Continuing Education Course

Approved by the American Board of Opticianry

Lens Materials and Design

National Academy of Opticianry
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National Academy of Opticianry

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 evaluation form on the answer sheet. Please allow two weeks for the grading and a reply.

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.

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INTENDED AUDIENCE:

This course is intended for opticians of all levels.

COURSE DESCRIPTION:

This course will explain basic ophthalmic lens materials and designs. Information will include index of refraction, impact resistance, lens material classifications and Abbe value.

LEARNING OBJECTIVES:

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

- Understand different ophthalmic lens materials
- Explain the classifications of lens materials
- Explain the difference in lens design, spherical vs. aspheric
- List advantages and disadvantages of different materials

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There has been a literal explosion of newer high-tech lenses in the marketplace over the last few years. It is no longer just a case of **"Do you want glass or plastic lenses?"** Before you can really understand what the major differences are between the old and new materials you will have to familiarize yourself with a few terms.

More lens designs and materials have been introduced into the market during the last five years than in the previous 60. Keeping that in mind, as you study this document, newer technologically advanced lens designs and materials have already been introduced and more will continue to be introduced.

This course will present some manufacturers names and trade names. It is not the intent of these authors to attempt in any manner to sway you toward one manufacturer or another. It is our intent to simply present various options that may be available by a number of companies.

This course will NOT present digitally designed lenses as that will be another topic.

Very Brief Timeline of Lens Design ***1 – Information from System for Ophthalmic Dispensing – Third Edition***

- *1200 – 1800: Flat lenses*
  - *Not actually flat, but shaped more like a lentil. Central vision was OK, but dramatically digressed in the periphery*
- *1800's – Periscopic Lenses*
  - *Change in design utilizing a -1.25D back surface power*
- *Beginning around 1890's – Six-base meniscus lenses*
  - *Because of the minus curve on the back surface, vision was dramatically improved.*
- *Early 1900's – Correct Curve Lenses*
  - *Introduced by Carl Zeiss Company*
  - *Lenses were designed to approximate the rotation of the eye and were designed to correct for oblique astigmatism found in the periphery of the lenses.*
- *Early 1900's – Aspheric lenses*
  - *Originally introduced for use in very high plus "cataract" style lenses*
  - *Became more used in lower powers in late 20th century in plus as well as minus*
    - *Primarily as a result of more material availability*
- *Late 1990's – Atoric lenses*
  - *Aspheric design on both sides of the lens*
  - *Used to increase the field of view due to reducing optical aberrations in both principal meridians*

Lens Materials

As an optician, there are a number of factors you will be considering every time you select or recommend a lens material for your patients. While many ECPs feel that the patient's primary concern is how thick their lenses will be, that may not be the case in every situation. Therefore, one must determine which is the most important based upon the intended usage of the eyewear. These factors include the following:

- Index of Refraction
  - How much does it bend light?
- Abbe Value
  - What are the optical properties of the material?
- Specific Gravity
  - What are the lenses going to weigh?
- Impact Resistance
  - How safe are these lenses?

Now let's go a little more in-depth with each of these.

Refractive Index/Index of Refraction

Index of refraction is the term most eye care professionals are familiar with. The higher the index of refraction the more the material will bend light rays. Therefore, a higher index lens will require less material and be thinner.

The terms refractive index and index of refraction are considered interchangeable. As previously discussed in this program, the index of refraction is a numerical expression comparing the speed of light in a transparent medium to the speed of light in air (vacuum). The formula to determine index of refraction is:

$$\text{Index of refraction (n) of the substance} = \frac{\text{Speed of light in air}}{\text{Speed of light in substance}}$$

For instance, we know that the speed of light in air is roughly 186,000 miles per second. The speed of light through crown glass which is denser than air is 122,000 mps, so we can now determine the index of refraction of the lens made of crown glass.

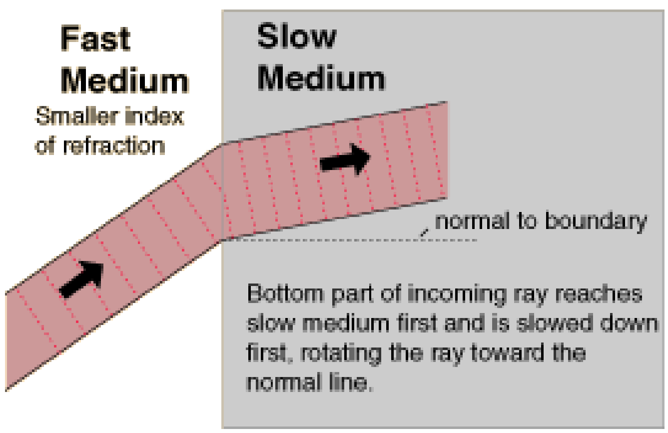
$$n = \frac{186{,}000}{122{,}000} = 1.523$$

The following is a table with some common index of refraction. However, we do not use these for ophthalmic lenses.

Material	Index of Refraction
Air	1.00
Ice	1.31
Water	1.33
Diamond	2.41

You will notice in the chart above that while water and ice are the same basic material, when water freezes and becomes ice, it also expands; therefore, the molecules are further apart and the specific gravity also changes. Ice weighs less and will float in water. It also has a lower index of refraction; therefore, will not bend light as much as water.

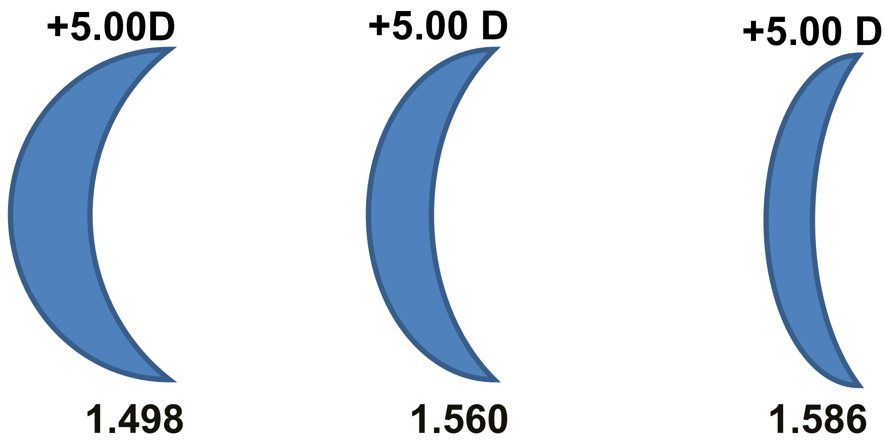
Refraction is responsible for image formation by lenses and the eye.



With the index of refraction of air being 1.00, we can safely assume that any transparent substance with a higher number will also be denser than air, therefore slowing the speed of light. When light reaches a denser material it also gets refracted more. Another hard rule to remember is that the higher the index of refraction, the thinner the lens.

An increased index of refraction can have a dramatic difference on the final thickness, weight, and profile of a lens. The reduced thickness translates into a lighter and more comfortable product, too.

As the index of refraction increases, a lens of a given prescription and diameter needs less curvature and thickness to produce the same power. For plus lenses, this translates into thinner centers; for minus lenses, it means thinner edges.



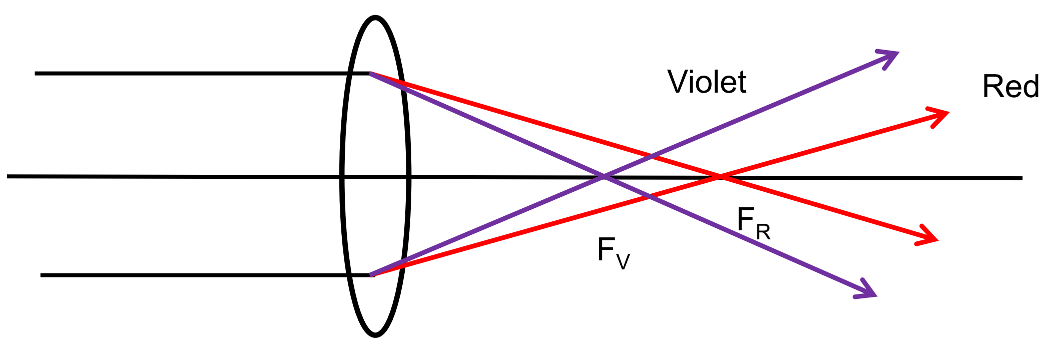
Abbe Number

Ernest Abbe, working with Carl Zeiss and Otto Schott, developed a mathematical formula to determine the amount of chromatic aberration a lens material will produce. The higher the number, the better the optics of the material due to the decrease of the amount of chromatic aberration caused by light passing a refractive medium and breaking down into its component colors (dispersion).

The Abbe value of a lens material (sometimes referred to as Nu value or V number) is the reciprocal of the dispersive power of the lens. Dispersive power being the characteristic of a lens that breaks up white light into its component colors, a rainbow. Abbe numbers range from 20 - 60. The higher the Abbe number, the less chromatic dispersion occurs.

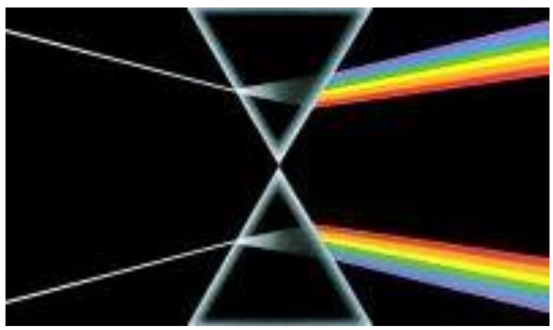
When white light (e.g., sunlight) is refracted, it breaks down into a rainbow. This is referred to as "dispersion," which results in a chromatic aberration. Abbe value is the measure of a material's characteristic of breaking light into its component colors. It has been a constant concern with high index lens materials. If the color aberration is significant enough, the lens wearer will likely see some reduction in vision quality, and possibly colored ghost images around objects.

The index of refraction of a material varies with wavelengths; different wavelengths of light are focused at different focal points by a lens.



All lenses will have chromatic aberration. Here is a plus lens. Hyperopes usually will not complain about the "rainbows" as they travel along the optical axis of the lens.

Myopes generally will be very sensitive to the "rainbows" around the edges. The higher the minus, the more they will notice. As lens size will have an effect also, large eyesize equates to more color. Abbe needs to be at the forefront of your lens material choice.



ABBE Values of Some Common Lens Materials

Material	Manufacturer	ABBE Value
Crown	Many	59
CR-39	Many	58
Spectralite	Carl Zeiss Vision	47
Trivex®	Many	43-45
Polycarbonate	Many	29-36

Specific Gravity

Specific gravity is a weight issue. The higher the specific gravity the heavier the lens will be. We need to balance the thinness of a high index material with its weight. It is the given comparison of a lens material to an equal volume of water. Specific gravity is independent of index of refraction and Abbe value.

This is a measurement of physical density, not an optical characteristic. The weight of the material is measured in grams per cubic centimeter. For our purposes, the lower the specific gravity of a lens material the lighter the lens will be. We all know that lightweight is a very highly desirable patient benefit.

$$\frac{\text{Weight of a given volume of a substance}}{\text{Weight of equal volume of water}}$$

Weights of high index materials vary considerably, with glass products leading the list as the heaviest. Thinner doesn't necessarily mean lighter weight. Some high index products have a higher specific gravity than others. An aspheric lens design is a good way to make lenses thinner, which also makes them lighter.

Material	**Manufacturer**	**Specific Gravity**
Trivex®	Many	$1.11 g/cm^3$
Spectralite	Carl Zeiss	$1.21 g/cm^3$
Polycarbonate	Many	$1.21 g/cm^3$
CR-39	Many	$1.34 g/cm^3$
Crown Glass	Many	$2.62 g/cm^3$

Impact Resistance

Safety is a major concern to ECPs and to patients. Most lens materials offer impact resistance higher than CR-39. Polycarbonate and Trivex® lenses pass ANSI Z87.1 (safety eyewear) impact resistance testing. Impact resistance testing will be discussed more in-depth later in this program. When you are selling dress/industrial safety impact-resistant lenses of these materials, you are selling the safest lens materials currently available.

The two recently added lens safety tests are the High Velocity Impact Test and the High Mass Impact Test.

High Velocity Impact Test

One of the impact resistance tests is called the High Velocity Impact Test. Lens materials that pass this test can withstand an impact from a 1/4-inch round pellet fired at 150 feet per second and not break. This is the level of impact resistance required of some safety eyeglasses. That substantial impact resistance is a huge selling point at the dispensing table, no matter how high or low the patient's prescription may be.

Though it seems the opposite may be expected, high impact requirements allow the lenses to be thinner than basic-impact lenses. The thickness requirement for high-impact safety lenses is a minimum of 2.0 mm for both Rx and plano. AR coatings generally reduce the impact resistance of the same lens in the uncoated state. The reduction will depend on the material and the type of coating.

Tests have been conducted on both polycarbonate and Trivex that concluded if you are going to use a multi-layer AR coating, these lenses should not be used in industrial or sports eyewear at the 2-mm center thickness where there is a high risk of exposure to high-energy impacts. The tests were conducted by firing an industrial sewing machine needle at the lenses. The lenses were more susceptible to the penetration of the sharply pointed missile than to a blunt missile.

High Mass Impact Test

Polycarbonate and Trivex® will also pass the High Mass Impact Text making them the safest lens materials available for dress eyewear. The High Mass Impact Test uses a 500g (17.6 oz.) pointed projectile dropped from a height of 127cm (50 in.)

Formerly, dress ophthalmic lenses had a minimum thickness requirement of 2.0 mm. Now there is no thickness requirement, regardless of lens material. Impact resistance requirements are performance based. If a lens thinner than 2.0 can pass the standard drop ball test, (meaning it doesn't break) which is having a 5/8 inch steel ball, weighing .56 ounces from a height of 50 inches, the lens material is considered acceptably safe for dress use, not industrial use. Many lens materials today can meet the current requirements for dress lenses.

Classifying Lens Materials

Most ECPs recognize four material index categories—low, mid, high, and ultra-high. There is no official standard that subdivides these materials, but the optical industry generally follows this breakdown:

- Low index: <1.53
- Mid index: 1.53 to 1.58
- High index: 1.59 to 1.66
- Ultra-high or super-high index: >1.66

ECPs are moving to higher index lenses. The optical advantage of flatter base curves helps the lens shed some thickness. Additionally, thinner lenses look more attractive and are lighter in weight, making them more comfortable to wear. 80% of the Rx's can be fit using mid index materials.

Low Index Lenses

Material	Manufacturer	Refractive Index	ABBE	Specific Gravity
CR-39	PPG- Many	1.50	58	1.32g/cm^3
Supefin®	INDO Lens	1.52	48	1.31g/cm^3
Crown Glass	Many	1.52	59	2.55g/cm^3

Mid Index 1.53 - 1.58

Material	Manufacturer	Refractive index	ABBE	Specific Gravity
Trivex™	Hoya Vision Care; Yonger Optics; Thai Optical Group; Augen Optics; X-Cel Optical Co; Shamir Insight Inc; Signet Armorlite, Inc.	1.53	43-45	1.11g/cm^3
Spectrlite	Carl Zeiss Vision, Inc	1.53	47	1.21g/cm^3
High-X 1.55	X-Cel	1.55	38	1.20g/cm^3
1.56 EvoClear™	Signet Armorlite	1.56	38	1.17g/cm^3
1.56 Corning® SunSenors®	Signet Armolite	1.56	38	1.17g/cm^3
Varilux® Ormex	Essilor	1.56	37	1.36g/cm3

High Index 1.59 -1.66

Material	Manufacturer	Refractive index	ABBE	Specific Gravity
Polycarbonate	Many	1.59	32	1.21g/cm³
Thin&Lite 1.6	Essilor	1.60	36	1.34g/cm³
Finalite1.6	Carl Zeiss	1.60	42	1.22g/cm³
EYAS	Hoya	1.60	41	1.34g/cm³
TLX 1.6	Signet Armorlite	1.60	42	1.30g/cm³
EvoClear 1.6	Signet Armolite	1.60	32	1.34g/cm³
Hyperindex 1.66	Optima	1.66	32	1.35g/cm³
Claret	Carl Zeiss	1.66	42	1.36g/cm³

"Ultra-high" Index 1.67 and Above

Material	Manufacturer	Refractive index	ABBE	Specific Gravity
1.67 Ultra Thin UV	Pentax Vision	1.67	32	1.35g/cm³
1.67 Super AVAR	Seiko Optical	1.67	32	1.36g/cm³
Thin & Lite 1.67	Essilor	1.67	32	1.36g/cm³
ViZio	Carl Zeiss	1.67	32	1.36g/cm³
Eyry	Hoya	1.70	36	1.41g/cm³
Thin& Lite 1.74	Essilor	1.74	34	1.46g/cm³
NLS5-AS 1.74	Nikon	1.74	34	1.46g/cm³
Lantal 1.9(glass)	Carl Zeiss	1.90	30	3.37g/cm³

Lens Materials

We will be touching on some of the highlights of the different lenses here.

CR-39

The most commonly used plastic lens material for years was CR-39. It was first developed as a replacement for glass lenses during World War II. It still has 55% of world market at age 60. The patent was awarded to Muskat and Strain of Pittsburgh Plate Glass Company (now named PPG) in 1946. CR-39 is available in all lens styles and from multiple manufacturers. The basic monomer comes from PPG, and then each company adds their own materials to create their lenses. Advantages include light weight, good optical properties, and tinting well. Disadvantages of CR-39 are that it is the thickest material and scratches easily.

Glass Lenses

We will be addressing several different types of glass at this time.

Crown Glass is the most commonly used clear glass for ophthalmic lenses. In general, glass is the most durable material used for lenses. Crown glass is used mainly for single vision lenses and the distance carrier for most glass bifocals and trifocals. It has an index of refraction of 1.523, and an Abbe value of 59. It is approximately 4% thinner than CR-39 resin lenses and is 40% heavier than polycarbonate lenses and is slightly lighter than high index glass. It blocks out about 10% of UV light.

Flint Glass uses lead oxides in its chemical make up to increase its index of refraction to approximately 1.58 to 1.69. Its Abbe value ranges from 30 to 40. This material is relatively soft, displays a brilliant luster and has chromatic aberration. Although it was used in the past as a single vision alternative for higher Rx lenses, its use today is often limited to segments for some fused bifocals.

Barium Glass is a lens that uses barium as its main ingredient. This gives it an index of refraction from 1.51 to 1.616 and an Abbe value of 55 to 59. This allowed this material to be used in the bifocal segment in the Nokrome series of fused bifocals. The high Abbe value allowed those using the bifocal to experience no color dispersion when reading.

Highlite 1.7 Glass, here the name identifies the index of refraction. Its Abbe value is 32. This lens is about 25% thinner than CR-39 and blocks approximately 18% of UV light.

Thindex 1.8 Glass, again the name gives its index of refraction. This lens uses a titanium oxide in its ingredients. It is about 35% thinner than CR-39, 18% heavier than crown glass, and offers 18% protection from UV light.

The advantages of glass lenses include optical clarity, resistance to scratches, and it is the least susceptible to chemicals. The disadvantages include that it is the heaviest material and it is less impact resistant than other materials

At the beginning of this course, we said that the higher the index, the thinner the lenses. Well, with glass, the higher the index, the heavier the lenses. Glass is not the material of choice when weight is a factor. But even in today's market, glass still has a place as the lens of choice for certain wearers.

Trivex®

Originally developed as “visual armor” for the military, PPG Industries adapted the plastics technology in 2001 for use in the ophthalmic industry and called it Trivex® lens material because of its unique tri-performance properties. An entirely new category, Trivex® material is the first to offer the combination of excellent optics, strength characteristics and ultra-lightweight qualities in a single lens material. Another advantage of Trivex® is ultraviolet light protection inherent in the material. A disadvantage could be cost, and there could be some lens designs that aren’t available.

Polycarbonate Lenses

Polycarbonate lenses were first developed by a company named Gentex. Polycarbonate is a thermoplastic which means it is moldable under sufficient heat. In the 1950's it was marketed under the name Lexan and due to its extraordinary resistance to impact was originally manufactured for safety devices. In 1978 the first single vision lens appeared for industrial usage. It was two years later that the first dress wear lenses appeared. Because of the low Abbe value, color dispersion may be present.

Most advances in the quality of polycarbonate are thanks to the music and DVD industry. Not all polycarbonate is manufactured using the same methods. Resolution by Optima, now PFO Global, is one company that has eliminated the birefringence (double refraction) that occurs in polycarbonate lenses as they are molded. The elimination of birefringence improves the optics of the lenses. Birefringence is the optical property of a lens material that causes the polarization of light to travel at different speeds causing dispersion. Advantages include improved impact resistance, lighter weight over some lens materials, and ultraviolet light protection inherent in the material. Disadvantages include lower light transmittance than glass, hard resin or Trivex®; poor scratch resistance; and chromatic aberration. Because it is considered the softest lens material, it requires a hard coating to prevent scratching

High Index and Ultra High Index Lens Materials

These higher index lenses would only have benefits for those approximately 20% of your patients that have higher power prescriptions. They should be considered for your patients looking for lenses with the following advantages:

- Are up to 50% thinner and 50% lighter than a regular resin lenses
- Offer superior optics, when compared to traditional polycarbonate
- Have flatter front curves for improved cosmetics and ease of insertion in frames
- Have an impact resistance that exceeds CR-39

Tensile Strength

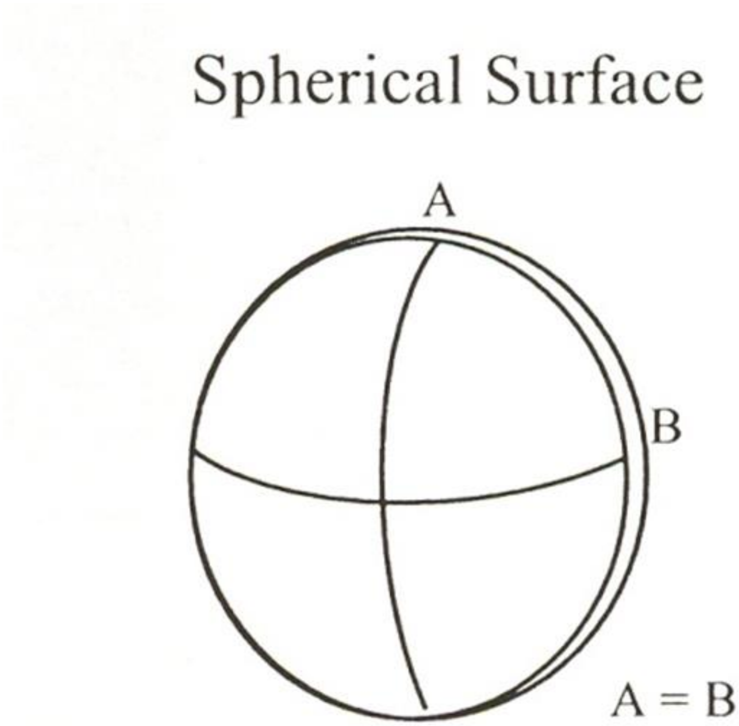
Another consideration for lens material selection, especially in rimless styles and drill mounts, is the tensile strength of a material. Tensile strength measures the force required to pull a material apart or break.

Lens Designs

Now that you have selected the appropriate lens material, you now have to determine the appropriate lens design. Lens designs include spherical, cylindrical, aspheric and atoric.

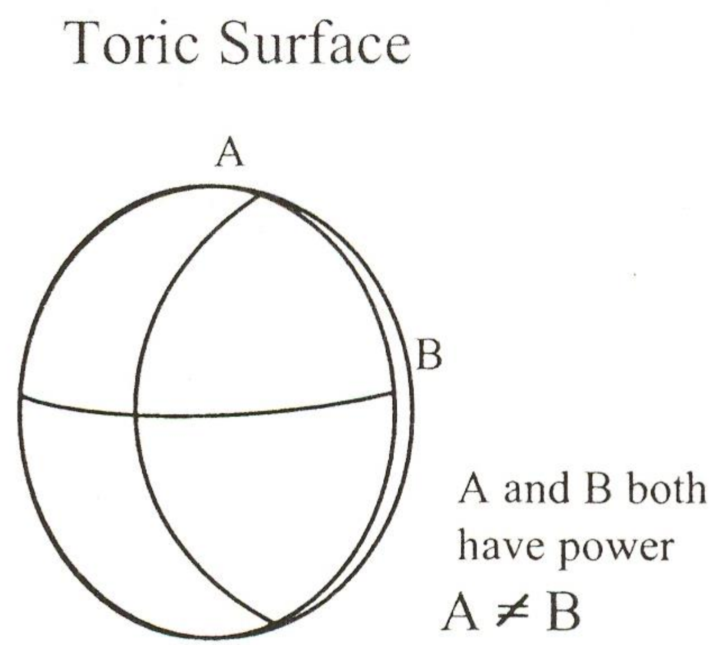
Spherical

A spherical lens surface design is one in which the surface has the same power in all meridians. It also has the same curvature from the center to the edge. The spherical surface may be on the front, the back or on both surfaces. An example of a spherical lens surface design is illustrated below.



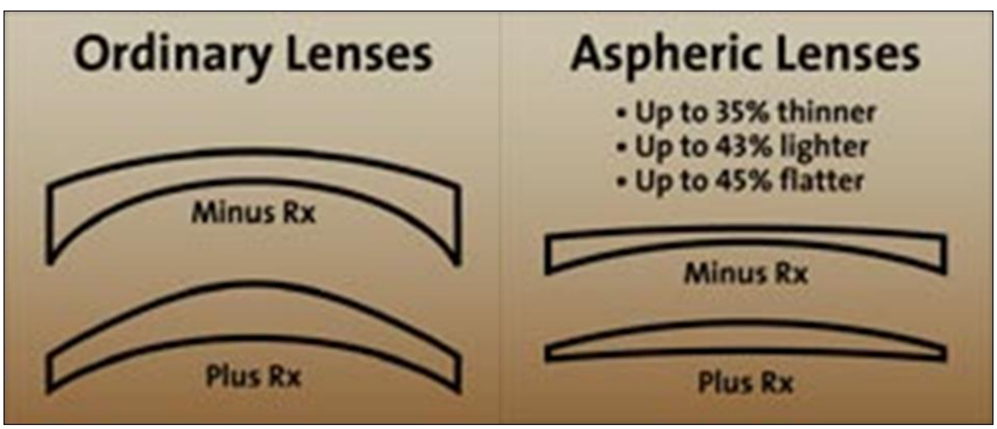
Cylindrical

A cylindrical lens surface design is one that will have two distinct curves on a surface. Historically a cylindrical surface could occur on either the front or the back surface. Today, the cylindrical surfaces are found on the back. In the cylindrical, there are two curves of different power. They do not vary from the center of the lens to the edge of the lens in their respective meridians. A spectacle lens will not have a TRUE cylinder surface because in one of the two principal meridians the curve is flat. A spectacle lens actually has a toric cylindrical surface. An example of a cylindrical lens surface design is illustrated below.



Aspheric

An aspheric lens surface design is one in which the curvature of the lens gradually flattens as you move from the optical to the edge of the lens. An aspheric design offers a better looking profile to higher power lenses, especially high power plus. The overall lens surface profile will be flatter.



Atoric

An atoric lens design is a lens which has both front and back aspheric surface designs on the lens surface. Atoric lens designs are used in many free-form lens designed lenses. It is also a design used for lenses in wrap frames to improve the peripheral optics in a lens. Atoric lenses can improve the optics in both the sphere and cylinder components of a prescription.

You may find the following chart useful, while not complete in every lens material; it will give some guidance on properties of basic materials

Lens Material Properties

Material	Index	Specific Gravity (g/cm3)	Abbe	Reflectance Per surface	Transmittance UVA (286 – 320 nm)	Transmittance UVB (320 – 380 nm)
Crown Glass	1.52	2.54	59	4.3	84.3	30.5
CR-39	1.50	1.32	58	4.0	10.3	0.0
Trivex	1.53	1.11	43 - 46	4.4	0.0	0.0
Poly	1.58	1.21	29 - ***32***	5.2	0.0	0.0
1.60 (MR6)	1.60	1.22	42	5.3	0.0	0.0
1.60 Glass	1.60	2.60	42	5.3	39.1	0.1
1.66 (MR7)	1.66	1.35	32	6.2	0.0	0.0
1.67	1.67	1.35	32	6.2	0.0	0.0
1.70 Glass	1.71	3.20	35	6.7	24.6	0.0
1.80 Glass	1.81	3.66	25	8.2	19.5	0.0
1.70 Glass	1.71	3.20	35	6.7	24.6	0.0
MR – 174 Resin	1.74	32	1.47	6.8	100	100
Lantal Glass	1.90	31	4.02	8.8	76	100
1.71 Resin	1.71	30	2.93	6.4	76	100

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