POWER SPECIFICATION
&
MEASUREMENTS

Lecture -2-

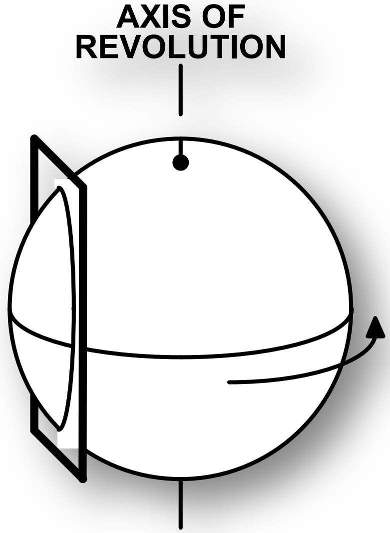
Power specification

- One of the primary applications of an ophthalmic lens is to **change the vergence of incident light**, typically to compensate for a refractive anomaly of the eye.
- The ability of a lens to change the vergence of light is referred to as **focal power**.
- The refracting power is defined as the change in vergence that occurs when light passes through a lens.
- The unit for Power measurement is the Diopter.

Power specification

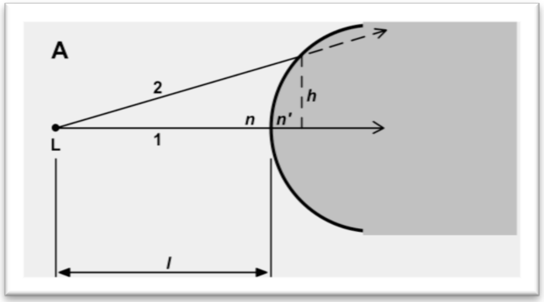
Curved refracting surfaces:

- Lens surfaces are often referred to as **surfaces of revolution**.
- The most common example of these surfaces is the **sphere.**
- A lens surface is cut from a section of this spherical surface of revolution. Any point on the surface of a sphere is equidistant from its center of curvature.



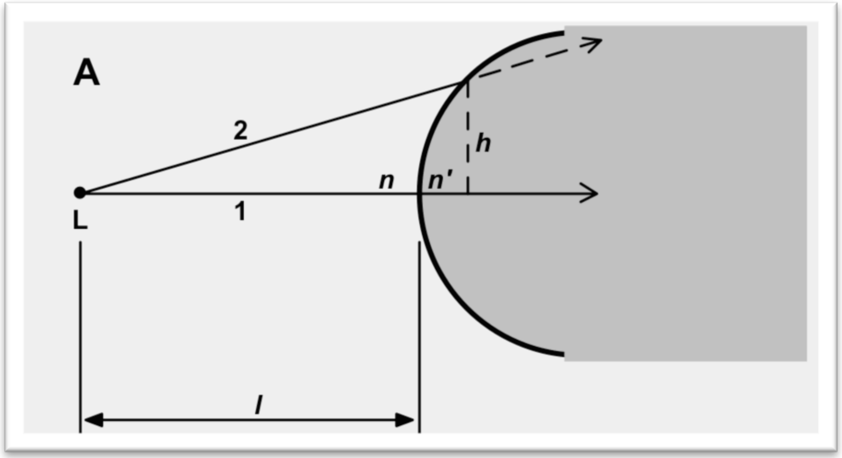
Curved refracting surfaces

- A lens surface is simply an ***interface*** between two media with different indices of refraction.
- This interface is between air and the lens material.
- The common curvature of this interface, which is determined by the radius of curvature *r*, and the difference in refractive index between the two media determine how light is affected (or 'refracted') as it passes from one medium to the other.



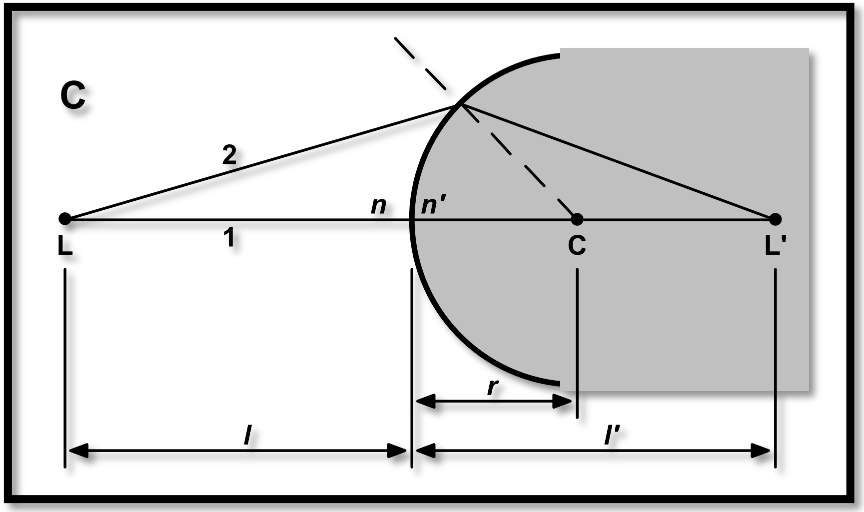
Curved refracting surfaces

- we will use *n* to represent the medium to the *left* of this interface in *object* space, and *n'* to represent the medium to the *right* in *image* space.
- If we know the distance of an object from the surface, and its surface power, we can determine the distance at which the image of the object will be formed.



Curved refracting surfaces

- the *object* distance *l* is the distance of an *object* from the surface.
- the *image* distance *l'* is the distance of the resultant *image* from the surface.



Snell’s law

- Snell’s law of refraction can be simplified to develop a relationship between:
  - the refractive indices of the two media (n and n') surrounding the surface,
  - its radius of curvature r
  - the image distance l' from the surface that rays of light are brought to a focus at point L' after refraction.
  - This formula, known as the **conjugate foci formula** for lens surfaces:

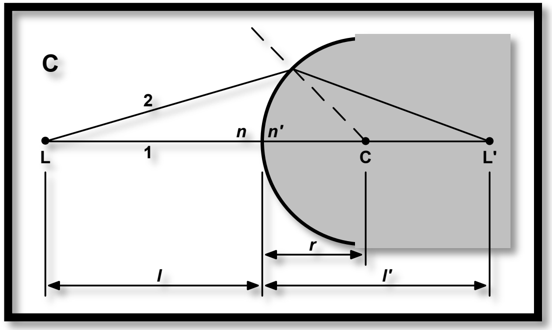
$$\boxed{\frac{n'}{l'} = \frac{n' - n}{r} + \frac{n}{l}}$$

Snell’s law

- $\boldsymbol{n}$ is the refractive index of the medium to the *left* of the surface in *object* space
- $\boldsymbol{n'}$ in the index of the medium to the *right* in *image* space, l is this image distance
- $\boldsymbol{l'}$ is the object distance
- $\boldsymbol{r}$ is the radius of curvature of the surface (or *interface*).

All of these distances are measured in meters.

$$\frac{n'}{l'} = \frac{n' - n}{r} + \frac{n}{l}$$



Snell’s law

- Dioptric Equivalent of these three terms of the formula:
  - the term on the left side of the equation, n' / l', represents the *image vergence* L' in diopters.
  - The last term on the right side of the equation, n / l, is the *object vergence* L in diopters.

$$\boxed{\frac{n'}{l'} = \frac{n' - n}{r} + \frac{n}{l}}$$

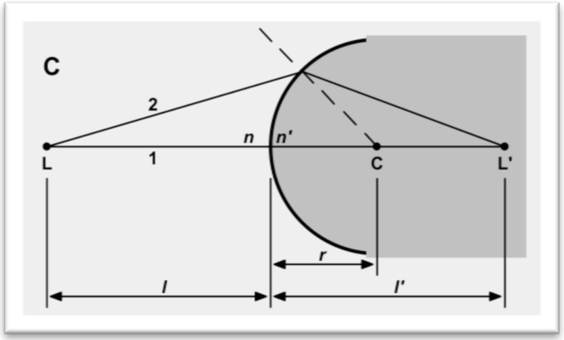
- Gives us:

$$\boxed{L = \frac{n}{l} \quad \text{and} \quad L' = \frac{n'}{l'}}$$

- $(n' - n) / r$, is the *surface power* F_S in diopters.
- the basic **surface power formula** is:

$$\boxed{F_S = \frac{n' - n}{r}}$$

Snell’s law



- Substitute the spherical equivalents into the conjugate foci formula:

$$\boxed{L' = F_S + L}$$

- This variation of the formula tells us that the image vergence L' produced by a lens surface is simply equal to the sum of the surface power F_S and the object vergence L.
- *(The image vergence is the net result of the effect that the surface power has on the object vergence).*

THIN LENS POWER

- We will first consider **‘thin’** lenses whose center thickness is small and relatively inconsequential.
- When the two surfaces of such a lens are virtually in contact at the optical axis, we refer to the lens as a **thin lens**.
- Once the vergence of incident light is affected by the power of the first surface, it is immediately subjected to the effects of the second surface.
- each surface power is given by:

$$\boxed{F_S = \frac{n' - n}{r}}$$

THIN LENS POWER

$$F_S = \frac{n' - n}{r}$$

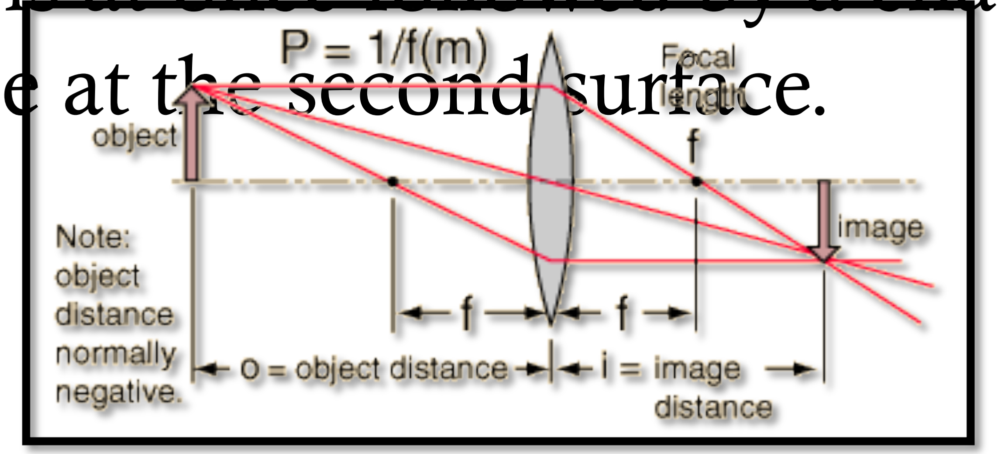
each surface power is given by:

- F1 → surface power of the front curve
- F2 → surface power of the back curve
- n → refractive index of the lens material

$$F_1 = \frac{n-1}{r} \quad \text{and} \quad F_2 = \frac{1-n}{r}$$

THIN LENS POWER

- Theoretically, there is no separation between the surfaces of a thin lens.
- The change in vergence imparted by the first surface is at once followed by a change in vergence at the second surface.



THIN LENS POWER

- Our *conjugate foci formula* to allow for the effects of both the front *and* back surfaces (*F*1 and *F*2).
- *The focal power of a thin lens is equal to the algebraic addition of the front F*1 *and back F*2 *surface powers* → **Lensmaker's formula.**

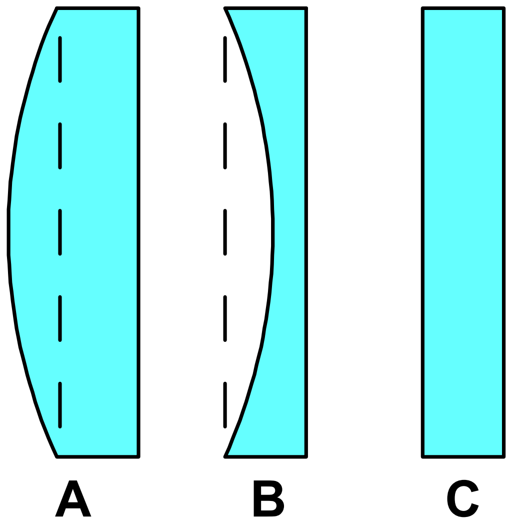
$$\boxed{L' = F_1 + F_2 + L}$$

$$\boxed{F = F_1 + F_2}$$

$$\boxed{F = \frac{n-1}{r_1} + \frac{1-n}{r_2}}$$

Types of lenses

- Referring specifically to lens surfaces in air, we often distinguish between the following three basic types of surface curvatures and power.

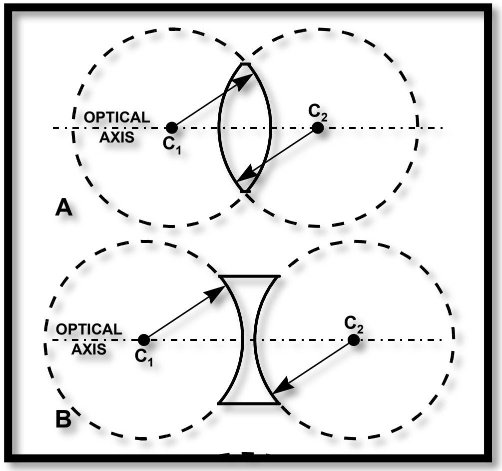


Types of lenses

- **Convex curves** (think of the *outside* of a bowl) produce a *positive* (+) surface power, and add *convergence* to incident rays of light.
- **Concave curves** (*inside* of a bowl) produce a *negative* (-) surface power, and add *divergence* to incident rays of light.
- **Plano curves** (*flat*) produce *zero* surface power (0), and do *not* change the vergence of incident rays of light. (The radius of curvature of this surface is infinitely long.)

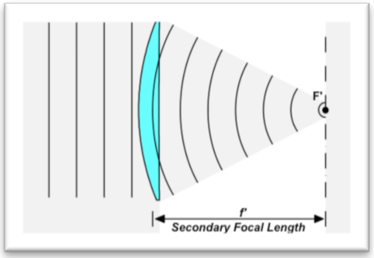
Optical Axis

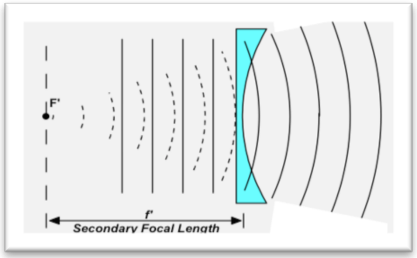
- The **optical axis** is an imaginary line of reference passing through both centers of curvature (C1 and C2) of a lens.
- Since a line passing through the center of curvature of a surface is perpendicular to that surface, the optical axis is *normal* to both the front *and* back surfaces.
- The front and back surfaces are exactly parallel with each other at the two points intersected by the optical axis.



A) Optical axis of lens with two *convex* surfaces
B) A lens with two concave surfaces

Secondary Focal length



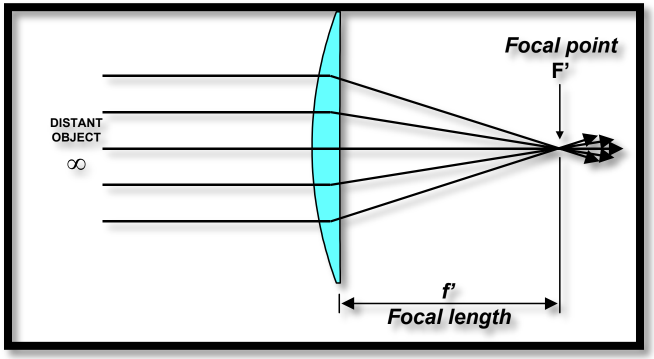


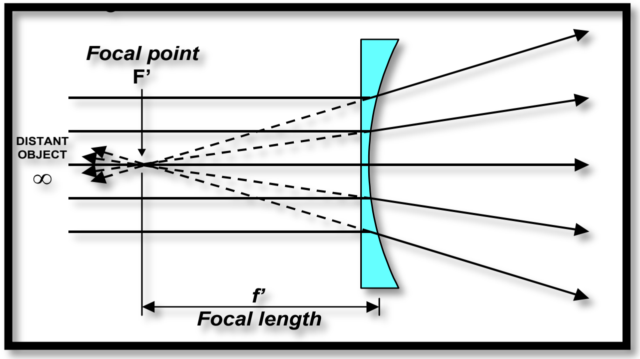
Secondary focal length of the lens:

- You should now realize that the reciprocal of the focal power provides the image distance from the lens at which light from an object at infinity will either converge to a *real* point focus for *plus* lenses, or appear to diverge from a *virtual* point focus for *minus* lenses—after refraction through the lens.
- The image plane that contains all of the image points from such an object is referred to as the *secondary focal plane*; this plane is positioned at the secondary focal point and is perpendicular to the optical axis.

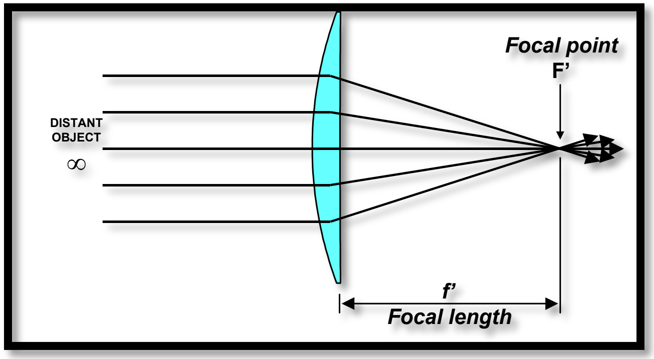
Secondary Focal length

- The reciprocal of the focal power provides the image distance from the lens at which light from an object at infinity will either:
  - converge to a *real* point focus for ***plus* lenses**, or
  - diverge from a *virtual* point focus for ***minus* lenses**—after refraction through the lens.

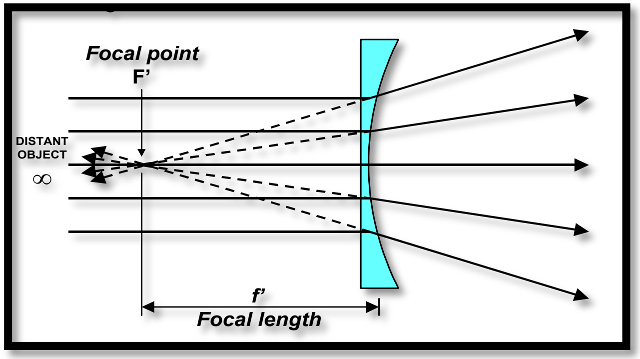




Secondary Focal length

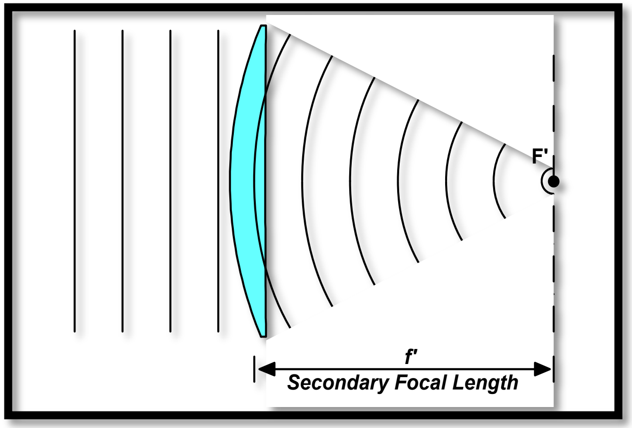


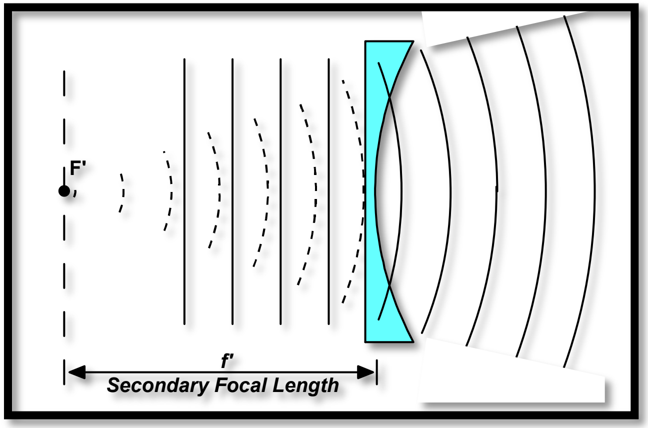
Cross-sectional view shows parallel rays of light, from a *real* object at infinity (∞), converging to form a *real* point focus at the secondary focal point F' of a *plus* lens. A *real* image is created.



Cross-sectional view shows parallel rays of light, from a *real* object at infinity (∞), diverging as if from a virtual point focus located at the primary focal point F' of a *minus* lens. A *virtual* image is created.

Secondary Focal length



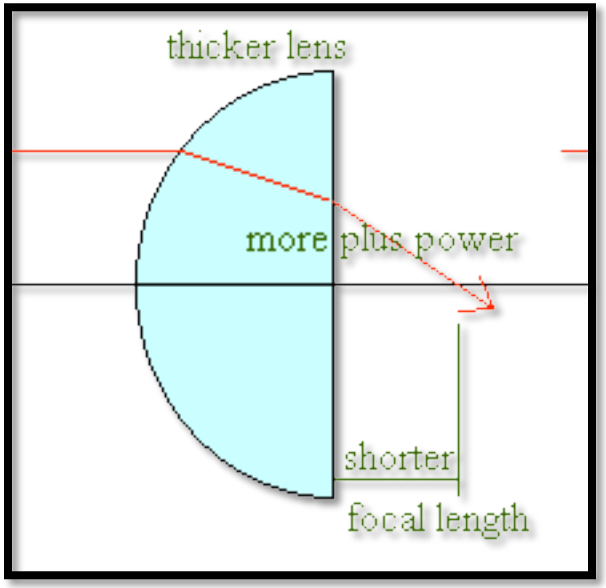


The action of a *plus* lens upon light can also be described by wave fronts *converging* to point F’

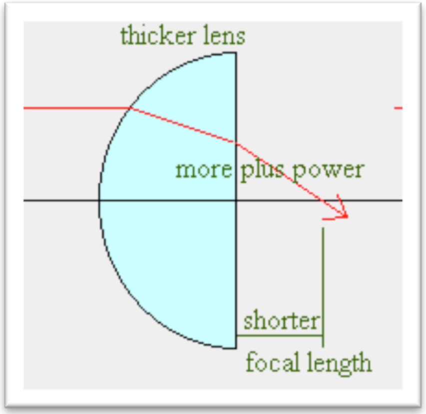
The action of a *minus* lens upon light can also be described by wave fronts *diverging* as if from point F’

BACK VERTEX POWER (THICK LENS)

- The lensmaker's formula for *thin* lenses quickly loses accuracy for lens forms of significant thickness or curvature.
- For *thick* lenses, the vergence of light as it passes through the lens also needs to be taken into consideration.
- The power of a **thick lens** is no longer simply equal to the combination of the front and back surface powers.



BACK VERTEX POWER (THICK LENS)



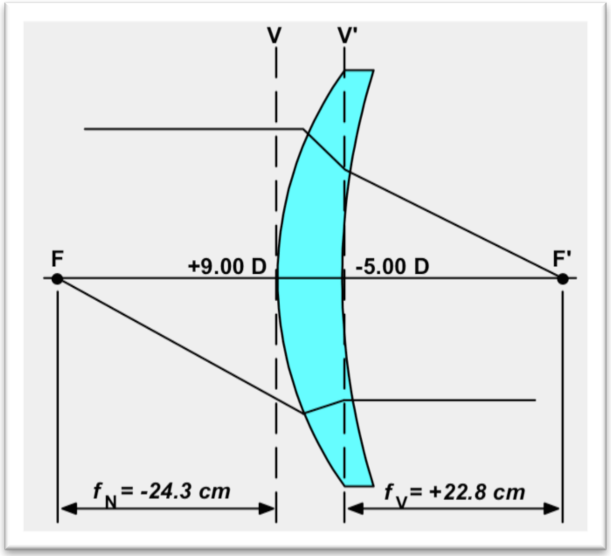
- Assume a theoretical reference plane centered between the two surfaces of a *thick* lens (at their imaginary contact point).
- This is no longer practical since the front and back surfaces are separated by an appreciable amount.
- Consequently, the focal lengths of a thick lens depend upon the reference plane that the focal points are measured from.
- since the focal power of a lens is equal to the reciprocal of the focal length, the reference plane will also affect the stated **focal power.**

BACK VERTEX POWER (THICK LENS)

- **Vertex power:** focal power of a lens , measured relative to a plane containing one of the vertices, either the front or back surface.
- A thick lens generally produces powers that actually differ between measurements from the front and the back surfaces (or vertices).

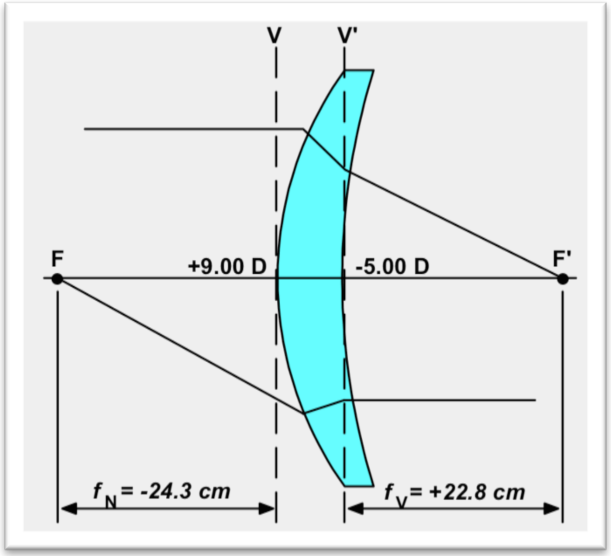
BACK VERTEX POWER (THICK LENS)

- The **back vertex power** F_V is the vertex power of the lens, produced by an infinitely distant object, as measured from the back vertex V' of the surface.
- In ophthalmic optics the *back* vertex power is **most commonly used.**



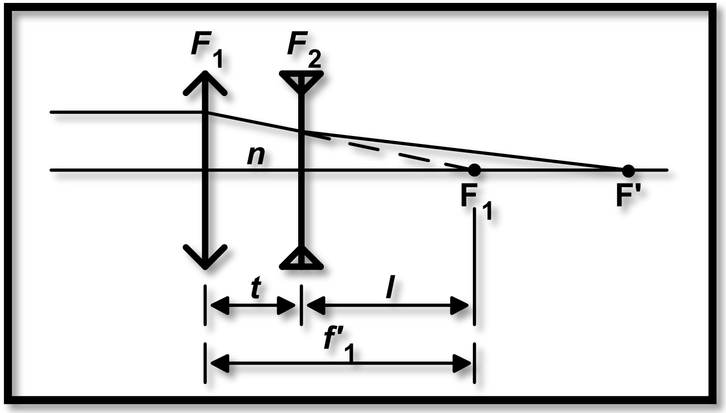
BACK VERTEX POWER (THICK LENS)

- The back vertex power F_V of a lens can be calculated if the **front** and **back** surface powers ($F1$ and $F2$), the refractive index ***n***, and the center thickness ***t*** in meters are **all known**.
- The ***equivalent thickness*** **(*t* / *n*)** of the lens is also considered, which is the vergence of the light passing through the thickness of the lens.



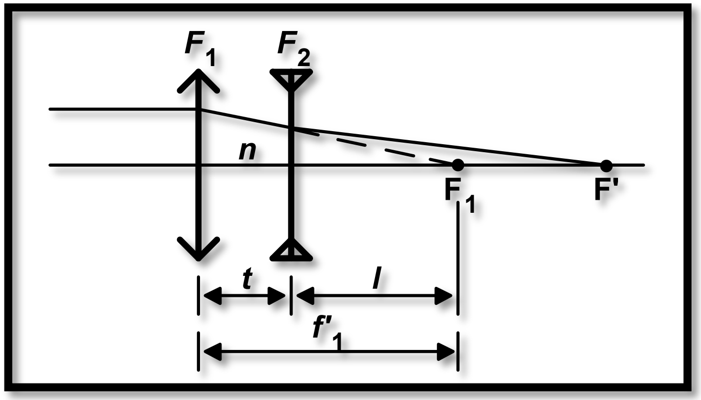
BACK VERTEX POWER (THICK LENS)

- To determine the back vertex power, we need to consider the refraction at each surface of the lens *and* the *equivalent thickness* ($t\ /\ n$).
- The thick lens in the Figure utilizes a **convex** front curve $F1$ and a **concave** back curve $F2$.



BACK VERTEX POWER (THICK LENS)

- To determine the *back vertex power* of a thick lens, the vergence of the light, n / l, as it passes through the thickness of the lens must be determined.
- The reduced thickness of the lens is given by t / n ***(equivalent thickness)***.
- The vergence of light at the back surface is given by **$n / (f1' - t)$.**



(step-by-step) How incident light is affected as it passes through a thick lens !

- The radius of the wave front striking the back surface, which is the new object distance ***l* = *f*′1 - *t*.**
- where ***n*** is the refractive index of the material and ***t*** is the center thickness of the lens in meters.
- **Secondary focal length *f*′1 =** *n* / *F*1

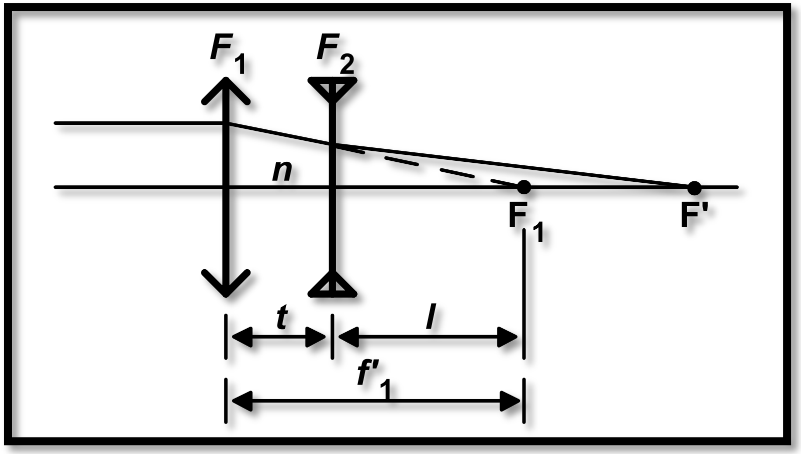
$$\boxed{L = \frac{n}{l}}$$

$$\boxed{L = \frac{n}{f_1' - t}}$$

$$\boxed{L = \frac{n}{\frac{n}{F_1} - t}}$$

(step-by-step) How incident light is affected as it passes through a thick lens !

$$\boxed{L = \frac{n}{l}}$$



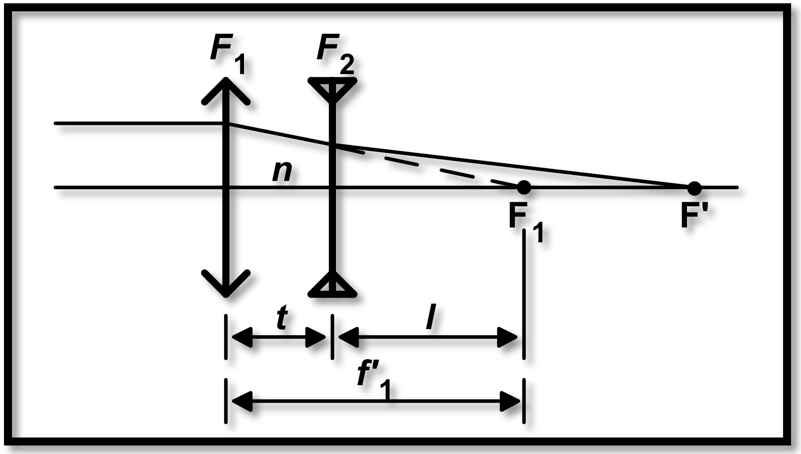
$$\boxed{L = \frac{n}{\frac{n}{F_1} - t}}$$

$$\boxed{L = \frac{n}{f_1' - t}}$$

$$\boxed{L = \frac{F_1}{1 - \frac{t}{n} F_1}}$$

(step-by-step) How incident light is affected as it passes through a thick lens !

- The *object* vergence at the back surface is ***L*.**
- To determine the final *image* vergence $\boldsymbol{F}_{\mathrm{V}}$ → add the change in vergence produced by the back surface power ***F*2.**



$$F_V = \frac{F_1}{1 - \frac{t}{n} F_1} + F_2$$

$$F_V = L + F_2$$

FRONT VERTEX AND ADD POWER

- ophthalmic lenses will also produce a **front vertex power** F_N, or **neutralizing power**, when measured from the *front* vertex.
- This is the vergence of light from the *primary focal point* F to the *front* vertex V of the lens.
- The equation for the front vertex power F_N of a lens is given by:

$$\boxed{F_N = \frac{F_2}{1 - \frac{t}{n} F_2} + F_1}$$

FRONT VERTEX AND ADD POWER

- The equation for the *front* vertex power F_N is very similar to the equation for the *back* vertex power F_V.
- Indeed, the only difference is that the front curve has been substituted for the back curve—and vice versa.
- The distance from the *front* vertex of the lens to the *primary* focal point F is known as the **front focal length** f_N.

FRONT VERTEX AND ADD POWER

- The additional plus power provided by the lens is referred to as its **add power**, and is generally produced within a small region of the lens referred to as the near zone or **segment**.
- When the segment is on the *front* surface, which is generally the case, the add power is related to the *front vertex power* of the segment.