ and $D_2 = -3.75$
    - $D_1 = +5.00$ and $D_2 = -6.00$

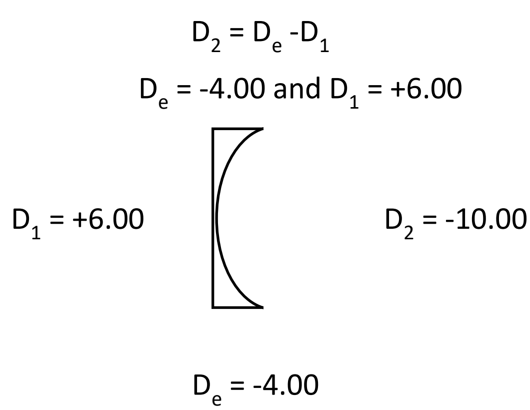


Example:
$D_e = D_1 + D_2$
$D_e = (+10.00) + (-6.00)$
$D_e = +4.00$

Same formula format:

$D_e = D_1 + D_2$
D_1 = Front (base) curve (power of the front surface)
D_2= Back (ocular or tool) curve/s

2. Find the back surface (D_2) if:
    - $D_e = -4.00$ and $D_1 = +6.00$ – see example below
    - $D_e = -2.00$ and $D_1 = +8.50$
    - $D_e = -8.00$ and $D_1 = +5.75$
    - $D_e = -5.00$ and $D_1 = +1.00$



Example:

$D_e = D_1 + D_2$ so convert the formula to
$D_2 = D_e - D_1$
$D_2 = (-4.00) – (+6.00)$
$D_2 = -10.00$

Now let's give some examples using the different form for the formula:

$D_N = D_1 + D_2$
D_N = Nominal power of lens in diopters
D_1 = Front (base) curve (power of the front surface)
D_2= Back (ocular or tool) curve/s

3. Find the front surface (D_1) if:
    - D_N= +10.00 and D_2 = -2.00
    - D_N = +2.00 and D_2 = -8.50
    - D_N = +8.00 and D_2 = -2.75
    - D_N = -1.25 and D_2 = -7.75
    - D_N = -5.00 and D_2 = -3.00

$D_N = D_1 + D_2$
$+10.00 = D_1 + (-2.00)$
$+12.00 = D_1$

4. I need a lens with power +3.50D. If I use a lens blank with a front surface of +8.00D, what back surface do I need to make? You know D_e (or D_N) = +3.50 and you know D_1 = +8.00.

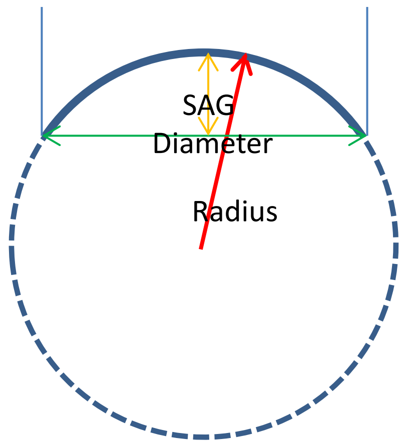
5. I have a lens with a front surface of +9.25D and a back surface of -2.25D. What is the power of the lens?

6. I want my lens to have a power of -3.00D. What back surface do I need if the front surface is +8.00D?

You may encounter the terminology "bent design lenses". This simply means that you have one surface that is plus/convex and the other surface is minus/concave. In a conventional cylindrical lens, you will have two curves on the back with one on the front, while a conventional spherical lens only has one curve on the back one curve on the front. More technologically advanced surfaces and designs will be covered later in the program.

Sagittal Depth/Sagittal Value

The definition: Sagittal depth is the straight-line distance between the back surface of a lens at its vault and the chord diameter of the lens. The height (or depth of a convex or concave lens surface is referred to as the sagitta or more oftentimes simply SAG of the surface. Simply put, it is the perpendicular distance from the vertex of the curve to some plane cutting through the curve. It is also referred to as the vertex depth of the lens surface. The diameter of a lens is calculated by the distance (or chord) from one side of the curve to the other across the plane that cuts through the curve. When we use a lens clock (lens measure) in effect we are measuring the SAG of the curve. We translate that to the power of the curve. For a spherical surface, the sagitta of a lens surface is defined by the radius of curvature of the surface at a given diameter (that is, the size of the lens blank).

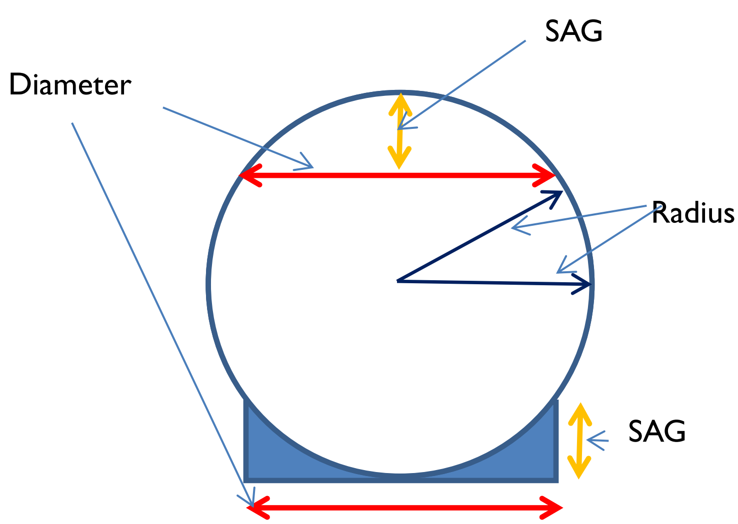


In addition, the sagitta of a *convex* curve is equivalent to the sagitta of a *concave* curve when the radii of curvature of both surfaces are equal. So, what is the significance of sagittal depth? We can calculate the center thickness of a convex lens or the edge thickness of a concave lens with the use of the sagittal depth formula. The formula is:

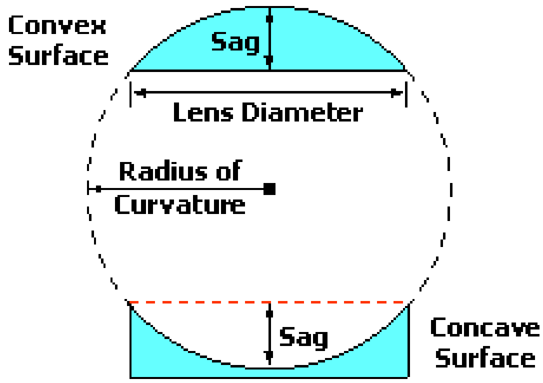
- Thickness = $\dfrac{\text{Radius}^2 \text{ X Power}}{2000\ (N - 1)}$

- Where:
- N = index of refraction of lens material used
- Thickness is in mm

The illustration below demonstrates how the surface curvature and the diameter relate to the sagittal depth/height of the lens. In determining actual thickness, keep in mind that the formula must be calculated and then added to the edge thickness of a plus lens or the center thickness of a minus lens. *The formula is based upon 0 CT or edge thickness*.



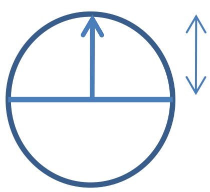
Another illustration that may help you visualize SAG is below.



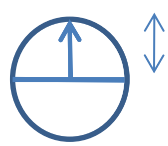
Geometry of a Lens Surface

The following illustrations may help you to visualize the relationship.

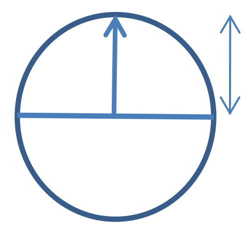
Sagittal Depth Relationship



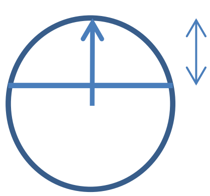
One radius



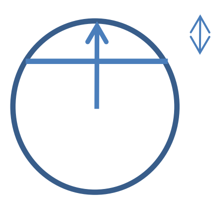
Shorter radius



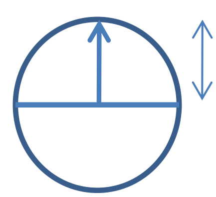
Larger radius



One radius



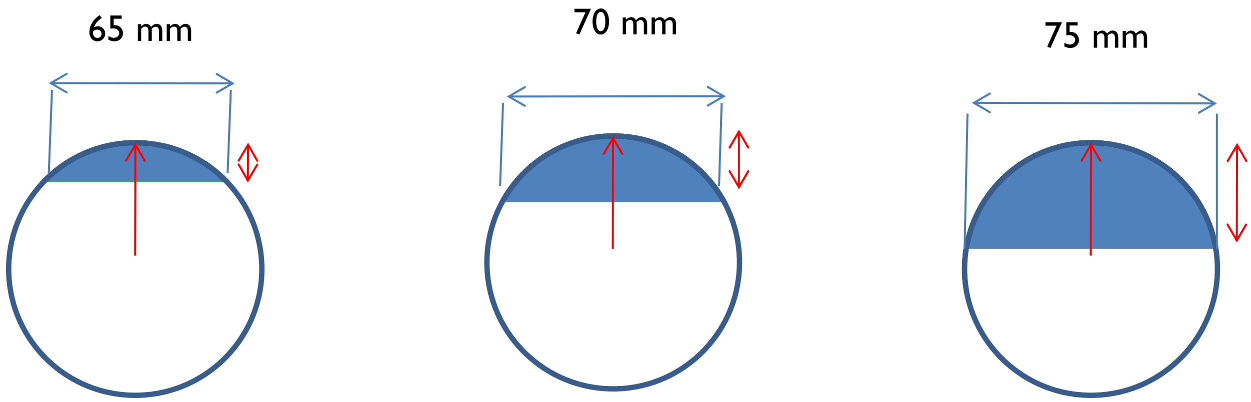
Same radius
Shorter diameter
Shorter sagittal depth



Same radius
Longer diameter
Longer sagittal depth

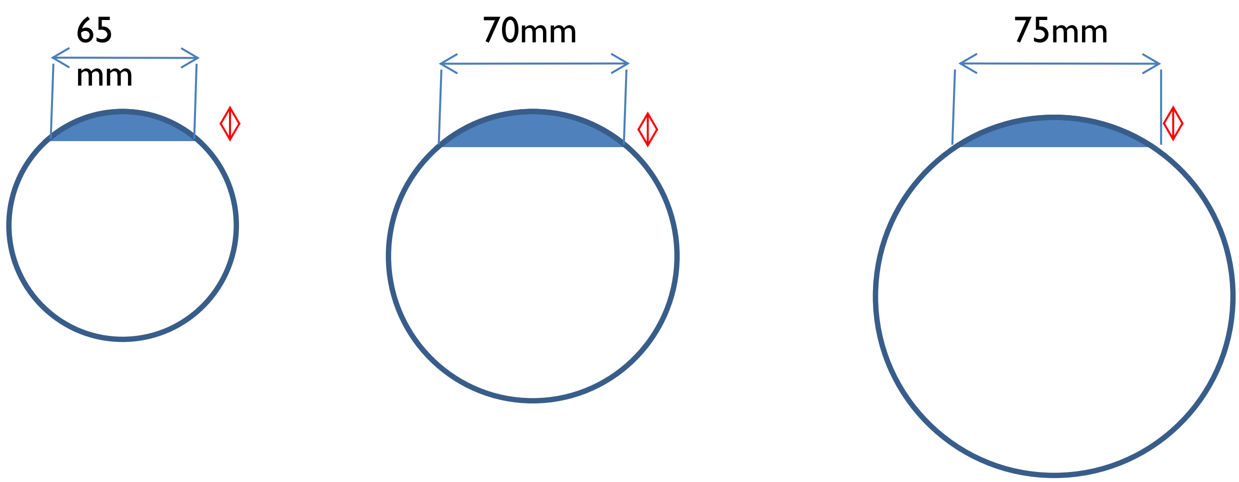
Same Radius - Different Diameters/Different Sagittal Depths

If the radius remains the same and the diameter changes, the thickness will change, and the sagittal depth will change. For example, a shorter radius will create a steeper surface curvature. A longer radius will create a flatter surface curvature. If the radius remains the same, but the diameter is smaller, the sagittal depth will be shorter. If the radius remains the same but the diameter is larger, the sagittal depth will be longer.



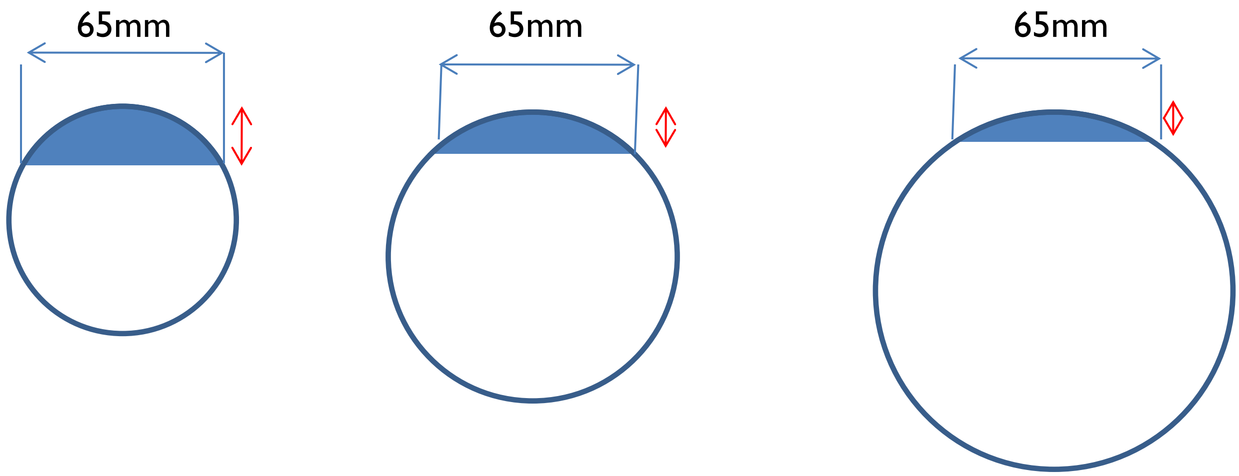
Same Sagittal Depth - Different Radius/Different Diameter

If the sagittal depth remains the same, but the diameter increases, the radius will also increase. As the diameter and the radius increase, the surface becomes flatter.

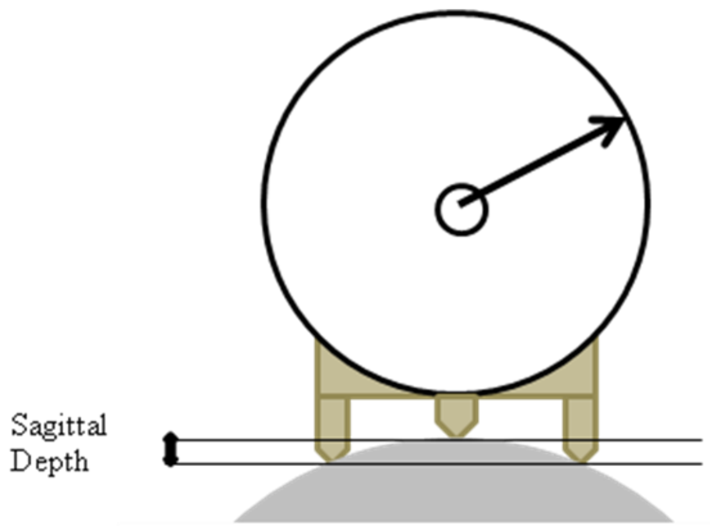


Same Diameter - Different Radius/Different Sagittal Depths

If the diameter remains the same, but the radius changes, the sagittal depth will also change. For example, if the diameter remains constant, but the radius increases, the sagittal depth will also be smaller, creating a flatter surface.



The illustration below demonstrates how a lens clock/lens measure measures sagittal depth.



For more information on sagittal depth, you may wish to refer to Systems Chapter 13

Thick Lens / Back Vertex Power

The back surface or ocular surface of a lens sits closest to the eye. Therefore, it is important that we be able to calculate the power of the lens based upon the position in front of the eye. In neutralizing the power of a lens on a lensometer, we position the back surface of the lens against the lens stop. That gives us the back-vertex power. In thinner lenses, there is very little difference between front surface power and back surface power as read in a lensometer. However, as the thickness of the lens increases, there can be a significant difference between the two readings.

Remember that the thin lens/nominal lens formula goes on the theory that there is NO thickness, so thickness does not influence the power.

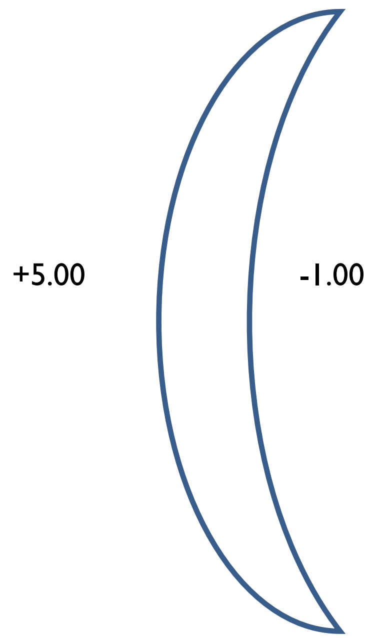
Vergence: The definition - The amount of divergence (negative) or convergence (positive) of a pencil of light rays entering or leaving a lens.

Based upon the principles of optics, as light strikes an optical medium at an oblique angle, the ray is bent toward the normal as it is passing through; which means it is bending (either divergent or convergent), within the lens.

For thick lens designs, we must also consider the equivalent thickness (t/n), which is the vergence of the light passing through the thickness of the lens. Because of the steep front curve and the thickness of the center, the thick lens will add convergence to the wave front as it passes through the lens. To find the back-vertex power (BVP) in addition to the simple combination of the powers of the front and back surfaces, we must also include the factors of the thickness of the lens in meters and the index of refraction of the material.

For example, using the nominal power/thin lens formula we would calculate the power and it would appear as the next illustration.

Thin Lens Design



Approximate power +4.00

However, when the power of a lens is over +/- 4.00D or if a steeper base curve is used, we need to consider the thickness as well, due to vergence within the lens.

Therefore, for the thick lens formula, we must include the equivalent thickness (t/n) to the formula.

The thick lens/back vertex formula is:

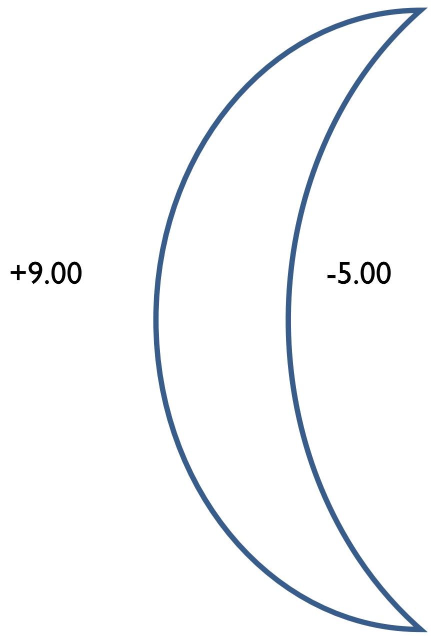
- $D_e = D_1 + D_2 + (t/n \times D_1^2)$

Where :

- D_e = effective, vertex or lensometer power
- D_1 = true power of front curve
- D_2 = true power of back curve
- t = lens thickness in meters
- n = index of refraction

The next illustration demonstrates the thick lens design. If we simply used the thin lens formula, the power would appear to be +4.00D, however, due to the high surface curvature, the thickness is increased, which not only increases the magnification effect of the lens but the power as well. Therefore, the approximate power using the thick lens formula would be +4.39D.

Thick Lens Design



t = 7.0mm
n = 1.50
Approximate power +4.39

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