I’m 92 years old. I have dry eyes, iritis, astigmatism, blepharitis, macular degeneration, end-stage glaucoma …

… and I’ve had a pneumatic retinopexy, scleral buckle, and three corneal transplants …

… and I still don’t need glasses!

I drink straight from the bottle!
Introduction to Optics
by Tim Root, M.D.

Before I started my ophthalmology residency I didn’t know a thing about optics. It was embarrassing during my internship year when friends would ask me to renew their glasses only to discover I hadn’t a clue as to how to decipher their prescription! Optics principles are easy to grasp, but I think you’ll find it difficult for these concepts to permanently “sink into your brain” until exposed to this stuff on a daily basis. Nevertheless, a review at this point is useful. These are the basics I wish I’d known before my first month as a “prescription-writing resident.”

Myopia and Hyperopia
A myopic eye just means a “nearsighted” eye. If we draw a picture of a myopic eye, we see that it looks big (and long) and that light focuses not onto the retina, but in front of the retina within the vitreous jelly! To correct this refractive error we use a minus (concave) lens to diverge the incoming rays of light. This effectively weakens the overall refractive power of the eye and pushes the image back onto the retina where it belongs.

![Myopic eyes diagram]

Myopic eyes are big, and powerful, focusing into the middle of the eye. A minus lens will weaken the overall refractive power and push images back onto the retina.

Hyperopic eyes are small, short eyes. The axial length of these eyes is so short that light focuses behind the eye. To get that image onto the retina we have to add power to the overall refractive power of the eye by using a plus (convex) lens. These convex lenses are basically your traditional magnifying glass and can make your patient’s eyes look enormous at high power.

![Hyperopic eyes diagram]

Small, weak-powered eye that focuses light behind the eye. Some extra refractive power (a plus lens) will help bring the image forward onto the retina.
Near-reading and Presbyopia

Once we get a patient corrected for distance vision we need to take care of close-up vision. With distance vision, the incoming light rays are coming in parallel before entering the eye. A near object, however, produces expanding divergent rays of light. When these rays hit the eye they end up focusing behind the eye.

To get this near object in focus the eye needs some more refractive power. Fortunately, we are born with the natural ability to increase the strength of the lens by making it rounder. This morphing process is called "accommodation."

The lens works because it is suspended like a trampoline by surrounding zonular fibers. These fibers attach 360 degrees around the lens and tether the lens to the surrounding ciliary muscle. When the ciliary sphincter contracts the zonules relax and the lens becomes rounder. This rounding of the lens increases its magnification/refractive power and allows us to see near objects. With age, the lens becomes dense and does not easily round out. This presbyopia presents after age 40 and progresses with age, explaining the need for near-reading glasses in this age-group.

Extra bifocal power allows us to focus on near objects.
Implanted acrylic/plastic/silicon lenses can’t change shape at all, meaning that all post-cataract patients will need reading glasses. However, new lenses are being designed to help with accommodation. Some have concentric fresnel rings that create multiple focal points (one optimized for distance and the other for near vision). Other designs work by moving the lens in an anterior/posterior direction like a telescope. Neat, huh?

**Astigmatism**

The cornea surface provides the majority of the refractive power of the eye. In the examples above we assumed that the cornea surface was perfectly spherical like a basketball. However, many patients have some degree of **astigmatism**, where the corneal surface is shaped more like a football. Thus, one axis of the cornea is steeper than the other.
Spherical correction alone will not work for these eyes. For astigmatism, we need to add a cylindrical shaped lens to correct the refractive aberration along one axis. When we check for glasses, we determine the amount of cylinder power, and the exact angle axis this cylinder needs to be oriented to work. To measure this we use the foropter.

Using the Phoropter:
The phoropter is the mechanical device we use to determine glasses prescription. It’s just a big box full of lenses on dials. When manifesting a patient, we go through three steps:

1. Figure out the overall spherical error
2. Figure out the extra cylinder to correct for any astigmatism
3. Tweak the angle of the cylinder correction

When we’re done, the foropter gives us three numbers to write down on a prescription pad:

<table>
<thead>
<tr>
<th>Sphere</th>
<th>Cylinder</th>
<th>Angle of cylinder</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1.00</td>
<td>+2.00</td>
<td>175 degrees</td>
</tr>
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</table>

Manifesting is a little more complicated than this, but this is enough to get us started. Let’s analyze a few sample patients and maybe this will make more sense.

Patient One
A patient hands us this prescription. He’s an engineer, and would like us to explain what the numbers mean.
There are several parts to an eye prescription, so I’ll go through them one item at a time. The first number is the spherical error. This patient requires a +2.50 lens … this tells us that he has a small, hyperopic eye that focuses images behind the retina. He needs a little more “oomph” in his refraction to move everything forward.

The second number is the cylinder. This patient needs an additional +1.25 diopters of power to fix the astigmatism in his “football” shaped eye. The last number is the axis angle of how to orient that cylinder. His “football” is tilted at an axis of 35 degrees.

**Patient Two**

A 61 year old man presents to you with the following prescription after cataract surgery. He wants you to check the numbers to see if they make sense. What do the numbers mean?

With cataract surgery we go through great pains to calculate the exact power of intraocular lens for implantation, with the desire for emetropia so that the patient doesn’t need glasses for distance. In this gentleman’s case, he is still a little myopic with a negative sphere of −1.25. We must have implanted a powerful lens implant that is focusing in the vitreous jelly. To offset this powerful implant, we need to weaken the eye by −1.25 diopters. He also has a little astigmatism of +0.50 with a cylinder angle of 5 degrees. The patient probably had this astigmatism before, but you can induce some astigmatic error via corneal incisions and sutures.

There is another number on this prescription called the “add.” This is simply the amount of extra bifocal power needed for reading. This gentleman has a plastic lens in his eye that can’t change shape at all, so he needs a +3.00 bifocal adjustment if he wants to read at approximately 1/3 of a meter.
Patient Three

A woman brings you this prescription for her child.

As you can see, the child is hyperopic ... he must have small eyes with images focusing behind the eye. This is a common finding in infants, as their eyes are still growing. His prescription indicates he needs some plus power to pull the image forward onto the retina. In addition, the child has a little bit of astigmatism. The angle of the astigmatism is 90 degrees. We call this “with-the-rule-astigmatism” and this is common with children. With-the-rule means that corrective positive-cylinder glasses would place the cylinder axis at 90 degrees. Elderly patients often have “against-the-rule astigmatism” with their glasses having positive cylinder at an axis of 180 degrees. Here's a picture to demonstrate what I'm talking about:

Don’t kill yourself memorizing “with the rule,” as I just wanted to familiarize you with the subject. More importantly, notice that this child has a large difference in prescription power between his eyes. This anisometropia is concerning because it can lead to amblyopia if the child begins to favor one eye over the other.
Minus or Plus Cylinder

As you’ve noticed, astigmatism can be a little confusing. It also doesn’t help that ophthalmologists and optometrists like to fix astigmatic errors differently. Ophthalmologists like to correct using a positive cylinder (which is conceptually easier in my mind) while optometrists prefer using minus cylinder (which is more useful when grinding glasses). The phoropter machine comes in both flavors and your office may have both types. They both work and are conceptually the same, but with an axis that is written 90 degrees off.

Converting Cylinder

You can convert a glass prescription from +/- cylinder format by the following method:

a. add the cylinder to the sphere (you remember how to add negatives, don’t you?)

b. change the sign of the cylinder

c. change the axis by 90 degrees

Thus:

+2.00 +3.00 at 170 converts to +5.00 –3.00 at 080

Retinoscopy:

Refactoring through that phoropter is great, but what do you do with a child or confused patient who can’t communicate? You can actually estimate the refractive power of the eye by examining the foveal red-reflex (the red-eye you see in photographs) as you flash a light over the front of the eye. This technique is important, but tricky to perform on a child. Don’t worry too much about retinoscopy until you start your residency and have to do this yourself.
1. What bends light more -- the cornea or the lens? What percentage of the eye’s total refractive power does the lens contribute?

The cornea does the majority of the refractive power of the eye, because the air-cornea interface has very different densities. The lens is only important for approximately one third of the overall refractive power of the eye.

2. A child has a cataract operation and a lens implant is inserted. A month after surgery the child sees 20/20 on the distance Snellen chart. Will this child need glasses when he returns to school?

Yes, the child needs reading glasses. An implanted plastic lens can’t accommodate (change shape) with near reading, necessitating a +3 lens or bifocal for close-up vision.

3. Your patient hands you the following prescription that they got from the optician at Wal-Mart. The prescription appears to be in minus cylinder while your favorite foropter is based on plus-power cylinder. What would be the equivalent plus cylinder prescription power for this patient?

To switch from plus to minus (or vice versa) you add the cylinder to the sphere, change the polarity of the cylinder, then change the axis by 90 degrees. Thus, the equivalent prescription for this patient is:

\[-3.75 + 1.50 \text{ at 005}\]
4. A patient wants you to grind his eyeglass prescription into his diving mask before his next wreck dive. Your new optical-tech has never done this before, and asks you whether she should grind the lens curvature on the inner or outer surface of the diving mask. Which one is correct?

You have to grind that mask on the inside of the mask so that the lens interface is facing the mask air-bubble. A lens needs a good glass-air interface if it’s going to bend light according to Snell’s Law.

*Note: this is just an example to illustrate Snell’s Law. Scuba masks actually have inserts that are ground and placed on the inside.*

5. When accommodating to view near objects, does the ciliary body relax or contract? Do the zonules get tighter or looser?

To see close objects, the lens needs to become more powerful and get rounder. To accomplish this, the circular ciliary muscle, which is a spincter muscle, contracts. This releases tension on the zonules and the lens is allowed to become rounder.

**Fun Fact**

The sea nautilus is a great example of eye evolution. The nautilus has neither a cornea nor a lens, but instead has a pinhole that it uses to focus light onto the retina. This concept is similar to the pinholing technique we use when checking vision and pinhole systems that are popular in spy cameras.

This pinhole eye is only a step in the evolution of the visual system: the simplest eye is merely a light-sensitive patch such as that found on the planarium worm. This light-patch can determine light-and-dark only, with no directional component.

The next evolutionary step is to curve the eye into a bowl – since light has to get over the lip of the bowl and hits only part of the retina, this conveys some basic directional information. By closing the bowl into a sphere with a pinhole opening (like our nautilus here), we get fine focusing of light. The disadvantage is, of course, that only a small proportion of available light is able to get into the eye through that tiny hole. Our more advanced lens system allows focusing of much more light.