The focimeter—
measuring the power of eyeglass lenses

Douglas A. Kerr

Issue 13
August 13, 2022

ABSTRACT

The *focimeter* (also called lensmeter, Lensometer, and Vertometer, the last two being trademarks) is an instrument for measuring the optical parameters ("prescription") of an existing vision correction lens (eyeglass lens or contact lens). Although there exist today digital readout, and wholly automatic, focimeters, in this article I concentrate on the classical manual focimeter. I also concentrate on the use for eyeglass lenses. The principles, however, are essentially the same for contact lenses.

After the instrument is introduced, background is given on various topics in lens optics and human vision correction. Then the operation of a typical focimeter is described in considerable detail. Appendixes give background in the scheme of power measurement used for vision correction lenses; describe the actual optical principles of a typical focimeter; give some history of the development of the instrument, including detailed descriptions of benchmark instruments along that path from two manufacturers; and discuss special considerations in measuring the properties of a bifocal lens.

1 INTRODUCTION

The *focimeter* is an instrument for measuring the optical parameters ("prescription") of an eyeglass lens. It is also called "lensmeter", "Lensometer", and "Vertometer", the last two being trademarks, respectively, of American Optical Company (and its predecessor and successor) and Bausch & Lomb, Incorporated.

This instrument is useful in a number of situations, notably:

- Allowing an optometrist or ophthalmologist to become informed of the current corrective lens context of a new patient from his current eyeglasses.
- Confirming that a new pair of eyeglasses has been correctly made.
- Making certain determinations of an eyeglass lens "blank", or a partially-finished lens, to allow it to be properly oriented when it is further processed or shaped to be mounted in the eyeglass frame.

There exist today focimeters with digital readouts, and computer-driven fully-automated focimeters, but here we will only examine the classical manual focimeter.

In Appendix C, there is a concise history of the development of the focimeter, and there and in Appendix D there are extensive descriptions with photographs of illustrative instruments of different vintages (including contemporary) from two product lines.

In figure 1, we see a Bausch and Lomb "Model 70" (formally, model 21-65-70) [1], considered by many to be the *sine qua non* of manual focimeters.[2] The photo is of an instrument once in our personal collection.[3] I will use it to explain many of the common features of this kind of instrument.

Figure 1. B&L Model 70 Vertometer

Before we take this beauty out for a (virtual) test spin, I'll provide some background in pertinent areas.

---

[1] Sometimes called "The Whale".

[2] An honor often shared, though, with the American Optical Company Model M603.

[3] As of 2012; sadly, no longer with us, a victim of downsizing!

2 LENSES

2.1 Focal length

An important parameter of a lens is its *focal length*. Theoretically, if we have rays of light from some point on an object located an infinite distance (in realistic practice, a “very great distance”) in front of the lens, the lens will bring those rays together at a point a certain distance behind the lens. The distance of that “second focal point” behind the lens is the focal length of the lens.

Actually, in formal optical writing, that distance is called the ”effective focal length” of the lens. That makes it sound as if this is not the real focal length, just what the focal length seems to be. But in fact, that is **the** focal length. The odd name was assigned during the emergence of optical theory in order to distinguish this distance from other, earlier important, ways of describing the location of the second focal point.

To be precise, the distance to the second focal point is defined from a certain point in the lens, the second principal point. Despite my use of the word “in”, this point may in fact not lie in the lens at all (like the center of gravity of a donut, or a boomerang).

2.2 Lens refractive power

The *refractive power* (“power”) of a lens is the degree to which it will converge (or diverge) rays of light emanating from the same point on an object and entering the lens at different points on the front of the lens.

Quantitatively, the power of a lens (as used in general optical writing) is the reciprocal of its *focal length* (that is, to be rigorous, its *effective focal length*), customarily for the focal length in meters. The formal scientific unit of refractive power is the inverse meter (m^{-1}), but the traditional unit, today always used in practical optometry and ophthalmology, is the diopter (symbol D) which is the same as the m^{-1}. Thus, a lens with a focal length of 1 m has a refractive power of 1 diopter.

2.3 Vertex power

But in optometry and ophthalmology, the refractive power of a lens is described by its (back) *vertex power*. This is the reciprocal of the *back focal length*, which is the distance from the rearmost point of the lens on its axis (its *back vertex*) to the second (back) focal point.

It turns out that the use of this parameter, rather than the power based on the effective focal length, simplifies many practical matters in the field of corrective lenses. Among other things, it allows us to deal with the position of the lens with respect to the eye (which has a great influence on the effect of a corrective lens) in terms of the visually-obvious back vertex of the lens, rather than in terms of the second principal point of the lens (whose location we usually can't immediately recognize at sight, and which may not even be within the lens itself).

This topic is discussed in much greater detail in Appendix A.

3 TWO KINDS OF LENSES

3.1 Spherical ("sphere") lenses

In optics, a *spherical lens* is any lens whose surfaces are portions of a sphere. A spherical lens exhibits the same power along any direction.

There are also lenses that have the same power in all directions but whose surfaces are not portions of a sphere. These are called "aspheric" lenses.

In ophthalmology, a lens that has the same power in all directions, whether or not its surfaces are parts of a sphere, is referred to as a "sphere" lens, and I will follow that convention from here on.

A converging sphere lens (which has a positive focal length) is said in this field to have a "plus" power. A diverging sphere lens (which has a negative focal length) is said to have a "minus" power, and I will follow that convention from here on.

We can present the variation (if any) in the refractive power of a lens with direction on a polar chart. In figure 2, panel A, we see a plot of a sphere lens with refractive power +1.0 D (a converging lens). This is a trivial case, and hardly requires a chart to explain. But we show the polar plot here to establish the format and notation.

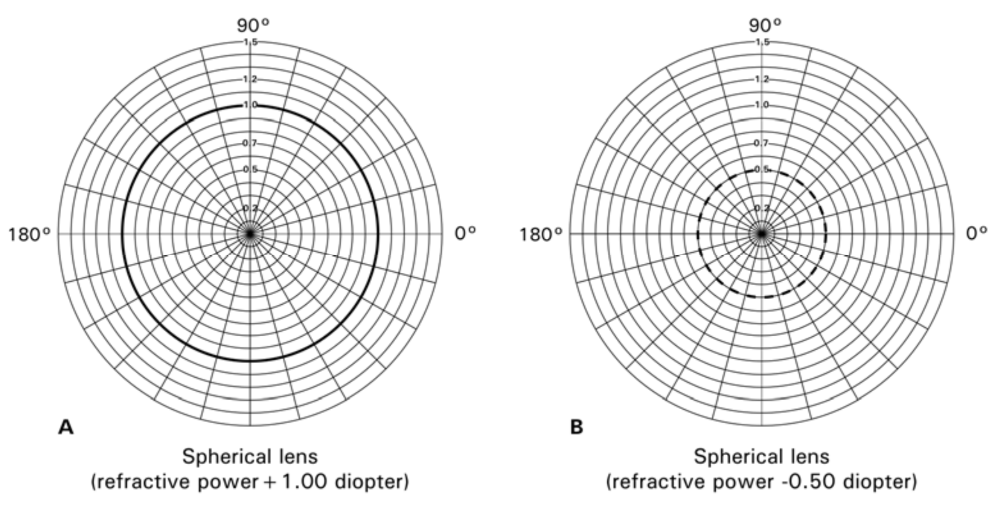


Figure 2. Sphere lens—power plot

The radius to the curve in a certain direction indicates the refractive power (in diopters) for that direction. Recall that a "direction" here means both ways: either way along the line at a certain angle ("a meridian"). Because of that symmetry, we only need to plot half the curve. But I show the curve for a full 360° for aesthetic completeness.

In this field, the usual scientific convention is followed, with the angle reference (0°) being to the right, and the angle increasing to the counterclockwise.[4]

It is difficult to express minus values on a chart in polar coordinates—a "minus" radius would put the point on the opposite side of the chart, where it would just look like the (plus) value for an angle 180° from the actual angle.

To escape this difficulty, here I will plot minus values of the refractive power as a dotted line. And we see that in figure 2, panel B, the plot for a sphere lens with a refractive power of –0.50 D (a diverging lens).

3.2 Cylindrical ("cylinder") lenses

A *cylindrical lens* has a surface that is a portion of a cylinder (which may or may not be exactly a circular cylinder). A cylindrical lens exhibits a certain power (its "rated" power) in one direction (perpendicular to its axis). Along its axis, it exhibits zero power. At intermediate angles, it exhibits intermediate values of power.[5]

In ophthalmology, a cylindrical lens is referred to as a "cylinder" lens, and I will follow that convention from here on.

We see this behavior illustrated in figure 3 for two cylinder lenses, one with a plus power and one with a minus power.

---

[4] In optometric practice, sine lens behavior is symmetrical, the angle can be considered to vary over only the range 0° to 180°, and by custom, exactly 0° is usually called 180°.

[5] Although the lens' behavior along such "oblique" directions is not simply what would be suggested by the power value.

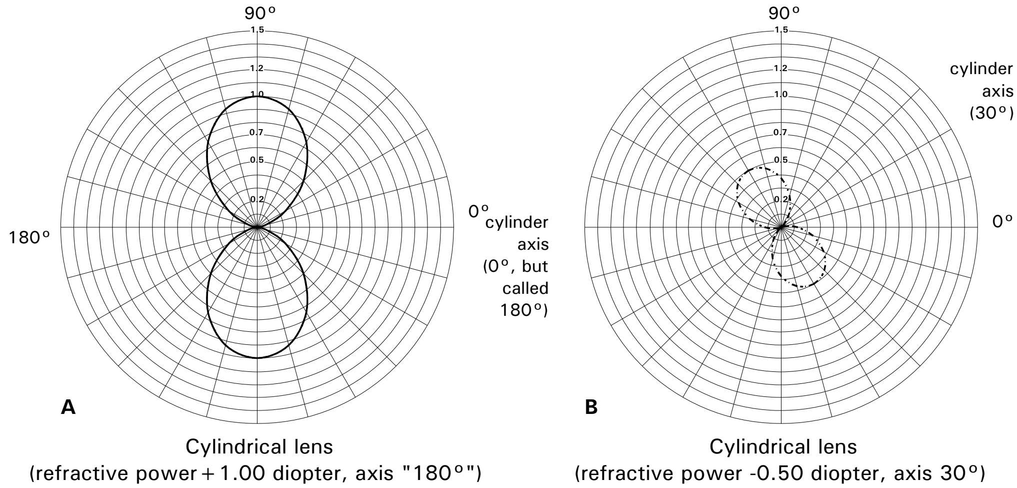


Figure 3. Cylinder lens—power plot

Note that while the lobes of the plot may at first look like ellipses, they are not quite; the power, P_Θ, at an angle Θ (measured from the "axis" meridian) is given by:

$$P_\Theta = P_o \sin^2 \Theta \qquad (1)$$

where P_0 is the "rated" power of the cylinder lens. That function does not describe an ellipse on a polar plot.

Imagine that we combine a sphere lens and a cylinder lens (and we assume here the convenience of the fanciful "thin lens" conceit, which, although impossible to have in practice, makes all the math work out in a very simple way).

In the direction of the cylinder lens axis, where the cylinder lens has zero power, there is no effect of the cylinder lens on the overall result. In the direction at right angles to that, the power of the cylinder lens combines with that of the sphere lens (taking into account the applicable algebraic signs) and so we have a power different from that of the sphere lens alone (perhaps even of the opposite sign).

In figure 4, we see one example of this.

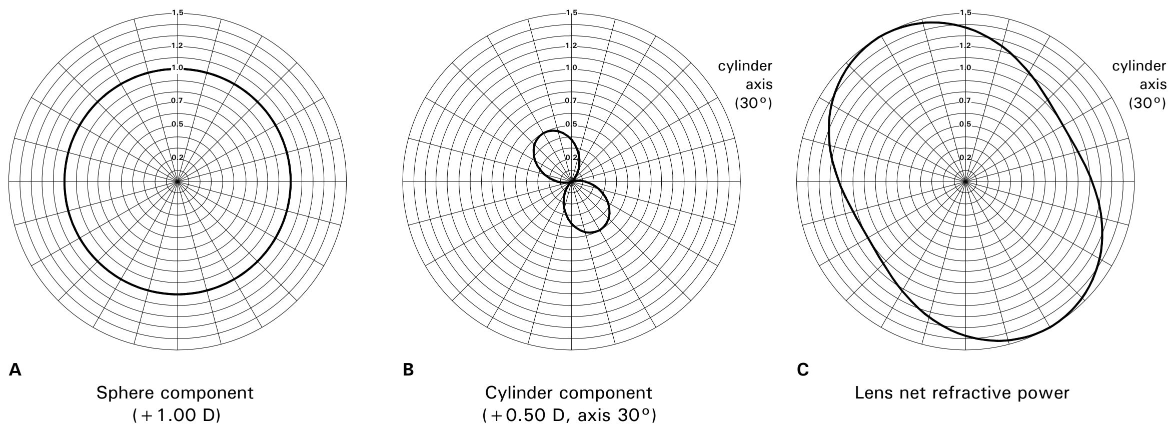


Figure 4. Composite lens—power plot

In figure 5 we see a different example.

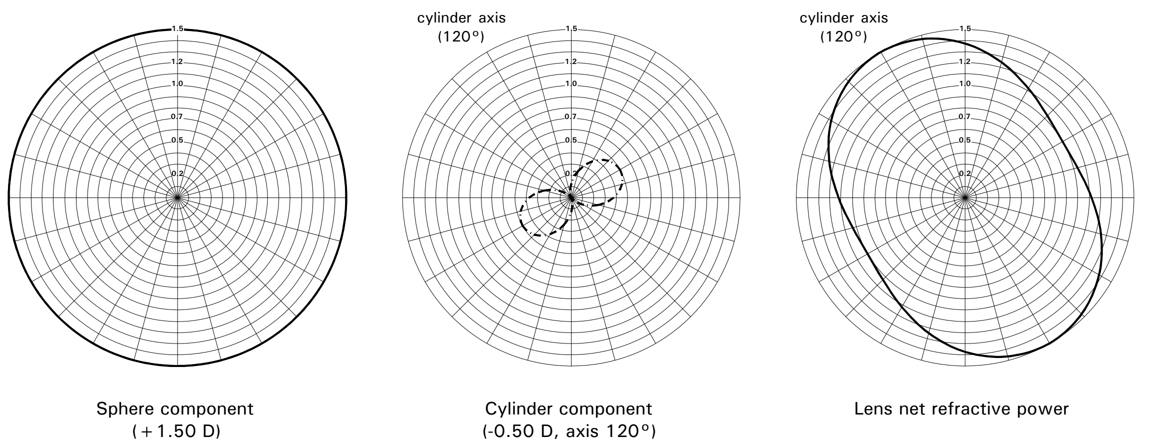


Figure 5. Composite lens—power plot

Note that the result here is identical to the previous case.[6] This is reminiscent of the two ways we might make an ellipse. We might start with a circle of small diameter, and stretch it in the direction of the ellipse's major axis. Or we might start with a circle of large diameter, and shrink it in the direction of the ellipse's minor axis.[7]

We can of course make a single lens that will exhibit this overall behavior. A simple implementation (not usually used in modern corrective lens practice) would have a front surface that is a portion of

---

[6] The specific mathematical variation of the power of a cylinder lens with angle makes this equivalence exact.

[7] "Ellipse" is only a metaphor; the plot of the power of such a composite lens is not actually an ellipse.

a sphere and a rear surface that is a portion of a cylinder. Note that this would have the result shown regardless of which of the two "recipes" we thought of as describing it.

4 HUMAN VISION

4.1 Accommodation

Ideally, the human eye can focus on objects at a wide range of distance, from very near to "infinity". This is called *accommodation*.

Typically, with advancing age, the eye's accommodation ability can become compromised (and the same may be true of young people as a result of congenital malformation of the eye or of various ailments). Several types of deficiency are common.

Hyperopia (also called hypermetropia, and often popularly, but somewhat-misleadingly, called "far-sightedness") is the deficiency in which the total range of accommodation is "offset out", such that the person cannot focus on near objects, and in extreme cases not even on far objects.

Myopia ("near-sightedness") is the deficiency in which the total range of accommodation is "offset in", such that close objects can be focused on but the far limit is not to infinity (nor even to a great distance).

Presbyopia (the term means "old person's seeing") is the deficiency in which the total range of accommodation (the *accommodation amplitude*) is decreased (perhaps to none at all). The remaining limited range may be in the far, intermediate, or near regimes, in the individual case.

4.2 Astigmatism

Astigmatism is the deficiency in which the refractive power of the eye's lens is not the same in different directions. An illustrative result is that if we have astigmatism and look at a cross of thin lines on a card, we can perhaps focus so that the vertical line is sharp, or the horizontal line is sharp, but not both at the same time.

4.3 Correction with lenses

We can overcome basic deficiencies in accommodation with the use of a corrective lens. For "farsightedness", we can use a (sphere) corrective lens with a plus power; this will shift the range of focus in the "nearer" direction. For "nearsightedness", we can use a (sphere) corrective lens with a minus power; this will shift the range of focus in the "farther" direction.

We can overcome astigmatism with the use of a cylinder lens.

Not surprisingly, in typical cases, both "sphere" and "cylinder" components are combined in the corrective lens to deal with the overall visual error syndrome.

4.4 Two notations for the prescription

Recall that, as we saw in figures 4 and 5, the identical lens result can be described with either of two conceptual "recipes". For that particular example, if those properties were needed in a corrective lens, we could combine the effects of:

- A sphere lens with power +1.00 D
- A cylinder lens with power +0.50 D and axis 30°

or

- A sphere lens with power +1.50 D
- A cylinder lens with power –0.50 D and axis 120°

Note that in reality the way the lens is actually made may not directly follow either of those "recipes".

Either model could be used as the premise for defining the desired lens in written form: the lens *prescription*. It turns out that, when the prescription is written by an ophthalmologist (a physician and surgeon specializing in the eyes), it would be in the first form (the cylinder component always being with a plus power), called the "plus cylinder" form.

When the prescription is written by an optometrist (a Doctor of Optometry, qualified and certified to examine eyes and issue eyeglass prescriptions), it would be in the second form, (the cylinder component always being with a minus power), called the "minus cylinder" form.

The historical reason for this practice is complicated, and is beyond the scope of this article.[8]

In any case, we might wonder, when we ask a focimeter to tell us the nature of an eyeglass lens submitted to it, how it knows whether we are an optometrist or an ophthalmologist. It doesn't know; we manipulate it following one of two procedures to force the answer to be delivered in the desired form.

[8] It is discussed in detail in the article "Plus and minus cylinder notation in ophthalmology and optometry", by the same author, probably available where you got this.

5 OPTICAL THEORY

The theory of the optical system of the focimeter is discussed in considerable detail in Appendix B.

6 OPERATING THE FOCIMETER

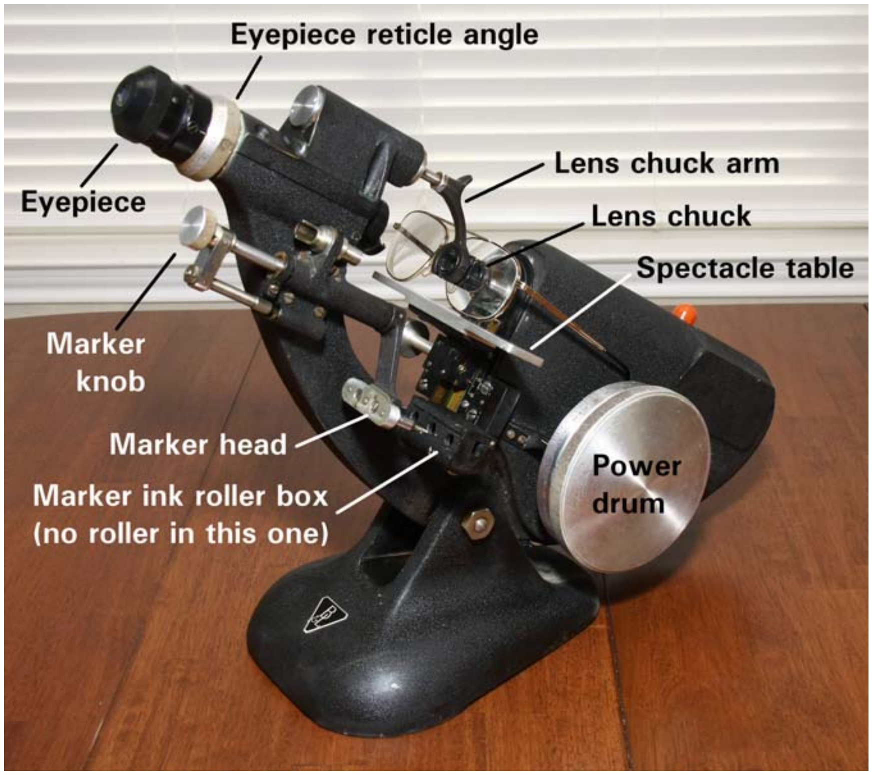


Figure 6. Focimeter parts and controls

Refer to figure 6. We will assume that the lenses being measured are part of a complete pair of eyeglasses (as seen in the figure).

We place the glasses on the spectacle[9] table, with the lens to be measured in front of the measuring aperture (with the "toward the face" side toward the measuring aperture, which I sometimes call the "focimeter nose"), with its optical center (as best we can guess where that is) aligned with the aperture. (We will refine that shortly). The spectacle table can be raised or lowered as needed for this.

A "lens chuck", an articulating spider-like assembly with four plastic-tipped prongs, under spring pressure, presses on the face of the lens to hold it against the rim of the aperture. This assures that the rear vertex of the lens is at exactly the proper position along the instrument axis, and that the lens surface at the aperture is perpendicular to the instrument axis.

---

[9] It is common in current technical writing in the field of ophthalmology to refer to eyeglasses with the otherwise-archaic term "spectacles". I will not in general do that here.

When we look through the eyepiece, we see a pattern of green lines, illuminated by a lamp at the far end of the instrument shining through a reticle-like target[10] bearing the pattern.

The basic pattern is seen, all in focus, in figure 7. There are three thin, closely-spaced lines in one direction, and three wider, more widely-spaced lines in the direction exactly 90° to that.

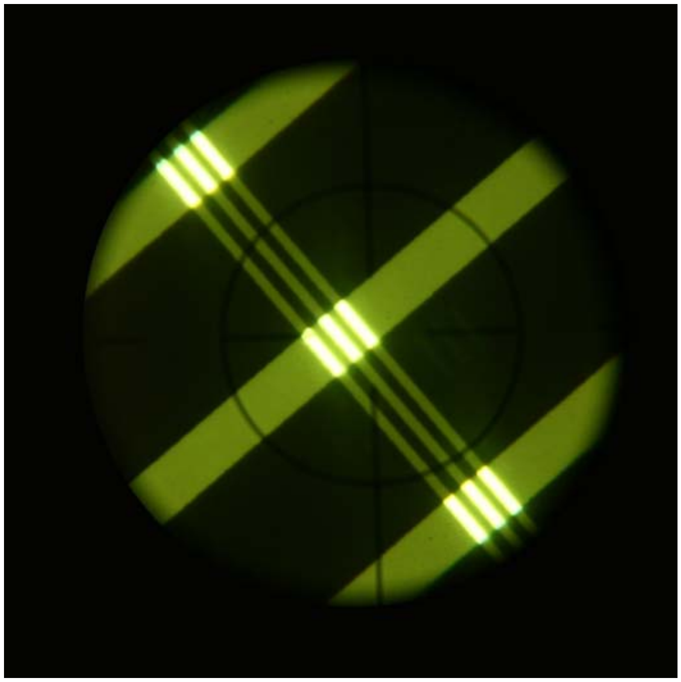


Figure 7. All lines in focus

(The field of view in this photo is less than the operator would see; more of the length of the fat lines would be visible.)

The location of the target carrying these lines can be shifted along the axis of the instrument by rotation of the large wheel on the right side (called the *power drum*). It carries markings in diopters, from −20 through zero and on to +20, and there is a fiducial pointer against which that scale can be read.

The target can also be rotated about the instrument axis. In this instrument, this is done with a drum on the left side of the instrument, seen in figure 8. It has a scale (1°-180°), read against a fiducial line, showing the orientation of the target. In a typical instrument of the American Optical Company design, there is a different arrangement (we will see it later).

---

[10] Although this would ordinarily be called a reticle, it is generally referred to in the literature as a target, and I will use that terminology from here on. The use of "target" rather than "reticle" is perhaps to avoid confusion with another reticle, called that, in the eyepiece telescope.

Figure 8. Cylinder axis drum

If the lens has no cylinder power component, then the lens does not exhibit astigmatism: its power is the same in all directions. When the power drum is turned to the optimum position, the entire pattern (both sets of lines) will be seen in sharp focus (just as we saw in figure 7). The overall optical arrangement is such that, at this point, the reading of the power drum will be the power of the lens.

If the lens has a cylinder power component, then (just as for a human eye with astigmatism) the two sets of lines cannot both be in sharp focus at the same time.

If we have the orientation of the thin lines of the target at 90° to the axis of the cylinder component, and the power drum is set to the value corresponding to the power of the sphere component (which is the power of the entire lens in the direction along the cylinder lens axis, where the cylinder power has no effect), the set of three thin lines will be in perfect focus. And the fat ones won't be.

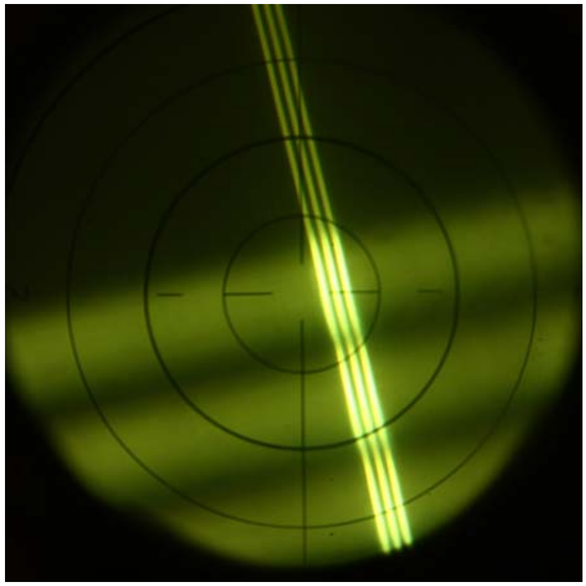


Figure 9. Thin lines in focus

Figure 9 shows that situation (we have a slightly larger field of view in this, and the following, photos).

Incidentally, the pattern of black lines we see here is the eyepiece reticle, used for various purposes (more about it in Appendix B).

With that same orientation of the target, but the power drum set to the power of the lens along the direction perpendicular to the cylinder lens axis (which is affected by the both the sphere power and the cylinder power of the lens), the set of three fat lines will be in perfect focus.

Figure 10 shows what that looks like.

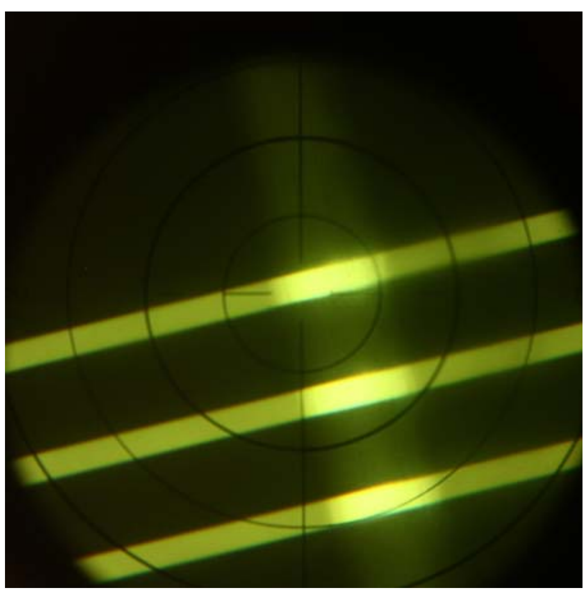


Figure 10. Fat lines in focus

The difference between these two readings of the power drum (the second minus the first, observing the sign) will be the power of the cylinder component of the lens behavior. And the orientation of the target (read from the axis knob) is the value of the cylinder component axis.

6.1 Use for plus vs. minus cylinder notation

That description of the test regimen didn't seem to offer the operator any choice as to whether the cylinder power (the second power drum reading minus the first) comes out plus or minus. How to we cater to the two different conventions?

6.1.1 *To get the result in plus cylinder form*

If we want the cylinder power to come out plus, we start this process by moving the power drum to a large minus power. Then we rotate it in the plus direction, with the other hand on the axis knob, manipulating it as required, until we **first** have the three thin lines in best focus. We note the power drum reading (the sphere power for this case).

Then we leave the axis knob alone and continue the plus-ward motion of the power drum until the three fat lines come into best focus. We note this as the second power drum reading.

We subtract the first power drum reading from the second to get the cylinder power. Clearly, the sign of the difference will be plus. Thus we have a plus value of the cylinder power, as needed for the plus-cylinder notation scheme we wanted to use.

6.1.2 *To get the result in minus cylinder form*

If we want the cylinder power to come out minus (for minus cylinder notation), we just start with the power drum at a large plus power setting and then move it in the minus-ward direction, manipulating the axis control as well, until the three thin lines are first in best focus. We note the power drum reading (the sphere power for this case).

Note that this will happens with the axis control set to a position 90° from that of this stage in the plus cylinder procedure.

Then we leave the axis knob alone and continue the minus-ward motion of the power drum until the three fat lines come into best focus. We note this as the second power drum reading.

We subtract the first power drum reading from the second to get the cylinder power. Clearly, the sign of the difference will be minus. Thus we have a minus value of the cylinder power, as needed for the minus-cylinder notation scheme we wanted to use.

6.1.3 *Comparison*

Note that in the minus-cylinder scenario the first drum setting at which we can get the three thin lines in focus is not the same setting as it was in the plus-cylinder scenario —it will be at a more plus setting of the power drum (actually at the position of the second good focus reading—for the fat lines— in the plus-cylinder scenario).

And the drum setting where we then get the three fat lines in best focus is the same drum setting at which we got the thin lines in best focus in the plus-cylinder scenario.

And the axis setting for these events will be 90° from the axis setting for those events in the plus-cylinder scenario. Thus all the ingredients of the prescription, the sphere power (first power drum reading), the cylinder axis (axis knob reading at that time) and the sign of the cylinder power, will differ between the cases, as we expect between a plus-cylinder and minus-cylinder "prescription" for the same lens.

6.1.4 *But how do it know?* [11]

In the literature we often see the set of three thin lines identified as the "sphere" line and the set of three fat lines as the "cylinder" lines.

And indeed, in the description of the use of the focimeter, when we have brought the thin lines into focus, we read from the power drum the **sphere** component of the lens power. And we read from the axis control the **cylinder axis** of the lens power.

Next, after we have brought into focus the fat lines, we read the power drum, subtract from its reading the sphere power reading from the fist stage, and note the result as the cylinder power.

And in fact, the design of the target is that, when we bring the thin lines into focus, we are able to precisely set the cylinder axis, and thus insure that the focus on the thin lens is optimal.

So this while scheme plays out well.

But how does the "mechanism" of the focimeter know how to put the thin lines into best focus when we are interested in the "sphere" meridian of the lens and the thick lines when we are interested in the "sphere pus cylinder" meridian?

It doesn't. **We** make that happen in the appropriate way by our scheme of manipulation of the drums. In the plus-cylinder scenario, for example, we start with the power drum ist a large minus setting.

[11] Apologies to the famous Thermos bottle in the old joke.

Then we move the power drum in the plus-ward direction while “scanning” with the axis drum until the thin lines begin to come into good focus and ultimately come into best focus.

Now, as we did that, might we begin to see the fat lines coming into good focus? Yes. But that is not our objective in this phase of the process—we want to bring the thin lines into best focus. So we don’t encourage the focus of the fat lines to improve. If fact, if we see the fat lines starting to come into good focus, we shift the axis control by about 90° (either way; we are working on a scale that is only 180° long, so either will have the same result).

This shifts the incipient good fortune of the fat lines onto the thin lines, since our objective is to bring **them** into best focus with the least-plus possible setting of the power drum.

So in either scenario it is we that cause the process to, in its first phase, end up with the thin lines, rather than the fat lines, being in best focus.

6.1.5 *Why do we use the thin lines first?*

We have seen that the association of the use of the thin lines or the fat lines with the two meridians of interest in the lens under test is essentially arbitrary. So why do we always bring the thin lines into best focus first (whether were are using the “plus-cylinder” or “minus-cylinder” technique)?

The answer is that in the first phase of the procedure we are not only interested in determining the power of the lens along one of its meridians but also in determining, as precisely as possible, the cylinder axis of the lens. And the clever provision of the focimeter to facilitate a precise determination of the cylinder axis works best when bringing the thin lines into best focus. It is described in detail in section 6.2, and in more detail in section B.6 in Appendix B.

6.2 Help with the axis setting

We have said that in the first phase of the procedure we move the power drum and the cylinder axis drum until the three thin lines are in best focus. Small discrepancies in axis setting do not make a prominent change in the apparent degree of focus of the thin lines, so it might seem to be difficult to precisely find the correct axis setting.

The instrument includes an ingenious scheme to help with this. It is slightly reminiscent of the “split-prism” focus aid found on some single-lens reflex (SLR) cameras.

We see it at work in figure 11. On the left, we have the axis setting not quite at the proper point. Notice that, although the thin lines might not be noticeably out of focus, the individual segments of them (they are separated on the target by dark regions) seem to be "rotated" out of alignment with the other segments. This clearly reveals that we are not quite at the proper axis setting.

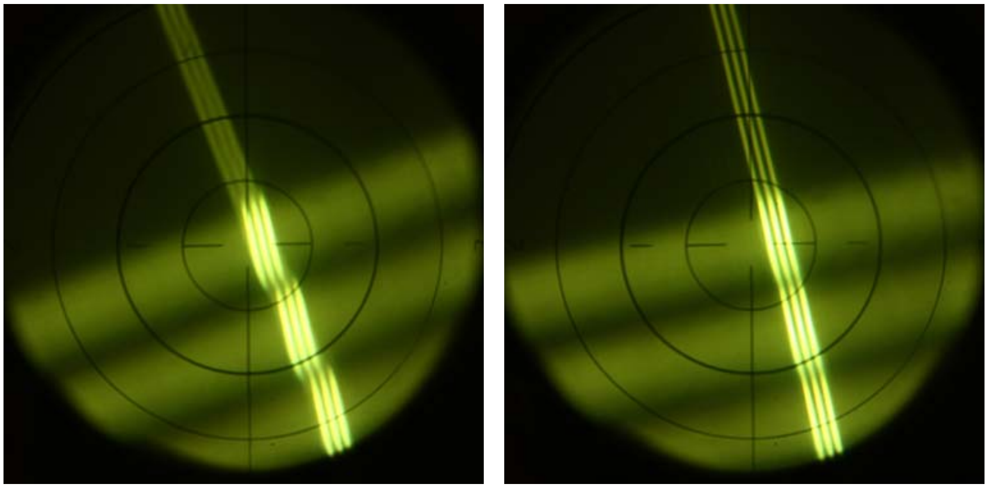


Figure 11. Axis adjustment help

On the right, we have the axis setting "right on the money". Not only is the degree of focus better (maybe not noticeably so), but (more prominently) all the segments of the lines are now appear to be aligned.

The reason it works this way is discussed in section B.6 in Appendix B.

7 ODDS AND ENDS

7.1 Why is everything green?

What we see in the eyepiece is mostly green owing to a green filter in the upper part of the system. This is to minimize "spreading" of the lines due to chromatic aberration (the differing behavior of the optical system at different light wavelengths). Here, only a restricted range of wavelength is used. In some focimeters, this filter can be moved out of the way, so when measuring dark sunglasses, where the patterns are seen a bit dimly, this makes the view a bit brighter.

7.2 Another approach to axis setting

Most focimeters made by American Optical Company (AO) (under the name "Lensometer") use a different scheme of adjusting the axis orientation of the target. Rather than using a drum on the left side of the machine (as in the Bausch and Lomb unit illustrated before), these units have an axial protractor-like handwheel that directly rotates a barrel containing the target.

Figure 12. American Optical Wellsworth Lensometer (1920)

We see an example of this control in figure 12, a lovely advertising illustration (*ca*. 1920) for the first commercial American Optical Lensometer, the "Wellsworth[12] Lensometer".

The operator's left hand is on the axis handwheel.

Many operators find the side-mounted axis drum of the B&L design to be more convenient.

As an aside, in the photo you may note the two pins projecting from the rear of the unit (at our right). This is a connector to which the power cord for the lamp is to be attached. Evidently the photographer (or director) decided that having the cord in place would mess up the beauty of the scene.

7.3 The marking device

Especially when making measurements of partially-finished lenses, it is desirable to mark the location of the optical center and the reference axis that should be horizontal when the lens is cut to shape and mounted in the frame (often called "spotting" the lens). Once the lens is positioned appropriately, a marking device will place three small ink dots in a line along the horizontal axis, the centermost being at the optical center. We see this in figure 13.

---

[12] The name "Wellsworth" was a common AO trademark at the time, honoring the name of George Washington Wells, who founded the company that was AO's principal ancestor.

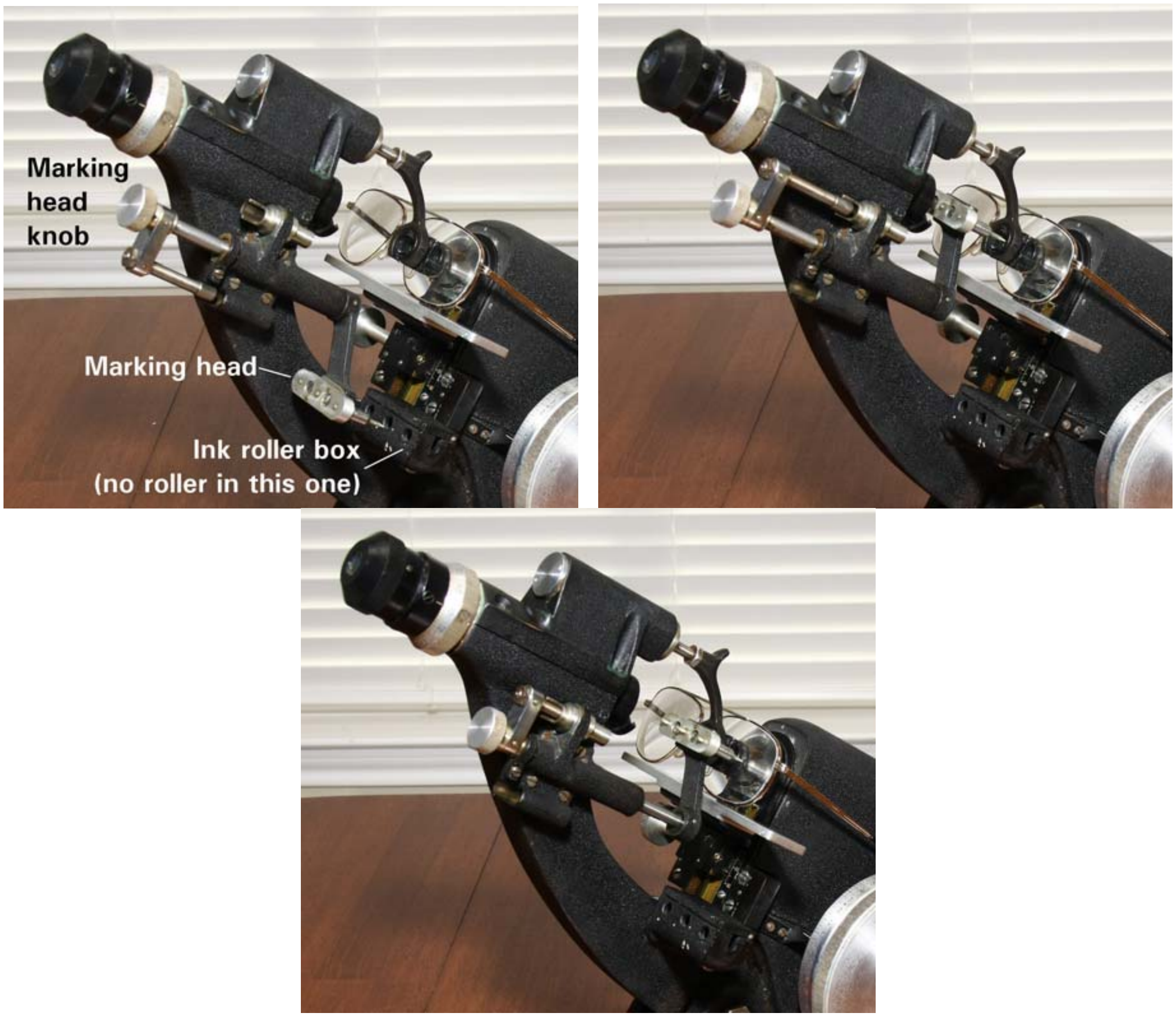


Figure 13. Marking device

On the left, we see the marking head (the shiny bar with the three prongs) in its rest position. Using the knob just below the eyepiece, the operator moves the marking head forward so the prongs contact an ink roller in the small black rectangular box (this unit did not have an ink roller when that shot was taken). On the right we see that the operator has allowed the head to retract from the ink box and rotated it to its upper position (in front of the lens). Below, we see the head pressed forward so the three inked prongs contact the lens.

7.4 Centering the lens

I referred to this earlier, but delayed discussing it until now so as to not disrupt the overall story.

For the measurement process to work properly, the optical center of the lens must be centered in the measuring aperture. When it is, the pattern of lines will be centered on the pattern of the eyepiece reticle, as we see in figure 7 (but not in figure 9 and later, since I had neglected to make that adjustment before taking those shots).

7.5 Reference axis

On completed eyeglasses, the horizontal reference direction for the specification of the cylinder axis[13] is a line tangent to the bottom of both frame sides. When measuring completed glasses, this is automatically set as the reference since the bottoms of both frame sides sit on the spectacle table.

In some work involving partially-finished lenses (which are still round, the shape of teh semi-finished blanks), we must also orient horizontally a reference direction on the lens, which is often marked on the blank as a line in temporary ink.

Figure 14. B&L Model 70 Vertometer—Reference axis locating pins

The B&L Model 70 Vertometer has provision for dealing with this (see figure 14).

We see, on either side of the nose, two brass pins with blunt points, which are spring-loaded and removable. They are removed when not needed for this operation. [14] The lens is put in place so that the tips of these pins fall on the marked reference line.

In the photo, the lens chuck has been “retracted” to allow a clear view of the pins.[15]

---

[13] Scientists would call this 0°; in optometry, it is called 180°.

[14] On our machine, they had indeed been removed, and not replaced before we got it. The picture is of another specimen of the same model.

[15] Actually, we believe that on that specimen, the chuck arm was maladjusted so that, at the “6 o’clock” position, as seen, it could **only** be retracted (that is, couldn’t really be used). Normally, when at “6 o’clock”, the spring would always push the arm toward the lens, but it can be “parked” retracted at the “12 o’clock”, “3 o’clock”, and “9 o’clock” positions.

Not all focimeters have this feature.

8 BIFOCAL LENSES

In a bifocal lens, the power in a small region (the near vision segment) is greater than the power of the lens overall. This enables a subject whose ability to focus on objects at different distances is degraded (or absent) to, through the near vision segment, focus on near objects (the newspaper, perhaps).

In the prescription for the lens, the additional power in the near vision segment is specified by a value called the “Add”.

In measuring an existing eyeglass lens with the focimeter, perhaps to confirm that is has been made consistent with the prescription, special considerations apply to determining if the near vision segment is in fact as prescribed by the Add in the prescription. This is discussed at length in Appendix E.

9 CONTACT LENSES

We have concentrated here on conventional eyeglass lenses. Contact lenses use essentially the same principles for vision correction, and their refractive properties are specified by a prescription following generally the same conventions we discussed here (with certain additional parameters, primarily relating to the lens dimensions, included).

The refractive behavior of a contact lens can be measured by a focimeter. An issue, though, is properly holding the lens in place. The arrangement described above for “classical” focimeters is not workable.

If the axis of the focimeter can be placed in the vertical position (true for most “modern” focimeters, but not the B&L Model 70), it is possible to just have the contact lens lie on the measuring aperture nose. There are other ploys for holding contact lenses in a focimeter. These techniques are beyond the scope of this article.

10 PRISM COMP0NENT IN A LENS

10.1 Phorias

In a well-behaved vision system the two eyes, when not actively addressing a specific object, have sight lines in about the same direction. When attention is on a specific object, the eyes converge their sight lines on it, allowing the images from the two eyes to be readily fused.

But in some persons, the “neutral” aim directions of the two eyes are not consistent, and as a result, the system has difficulty converging on a specific object, leading soon to eye strain. In more extreme cases, convergence sufficient for fusion cannot occur at all, leading to "double vision".

The error in neutral aim may be horizontal, vertical, or at an oblique angle.

The various forms of this type of defect are collectively called *phorias*.

10.2 Correction with a prism component

Often a phoria can be corrected with a prism component in the corrective lenses. This serves to deflect the line of sight so as to compensate for the phoria.

Generally, the needed correction is "split" between the two lenses, having the same magnitude but opposite directions between the two lenses. This minimizes the magnitude of prism component needed on either lens. The larger the magnitude of the prism component, the more difficulties it introduces in the design and manufacture of the lens.

The magnitude of a prism component is denominated in the unit *prism diopter* (a strange term, presumably chosen to as not to seem "foreign" to the workers in the field). A prism component of one prism diopter (written 1^{Δ}) deflects the line of sight by 1 cm at a distance of 1 m. Thus the prism power value is essentially 100 times the tangent of the angle of deflection.

10.3 Measuring the prism component of a corrective lens

A property-equipped focimeter can be used to measure the magnitude and direction of the prism component of the lens under test,.

First, the optical center of the lens is physically centered on the measuring nose. Having done so, if there is any deflection caused by a prism component, the pattern of lines from the target will not appear centered in the field of the telescope. The degree and direction of this decentering correspond to the magnitude of the prism component and its direction, respectively.

These are quantified by means of a pattern on the eyepiece reticle. There are concentric circular lines (or fragments thereof). Their spacing corresponds to a prism power of 1^{Δ}. As to the direction, the reticle has a fiducial "crosshair". The reticle is rotated until the crosshair aligns with the center of the target pattern.

Then the angle of the reticle is read. In some focimeters (*e.g.*, AO M603A/B), the reticle angle us shown by a scale on the reticle rotation ring on the eyepiece. In other focimeters (*e.g.*, AO 12603), there is visible through the eyepiece a non-rotating protractor-like scale, against which the hairline of the rotatable reticle is read.

Figure 15 shows the view through the eyepiece for the AO 12603 (this figure from an AO brochure for that instrument).

Figure 15. AO 12603—eyepiece view

Here, the target pattern is centered, indicating that there is no prism component. The eyepiece reticle is (here, arbitrarily) set at 85°.

Note that the prism power circles above 2^{Δ} are partial, and the ones greater than 3^{Δ} are not labeled, to avoid clutter in the eyepiece view when the basic measurement tasks are being done.

When an offset due to a prism component is being measured. we rotate the reticle until the hairline passes through the offset center of the target pattern. Then, the target center will fall on (or between) the partial prism power circles, and the magnitude of the prime power can be readily read from them.

10.4 Emergence of the feature

In the American Optical line of focimeters, the eyepiece reticle arrangement used to measure prism components first appeared, as an option, on the M603 focimeter*. In the succeeding model, the 12603, it was a standard feature. I think the same is true for the succeeding models in the line.

I do not have corresponding insight for the B&L line. I seem to recall that my "Model 70" had an eyepiece reticle system.

10.5 Auxiliary prism

If the prism component of the lens has a power of over about 5^{Δ}, the center of the target pattern will fall outside the field of the telescope, so the magnitude of the prism power cannot be measured.

This problem is solved by putting an auxiliary prism (typically of power 5^{Δ}) just in front of the telescope. By properly orienting its direction, it will in effect cancel out 5^{Δ} worth of the prism power of the lens under test. The residual priem power is measured as described above.

The physical arrangements for this are generally predicated on using a "prism lens" as found in trial lens sets (38 mm in diameter, about 1.5 mm thick at the rim). For example, on the AO M603A/B Lensometer, the front end of the telescope has a cylinder of just about that diameter, and there is a slip-on cap to hold the prism lens in place on its face.

On the AO 12603 Lensometer, there is a partial cylinder on the front of the telescope with a groove into which a prism lens of the trial lens size can be placed.

10.6 Other modern focimeters

Other modern focimeters typical have all these arrangements in one form or another.

11 "NEUTRALIZING" A LENS WITH THE FOCIMETER

We will often see determining the prescription of a lens with a focimeter called "neutralizing" this lens. This is a nostalgic nod to the earlier (pre-focimeter) way of determining the power of an eyeglass lens. It involved placing calibrated lenses from a trial lens set against the lens under test until the net power of the pair became zero (ascertained by moving the lens pair and noting if the scene seen through them moved). That situation was seen as the power of the trial lens exactly "neutralizing" the power of the lens under test; the power of the lens under test is the negative of the successful trial lens' power.

Of course when we measure a lens with the focimeter, there is no such concept involved. But the term lives on as a metaphor for determining the power of a lens.

12 THE APPENDIXES

Appendix A reviews the concept of *vertex power*, used to quantify the refractive power of ophthalmic lenses.

Appendix B discusses in detail the internal arrangement of the optical system of a typical focimeter, and shows why the position of the power drum is able to run linearly with the power of the lens under test, allowing its scale to be a linear one in terms of power.

Appendix C discusses the evolution of the American Optical Company line of focimeters, and gives descriptions (in some case quite detailed) of benchmark instruments along that line.

Appendix D describes some important instruments in the Bausch & Lomb Company line of focimeters.

Appendix E discusses special considerations in the measurement of finished bifocal lenses.

13 ACKNOWLEDGEMENT

Many thanks to John Baer of Reichert Technologies, Inc. for his assistance in determining the manufacturing dates for some of the specimens of interest, including the two beauties in our current personal collection

#

Appendix A
Vertex Power

A.1 EFFECTIVE FOCAL LENGTH

In most optical work, when we mention the focal length of a lens, we mean what is called formally the "effective focal length" of the lens. That term suggests that this is not the "real" focal length of the lens, but instead is the "real" value adjusted in some way to suit some situation.

But that's not so—it is the "real" focal length of the lens. It gets that misleading name from a matter of historical evolution.

When lens behavior was first studied, it became apparent that if we had a well-behaved lens regard a very distant object ("at infinity"), an image of that object was formed behind the lens. The distance to that image varied with the surface curvature of the lens, and it was clearly an important parameter of the lens.

The location of this image was said to be the *back focal point* of the lens, and the distance to it was measured from the rearmost point of the lens (on the axis)—the *back vertex* of the lens. This distance was called the "back focal distance", or *back focal length*, of the lens.

But soon it was realized that the number that affected many properties of the lens (and thus was needed in many equations about lens behavior) was not the back focal length, but rather a distance. Not surprisingly, given this history, this came to be called the "effective focal length".

This was in fact the distance to the rear focal point from a place (usually) inside the lens called the *rear principal plane*. That's not something we can see, nor locate in any simple way, so it was understandable that the effective focal length remained an ethereal, if theoretically important, distance. In formal writing, the designation *effective focal length* continued in use to denote it. In other than formal writing, it is just called the *focal length* of the lens.

And this distance **is** the "real" focal length of the lens—the only number that is of importance in such things as focus equations, photographic magnification and field of view reckoning, and so forth. It is a constant for the lens, not dependent on any "circumstance" of its deployment.

A.2 THE POWER OF A LENS

The *refractive power* of a lens (often called just its **power**) tells us the degree to which it converges, or diverges, arriving rays of light. In regular optical science, we quantify the power of a lens as the reciprocal of its *effective focal length* (to again use the full formal name to avoid any misunderstanding).

The modern scientific unit of power is the inverse meter (m^{-1}), but traditionally, and always in ophthalmic work, the same unit is called the diopter (D). A lens with an effective focal length of one meter has a power of one diopter.

A.3 VERTEX POWER

A different convention is used for power in connection with ophthalmic lenses. Their power "rating" is not the reciprocal of the effective focal length but rather the reciprocal of their *back focal length*. The rationale for doing so is rarely clearly explained in the literature. Here is the short story.

The effect of a lens on the correction or near- or farsightedness depends both on the power of the lens and its distance in front of the eye. In conventional optical theory work, we would define the power as the reciprocal of the effective focal length (to be formal), and the distance that matters is from the second principal point of the lens to the first principal point of the eye's lens system.

To facilitate the whole process of prescribing, making, and fitting eyeglass lenses, wherever possible we place the lens at a fixed standard distance from the eye. But this is not measured to the second principal point of the lens. If we did that, then lenses of differing shape, in which the second principal point falls at different physical locations, would not have a consistent "overall" location—"meniscus" lenses, which have an overall curvature, would be much closer to the face than lenses that are flat on the rear.

Accordingly, the practice emerged of placing the lenses so that the rear vertex of the lens is at a consistent distance from the eye.[16]

Having adopted that practice, of course for lenses of differing shape the distance from the eye to the second principal point will vary. And thus, for lenses of differing shape, the power (in the normal optical sense) needed for proper vision correction will vary. Not handy at all—for one thing, the prescriber of the lens has no idea what shape will be used for the actual lens to be made.

But it turns out that for lenses placed with their rear vertex a consistent distance from the eye, the effect on vision correction is consistently given by the *back focal length* of the lens.

---

[16] And that's from the front of the cornea, not the eye's first principal point. It is of course hard to measure the latter, but the distance between them is very consistent. Thus measuring from the front of the cornea is much more practical.

Of course we would rather speak in terms of power than focal length. So we define the *vertex power* of a lens as the reciprocal of its back focal length. And we describe, or prescribe, the power of an ophthalmic lens in terms of its vertex power.

Because this is the value that describes the "effect" of the lens on vision correction (**assuming that the rear vertex is at a standard distance from the eye**), regardless of the shape of the lens, in ophthalmic work it is sometimes called the *effective power of the lens*.[17]

Sometimes is it even spoken of, in an ophthalmic lens context, as the "true power" of the lens! (That's hard to justify. Guys, you should have quit when you were ahead with "effective power"!)

The focimeters we discuss here inherently measure the vertex power of the lens, and in fact that is the premise for the tradename, "Vertometer", used by Bausch & Lomb for some of their focimeters.

#

[17] Note that this term, the "effective power" of the lens, has two other meanings in an area outside the scope of this article.

Appendix B
Optical system of the focimeter

B.1 INTRODUCTION

First, we will first examine the conceptual principle for the determination of lens power upon which the focimeter is based, and we see why it would not be practical to directly implement that in an actual instrument.

Then, we will examine (in somewhat simplified way) the actual optical system of contemporary focimeters, and see how the power is indicated on a linear scale on the power drum.

Finally, we will look into an elaboration in the basic mechanism found in the first commercial American Optical Company focimeter, the Wellsworth Lensometer.

Several of the illustrations in this appendix were earlier seen in the body of the article.

B.2 THE CONCEPT OF MEASUREMENT IN A FOCIMETER

Figure 16 shows a conceptual setup for measuring the power of a lens.

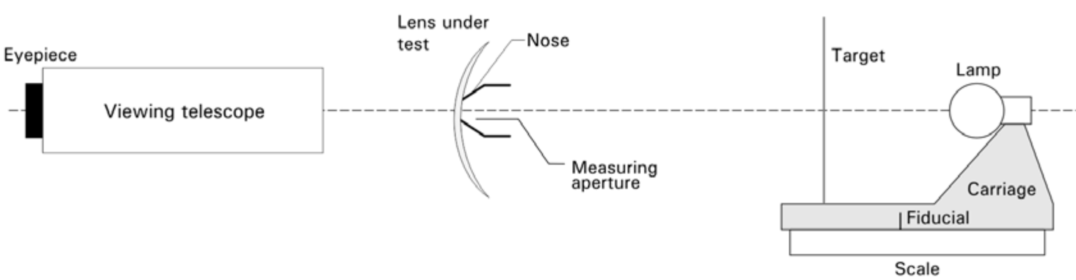


Figure 16. Principle of power measurement

On the left, we have the viewing system, a telescope focused (quite precisely) at infinity. The lens being measured is placed in a controlled axial position by being held against the fixed "nose" of a measuring aperture. Thus its rear apex is in an essentially fixed location, as by now we might suspect would be needed to fit in with the apex power concept.

Behind the aperture is a reticle-like *target*, carrying a transilluminated pattern of crossed lines. It is mounted on a carriage allowing its axial position to be changed. A fiducial on the carriage is read against a scale to indicate the carriage position.

If the telescope were presented with an object "at infinity", it would deliver its image perfectly focused to the viewer.

Now, as we saw earlier, if we place an object “at infinity” in front of a lens, its image will be formed at the back focal point of the lens. The distance of that point is the back focal length of the lens, and the reciprocal of that is the back vertex power of the lens.

This works in reverse. If we place an object at the back focal point of a lens, it will create an image of that object “at infinity”. Such an image can well serve as the object of the telescope, and in fact from it the telescope will delver a perfectly formed image to the viewer.

Thus, in general, if we move the target until the image appears perfectly focused in the telescope, then the distance from the nose to the target is the back focal length of the lens, and the reciprocal of that is its vertex power, the parameter in which we are interested.

But there are several flies in the ointment, particularly:

- This will only work for converging lenses (with plus powers). The nearsighted need not apply.

- For the range of powers we are likely to encounter, the distance to the target will be quite large (making it impractical for it to remain inside an instrument of any reasonable size). For example, for a lens with a power of 1.00 D, the target would have to be one meter behind the aperture nose; for a power of +0.125 D (typically the smallest value accommodated on a focimeter), it would have to be eight meters behind the nose (over 26 feet).

- The reading of the scale on the carriage would be linear with back focal length, but would therefore not be linear with power, its inverse (the parameter of interest, in terms of which we would like to mark the scale). This would not be attractive.

Thus, a clever optical trick is employed. Rather than trying to place a physical target at the back focal point of the lens under test, we can create (using a lens in the instrument) a virtual image of the pattern on the target, which virtual image will be the target for the lens under test. This virtual image can be placed at any distance necessary (to accommodate the location of the back focal point of the lens under test). Having done this, we find that the scale on our “new” target carriage will in fact be linear with the power of the lens under test. (Sometimes a designer just gets lucky!)

B.3 THE ACTUAL OPTICAL SYSTEM

Figure 17 shows schematically the actual optical system of a typical focimeter, taking advantage of the ploy just mentioned, in schematic form.

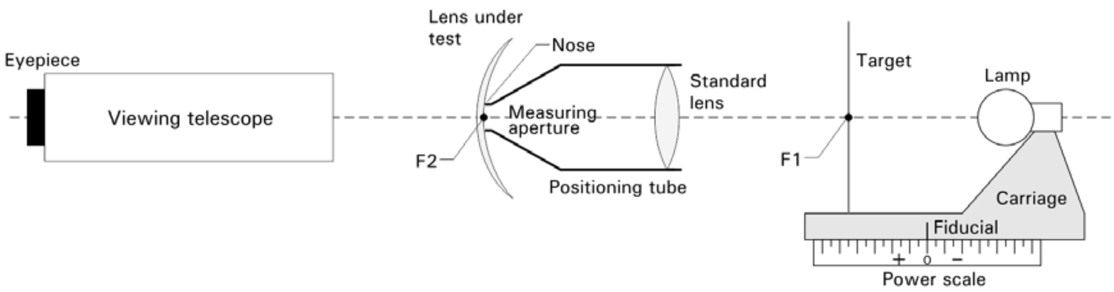


Figure 17. Focimeter optical system schematic

Here we have a new ingredient, a *standard lens*. The standard lens has its focal length carefully controlled (it is actually a compound lens, and its focal length can be tweaked by adjusting the spacing between its two elements), and the plane of the nose of the measuring aperture is precisely at the rear focal point (F2) of the standard lens (shown as a black dot). This relationship, once set, is precisely maintained by the positioning tube.

The lens under test is held against the nose of the measuring aperture, at the end of the positioning tube.

The target and the illuminating lamp are on a carriage that can move axially under control of the power drum (not shown). The drum carries markings, on which we read the power of the lens under test. (In the figure, we suggest this with a straight scale for the carriage itself.) The scale is linear.

The standard lens creates an image (always a virtual image) of the target. That image is the object for the lens under test. If that image were to be at the back focal point of the lens under test, then the lens under test creates a virtual image of that image (and thus of the target) at infinity.

As before, the eyepiece through which we observe is part of a Keplerian telescope, focused (precisely) at infinity. And if its object (the image formed by the lens under test) is at infinity, the telescope will present a perfectly-focused image to the viewer.

And of course that object is at infinity if the object of the lens under test is at the back focal point of that lens. If we know where that object is when we see a perfectly-focused image, we will know the back focal length, and thus the back vertex power, of the lens under test. And in fact can read it directly on the scale.

Where the virtual image created by the standard lens falls along the axis of the instrument, compared to the location of the standard lens, depends on the position of the target (following the customary focus equations). If the power drum is set to zero (the situation illustrated in the figure), the target will fall at the front focal point (F1) of the standard lens, and the image created by the standard lens falls at an infinite distance forward of the measuring aperture, or an infinite distance behind it if we want to think of it that way (this is a “singularity” in the focus equation—one of those “divide by zero” things).

If we move the power drum a little in the direction of plus powers, the image created by the standard lens is now a substantial but finite distance behind the standard lens; with the drum set to +0.25 D, it will be four meters to the rear of the measuring nose, wholly out of the instrument (but since it is only a virtual image that is not at all problematic).

If instead we move the power drum a little in the direction of minus powers, the image is now a substantial but finite distance toward the front of the instrument; with the drum set to –0.25 D, it will be four meters to the front of the measuring nose, well behind the operator (again not problematic since it is a virtual image).

In fact, for all drum settings in the range of the instrument, the image created by the standard lens will be a virtual one, and it will never fall between the lens under test and the standard lens. But never mind—the telescope, looking thorough the lens under test, will be able to focus on it—“perfectly” if it is at infinity.

B.4 A LITTLE ALGEBRA

Now, it’s time for some optical algebra.

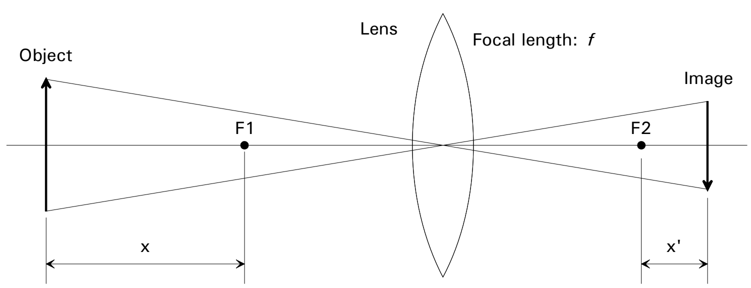


Figure 18. Reference for the Newtonian focus equation (not to scale)

In figure 18, the points F1 and F2 are the front and rear focal points, respectively, of a lens. (The figure is not drawn to scale.) We then consider the “Newtonian” form of the focus equation:

$$xx' = f^2 \qquad (2)$$

where x is the distance of the object from the front focal point of the lens, x' is the distance of the image from the rear focal point of the lens, and f is the focal length of the lens. (We have to be careful about the algebraic signs in all this!)

Now, if we consider our standard lens (figure 17), we note that its rear focal point is located at the measuring aperture (at the rear vertex of the lens under test). Thus, x′ also is the distance of the image from the rear focal point of the standard lens—which is thus the distance of the image from the rear vertex of the lens under test, which is the value we want to know, since it indicates the power of the lens.[18] In particular:

$$\Phi = \frac{1}{x'} \tag{3}$$

where Φ (upper-case Greek *phi*) is the power of the lens under test (the power as used in normal optical theory, not one of the vertex powers of interest in optometry).

Now, solving equation 2 for x′, we get:

$$x' = \frac{f^2}{x} \tag{4}$$

Substituting for x' from equation 3, we get:

$$\frac{1}{\Phi} = \frac{f^2}{x} \tag{5}$$

Inverting, we get:

$$\Phi = \frac{x}{f^2} \tag{6}$$

which we can rearrange as:

$$\Phi = \left(\frac{1}{f^2}\right)x \tag{7}$$

Now, $1/f^2$ is a constant (the square of the power of the standard lens, in fact). Thus, we see that the power of the lens under test (Φ) is proportional to the position of the target (given by x). Accordingly, the scale of the power drum, which linearly moves the target, can be directly marked to indicate Φ, the power of the lens under test.

I emphasized above that Φ is the lens power as used in general optical theory work (the reciprocal of the lens' *effective focal length*). But in

[18] Note again that, since the image of the reticle pattern is a virtual image, and may not even lie inside the instrument (and in no case between the lens under test and the standard lens), we cannot think of figure 18 as actually illustrating the situation. The algebra still holds, however.

optometric work, we are interested in the lens' *back vertex power* (the reciprocal of its *back focal length*).

But the derivation above is predicated on the infamous and fictional *thin lens*, for which those two focal lengths (and thus those two powers) are identical.

However, in actual optometry, we are dealing with a "thick lens", for which those two powers are not the same.

We solve that problem in a very simple way. We place the lens under test so its back vertex (rather than its second principal point) is at the origin of our focal length measuring system. Of course we do that by arranging the measuring system so that its reference point is at the "nose" of the instrument, and then we just place the lens under test so its back vertex is up against the nose (which is of course much easier than any alternate positioning). All the algebra still works out the same in this context.

How nicely this all worked out for the designers of the instrument!

B.5 TELESCOPE FOCUS AT INFINITY

We note that the theory of all this is predicated on our observing telescope being precisely focused at infinity. Changes in the refractive situation of the observer can disrupt this, albeit very slightly, leading to a very slight error in measurement. Nevertheless, the designers of the focimeter were very fastidious,[19] and made provisions to avert any such slight discrepancy.

Inside the telescope is an *eyepiece reticle* (we see it as the pattern of black lines and circles in figure 9). One of its roles is to make measurements beyond what I have described here (such as the orientation and magnitude of a *prism* component in the lens, used to correct misconvergence of the eyes). In fact, in connection with such measurements, it can be rotated with a ring behind the eyepiece, usually marked to show the angular orientation of this reticle.

But this reticle has a second purpose. It is at the front focal point of the telescope objective lens. The eyepiece lens proper, in this kind of telescope, should prepare the viewer's eye to focus exactly at this point.

---

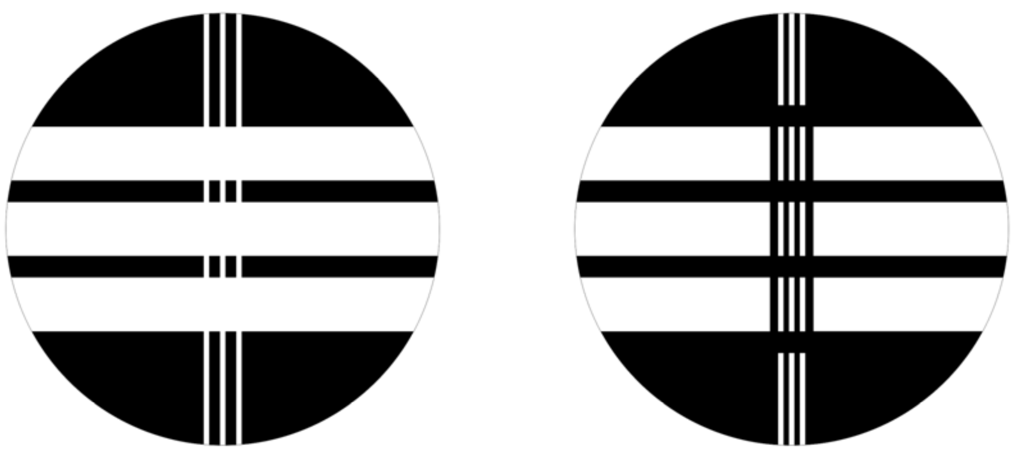
[19] A principal developer of the AO focimeter shown in figure 12 described it in an article in the Journal of the Optical Society of America (December, 1922) as being equivalent in precision to the company's standard reference lenses, traceable to the National Bureau of Standards.

This focus situation can be perfected by turning the eyepiece, moving it axially. It is adjusted so the eyepiece reticle itself is in best focus as seen by the operator. Then, the intended focus of the "operator plus telescope" at infinity is perfected.

B.6 AID IN MAKING THE AXIS SETTING

In the body of the article, we saw that making the proper setting of the axis was helped by an interesting display phenomenon (seen in figure 11). I drew the parallel with the split-prism focusing aid familiar in SLR cameras. But in fact, in the focimeter, this effect is produced without benefit of any such special optical components. It is inherent in the behavior of the image of the target.

We will now examine the form of that target more carefully than before. In Figure 19, on the left, we see the way that the target is ordinarily visualized. But in fact, its actual arrangement more nearly as shown on the right.[20]



Simplified Actual

Figure 19. Focimeter target pattern

The small pieces of the thin lines (running vertically (in this figure) across the width of the thick lines) are sometimes spoken of as *boxes* (they are indeed actually small rectangles).

When the lens has correction for astigmatism, by way of a cylinder component of its power, the lens itself exhibits astigmatism, which is why, in such a case, we can selectively perfect the **apparent** focus of either the thin lines or the fat lines. I say *apparent* because it is only

[20] This is the arrangement used in the Bausch & Lomb "Model 70" focimeter, and is typical for other instruments from that manufacturer. American Optical Company used a slightly different layout of the target.

across the width of the chosen lines that focus is perfected, not also along its length.

Now consider the situation in which the axis of the target is not set to match the axis of the cylinder component of the lens being measured.

We often say of a cylinder lens that in the direction perpendicular to its axis, it exerts the maximum power; in the direction of its axis it exerts zero power; and at intermediate angles ("oblique" directions) it exerts an intermediate power.

But the latter is simplistic. In an oblique direction, the effect of the power of the lens is a bit complicated. A full explanation of this is beyond the scope of this article.

But the bottom line is that, if we consider an object that is a little rectangle (such as the "boxes" of the focimeter target), with the axis of the cylinder lens component oblique to the lengths of the boxes, the best-focused image we can get is "smeared" to look something like what we see in figure 20.

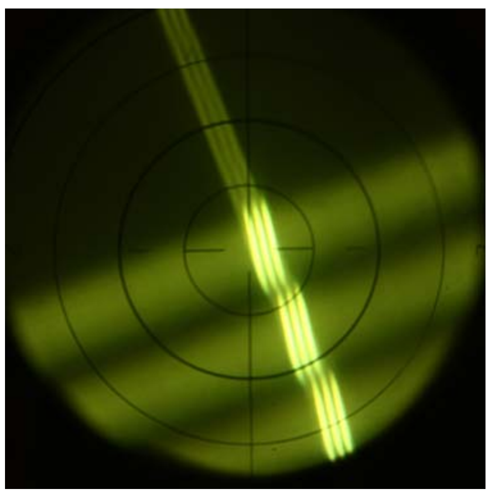


Figure 20. Thin lines in focus but axis not proper

The visual impression given is that the line segments are rotated, and do not form an unbroken line.

When the axis is set ideally (as it is almost[21] in figure 9, and as we see again in figure 21), the phenomenon is not in effect, , and the "boxes" appear to have the same azimuth and thus appear as an unbroken line.

[21] Well, I was a little sloppy while doing this.

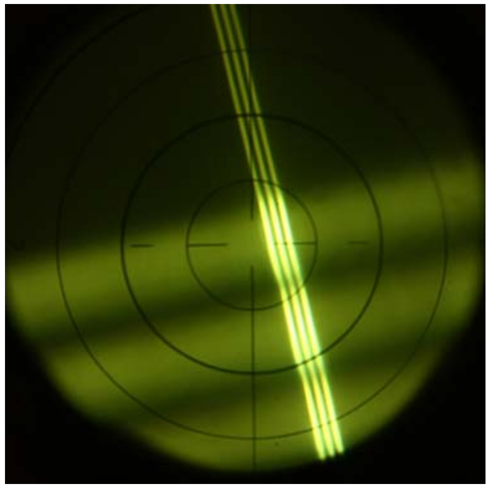


Figure 21. Thin lines in focus and axis (almost) proper

In cases where the cylinder component is smaller, and thus the degree of “smearing” is less when one or the other set of lines is brought to the best apparent focus, the phenomenon is more limited. Still, it is compelling visually.

B.7 A MORE ELABORATE TARGET SYSTEM

The AO Wellsworth Lensometer (see figure 12) had a more elaborate design in one respect than what was discussed above for the B&L “Model 70”. Firstly let me note, for reference, that the target pattern here does not have three thin lines in one direction, and three fat line in the other, but rather a single thin line in one direction and a group of three thin lines in the other.

More importantly, the single line and the group of three lines are on separate target reticles, on coaxial plungers, which can be separately moved along the instrument axis (always retaining their relative orientations), using separate, coaxial knobs with associated indicator drums

Thus, even for a lens with a cylinder component, both sets of lines can be brought into focus at the same time. Therefore the sphere and cylinder power result can be read simultaneously. (But you still have to subtract two readings to get the cylinder power.)

What if there were no cylinder component? Then the two targets would have to be at the same place, obviously not possible.

To avert this, the instrument includes a cylinder lens immediately in front of the single-line target (the frontmost one). Its axis is parallel to the direction of that target line.

We rely on the focus of a line or group of lines in the direction across the lines. Thus this cylinder lens contributes to the focus of the single line. And in doing so, it displaces the apparent axial position of the single-line target so that it can be moved to be “virtually” in exactly the same place as the three-line target (as would be the situation needed to bring both sets of lines into focus when the lens under test had only a sphere component).

This shifts “forward” the physical range over which the single-line target must operate, avoiding the possibility of any collision. The cylinder markings on the power indicator drum for the single-line line target are offset to recognize this.

But as to the three-line target, again there we are only concerned with focus as across the lines. In that direction, the cylinder lens associated with the other target has no power, so it does not displace the apparent axial position of the three-line target.

Evidently, the mechanical complications of this feature were later found to not be justified by its benefits. In all later models, we must consecutively set the single power drum to two positions to make the complete measurement, not really any more complicated than with the more complicated arrangement.

#

Appendix C
Evolution of the American Optical focimeter line

C.1 ORIGINS

In 1876, Herman Snellen (whom we mostly honor for the development of the widely-used eye chart, the one typically with the big "E") developed a technique for determining the power of eyeglass lenses which serves as the principle of today's focimeters.

In 1912, Charles J. Troppman, of F. A. Hardy & Co., a dealer in optical instruments and opticianry supplies, developed the first practical instrument exploiting that principle. Successive designs were covered by U. S. patents in 1914, 1916, and 1918. The name "Lensometer" was evidently first used in connection with instruments made by the Hardy firm.

In 1913, the Hardy firm was merged into American Optical Company. Troppman continued his work on lens measurement instruments, evidently in collaboration with Edgar D. Tillyer, American Optical's chief optical wonk for many years. Tillyer presumably helped refine the design, helped to articulate the theoretical basis of the instrument, and contributed to its introduction as a practical commercial product in about 1919 (see section C.2). Tillyer become widely associated with the instrument.[22]

Essentially that commercial instrument configuration was essentially the premise of Troppman's 1926 U. S. Patent (1,609,895), considered the definitive patent in this area.

In December, 1922, Tillyer co-authored (not with Troppman—rather with Tillyer's boss, Charles Sheard) the seminal paper on the instrument for the Journal of the Optical Society of America. Although AO often applied Tillyer's name to commercial products (such as an important series of eyeglass lens blanks), in the case of their focimeter, they declined to honor either of the key figures in its development, but rather called it the "Wellsworth Lensometer".

In the sections that follow, I will describe a number of focimeters that descended from this origin. In Appendix D, I will discuss a few focimeters from American Optical's major competitor, Bausch & Lomb.

---

[22] The May, 1922 issue of the Rutgers Alumni Monthly (Tillyer got his undergraduate degree at Rutgers in 1902) said, "Mr. Tillyer's latest invention is an instrument called the Lensometer." We might conjecture that there were could have been some ill feelings between Troppman and Tillyer over this state of affairs, although I have never seen this spoken of in the historical record.

C.2 THE HARDY LENSOMETER (M117)

In figure 22. we see the Hardy Lensometer, which once the Hardy firm had been absorbed into American Optical Company was seemingly also identified as the No. M117. We suspect its introduction was in 1918 or so.

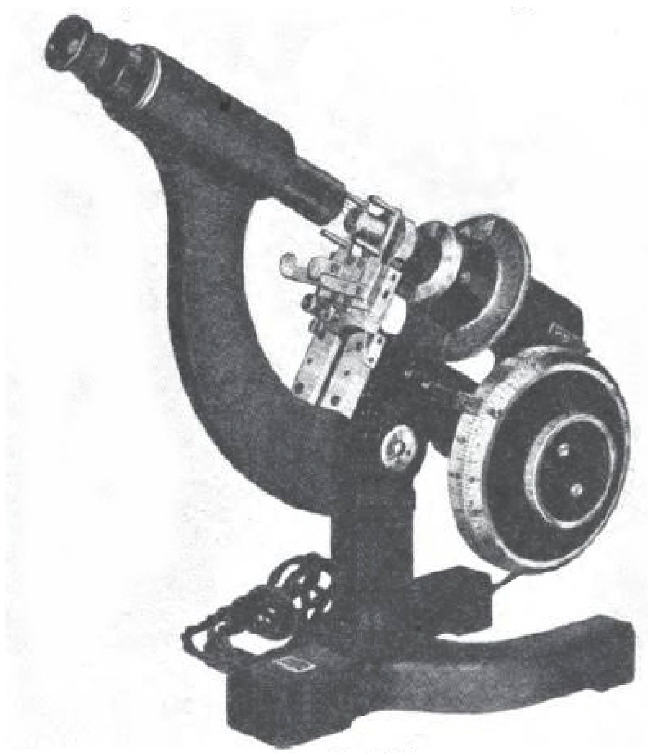


Figure 22. American Optical Hardy Lensometer (M117)

We have little additional information on this model.

C.3 WELLSWORTH LENSMETER

In figure 23 we see again the American Optical Wellsworth Lensometer, introduced in 1919 (this photo said to be from a 1920 advertisement).

This is described in some of the contemporary literature as being the "Hardy Lensometer as modified by Edgar D. Tillyer."

Figure 23. American Optical Wellsworth Lensometer

As discussed in section B.7 in Appendix B, this instrument has separate targets with the lines in the two orthogonal directions, separately moved by the coaxial knobs we see under the operator's right hand, each of which also turns an indicator drum. These drums are marked with the power in diopters. [23]. This feature is believed to be one of Tillyer's contributions to the design of this model (although that target concept is actually attributed to G.A.H. Kellner of Bausch & Lomb Optical Company).

The targets are rotated (together) for the cylinder axis setting by a large knurled disk, seen under the operator's left hand. It has a protractor-like angle scale, in degrees, with two 1-180° ranges.

For this and later AO models, this form of the axis control was touted by AO as being able to be equally well operated by either hand. That argument, although true, is not of much consequence, given that in the most common operations with the instrument the operator must simultaneously manipulate both the axis control and the power controls—the latter of which were located (only) on the right side of the instrument.

We are not aware of the model number or the like (if any) associated with this model.

---

[23] An interesting fact: the "0" positions of both power drums are marked "X 0". My conjecture is that, since on prescriptions a sphere power of 0 is often just not written (there being "no" sphere component needed in the lens), or indicated as "plano", the "X" is a proxy for such indications. This is followed on succeeding AO Lensometer models up through the Model 12603.

C.4 THE WELLSWORTH JUNIOR LENSOMETER

Figure 24 shows the Wellsworth Junior Lensometer[24], seemingly introduced in around 1921.

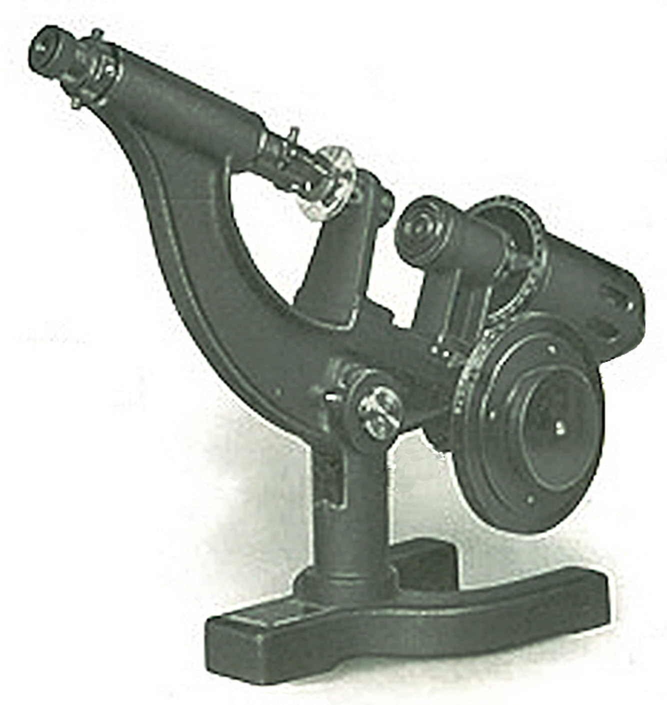


Figure 24. American Optical Wellsworth Junior Lensometer

We have little information on this model. We conjecture that the name alludes to it being smaller, lighter, and/or less costly than its predecessor, the Wellsworth Lensometer. (In 1924 it sold for $185.00.) We don't know what it or its predecessor weighed. (We hate to think!)

It had a simpler optical system, having only a single target with two orthogonal sets of lines (as in essentially all modern focimeters).

We are not aware of the model number or the like (if any) associated with this model.

C.5 THE AMERICAN OPTICAL M602

This model comes next in chronological order. We do not know when it was introduced, but it seems that its historical role is as the "field trial" for a design that was improved for use in the widely-used M603. It is sort of the "M603 1.0". Its features are essentially the same as those of the M603 but in many cases with a noticeable but not consequential design difference. There were a number of small changes (toward the M603 design) during its presumably-short life.

---

[24] Sometimes called the "Wellsworth Lensometer Jr."

Because the M603 had such a prominent role in this field for many decades, I will put off description of the M602 for now and instead describe (in considerable detail) the M603. Only then (in section C.7) I will revisit the M602, describing its features as they differ from those of its successor, the M603.

C.6 THE AMERICAN OPTICAL M603

C.6.1 General

The next AO commercial model (seemingly introduced *ca*. 1938) was originally billed as the "Lensometer Junior—Improved Version".[25] It was identified as Catalog Number M603[26]. It is often confused with its predecessors the Wellsworth Junior Lensometer and the Lensometer Junior.

When I say that a certain feature was found for the first time on this model, often that is not quite right—it may have first appeared on the mostly forgotten Model 602. I will confess to this inaccuracy by an asterisk after a statement about a feature being first introduced on the M602.

Figure 25 shows an AO M603B Lensometer (the "B" means it has both the optional prism measuring and marking device features). This photo is of the specimen currently (as of 2022) in our personal collection.

Figure 25. American Optical M603B Lensometer

---

[25] The once ubiquitous name "Wellsworth" essentially disappeared in 1927, when it was realized that many consumers knew of "Wellsworth", even thinking it to be the name of a company (encouraged by the advertising verbiage), but had never heard of "American Optical Company".

[26] A 1952 catalog sheet suggests that at that time this model was known as the "603-", but all specimens seen with data codes later than that still show the model as "M603-"

Its basic design is taken from the Model M602, but with a number of improvements (the significant differences are described in section C.7).

We do not know whether the “Improved” in its name referred to *vs*. the M602 or *vs*. the Wellsworth Junior. It was certainly improved compared to both.

Early in its history this model indicated on the nameplate that it was made by Spencer Lens Company, at that time a wholly-owned subsidiary of American Optical Company. The same was true of the American Optical Phoroptors (refractors) of that era. That operation eventually became a division of American Optical Company itself, and its former corporate name was no longer mentioned.

This model was for several decades the centerpiece of the AO commercial focimeter line, considered (along with the Bausch & Lomb “Model 70”) to be the *sine qua non* of focimeters.

C.6.2 Power and axis controls

The large drum on the right, with an integral knob, moves the target carriage to determine the power of the lens under test, which is read directly from a scale on the drum. For positive powers the markings are white (on the dark drum); for negative powers, the markings are red. The drum scale is generally marked to a precision of 0.25 D, but in the range from 0 to ±0.75 D it is marked to a precision of 0.125 D.

There was available, as an optional accessory, a small magnifying glass to help in reading the drum.

Following a practice introduced on earlier models (and continued on later models), the zero point on the drum scale is marked “X0”. We conjecture that the significance of this is that if on a prescription, the sphere power is zero, that value is just not written, or the word “plano” (which implies a powerless lens) is written. We conjecture that the “X” is indicative of these various forms of indicating “none”.

The ”protractor wheel” just in front of the lamp housing rotates the target. The cylinder axis is read from the scale on that wheel. The scale has two 1-180 portions and can be read to a precision of one degree.

There was available, as an optional accessory, a small magnifying glass to help in reading the wheel.

C.6.3 The marking device

The variant of the model shown in the figure is equipped with a marking device (which first appeared on this model* [27]). Variants with this feature have the suffix ″B″ on their model number[28]. The operator, working with a lens that had not yet been shaped to fit into the frame, would (by observation with the optical system) properly center physically the optical center of the lens and orient the lens with its reference axis horizontal. Then, using the marking device, three small dots in temporary ink would be made on the lens, the center one at the optical center, and all three marking the horizontal reference axis.

We see this device at work in Figure 26. (These pictures were taken when this specimen did not have lens alignment plate (“mustache”).

Figure 26. Marking device

In the upper left picture we see it in its idle state. A head carries three bullet-like cylinders, each of which carries a spring-loaded stylus. On the right of that picture we see what looks like a flattened trumpet bell. This is the operating knob. Its outer rim is knurled, so it can be pressed and/or turned.

---

[27] The asterisk means, “Truthfully, it first appeared in very similar form, on the M602,” In later statements of this type, the “truthfully” note is just indicated by an asterisk.

[28] This also indicates that it is equipped with the prism measuring feature described in section C.6.4

Below the knob, at the end of a black arm, we see a plunger (the *guide plunger*) about to enter the closed portion of a tube (the *lower guide tube*).

In the upper right picture we see that the moving assembly has been pushed forward by the operator pressing on the operating knob. The tips of the three styli have passed through three small holes into a rectangular chest, which contains a felt-lined roller soaked in the marking ink. The roller can be turned via the small knob seen at the end of the chest to redistribute the ink and bring a fresh portion of the ink-soaked felt into play.

At this point, the stylus tips each pick up a small amount of ink.

During this movement, the *guide plunger* has entered the closed portion of the *lower guide tube*, which assures that the forward movement of the stylus head is along a straight line to its target on the ink chest.

Then the assembly is allowed to retreat (under spring pressure), and the operator turns the operating knob to rotate the head arm up until it lies along the axis of the optical system (see the lower left picture).

Then (see the lower right picture) the operator again pushes the assembly forward until the stylus tips press against the lens. During this movement, the guide plunger goes into the closed portion of the *upper guide tube* so that the orientation of the head would be proper for the center stylus to exactly follow the optical axis toward the lens.

The operator the allows the moving assembly to retreat and helps it fall to its idle position.

And all this was chrome plated for an elegant, if slightly scientific, appearance. (It is, after all, a scientific instrument.)

C.6.4 Prism measuring feature

Available as an option on this model (although seemingly always provided) is a way to quantify a prism component in the lens under test.

The lens under test has its optical center physically centered on the axis of the measuring aperture, and the horizontal axis of the lens is aligned with the horizontal axis of the instrument.

When this is done, the intersection of the two sets of lines on the target is offset from the center of the field of the observing telescope.

In a specimen equipped with the prism measurement feature (its model number would have the suffix “A” or “B”), there is a reticle in the eyepiece with circular rings. These are at distances from the center of the field corresponding to an offset of the intersection of the target lines corresponding to a prism component of 1,,2, 3 etc. prism diopters.

In addition, there is a rotatable reticle with a radial line. It can be rotated with a knurled ring on the exterior of the eyepiece. It is rotated until the line passes through the intersection of the target lines. Its orientation indicates the base orientation of the prism component. Its orientation is read on a small scale on the knurled ring, read against a very small black arrow on the eyepiece barrel.

C.6.5 The mustache

This model also normally included, for the only model* in the AO line, a *lens alignment plate*. This thick plate, mustache-shaped (and I will refer to it henceforth as *the mustache*), is located just behind the measurement nose, and carries both horizontal and vertical reference lines. Figure 27 shows as closeup of the one on the specimen seen in figure 25.

Figure 27. Lens alignment plate

Its purpose was seemingly to allow the operator, working with an unmounted lens which carried a temporary horizontal axis marking, to properly position and orient that lens.

The long arms are seemingly to allow a completed pair of eyeglasses to be properly aligned in rotation by aligning the marked center of the “opposite” lens with the extended reference line the mustache.

The odd shape is to provide clearance for the temple pieces of eyeglasses whose lenses are being tested (since normally the glasses are oriented with the “rear” surface of the lens against the measurement nose so the temples extend away from the operator, crossing the plane of the mustache).

The specimen shown in figure 25 did not (as received) have a mustache, and it seems likely that in later years the model could be ordered without it. (It was always, in my opinion, of questionable utility.) That notwithstanding, we were able to acquire an unfinished mustache, finished it, and added it to the instrument.

C.6.6 The spectacle table

This model included, for the first time in the AO line*, a "spectacle table", a long rectangular plate on which a pair of eyeglasses would rest while one lens of the other was being measured. It can be raised and lowered by a small knob working through a double rack and pinion mechanism on the supporting posts. A scale showed the table elevation relative to the axis of the measurement aperture.

We note that the use of this feature properly aligns a complete pair of eyeglasses in rotation, making us wonder why the mustache really needs its long arms.

C.6.7 Returning to the matter of names

A "manual" for this model (believed to be from 1938) has on the cover what we see on figure 28.

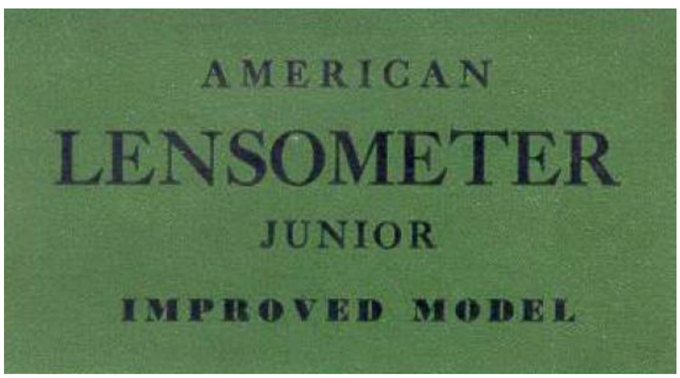


Figure 28. M603 manual cover item

Note that the first line is not "American Optical" (although that name appears at the bottom of the cover).

In any case, the "Junior—Improved" moniker was eventually dropped.

A later instruction manual for this model (believed to be from 1952) just calls it "The Lensometer", and no model number is mentioned.

According to the 1938 manual, the price then was $225.00 for the M603B, the "B" suffix indicating that it had both the prism measuring and marking device features, "Western prices slightly higher". That price is considered equivalent to $4.575.00 in 2022.

C.6.8 Alternate lamphouse design

What is perhaps a late M603B (date code from 1959) has a bullet-shaped lamphouse, but in this case seemingly spun from thin metal, and bereft of any chrome rings. Its frontmost cylindrical section has lacework perforations (presumably for ventilation). I cannot score this change highly on aesthetic grounds.

C.6.9 Overall finish

The standard M603 was mostly finished in a black wrinkle finish. Accents were chrome.

C.7 THE AMERICAN OPTICAL MODEL M602—THIS TIME FOR REAL

This model is a rarity, and I have only seen pictures of four examples in the wild. I do not know when it was introduced. I have no literature on it.

Figure 29. American Optical M602 Lensometer Jr.

Figure 29 shows one of these known specimens. From the serial number, I suspect it was made in 1937.

This model, perhaps short-lived, was clearly the precursor to the model M603 (discussed at length in section C.6). It is identified on the nameplate as “Lensometer Jr.” (the model number is also shown).

This specimen has no marking device (but it was seemingly available as an option, since it appears on three of the other specimens of which I have pictures), but the configuration of the telescope eyepiece suggests that it did have the eyepiece reticle system for measuring the prism component of the lens.

C.7.1 Differences from the M603

C.7.1.1 *Introduction*

In this section I summarize the changes in design from this model to its immediate successor (already described), the M603.

C.7.1.2 *Lamphouse*

In the M602, the lamphouse has a “covered wagon” shape, extending up from the bed of the optical system. In the M603, the lamphouse had a bullet shaped ”art deco” design, of Bakelite, with chrome ring accents. In both cases, the lamphouse travels with the target carriage.

Interestingly enough, on the model 12603 (the successor, after many years, to the M603), the lamphouse was returned to the “rising from the bed” design, then looking more like a tool shed than a covered wagon.

C.7.1.3 *Lens clamp*

The lens clamp system of the M602 is essentially the same as on the M603, except that, in most specimens of the M602, the cylinder that supports the marking device was fixed to the plate that supports the “nose”, whereas in the M603 (and other specimens of the M602) that cylinder was fixed to a bracket on the instrument frame just forward of the part that supports the observation telescope.

C.7.1.4 *The spectacle table*

This model included, for the first time in the AO line, a “spectacle table”, a long rectangular plate on which a pair of eyeglasses would rest while one lens of the other was being measured. It was mounted atop a single square post, which can be raised and lowered by a small knob working through rack and pinion mechanism. A scale showed the table elevation relative to the axis of the measurement aperture.

In order to cater to the two possible positions of a pair of eyeglasses (to measure one lens or the other), the table proper was mounted on the supporting plate via a gibway, allowing it to be moved from side to side to match the position of the glasses.

In the M603, the spectacle table is supported by two posts, with a rack and pinion (worked of course by the same knob) on each (probably for increased robustness and stability).

In the M603, rather than having the spectacle table mounted so that it could be moved from side to side to accommodate the two possible positions of a pair of eyeglasses, the table was fixed in its lateral position but was just made longer than in the original M602.[29] (Ain’t science grand!)

C.7.1.5 *Marking device*

---

[29] But we have seen pictures of an M602 without the laterally movable spectacle table, and an M603 with it, so go figure.

This model also optionally included, for the first time in the AO line, a *marking device*. Its purpose is described in section C.6, covering the Model M603. The one in the M602 appears to work essentially identically to that in the M603.

However, in the M602 the cylinder that supports the marking device is fixed to the plate that supports the "nose", whereas in the M603 that cylinder is fixed to a bracket on the instrument frame just forward of the upward-curving part that supports the observation telescope.

C.8 THE AMERICAN OPTICAL 12603 LENSOMETER

C.8.1 General

In about 1969, the American Optical Model M603 was essentially superseded in the product lineup by their Model 12603 Lensometer. We see one in figure 30, this one from our current (as of 2022) personal collection.

This model came in one's choice of "American Beauty" colors—Coral, Jade Green, Ivory Tan, and Black. (We had the good judgment to get a black one.[30]) The finish was essentially a "high satin".

Figure 30. American Optical Model 12603 Lensometer

The model number, 12603, was certainly assigned to suggest that it was the replacement for the very-well-thought-of model M603. In fact, in a 1977 brochure for the model 12603, at first mention, the model number is styled as "12603" so we don't miss that point.

C.8.2 Major optical controls

---

[30] However, it looks as if, on our specimen, one part had originally been painted Jade Green (it can be seen on a portion of the part that cannot normally be seen), so perhaps the finished parts inventory was updated as market tastes evolved!

In the promotional literature, the arrangement of the power and axis controls is described as providing "simple one-hand operation", but that is a little misleading. The large drum at the right (with a smaller knurled knob) controls the power. The axis is set on a large knurled circular "protractor" wheel protruding from the body (its center carries the target), and the axis is read on a scale on that wheel, with a small magnifying glass to read it accurately.

One can of course operate both controls with the right hand, moving it from one control to the other as needed!

In some versions, the fiducial pointer on the axis wheel was at "12 o'clock". In other versions it was at "3 o'clock". The latter presumably was to make it easier to read by the operator who was probably leaning to the right to read the power drum. Either arrangement seemingly was provided with a magnifier.

C.8.3 Cover system

Unlike the previous model (M603), the optical system behind the lens under test (including the target) is enclosed by a cover. There are sliding cover portions that travel with the carriage that carries the target, so that the "enclosure" remains intact over the range of carriage movement..

C.8.4 Lamphouse

The lamphouse is of the "tool shed" design and does not travel with the target carriage (as did the lamphouse in all earlier models).

C.8.5 Articulated lens clamp ring

For the first time in this model (for AO) the lens clamp has an articulated ring. This assures that the attitude of the lens is determined by its sitting on the measurement nose and not by the lens clamp ring (as might have been with the non-articulated lens clamp ring used on the M603). The difference can be important if the lens has a prism component and thus its front and back surfaces are not what we can call, somewhat imprecisely, "parallel".

C.8.6 Marking device

This model includes a marking device, for the purpose discussed above under the M603. But its design and operation are quite different. We see its operation in figure 31.

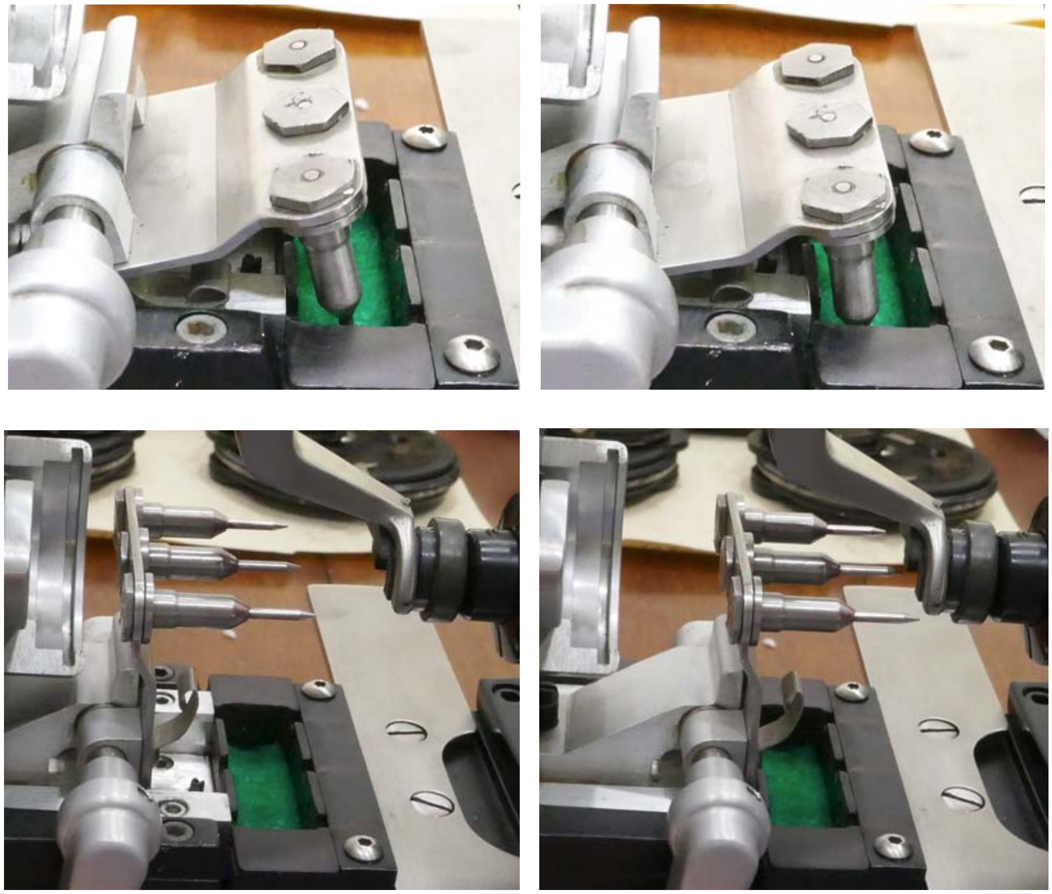


Figure 31. Marking device operation

The upper left picture shows the device in its idle state. As with the M603B, a head carries three bullet-like housings each carrying a spring-loaded stylus. A flat spring (barely visible, with a curled end) keeps the head high enough that the tips of the styli do not normally touch the ink pad (green and uninked in this picture).

As seen in the upper right picture, the operator first lifts the operating lever, which tips the head carrying the three styli down to bring their tips into contact with the ink pad. The tips each pick up a small amount of ink.

Next the operator presses the lever down, which rotates the head up as seen in the lower left picture. Then, forward pressure on the lever pushes the carriage carrying the marking head forward (against a retracting spring) so the styli move to contact the lens, as seen in the lower right picture (there is no lens in place here).

C.8.7 New parentage

This model was eventually made by Reichert (now known as Reichert Technologies) after it took over American Optical's ophthalmic instrument business in 1982.

C.9 THE AMERICAN OPTICAL 12620 LENSOMETER

Shortly after introducing the 12603 (*ca*. 1969), American Optical introduced the Catalog Number 12620, much like the 12603 but including digital readout of the various settings. We see it in figure 32.

Figure 32. American Optical 12620 Lensometer

We have no further details on this model.

C.10 OUT OF SEQUENCE

We suspect from their catalog numbers that the two following models were introduced earlier than the 12603 and 12620, previously described, but I put off their description since they are not members of the primary line of descent of American Optical Lensometers

C.11 THE AMERICAN OPTICAL 11210 LENSOMETER

Figure 33 shows the American Optical Catalog Number 11210 Lensometer.

Figure 33. American Optical 11210 Lensometer

To the best of my knowledge this model departs from all those we have seen heretofore in that the setting of the power drum is not read on the drum itself. Rather, an image of a linear scale is visible in the eyepiece, with a fiducial showing the current setting. [31],

The image of this scale, which is actually attached to the target carriage, is conducted back to the eyepiece through a "subway" in the lower part of the housing by a system of lenses, mirrors, and prisms.

The power drum (a large knob actually) is located on the right side. The axis drum, with a direct-reading scale, is located on the left. Its scale is read against a fiducial on a small bracket.

We have no further information on this model.

C.12 THE AMERICAN OPTICAL 11360 LENSOMETER

Figure 34 shows the American Optical Catalog Number 11360 Lensometer.

To the best of my knowledge, it uses essentially the same system of displaying the cylinder power as the 11210, seen just above, although the arrangement of the controls is different.

The power control, on the right side, is the large "wheel" seen in the figure. The smaller wheel, coaxial with the power wheel, is the axis control. It has a scale on it, read against a fiducial on a small stationary disk sandwiched between the two wheels.

---

[31] This *modus operandi* has been inferred from a detailed description, in its manual, of a seemingly-similar model made by Amcon.

Figure 34. American Optical 11360 Lensometer

We have no further information on this model.

C.13 THE REICHERT 15110 (ML1) LENSOMETER

The Catalog Number 12603 was later superseded in the Reichert line by the Catalog Number 15110 (ML1) Lensometer. It uses LED illumination, battery powered. We see it in figure 35.

Figure 35. Reichert 15110 (ML1) Lensometer

A marking mechanism is included.

-#-

Appendix D
Some focimeters in the Bausch & Lomb line

D.1 THE BAUSCH & LOMB TYPE 21-05-90 VERTOMETER

At one point, Bausch & Lomb, Incorporated, AO's chief rival in the optical field, introduced their Vertometer (made under license from AO under an early Troppman patent). Figure 36 shows what I believe to be essentially its first commercial version, the type 21-05-90. It is suspected that this specimen dates from *ca*. 1940.

Figure 36. Bausch & Lomb Vertometer type 21-05-90

As in most of the AO instruments, the axis control here is coaxial, a knurled knob at the front of the rearmost portion of the instrument (the "projector"), which turns a disk bearing a white fiducial that is read against a fixed circular scale (with the white scale lines). This disk directly rotates the target.

There is what appears to be a movable pointer on the power drum. I conjecture that this was used to "capture" the position of that drum after measurement of the sphere power of the lens under test so that later, when measuring the cylinder power, the difference in drum position (which indicates the cylinder power) could be read directly.

The unit seen has a marking attachment (we see it at rest with its three prongs in the ink cylinder drum). The operator pushes a tab on a slide to activate the unit by moving it forward. As the marking head begins to move forward, a rack and pinion arrangement swings the head up. Just as the head is fully erect, the pinion escapes the end of the rack, and the head continues to move forward in that attitude.

The lens clamp arm swings from an overhead pivot.

D.2 THE BAUSCH & LOMB TYPE 21-65-70 ("MODEL 70")

In the next generation, the famous "Model 70" (formally, type 21-65-70, and often called "The Whale"), is seen again in figure 37. Again, this photo is of a specimen formerly in our personal collection. This particular specimen was evidently manufactured in 1963 (based on its serial number). It was in fine working condition as acquired.

Figure 37. B&L Model 70 Vertometer

B&L gave this instrument a somewhat more "modern" design, and incorporated several improvements in the user interface, compared to the directly competitive American Optical Company model (the M603).

Most prominently, the cylinder axis control, which in the AO instruments and the earlier B&L 21-05-90 is a handwheel mounted coaxially with the rear instrument barrel (see for example figure 25), here was made a knob on the left side of the instrument. Many operators considered this a more convenient location. We see it in figure 38.

Figure 38. B&L Model 70—Cylinder axis drum

Many details of the operation of this model and of various optional features are given in the body of this article, in section 6, and will not be repeated here.

D.3 BAUSCH & LOMB TYPE 71-26-62

In figure 39, we see a more “modern” basic B&L Vertometer, the type 71-26-62.

Figure 39. B&L Vertometer type 71-26-62

We believe this specimen was made in 1965.

The axis control is on the front (under the eyepiece), and turns a full revolution for the range from 1°-180°. There is a duplicate power knob on the left side.

Its aesthetic design is very “practical”.

-#-

Appendix E
Measuring the Add of bifocal lenses

E.1 INTRODUCTION

E.1.1 Presbyopia

Presbyopia is a vision defect in which the eye's ability to *accommodate* (focus on objects at different distances) is less than normal (or absent altogether).

E.1.2 Bifocal eyeglass lenses

Commonly, to overcome this, bifocal eyeglass lenses are used. In these, a region at the bottom of the lens (the *near vision segment*) has a greater power (that is, a more plus power) than the rest of the lens. This power is appropriate for assisting the eye in focusing on near objects (specifically at a certain *near vision distance*).

E.1.3 The Add

The power in the near vision segment is not specified directly in the prescription,. Rather, a value called "Add" is stated, This is the amount by which the power in the near vision segment should be more plus that the power in the rest of the lens (which is earlier stated in the basic section of the prescription).

E.1.4 Measurement of the Add

When we measure a bifocal lens with a focimeter (to determine, or confirm, its prescription), we usually want the result for the near vision segment to be in terms of the Add value. But ironically, what we actually measure is the power through the main portion of the lens and then through the near vision segment, and record the difference between them as the Add of the lens. (To be precise, there are qualifiers for both of those powers, which I'll get to shortly.)

Current training in the use of a focimeter often directs that, in the case of an existing bifocal lens, the Add of the lens should be determined by, **with the lens reversed in its position against the nose of the focimeter**, first measuring the power in the distant vision portion of the lens, and then, with the lens still in reversed orientation, measuring the power in the near vision segment. The difference in those two powers (observing the algebraic signs) is recorded as the Add value for the lens.

Some training adds, "Except if the power of the lens proper is minus, in which case make those measurements with the lens in the normal orientation".

What is all that about?

E.2 THE RATIONALE

E.2.1 Introduction

Precisely, the add of an existing lens is the difference between the power through the distant vision part of the lens, **determined as when regarding an object at infinity,** and the power through the near vision segment, **determined as when regarding an object at the relevant "near vision distance"**.

But a focimeter measures the power of a lens as it would be as when regarding an object at infinity (which, in general, is different from the power as when regarding an object at a near distance). So a determination of the Add made in the obvious way with a focimeter will have an error. (This procedure, by the way, would be done with the lens in its normal orientation in the focimeter.)

E.2.2 A way around this problem?

It seems at first as if we have a clever way to get around this difficulty. The extra "bump" of glass on the front of a bifocal lens (in effect, a little auxiliary lens integral with the main lens), which makes the power through the near vision segment more plus than the power through the rest of the main lens, is what I call the "addition". It turns out that the actual Add of the lens is very near to the front vertex power of the addition (in one important situation, exactly the same) if we treated it as a distinct lens. So it would seem that if we could determine the front vertex power of the addition, we will very nearly (or perhaps exactly) have the true Add of the lens.

And it would seem that we could do that by measuring the front vertex power of the lens through its distant vision portion, and then through its near vision segment, and subtracting the former from the latter. That should be the front vertex power of the addition, and thus very nearly the Add of the lens. We would do this, by the way, with the lens in reversed orientation in the focimeter (with the lens in its normal orientation, the focimeter measures its **back** vertex power).

But it doesn't quite work out that way. If we have two lenses "in cascade", unless both are the fictional "thin lenses" so beloved of optics theory lecturers, the vertex power of the combination is not the sum of the vertex powers of the two lenses themselves. Thus if we subtract the vertex power of lens A from the vertex power of the combination of lenses A and B, we will not get the vertex power of lens B.

E.2.3 Our best bet

So neither of these two measurement schemes will give us precisely the actual Add value of the lens. But it turns out that for the determination made under the second scheme discussed above (done with the lens reversed), the error is normally significantly less than for the determination done under the first scheme above (with the lens in the normal orientation).

E.2.4 The bottom line

And so, the common wisdom is that we should use the second scheme (with the lens reversed) to determine what we will consider to be the Add of the lens.

E.3 WHY THE EXCEPTION FOR MINUS POWER MAIN LENSES?

It turns out that if the thicknesses of the two lenses (the main lens and the "addition") are "fairly small", measurement of the Add with the lens "normal" and "reversed" gives very nearly the same result.

One situation in which the thickness of the main lens is predictably "fairly small" is when the power of the main lens is minus (negative). So, in that situation, we can perhaps "safely" not bother to reverse the lens to determine the Add. (This is a simpler rule of thumb than actually thinking about the lens thickness, which we often don't know unless we measure it with a separate instrument!)

Note that this does not mean that when the power of the main lens is minus that we would get an "more incorrect value" of the Add by measuring with the lens in "reversed" orientation. It's just that in that situation, it is probably not worth the trouble to do so.

-#-