86th birthday series

**Evolution of the optometric refractor—
the deZeng-American Optical-Reichert dynasty**

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Issue 2
May 22, 2022

ABSTRACT AND INTRODUCTION

A refractor (often known as a phoropter) is the scary mask-like instrument used (in the main) to determine the prescription for vision corrective lenses. The trail to today's sophisticated instruments has been laid by many inventors and engineers, working through numerous industrial firms. A major thread of evolution—which we can think of as a *dynasty*—began in the early 1900s with the prolific inventor Henry L. deZeng II, and over the years led directly to an important family of instruments today. This article reviews this dynasty, describing in some detail all the benchmark instruments along the way.

1 COMPANION ARTICLES

The reader looking for more information on vision correction lenses, the prescriptions that define them, and the trial lens and refractor systems of refraction may be interested in companion articles on those topics, by the same author, available where you got this.

2 BACKGROUND

2.1 Vision defects

Corrective lenses (eyeglass lenses or contact lenses) are used to "cancel out" refractive defects in a person's vision. The principal such defects are (rather simplistically):

- *Myopia* ("nearsightedness") or *hyperopia* ("farsightedness"), Here, the range of distances at which the person can focus is offset such that either far or near objects (respectively) cannot be focused on.

- *Astigmatism*, in which the refractive power of the eye's lens system is not uniform in all directions, resulting in the inability to form a sharp image on the retina regardless of focusing ability.

2.2 Corrective lens components

To correct for myopia or hyperopia, we use a corrective lens that exerts its refractive power uniformly in all directions (spoken of in scientific writing as a *spherical lens*, but in eyecare practice as just a "sphere" lens), with a negative ("minus") power for myopia or a positive ("plus") power for hyperopia.

To correct for astigmatism, we use a *cylindrical lens* ("cylinder lens") which exerts its refractive effect in only one direction (and of course we must orient its axis in the appropriate direction).

2.3 Specification of lens power

2.3.1 *The unit*

The refractive power of a lens[1] is the reciprocal of its focal length in meters. The modern (SI) unit is the *inverse meter* (m^{-1}), but in optometry and ophthalmology, an identical unit called the *diopter* (D) is invariably used.

2.3.2 *Vertex power*

In general optical engineering work, the focal length of which we speak (and whose inverse is the refractive power of the lens) is defined as the distance from a certain point of the lens (the *second principal point*) to the *second focal point* (which is where the lens will form an image of an object at "infinite distance").

But in vision correction work, the power that is spoken of 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 that second focal point. This power is called the back vertex power, or in most cases just the "vertex power", and in fact in this context usually just the "power".

2.4 Determining the "prescription"

2.4.1 *Introduction*

To determine the "prescription" that is the refractive specification for each corrective lens, we "refract" each eye by, in effect, simulating the refractive effect of corrective lenses, varying their refractive parameters until best vision is attained. This is commonly done in one of two ways:

2.4.2 *Trial lens system*

A trial frame is a special kind of eyeglass frame with interchangeable lenses. The refractionist has a collection of several hundred trial lenses, of both cylinder and sphere types, with powers (yes, that is the back vertex power) that vary in small increments.

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[1] Do not confuse this with the "power" (more properly, "magnification") of a telescope, which is another matter altogether.

The trial frame is arranged so that in front of each eye we can put up to four lenses, most often, a sphere lens and a cylinder lens, the cylinder lens being in a rotating receptacle so that it can be rotated to change the orientation of its axis.

Following an orderly procedure, the refractionist proceeds until the lenses in place (and the axis of the cylinder lens, if one is needed) lead to the best attainable vision. The powers of the two lenses (and the axis of the cylinder lens) are written directly as the prescription for the corrective lens for that eye.

Figure 1 shows a contemporary trial frame (this in fact from our personal collection) with three lenses in place before each eye (the third lens, frontmost, being a second sphere lens used to determine the needed increment in power of the *near vision segment* of a bifocal lens).

Figure 1. Trial frame with three trial lenses for each eye

2.4.3 *The refractor*

The refractor is an instrument that does the same thing, just without the need to have (and fumble with) several hundred loose lenses.

Rather, for each eye, the refractor "composes" a simulated corrective lens with a certain sphere power component and/or a certain cylinder component (the latter with a certain axis direction). It does this by moving into the sight path for the eye as many as four or five lenses (some of the sphere persuasion, and some of the cylinder persuasion), which are held in rotatable disks.

The net power of the cylinder lenses, and the net power of the cylinder lenses, in the train (and the axis direction of the cylinder lenses), when best vision is attained, are directly written as the prescription for the needed corrective lenses.

Figure 2 shows a typical contemporary refractor (one about which we will learn more later in this article):

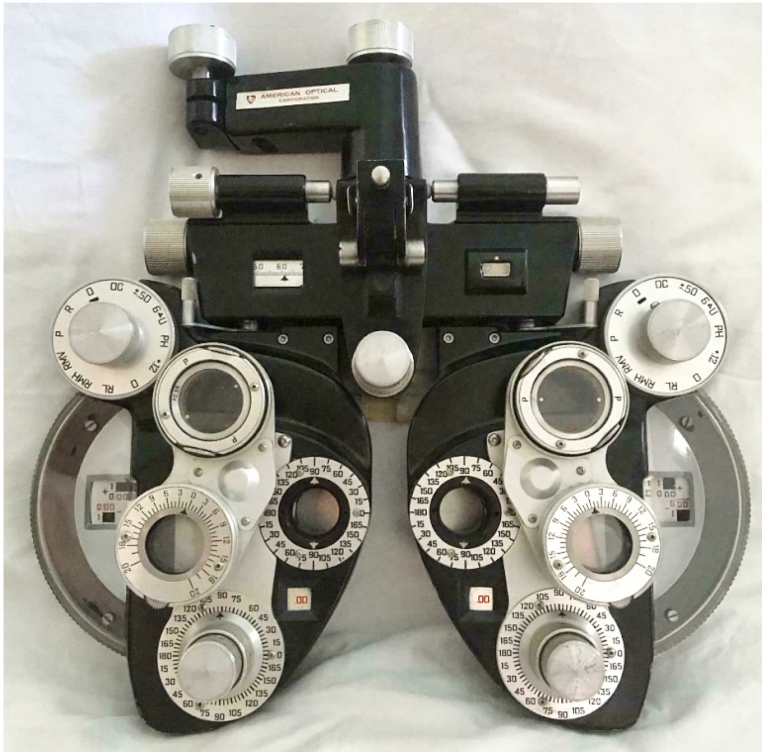

Figure 2. Typical contemporary refractor

3 THE LENS DISKS

3.1 The basic concept

In all refractors described in this article, for the sphere lens component of the simulated corrective lens, the component is built up of one lens chosen from lenses on each of two or three adjacent disks, each having around their edge a number of lenses of different powers. In the earlier models, these disks typically had eight lenses each; from the Model 590 on, these typically had 12 lenses each.

In a common arrangement, one of two disks carries lenses whose powers differ by a modest increment (most commonly 0.25 D). The second disk carries lenses whose powers differ by a greater increment (perhaps 2.00 D). These two disks are commonly referred to as the “weak sphere disk” and the “strong sphere disk”, respectively.

For all models from the deZeng No. 574 on, the cylinder lens component is built up of one lens chosen from one of 5 lenses on each of two adjacent disks (the “weak cylinder disk” and “strong cylinder disk”).

3.2 The duality of cylinder power

The complete "prescription" for a corrective lens (we will assume both a basic refractive error and astigmatism for the eye of interest) will comprise:

- The power of the cylinder lens component
- The power of the cylinder lens component
- The axis angle of the cylinder component

It turn out that a cylinder lens of a certain plus power, with a certain axis angle, is interchangeable with a cylinder lens of the same minus power, with an axis angle at 90° to the axis of the plus lens. (We also have to make an adjustment in the stated sphere power, since any cylinder lens also contributes a component of spherical lens power.)

As a consequence of this, in a refractor we need not have both plus and minus cylinder powers available. If we have, for example, only minus cylinder powers available, we can create an overall "simulated" corrective lens that will take care of any situation of astigmatism.

For most of the refractors discussed in detail in this article, only minus cylinder lenses are provided. From a certain model onward, variations were made with either minus or plus cylinder lenses.

3.3 Illustrative sphere lens repertoires

In a hypothetical but typical arrangement, the lenses of the strong sphere disk might have powers of:

-8.00, -6.00, -4.00, -2.00, 0.00, +2.00, +4.00, and+6.00 D.

The lenses of the weak sphere disk might have powers of:

0.00, +0.25, +0.50, +0.75, +1.00, +1.25, +1.50, and +1.75 D.

Thus, by combining one lens from each disk, we could get powers of nominally[2] -8.00 D through +7.75 D in steps of 0.25 D.

3.4 The zero lenses

On each disk, one position is allocated to a "zero power" lens. These might be just open holes in the lens disk. But there are certain technical reasons why, for these "zero lenses", an actual glass lens, with surface curvatures and center thickness such that its power is indeed 0.00 D (essentially just a glass "window"), may be desirable.

[2] I say "nominally" since when we combine two lenses of finite thickness and separated by a finite distance, the resulting power is not exactly the sum of the two individual lens powers.

That notwithstanding, in all the refractors discussed here, to the best of my knowledge, all the "zero" lenses are just holes in the lens disk.

3.5 Extending the range

In some situations, sphere powers greater that the maximum attainable with the basic lens disk system may be required. Usually, there are auxiliary sphere lenses on an auxiliary lens disk that can be put in place to extend the range of available powers.

For example, in the hypothetical refractor spoken of above, the auxiliary lens disk might include sphere lenses with powers of -8.00 D and +8.00 D. With these, sphere powers over the range of -16.00 D through +15.76 D can be attained.

Typically, the powers available in the basic sphere section are in steps of 0.25 D. In some work, it is needed to set a sphere power falling between those. To provide for this, the auxiliary lens disk often includes a sphere lens with power +0.125 D. With that in place, a setting of, say, +1.25 D on the sphere section becomes +1.375 D.

Note, however, that these "0.125 D" step values are the "ideal" values. In practice, the auxiliary lens of +0.125 D power is labeled "+.12", since it is the convention in this field to only state lens powers to two decimal places (often with no leading zero).

4 THE HISTORY OF THE REFRACTOR—THREE DYNASTIES

Numerous inventors contributed to the emergence of the refractor. Some of their inventions formed points on "threads" of commercial development by various companies (or chains of companies), while others, clever as they were, never achieved that status.

Thee major "dynasties" are generally recognized in this area by refractor historians. I will mention two briefly, and then the third in considerable detail.

5 THE SHIGON-WOOLF-GENERAL OPTICAL DYNASTY

In 1910 Nathan Shigon of New York, N.Y. was given a patent on a refractor that has many of the features we would today recognize as benchmarks of a refractor. In 1918, he received a patent on an improved version, including even more of these benchmarks.

In 1917, Michael Woolf of New York, N.Y. received a patent on a refractor that similarly included many of the benchmarks we today associate with a refractor.

These inventions formed the centerpiece of a refractor dynasty, once followed by General Optical Company of Mt. Vernon, N.Y. But, in the

United States, at least, this line of refractors died out sometime in the 1930s.

6 THE GREENS'-HUNSICKER-BAUSCH & LOMB DYNASTY

In the 1920s, Aaron S., Louis D., and M. I. Green, of San Francisco, California, developed a refractor and refined its design over several years. They teamed up with inventor Clyde L. Hunsicker (also of San Francisco) who completed the design and applied for a patent on it, which was granted in 1931, the rights assigned to Aaron and Louis Green. This refractor carried many of the benchmarks of today's refractors.

The Greens sold the rights under the patent to the famed optical company Bausch & Lomb, who, after a modest redesign, introduced the instrument in 1933 as the "Greens' Refractor". It was very successful in the marketplace for many years, considered by some to be the best refractor then available.

Production of this refractor ended in the mid 1970s, but there are many still in use (they are often said to be "indestructible"), and they enjoy a very devoted following.

7 THE DEZENG-AMERICAN OPTICAL-REICHERT AND SORT-OF-LEICA DYNASTY

7.1 Henry L. deZeng II

Henry L deZeng II of New Jersey (1867-1929) was a prolific inventor in the fields of optical devices and what we would today recognize as optometric instruments. His own firm (eventually known as the deZeng-Standard Company) manufactured and sold these instruments. In the area of refraction of the eye, deZeng developed successively more sophisticated instruments, inexorably sneaking up on what we would today recognize as the *refractor*.

7.2 The deZeng No. 560 Phorometer-Trial Frame

7.2.1 *Introduction*

The later of these pre-refractor instruments were in effect elaborations of the trial frame. An important one, introduced in 1909, was called the “deZeng Phorometer-Trial Frame” (sometimes identified as the “No. 560”). The name “Phorometer” reflected that the instrument could measure (“meter”) *phorias* (failures of the two eyes to properly aim on the same object, a type of vision defect I did not enumerate above). But that capability (and some other features) were “piled onto” what is, in effect, an elaborate trial frame.

Figure 3 shows this instrument. We see it from the viewpoint of the refractionist; the subject would be on its far side.

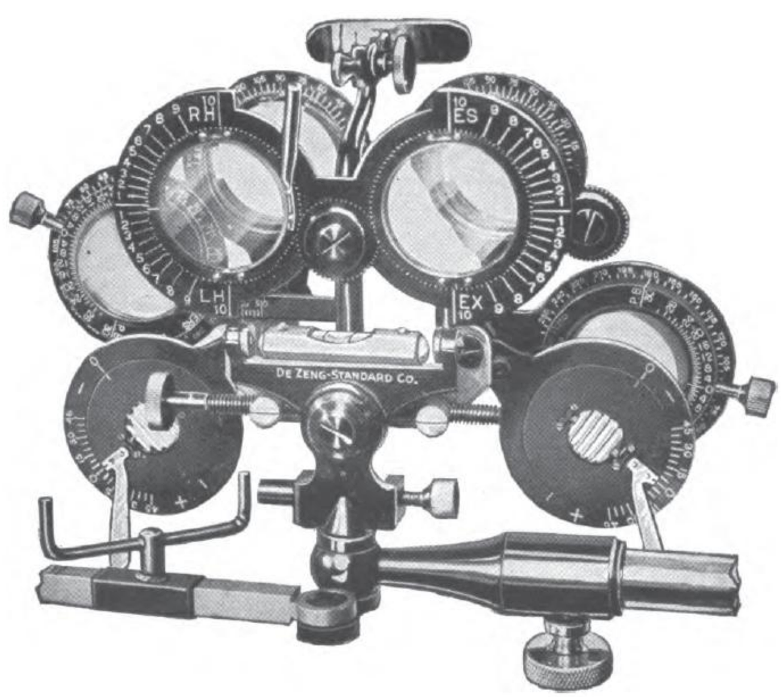

Figure 3. deZeng No. 560 Phorometer-Trial Frame

The instrument is supported by its bottom on an arm from an articulating stand. An arm extends upward to support a curved headrest, which serves to hold constant the distance between the subject's eyes and the optical system of the instrument.

A swingable telescoping arm is provided to hold a "near vision target card" for testing the required correction at near distances (as for reading). We see, on our left, near the bottom, its near portion with a U-shaped holder for the target card.

7.2.2 *The sphere lens component*

As with a basic trial frame, the sphere lens component, used to determine the needed correction for myopia or hyperopia, is done in this instrument by placing "loose" sphere lenses, drawn from a large arsenal in a case at the refractionist's side, into receptacles in the instrument, just in front of the subject's eyes.

7.2.3 *The cylinder lens component*

Again, as with a basic trial frame, the needed cylinder lens component (if any), used to determine the needed correction for astigmatism, is done by placing loose cylinder lenses in receptacles just in front of the ones for sphere lenses. These receptacles are arranged to be rotated, by a small wheel geared to the cylinder lens receptacle (well, the gear **is** the wheel), to set the axis direction of the cylinder lens (indicated on a scale).

7.2.4 *Integral accessory units*

7.2.4.1 Introduction

The instrument includes three integral accessory units used for various special tests, ready to be swung into place if needed to perform their tasks in the overall examination.

7.2.4.2 The Stevens Phorormeter

This is the "funny big eyeglasses" item, here shown in operating position. It folds down when not in use.

It consists of a prism lens (of power 5 prism diopters) on each side. The two prism lenses can be rotated (together, owing to the gear between them) with the small "baseball bat-like" handle we see upstanding just to our left of center.

This apparatus is used to detect and quantify various *phorias*, failures of the eye, when we do not try and focus on an object, to nevertheless aim at the same place.

The details of these vision defects and of the tests done with this apparatus is beyond the scope of this article.

7.2.4.3 The Maddox rod lens units

This lens essentially consists of a number of narrow cylinder lenses (with one flat side) arrayed immediately adjacent, then given an overall circular outline, and mounted in a larger opaque black circular disk. We see one, for example, on our right side of the figure,. currently hanging in about the "4 o'clock" position.

A small flat handle provides for rotating the disk and thus the lens to change the axis of the cylinder lenses. A scale is provided to indicate the axis setting.

This apparatus is used to diagnose and quantify several *cyclophorias*, which are misbehavior of the eyes typically caused by improper operation of the muscles that move the eye. A common such condition is *strabismus*, a condition in which the two eyes seriously do not converge on the same object.

The details of these vision defects and of the tests done with this apparatus are beyond the scope of this article.

7.2.4.4 The Risley prism units

We see one of these just behind the Maddox rod lens mentioned earlier

Its purpose is to simulate (and thus allow us to optimize) the prism component that corrective lenses sometime are required to have to mitigate the effect of various *phorias*.

Each unit one consists of two prisms, arranged so that they can be rotated with respect to each other, in opposite directions, by turning a small knob. The effect is to create a prism lens whose prism power can be adjusted from "none" to a maximum of 15 prism diopters (15^{Δ}). A scale shows the value that is set.

In addition, the entire unit can be rotated so as to change the "base orientation" of this variable power prism lens. A second scale shows the base orientation that is set.

7.3 The deZeng No. 570 Phoro-Optometer

7.3.1 *Introduction*

From this, it was a natural step to equip the instrument with a section that could provide a range of spherical lens powers with lenses placed on adjacent rotatable disks, rather than using loose trial lenses. Thus, the refractor, as we would today recognize it, was born. Figure 4 shows the deZeng No. 570 Phoro-Optometer, introduced in 1915.

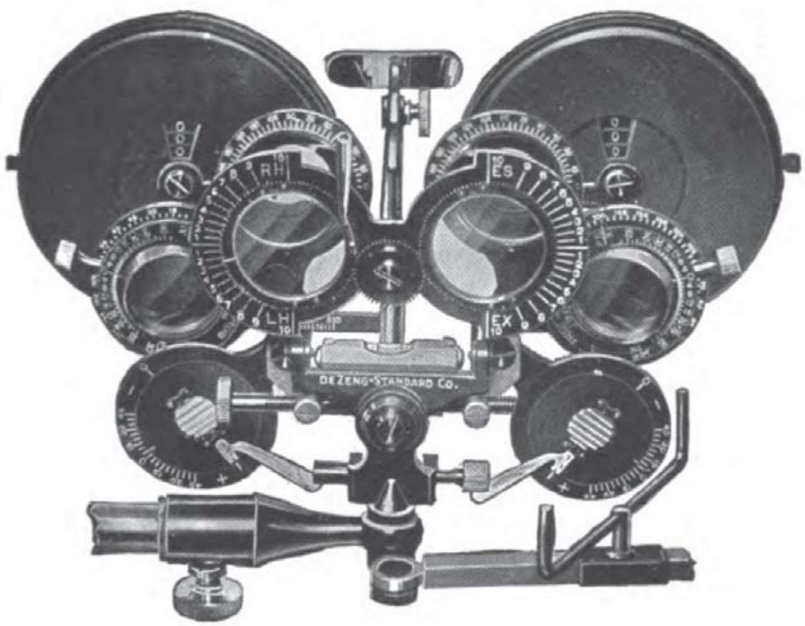

Figure 4. deZeng No. 570 Phoro-Optometer

The “phoro” part of the name again reflected that it included provisions for diagnosing and quantifying various *phorias*, and the “optometer” part (meaning “eye measure”) referred to its ability to “refract” the eyes for corrective lenses.

7.3.2 *The sphere lens section*

This instrument looks just like the Phorometer-Trial Frame but with the two canister-like sphere lens disk units grafted on. There are three disks inside each of those housings. The sides of the housing are open, and the edges of the disks, protruding through the open sides, are serrated, allowing them to be moved with the finger.

By manipulating the three disks, a range of sphere powers, both minus and plus, could be established. The current powers of all three lenses can be read though a single small window in the front of the housing, allowing the overall sphere power being introduced to be easily determined. We see that in figure 5.

Figure 5. deZeng No. 570–left eye sphere lens unit

The indication seen here is +5.50 D.

7.3.3 *Disk and lens layout*

The lenses in this model have a nominal diameter of 1 inch.

<u>Sphere disks</u>

- Sphere disk 1(I number them from the eye outward), the "strong sphere" disk, carries sphere lenses of power from -8.00 D through +6.00 D in steps of 2.00 D.
- Sphere disk 2, the "intermediate sphere" disk, carries minus sphere lenses of power from 0.00 through -1.75 D in steps of 0.25 D.
- Sphere disk 3, the "weak sphere" disk, carries plus sphere lenses of power from 0.00 through +1.75 D in steps of 0.25 D.
- Sphere disk 0 (nearest the eye), the auxiliary lens disk, includes lenses with powers -0.125 D, +0.125 D, -10.00 D, and +8.00 D. (A further description of this disk is given in section 7.3.4

In normal usage, only disk 2 or 3 (but not both) would have non-zero settings, the one used having lenses of the same sign as the sign of the region in which disk 1 was set. The point is that the values to be added by the refractionist always have the same power, thus simplifying the arithmetic.

The total range of sphere power is -10.00 D through +8.00 D in steps of 0.125 D (but all markings are to 2 decimal places); and

-19.75 D through -10.00 D and +8.00 D through +15.75 D in steps of 0.25 D.

Note that the indication shown in figure 5 does not reflect an ingredient of ±0.125 D from the auxiliary lens disk, which would be in play for powers not an integral multiple of 0.25 D.

7.3.4 *The auxiliary lens section*

The rearmost disk (closest to the eye) is the auxiliary lens disk. It is moved by a lever projecting though then open side of the housing, and the lens in place is shown through a small window on the rear.

Its arsenal includes:

- Sphere lenses of powers -0.125 D and +0.125 D for attaining "half step" powers between those given by the basic sphere section (these are actually marked "-.12" and "+.12")
- Sphere lenses of powers -10.00 D and +8.00 D for extending the range of sphere powers
- A sphere lens of power +1.50 D for retinoscopy (here, the refractionist uses an ophthalmoscope, looking through that lens on the refractor, to inspect the subject's retina)
- A blank position for blocking the vision of the eye while the other eye is being examined (two blanks, actually, only one marked as such)
- And of course, an open hole ("O") for when none of the lenses on this disk are being used.

7.3.5 *The cylinder lens provision*

As to the cylinder lens component, in the basic form of the instrument this is done (just as with the Phorometer-Trial Frame) by placing loose cylinder lenses in a rotatable receptacle in front of the sphere lens "department". We can see this nicely in figure 5.

But in this instrument a more elaborate arrangement for this purpose (known as a *rotary cross cylinder* unit) was available as an option. It is described in Appendix A.

7.3.6 *Integrated auxiliary units*

This models carried exactly the same battery of special measuring accessories as the No. 560 Phorometer-Trial Frame.

7.4 The deZeng No. 574 Phoro-Optometer

The deZeng No. 574 Phoro-Optometer, introduced in 1920, was very much like the No. 570 but was reduced a bit in size and weight. We see it in figure 6.

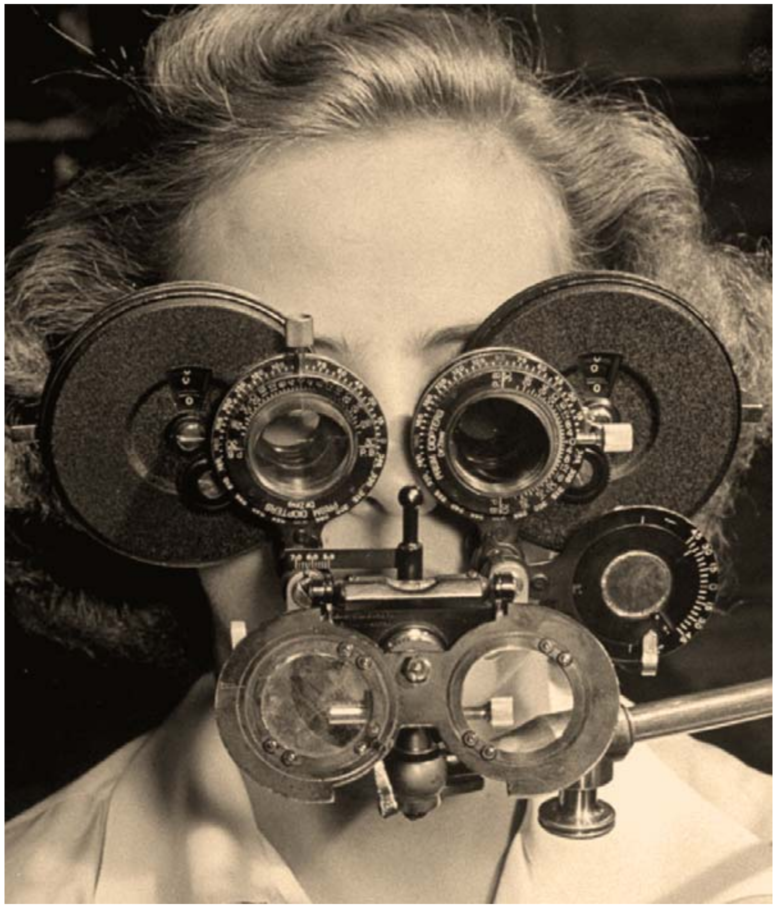

Figure 6. deZeng No. 574 Phoro-Optometer

Compared to the 570, the headrest was eliminated, and rubber eye cups were added to the “sight ports” to properly locate the subject’s head.

It could also optionally be equipped with the rotary cross cylinder unit mentioned above in connection with the No. 570.

The lenses in this model have a nominal diameter of 13/16 inch. This was the principal factor that allowed the reduction of size compared to the No. 570 (which had 1” diameter lenses).

The layout of the sphere disks and the range of sphere powers are the same as for the No. 570 (other than for the lens diameter).

The integrated auxiliary units are probably the same as for the No. 570.

In the No. 570, the curved post that held the headrest also carried, flaglike, the scale used to indicate the pupil distance measurement. In the No. 574, that post, no longer needed for its main original job, exists in vestigial form, mainly to carry that scale. But it extends a bit beyond what is needed for that to a small ball on its top. I conjecture is that this, read with respect to the tip of the nose, is used to roughly properly initially align the instrument with the subject's face.

7.5 The deZeng No. 584 Phoroptor

7.5.1 *Introduction*

A significant change was made with the No. 584 (1922)–a second set of two lens disks to provide the cylinder power rather than relying upon the placement of "loose" trial lenses. We see a typical specimen in figure 7.

Figure 7. deZeng No. 584 Phoroptor

To this model deZeng applied the shorter coined name "Phoroptor" (which he registered as a trademark).

7.5.2 *The sphere lens section*

The range of sphere lens powers is now attained with only two lens disks, simplifying the manipulation of the instrument. Here, the front and rear covers of the sphere lens housing are themselves also lens disks, both carrying various kinds of auxiliary lenses.

The sides of the housing are open, and the slightly protruding edges of the two sphere lens disks are serrated so that they can be moved by finger.

As with the earlier models, the powers of the two disks can be read with indications visible through a small window. But for negative powers, the large ingredient would be negative but the small ingredient would be positive, requiring a little signed number arithmetic to determine the overall power being indicated.

7.5.3 *The cylinder lens section*

Here, rather than having to work the cylinder power aspect with loose trial lenses, this model has a second set of two (smaller) disks, equipped with cylinder lenses of various powers. We see the housings for those disks closest to us in front of the larger sphere disk sections.

As with the sphere lens section, the sides of the cylinder lens housings are open, and edges of the disks, which protrude slightly from the housings, are serrated at their outer edges, allowing them to be moved by finger.

7.5.4 *Disk and lens layout*

The lenses in this model have a nominal diameter of 9/16 inch.

<u>Sphere disks</u>

- Sphere disk 1, the “strong sphere” disk, carries sphere lenses of power from -8.00 D through +6.00 D in steps of 2.00 D.
- Sphere disk 2, the “weak sphere” disk, carries plus sphere lenses of power from 0.00 D through +1.75 D in steps of 0.25 D.
- The front auxiliary disk has a lens with power +0.125 D
- The rear auxiliary disk has lenses with powers -10.00 D and +8/00 D.

The total range of sphere powers is -18.00 D through +15.875 D in steps of 0.125 D (but all markings are to two decimal places).

<u>Cylinder disks</u>

- Cylinder disk 1 carries minus cylinder lenses of power of 0.00 D and -0.125 D and then -1.50 D through -6.00 D in steps of 1.50 D.
- Cylinder disk 2 carries minus cylinder lenses of power from 0.00 D through -1.25 D in steps of 0.25..

The total range is 0.00 D through -1.25 D in steps of 0.125 D and -1.25 D through -4.75 D in steps of 0.25 D (but all markings are to two decimal places).

The powers of the lenses on the two disks can be read through two small windows, allowing the cylinder power being introduced to be easily determined. (The two components will always be of the same algebraic sign, always minus.)

7.5.5 *Cylinder axis setting*

The units containing these cylinder lens disks can be rotated about the optical axis in their entirety to set the cylinder lens axis direction. They have straight handles to facilitate this. There is a circular scale on which the axis angle can be read.

7.5.6 *The auxiliary lens disks*

Both the front and back covers are in fact auxiliary lens disks, and thus can be rotated. They both carry short conical posts for this purpose.

The front cover carries prisms of three different powers and base orientations; a sphere lens of power +0.125 D (marked "+.12), to attain sphere powers between those provided by the sphere lens unit proper; and of course an open hole ("O") for when no lens on this disk is to be used.

The rear cover carries sphere lenses of powers -10.00 D and +8.00 D (labeled just "-10" and "+8"), to expand the overall available range of sphere powers, a red filter (labeled "R.G." (which oddly enough means "red or green filter", but which is always red on this model); a blank position to block the vision of the eye when the other eye is being examined, and of course an open hole ("O) for when no lens on this disk is to be used.

7.5.7 *Integrated auxiliary units*

Compared to the No. 584, the Stevens Phorometer was deleted, it being recognized that it was too infrequently needed. But the Maddox rod lens units and the Risley prism units are still at the ready. The overall diameter of the Maddox rod lens unit was somewhat enlarged.

7.6 The American Optical No. 588 Phoroptor

7.6.1 *Introduction*

In 1925, American Optical Company bought the deZeng-Standard Company, and in 1927 introduced the No. 588 Phoroptor[3], which probably had been designed by deZeng himself (presumably originally intended to be introduced by his firm). Its full name is the "Wellsworth deZeng No. 588 Phoroptor". We see a typical one (this one, in fact, from our personal collection) in figure 8.

Figure 8. American Optical Wellsworth deZeng No. 588 Phoroptor

"Wellsworth" was a tradename used by American Optical for almost all its products from 1921 through 1927. It honors George Washington Wells, a key figure in the founding and early expansion of American Optical. "deZeng", of course, honored the designer of the instrument. His name was well recognized and respected in the industry at the time owing to his excellent instruments to date, and American Optical no doubt wanted to capitalize on that.

7.6.2 *Power setting and indication*

An important design feature of the No. 588 is that it natively could set both sphere and cylinder lens powers to any value in the respective range in increments of 0.125 D, rather than the 0.25 D basic increment of the earlier (and later) models. But of course that finer resolution came at a price.

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[3] Sometimes identified in AO literature as the "Model 588 Phoroptor" and in one case, as the "Wellsworth DeZeng Improved Phoroptor, Model 588". Here I will follow the nomenclature as shown on the nameplate.

In the sphere lens section, this required the use of three lens disks rather than two to cover the range expected of these instruments. But having added a third disk, the range now is substantially greater than in the prior models, -24.00 D through +23.875 D.

Another "price" paid for the finer resolution was that the range of the cylinder lens section now only extends to only -3.00 D rather than the -6.00 D of the prior models.

The front of the sphere disk housing is in fact one of the sphere lens disks, and its outer edge is knurled to allow it to be moved by finger.

Again, the power settings of all three disks are seen through a small window on a stationary disk in the center of the front cover of the sphere lens housing, requiring a little more arithmetic. For negative powers, one of the ingredients is negative and the other two positive, making the arithmetic all the more tricky. Figure 9 shows an example of this indication.

Figure 9. Sphere power indication

The indication is showing a power of +23.00 D. The markings "O" and "10$^{\Delta}$BI" that are visible in the picture are choices on the auxiliary lens disk, indicated by the handle on the rear cover of the housing, which is in fact the auxiliary lens disk.

As to the cylinder unit, as before, the power of the lenses in place from each of the two disks is visible through separate small windows.

7.6.3 *Disk and lens layout*

The lenses in this model have a nominal diameter of 11/16 inch.

<u>Sphere disks</u>

- Sphere disk 1 carries sphere lenses of power from -24.00 D through +16.00 D in steps of 8.00 D (and there are two blank positions).

- Sphere disk 2 carries plus sphere lenses of power from 0.00 D through +7.00 D in steps of 1.00 D.

- Sphere disk 3 carries plus sphere lenses of power from 0.00 D through +0.875 D in steps of 0.125 D. (But all powers are indicated to only two decimal places and with no leading zero, *e.g.*, for +0.875, "+.88")

The total range of sphere powers is -24.00 D through +23.875 D in steps of 0.125 D (but all markings are to two decimal places).

<u>Cylinder disks</u>

- Cylinder disk 1 carries minus cylinder lenses of power of 0.00 D through -2.50 D in steps of 0.625 D.

- Cylinder disk 2 carries minus cylinder lenses of power from 0.00 D through -0.50 D steps of 0.125 D.

The total range of cylinder powers is 0.00 D through -3.00 D in steps of 0.125 D (but all markings are to two decimal places).

7.6.4 *The auxiliary lens disk*

The back of the sphere lens housing is also actually the auxiliary lens disk. It has a protruding handle to allow it to be moved.

From the back of the instrument (the subject's side) the auxiliary lens in effect is indicated by a set of markings which are read against a imaginary horizontal fiducial.

On the front of the instrument (the refractionist's side), in the center of the front cover/lens disk there is a stationary disk. On it the various auxiliary lenses are marked as seen partially in figure 9). To determine the auxiliary lens in effect we read the auxiliary lens handle (at the back of the cylinder lens housing, but visible from the front with a little imagination) against that roster.

The arsenal of auxiliary lenses comprises prisms of three different powers and base orientations; a pinhole ("P.H."), used to distinguish refractive errors from, for example, degradation of the retina; a Double Maddox Prism (DMP); a blank; and of course an open hole ("O") for when none of these auxiliary lenses are to be used.

7.6.5 *Integrated accessories*

Again we see the familiar Maddox rod lens and Risley prism units. As with the prior model, they can each be swung down when being used. When one of these units is swung down into the line of sight, it hits an adjustable stop so as to be precisely located.

7.6.6 *Mounting*

The elbow for fixing the instrument to an arm from a supporting stand has a slot so that it will side over a clamping screw threaded into the arm. The slot in the elbow is “T-shaped” so that, after loosening the clamping screw, the instrument can be tilted fore-and-aft so that the sight lines will be horizontal.

The portion of the elbow that rides on the vertical column of the refractor is split and fits with an interference fit so that there is friction as the refractor is rotated. Thus prevents the refractor, once oriented as desired, from swinging around too freely. There is no provision for clamping the rotational position of the refractor.

7.6.7 *The near vision target rod support.*

The silver object just below the black support elbow is the attachment for the near distance target support rod (often called the “reading rod"). It allows the near target to be moved from side to side into the proper position, or to be swung up out of the way when not in use.

The portion of the attachment that rides on the vertical column of the refractor is split and fits with an interference fit so that there is friction as the attachment is rotated. This prevents the near target rod from swinging around too freely.

Oddly enough, in our specimen, on the reading rod attachment, the serial number of the refractor is stamped, both on the part that goes over the column and on the part that pivots vertically.

7.6.8 *Leveling adjustment*

The support block is mounted on a pivot in a yoke supported by the mounting elbow. A spring in a fitting on the left side of the support yoke pushes on a post on the support block. On the right side, a small knob turns a screw running in a fitting on the support yoke, which pushes on the opposite side of that post. Thus by tuning this knob the lateral tilt of the instrument can be changed to level it. A small spirit level is provided to show when the unit is level.

7.6.9 *Pupil distance adjustment*

The left and right units are each hung from the ends of two slides, running in the support block. A central knob turns a pinion which engages rack teeth in both slides, allowing the separation of the units to be adjusted so that the distance between the eye ports will correspond to the subject’s pupil distance (PD), while maintaining the units symmetrically with respect to the support block.

A scale on the left slide is read against the left edge of the support block to indicate the setting in effect.

7.6.10 *Additive effective power*

This model is said to have the “additive effective power” feature. That means the design of the lenses is such that the actual total power attained will be very nearly the sum of the indicated powers of the different lenses in effect. I say “very nearly” since it has been shown that the feature cannot be precisely achieved in a system with more than two ranks of lenses (the No. 588 has four ranks).

Readers interested in this knotty matter may wish to read “Tillyer’s Additive Trial Lens System”, by the same author, probably available where you get this.

I note that in the rigorous application of Tiller’s system , “zero lenses” must be actual lenses, albeit with zero power. In the No. 588 Phoroptor, for all four lens disks, the zero lenses are just empty holes in the disks.

7.7 The American Optical No. 589 Phoroptor

7.7.1 *Introduction*

In 1934, American Optical introduced the Additive Effective Power Phoroptor (No. 589). It made modest functional and aesthetic improvements to the design of the No. 588. It is significantly bigger and heavier. We see a typical one (this one, in fact, from our personal collection) in figure 10.

Figure 10. AO Additive Effective Power Phoroptor (No. 589)

On some (probably early) units, the nameplate reads DeZeng Additive Effective Power Phoroptor.

7.7.2 *Construction and organization*

In the immediately preceding models, the front and back "covers" of the sphere lens unit were in fact lens-carrying disks. and the lenses on them could be easily seen. In this model, the number of disks was reduced and the front and back covers became just that (again), no lenses being exposed. But the sides of the housing are open, and the cylinder disks have nice knurled rims so they can be moved by finger.

The auxiliary lens disk (included in the sphere lens unit) is moved by a projecting handle, which curls around to the front so its position can be read against markings there.

The reduction in the number of cylinder lens disks compared to the No. 588 was in part made possible in that the basic range of the sphere lens power was no longer in 0.125 D increments but rather in

0.25 D increments (as for most models before and after the No. 588). But sphere lenses of power -0.125 D and +0.125 D[4] on the auxiliary lens disk allow sphere powers in steps of 0.125 D to be achieved.

The sphere lens disks have nice knurled rims, exposed through the open sides of the housing, by which they can be turned as required.

Now, in both the sphere lens and cylinder lens sections, the powers of the two disks are shown adjacent in the same small window (see also sections 7.7.4.1 and 7.7.4.2).

As with the prior models, the cylinder units can be rotated in their entirety around the visual axis to set the axis direction of the cylinder lens component. The units have a handle to rotate them to set the cylinder lens axis. A circular scale is provided to read the axis setting.

In some versions (including the one shown), there is a long white long line on each cylinder unit corresponding to the axis direction to allow the refractionist to get a visual idea of the general axis setting without having to refer to the scale.

Figure 11 gives another view of the overall configuration.

Figure 11. AO Model 589 recumbent

7.7.3 *Disk and lens layout*

The lenses in this model have a nominal diameter of 3/4 inch. This will be the case for all subsequent models

[4] On the specimen shown, the +0.125 D lenses in the auxiliary lens disk have been removed and replaced by opaque black fiber disks. All "in between" powers can still be attained with the use of the -0.125 D lens in the auxiliary lens disk.

Sphere disks

- Sphere disk 1 carries sphere lenses of power from -18.00 D through +15.00 D in steps of 3.00 D.
- Sphere disk 2 carries sphere lenses of power from -1.00 D through +1.75 D in steps of 0.25 D.
- The auxiliary disk includes lenses at -0.125 D and +0.125 D.

The total sphere power range is -19.125 D through +16.875 D in steps of 0.125 D; the steps between multiples of 0.25 D require the use of the -0.125 D or +0.125 D auxiliary lenses. (All markings are to 2 decimal places.)

Cylinder disks

- Cylinder disk 1 carries minus cylinder lenses of power of 0.00 D through -6.00 D in steps of 1.50 D.
- Cylinder disk 2 carries minus cylinder lenses of power from 0.00 D through -1.25 D in steps of 0.25 D.

The total cylinder power range is 0.00 D through -6.00 D in steps of 0.25 D.

7.7.4 *Power indication*

7.7.4.1 Sphere section

The powers in effect from the two sphere disks are shown in a single window just inboard of the disk control rims. We see some examples in figure 12.

Figure 12. Sphere power indications

Plus (and zero) values are in white on black, minus values are in red on black.

We see here (l. to r.) powers of 0.00 D, +6.50 D, and -5.50 D.

Note that, as seen in the third picture, the refractionist may have to do some simple signed number arithmetic to learn the power in effect.

7.7.4.2 Cylinder section

The powers in effect from the two cylinder disks are shown in a single window near the edge of the cylinder unit, near the handle. We see two examples in figure 13.

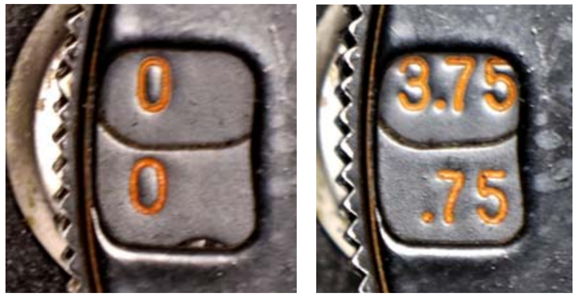

Figure 13. Cylinder power indications

We see here (l. to r.) powers of 0.00 D and -4.50 D.

Minus (and zero) values are in red on black. There are no plus power cylinder lenses. Accordingly, the refractionist does not really have to do any signed number arithmetic.

7.7.5 *Zero lenses*

Each of the lens disks (sphere and cylinder) has a “zero power” position, which is just an open hole in the disk.

7.7.6 *A precursor*

The organization of the sphere and cylinder lens powers in this model recurs in all later models in this line of evolution (although the physical design and mechanics may differ substantially).

7.7.7 *Separate auxiliary lens facility*

At the front of the sight line (on the front face of the cylinder units actually) is a holder for “loose” auxiliary lenses. A flexible clip holds the lens in place (but those are missing on the specimen seen here).

One of the provided lenses is a minus cylinder lens (I think -6.00 D) used to extend the range of cylinder powers. It has an axis mark that is aligned with a mark on the holder when it was put in place. Then its axis will be the same as that of the “internal” cylinder lenses as the cylinder unit is rotated.

7.7.8 *Integrated accessories*

Various versions of this model had two or three integrated accessory units, the candidates including the familiar Maddox rod lens and Risley prism units, plus a newcomer, the Jackson Cross Cylinder (JCC). As with the prior model, each can each be swung down when being used. The specimen shown has the Risley prism and the JCC.

The JCC is a very clever device used to enhance the refinement of the cylinder power and axis settings (the subject may not be sufficiently subjectively sensitive to the optimum setting of these parameters). It is discussed a bit (as it appears on Model 590) in section 7.8.11, which also gives a reference to a more detailed discussion of the theory of its operation.

The swing-down pivot arrangement for these auxiliary units is considerably more sophisticated than that of the prior model (the No. 588). When one of these units is swung down into the line of sight, it hits a stop (adjustable in the field) so as to be precisely located. A detent serves to keep the unit against the locating stop.

In the parking position the unit also hits a locating stop, and again the detent holds it reliably in that position.

7.7.9 *Mounting*

The elbow for fixing the instrument to the arm from a supporting stand is apparently intended for being fixed to the arm with a through bolt. The refractor can be tipped fore and aft after loosening two clamps, one with a wheel with fancy spokes and a second with a knob. I do not yet understand the point of this curious arrangement.

7.7.10 *Leveling adjustment*

The support block is mounted on a pivot in a yoke supported by the mounting elbow. A spring in a fitting on the left side of the support yoke pushes on a post on the support block. On the right side, a small knob turns a screw running in a fitting on the support yoke, which pushes on the opposite side of that post. Thus by tuning this knob the lateral tilt of the instrument can be changed to level it. A small spirit level is provided to show when the unit is level.

7.7.11 *Pupil distance adjustment*

The left and right units are each hung from the ends of two slides, running in the support block. A central knob turns a pinion which engages rack teeth in both slides, allowing the separation of the units to be adjusted so that the distance between the eye ports will correspond to the subject's pupil distance (PD), while maintaining the units symmetrically with respect to the support block.

A pointer on the left end of the "right" slide is read against a scale mounted on the left end of the "left" slide to indicate the setting in effect.

7.7.12 *Near vision target rod support*

The support arm attachment for the near vision target rod pivots on the support mast, and thus can be swung to the left or right. A detent stabilizes its centered position. The attachment is vertically articulated so that the arm (and target) can also be raised out of the sight line.

7.7.13 *Additive effective power*

The phrase "additive effective power" in the name of the instrument alludes to the fact that in this instrument the design of the lenses is such the actual total power attained will in fact be very nearly that the sum of the indicated powers of the different lenses in effect (a feature actually introduced with the No. 588).

As I had noted in connection with the No. 588 Phoroptor, in the rigorous application of Tillyer's system for attaining additivity (not actually exactly valid for trains of more than two lenses), "zero lenses" should preferably be actual lenses, albeit with zero power. In the No. 598 Phoroptor, for all four lens disks, the zero lenses are just empty holes in the disks.

7.8 The American Optical Model 590 Phoroptor

7.8.1 *Introduction*

The Model 590 Phoroptor, (note the subtle difference in the nomenclature, now with "Model") was reportedly introduced by American Optical in 1948. We see one in figure 14 (this one, in fact, from our personal collection).

This model took an entire new design approach in many different ways, essentially moving beyond the deZeng design tradition (although the principles of its operation followed directly in that tradition). It was the precursor of the modern line of Phoroptor instruments. It was significantly larger and heavier than the No. 589.

For the first time, all the disks on a given side, both sphere and cylinder, are enclosed in a single housing.

The main section of the housing contains two disks with sphere lenses and (nearest the subject) a disk with various auxiliary lenses. The cylinder section, immediately adjacent in front, also has two disks, smaller in size.

Figure 14. American Optical Model 590 Phoroptor

7.8.2 *A cone of its own*

To make the back side of the instrument seem less confining to the subject, the disks and housings were made conical (with the apex toward the subject). We can see this clearly in figure 15, with the instrument recumbent:

Figure 15. AO Model 590 Phoroptor showing conical configuration

This also has technical advantages, as it makes the disks much more rigid and thus facilitates maintaining exactly the intended separations between the four lenses of a "train".

It at first looks as if the two main units could be varied in their angle, so as to maintain the proper "converged" lines of sight when near vision tests were being made, but not so. That capability would have to wait for the next generation of Phoroptors.

7.8.3 *Control of the sphere disks*

As the same vein as the previous models, the two sphere disks are moved by way of their edges, but these now have quite elegant chrome plated rims with a "straight knurl" pattern. The rims of the two disks have slightly different diameters to allow both to be easily distinguished.

On each rim there is a narrow, basically-smooth track set back slightly from the knurled portion. These tracks have small notches at intervals of one step of the disk rotation. These are part of a detent system that facilitates setting the disks to exactly an exact lens position.

But the notches are carried across the knurled portion of the rim as well, where they provide another sort of grip for the finger of the refractionist as the disks are to be moved.

7.8.4 *Disk and lens layout*

The lenses in this model have a nominal diameter of 3/4 inch.

<u>Sphere disks</u>

- Sphere disk 1 carries sphere lenses of power from -18.00 D through +15.00 in steps of 3.00.

- Sphere disk 2 carries sphere lenses of power from -1.00 D through +1.75 in steps of 0.25 D.

- The auxiliary lens disk (nearest the eye) includes lenses of power -0.125 D and +0.125 D

The total range of sphere power is -19.125 D through +16.875 D in steps of 0.125 D, but the steps between multiples of 0.25 D require the use of the -0.125 D or +0.125 D auxiliary disk lenses. (All markings are actually to 2 decimal places.)

The total power of the two sphere lenses is directly shown in a small rectangular window by an ingenious scheme of interaction of markings on the two disks. No arithmetic by the refractionist is required. Figure 16 shows example indications. These pictures are from both right- and left-eye units, so, for example, the first and second pictures have a "mirror image" relationship..

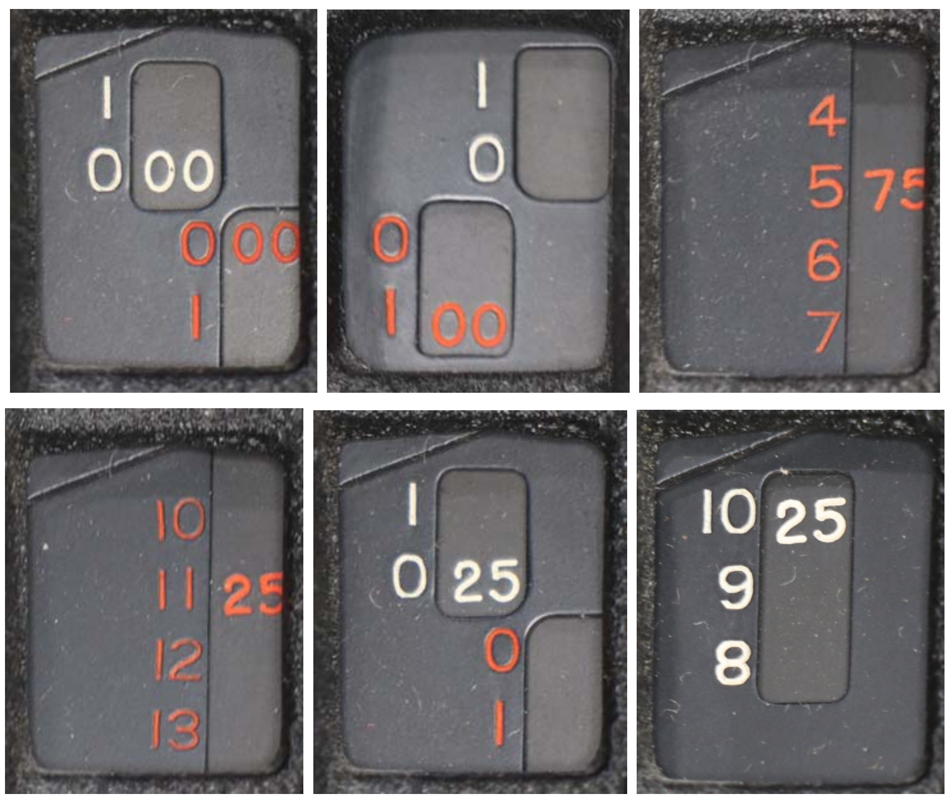

Figure 16. Sphere power indications

The figures are white for plus values and red for minus values, both parts of the indication always being consistent in color. Zero gets it both ways (as we see in the first photo).

The photo at the lower right shows a power of +10.25 D. That power is actually composed with a +9.00 D sphere lens on the strong sphere disk and a +1.25 D lens on the weak sphere disk. So the system is very clever to show so clearly and directly the correct total power as "+10.25".

As with the earlier models, when the refractionist wanted to, for example, increase the sphere power by several steps, when the weak sphere disk "cycled", the strong sphere disk would have to be separately moved up one step (the equivalent of a "carry" when adding decimal numbers). But, as with the previous models. the arrangement of the knurled rims allowed the refractionist, if alert to the fact that a "carry": is needed, to move both disks with a stroke of the same (properly placed) finger.

To facilitate this, in this model the rim of the weak cylinder disk (closest to the refractionist) has small radial red and white tick marks in certain positions, which provide cues when a carry maneuver is required.

We see both of these in figure 17. The marking "BL" is for the blank position of the auxiliary lens disk, and has nothing to do with what is being spoken of here.

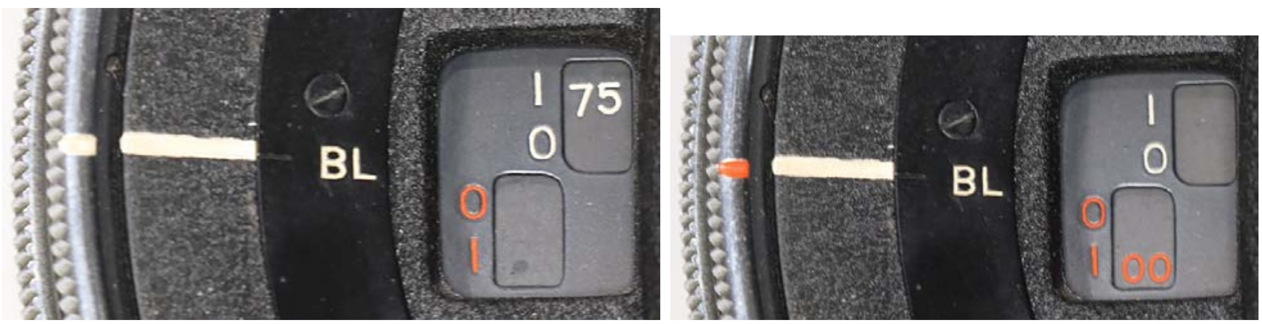

Figure 17. Carry cue marks

On the left we see a current power setting of +1.76 D. The next higher step (+2.00 D) uses a different lens in the strong lens disk, so to move up one step we must move both disks. The white tick mark alerts us to this.

On the right we see a current power setting of -1.00 D. The next lower step (-1.25 D) uses a different lens in the strong lens disk, so to move down one step we must move both disks. The red tick mark alerts us to this.

One of the notches in the knurled part of the rims of both disks is painted red. The purpose if this is not known to me.

7.8.5 *Control of the cylinder disks*

Unlike the earlier models, in this model the two disks of the cylinder lens section are controlled with a single knob. When turned, it advances the weak cylinder disk, and when a "carry" is needed, a

Geneva mechanism[5] does that for us. The resulting power of the two disks is shown directly in a small window by a rotating indicator disk with 25 positions.

Another knob, behind, and coaxial with, the cylinder power knob, rotates all the cylinder lenses (on both disks) so as to bring the axes of the two actually in the path to the desired orientation. (That all the others also move is no harm.) We see that whole area in figure 18.

Figure 18. Cylinder power control and indication

The Geneva mechanism is of an unusual design. The cylinder power setting knob actually moves the Geneva wheel itself, which has two parts. The first part, for every 1/5 rotation of the wheel, moves the weak sphere disk by one step (which is also 1/5 of a rotation). The second part, in more traditional Geneva mechanism style, after the end of every full revolution of the wheel, moves the strong sphere disk by one step (1/5 of a rotation).

The knob controlling the cylinder axis is turned clockwise to increase the axis angle, which results in the lenses being turned counterclockwise. While turning a knob clockwise to increase a value probably seemed logical to the designers, in fact, for optometrists and ophthalmologists, counterclockwise to increase the axis angle is intuitive. (This was changed on the following model!)

7.8.6 *Minus cylinder and plus cylinder versions*

By the time this model was introduced, the need to provide a refractor in either minus cylinder or plus cylinder form was well recognized. In fact, the nameplate for the instrument seen in figure 14 shows the model number as “390MC”, the “MC” likely being for “minus cylinder” (that specimen is a minus cylinder instrument).

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[5] Like the mechanism that does the “carry” between the digits in a mechanical automobile odometer.

7.8.7 *Disk and lens layout*

<u>Cylinder disk</u>

Minus cylinder units

- Cylinder disk 1 carries minus cylinder lenses of power from 0.00 D through -5.00 D in steps of 1.25 D.
- Cylinder disk 2 carries cylinder lenses of power from 0.00 D through +1.00 D in steps of 0.25.

The total range of cylinder power is 0.00 D through -6.00 D in steps of 0.25 D.

In plus cylinder units this is the same except that all signs are plus.

7.8.8 *The auxiliary lens disk*

The disk carrying the auxiliary lenses is moved by a thumbpiece (black or white at different eras) on a lever which travels over a limited arc near the knurled rims of the cylinder lens disks, in front of the disks. It moves the auxiliary lens disk through gearing so that its modest arc of travel moves the disk through its entire range. A sector-style scale, pointed to by the thumbpiece, shows which auxiliary lens item is in place.

The arsenal of auxiliary lenses comprises prisms of three different powers and base orientations; sphere lenses of power -0.125 D and +0.125 D (marked "-0.12" and "+0.12"), used to easily attain sphere powers between those provided by the basic sphere section; a pinhole ("PH"), used to distinguish refractive errors from, for example, degradation of the retina; a red filter ("RG"); a blank position (BL), to block the vision of that eye; and of course an open hole ("O") for when none of these auxiliary features are to be used.

Unlike in earlier models, the features on the auxiliary lens disk are not spaced at uniform angles over the entire repertoire. The prism lenses are of smaller diameter than some of the other lenses, and the pinhole requires a smaller surrounding space. Thus the latter items were more closely spaced around the disk than were the larger lenses.

7.8.9 *Separate auxiliary lens facility*

The "business end" of the sight line is a tube that accommodates "loose" auxiliary lenses, which are in mounts that slip into the tube. That tube rotates with the cylinder axis setting. This way, if a loose auxiliary cylinder lens is used (perhaps to extend the cylinder power to an unusually-large value), its axis will be set the same as for the two cylinder lenses in place from the disks. (Such lenses have a locating pin that goes into a hole on the front end of the tube so the proper relationship is set for the auxiliary lens.)

The end of the tube has two radial white lines that show the orientation of the cylinder axis currently set. There is no scale against which those marks can be read.

7.8.10 *The integrated accessory units*

Maddox rod lens, Risley prism, and Jackson Cross Cylinder (JCC) units are present, in the familiar “swing down” deployment. They have been somewhat redesigned to best fit in with the overall mechanical and aesthetic style of this instrument.

When one of these units is swung down into the line of sight, it hits a stop (adjustable in the field) so as to be precisely located. A detent serves to keep the unit against the locating stop.

In the parking position the unit also hits a locating stop, and again the detent holds it reliably in that position. This detent also holds the unit in the parked position.

7.8.11 *The Jackson Cross Cylinder (JCC)*

The Jackson Cross Cylinder (JCC) was new (as an option) on the No. 589 Phoroptor, but seemingly standard on this model..[6] We see it in figure 19 (not swung quite into place).

This ingenious mechanism is of great value when refining the needed cylinder power and axis. But this JCC does not have its axis automatically synchronized with the current axis setting of the cylinder lenses themselves. It has its own axis angle scale so it can be set to the appropriate axis angle, using the knob we see as a handle.

The JCC maneuver depends on flipping the lens over between two comparative stages of a determination, when the refractionist says that iconic phrase, “Which is better, one…[click]… or two? That is done here by twisting the knob. A detent holds the lens stably in one position or the other.

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[6] The theory of the Jackson Cross Cylinder is a bit complicated, and won’t be covered here. The reader who is interested in is working will find that described in the companion article, “The Refractor/Phoropter—An Important Tool in Vision Correction”, by the same author. It is probably available where you got this.

Figure 19. Jackson cross cylinder (JCC) unit

We see etched into the prism glass the markings "+.20" and "-.20". These are the powers of the plus and minus cylinder lens components, and the markings indicate the location of the axes of these two components. This clue as to the axis location is not really needed in the use of the mechanism; the refractionist follows a routine that relates to the red and white dots on the lens.

7.8.12 *Mounting and positioning*

In figure 20 we see the mounting facility and various positioning controls annotated.

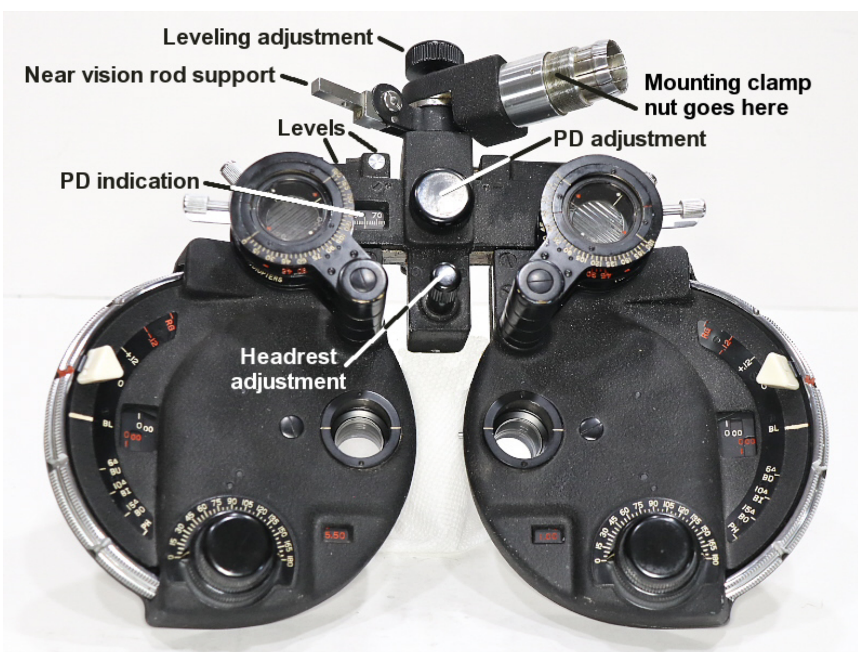

Figure 20. Positioning controls

The elbow by which the instrument is mounted to an overhanging arm from a stand has a collet-like arrangement, tightened by a knurled knob, for clamping the instrument to that arm.[7]

There is also the familiar arrangement for supporting a near vision target rod.

A slim but long knob just below the PD adjustment knob moves the headrest back and forth so as to change the distance between the subject's head (and thus eyes) and the instrument.

7.8.13 *Leveling adjustment*

The knob at the very top operates the "leveling" movement of the instrument by tipping the support block with respect to the support yoke that is suspended from the mounting elbow. A small level allows us to see when the unit is level in that regard. A second level shows if the unit is level in the "back and forth" direction (but there is no real facility for changing that unless the mounting arm is in a cooperating orientation).

7.8.14 *Pupil distance setting*

The large knob in the center controls the spacing between the two eye ports (the pupil distance, PD), operating in a way similar to that earlier described for the No. 588 and No. 598 phoropters. The distance that is set is indicated in a small window by a scale attached to the left slide.

7.8.15 *Corneal position sights*

This instrument has fold-up sights (much like old-style open rifle sights) on the back of both main units to allow the refractionist to confirm that the machine is positioned so the optical reference plane is at the proper distance from the corneas of the subject's eyes. If not, the headrest can be adjusted as required to correct that.

7.8.16 *Sanitary face shields*

This model, the first in the dynasty to do so, has provisions for placing replaceable plastic "sanitary face shields" on the area at the rear of the instrument that will be touched by the subject's face. The shields hook over small posts projecting inward from the "inside" edges of the housing, and slip under flat metal springs on the back of the housing (integrated with the corneal sight assembly, actually the same spring that serves as a detent for the erection of the corneal sights).

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[7] That knob is missing from the specimen shown in figure 7.

7.8.17 *A timeline curiosity*

A patent that describes in great detail almost exactly the complete design and intricate mechanisms of this model (down to the last rivet) was applied for in the spring of 1939 and issued in late 1941. A second patent, equally precisely describing the design of this model, and making additional claims, was applied for on the same date in 1939 and issued in mid-1943 (a common occurrence, when a patent is "divided" to allow separate negotiations with the patent examiners on contentious points).

Clearly, the detailed design of this instrument was 99.9% complete by the spring of 1939. Yet, according to the widely-cited historical recitations, the instrument was not introduced until 1948.

A further curiosity is this. American Optical bought Spencer Lens, a well-respected manufacturer of microscopes and similar instruments, in 1935. It became the corporate unit responsible for phoroptor manufacture.

Seemingly, for quite some while, AO operated that operation under the Spencer Instrument name (perhaps referenced as a division of American Optical Company), probably because that name was so well respected in its product area. The aspect of Spencer Lens that would have presumably been responsible for refractors was known as its Scientific Instrument Division.

But in 1945, AO stopped referring to that part of its operation as "Spencer Lens [a Division of American Optical Company]", and begin speaking of that organization as the Instrument Division of American Optical Company.

Yet the nameplate on our specimen contains the area shown in figure 21.

Figure 21. AO 590 nameplate

It may well be that the original plan was to introduce this model in, say, late 1941, and that all the parts (including the nameplates) had been made, perhaps even completed units assembled, but the onset of

Work War II (for which American Optical was called upon to produce many optical items) caused that introduction to be put off until 1948 (when AO had "recovered" from its wartime situation). Maybe.

7.8.18 *Personal comment*

This is my favorite refractor model.

7.9 The RxMaster

7.9.1 *Introduction*

In 1956, American Optical introduced the RxMaster Phoroptor series of refractors. Figure 22 shows a typical one.

Figure 22. RxMaster Phoroptor

We note that, just as for the kitchen appliances of the era, it could be obtained in several designer colors, although we see it here in the ever-popular black.

Illustrative catalog numbers are 11320 for the minus cylinder version (in the figure), 11325 for the plus cylinder version.

It carried forward many of the improvements of the Model 590. But the very ingenious conical configuration of the 590 was left behind. Evidently its advantages were outweighed by greater manufacturing complexity (or something).

But this model has the additional feature of being able to cant the two major units toward each other ("convergence") so as to maintain the appropriate sight lines when near vision tests were being conducted.

7.9.2 *Automatic "carry" from the weak sphere disk*

A significant improvement is that the "carry" from the weak sphere disk to the strong sphere disk is done for us by a Geneva mechanism, which had been introduced for the cylinder section on Model 590. Now, only the rim of the "weak sphere" disk, with its nice knurled edge, is exposed for the refractionist to manipulate. It again has the slightly depressed smooth but notched track for a roller detent arm to operate on. The rim of the strong sphere disk is not exposed at all.

For gradual changes in the needed sphere power, the refractionist moves the weak sphere disk, with the carry to the "strong sphere" disk being done when needed by the Geneva mechanism.

But if the refractionist really wants to move the strong sphere disk directly (to make a large change in the sphere power), it can be moved directly with the knob seen at the far left and right near the top of the unit.

Those small cylindrical housings behind that knob in fact hold the sphere Geneva mechanisms. (So that was a good place to put that knob to get access to the movement of the strong sphere disk!)

In any event, the total indicated power in effect is shown through a small window, essentially as we saw for the Model 590. The disk layout (for both sphere and cylinder lenses) is the same as on that model.

The Geneva mechanism here is of a rather unusual design, with two stages. For every 1/3 revolution of the weak sphere disk (four steps), the first Geneva stage moves an intermediate shaft by 1/3 revolution. Then, for every full revolution of the intermediate shaft (and thus a full revolution of the weak sphere disk), the second Geneva stage moves the strong sphere disk by one step (1/12 revolution).

Unlike the typical Geneva mechanism, the second Geneva mechanism does not lock the driven wheel (the strong sphere disk) in position when it is not being advanced. That is so the strong sphere wheel can be directly moved by the string sphere knob.

As to the strong wheel disk, we rely on a detent mechanism to hold it in an integral position after the Geneva mechanism has moved it (but then has "turned loose" of it).

There is a slip clutch in the train to avoid damage if the movement of the weak sphere disk is stopped when the Geneva mechanism is trying to move the strong sphere disk and the refractionist then tries to move the strong sphere disk directly with the strong sphere knob.

7.9.3 *Cylinder disk control*

As with the Model 590, the cylinder lenses are moved by a single knob, a Geneva mechanism taking care of the "carry" when the weak cylinder disk "carried". The mechanism is essentially the same as was described for the Model 590.

7.9.4 *Disk and lens layout*

The lenses in this model have a nominal diameter of 3/4 inch.

Sphere disks

- Sphere disk 1 carries sphere lenses of power from -18.00 D through +15.00 in steps of 3.00.
- Sphere disk 2 carries sphere lenses of power from -1.00 D through +1.75 in steps of 0.25 D.
- The auxiliary lens disk includes lenses of power -0.125 D and +0.125 D

The total range of sphere power is -19.125 D through +16.875 D in steps of 0.125 D. (All markings are to 2 decimal places.)

Cylinder disks

Minus cylinder units

- Cylinder disk 1 carries minus cylinder lenses of power from 0.00 D through -5.00 D in steps of 1.25 D.
- Cylinder disk 2 carries cylinder lenses of power from 0.00 D through +1.00 D in steps of 0.25.

The total range of cylinder power is 0.00 D through -6.00 D in steps of 0.25 D.

In plus cylinder units it is the same except that all signs are plus.

As with the model 590, The power that is set shown directly through a small window.

Also as with the Model 590, another knob, coaxial with and behind the cylinder power knob, rotated (all) the cylinder lenses, so as to set the desired axis angle of the lenses actually in the sight line. As with the Model 590, this cylinder axis knob is provided with a scale to show the angle that is set. Unlike the Model 590, the direction of this knob is the same as the direction in which cylinder axis values were considered to increase.

As with the Model 590, the “muzzle” of the sight line is a tube that accommodates “loose” auxiliary lenses, which are in mounts that slip into the tube. That tube rotates with the cylinder axis setting

This way, if a “loose” auxiliary cylinder lens is used (perhaps to extend the cylinder power to an unusually-large value), its axis will be set the same as for the two cylinder lenses in place from the disks. (Such lenses have a locating pin that goes into a hole on the front end of the tube so the proper axis relationship is set for the auxiliary lens.)

Arrows on the front end of that tube operate on a circular scale to show the setting of the cylinder axis. This scale is easier for the refractionist to see than the cylinder axis scale around the axis setting knob; they both show the same indication.

7.9.5 *Control of the auxiliary lens disk*

Somewhat as with the Model 590, the auxiliary lens disk is moved by a small lever (rather than a thumbpiece) running in a limited arc just behind the projecting knurled rim of the weak sphere disk (actually behind the hidden strong sphere disk as well). Its location to the rear simplifies the gearing between it and the auxiliary lens disk, and avoids any interference by the lever with the visibility of the sphere power indication. The "open" position (used when no auxiliary lens is to be used) is now all the way at the top.

7.9.6 *Integrated accessory units*

The Maddox rod lens and Risley prism units are still with us, now mounted in a three-position turret rather than individually swinging down into place when used). Now they are joined by a Jackson Cross Cylinder (JCC). The turret is laid out as if for four lenses, but one "leg" is absent, the empty place being in front of the sight line when none of these accessories are in use.

7.9.7 *The Jackson cross cylinder (JCC)*

As mentioned earlier in connection with the Model 590, this ingenious apparatus allows improved refinement of the needed cylinder power and cylinder axis. We see it (on a different specimen) in figure 23.

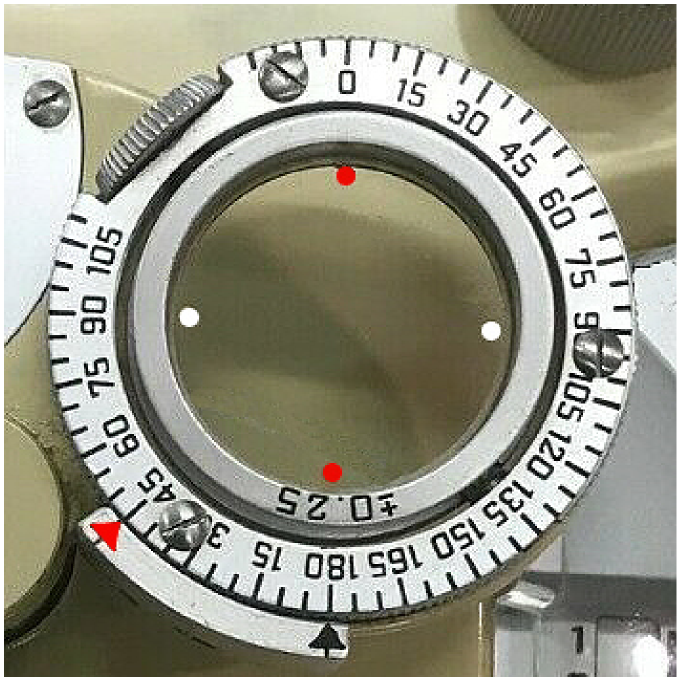

Figure 23. Jackson Cross Cylinder (JCC)

Here, the "flip" of the lens is done with a small thumbwheel (seen at the upper left). Rotation of the entire unit to the proper angle (to match that set for the cylinder lens) is done by grasping its knurled exterior (the "flange" with the axis scale on it is knurled).

Actually, there are two "proper" alignments, 45° apart, used in two different phases of the test (refinement of the cylinder power and refinement of the cylinder axis). The red and black fiducial arrows are for those two phases.

As discussed before for the Model 590, the red and white dots show the directions of the plus and minus cylinder axes of the lens, respectively.

The marking ±0.25 tells the power of the two cylinder components (plus and minus). It is not used to indicate the axis of either component as that is not actually needed during the procedure (the colored dots serving that purpose).

7.9.8 *Positioning controls*

In figure 24 we see the mounting facility and various positioning controls annotated.

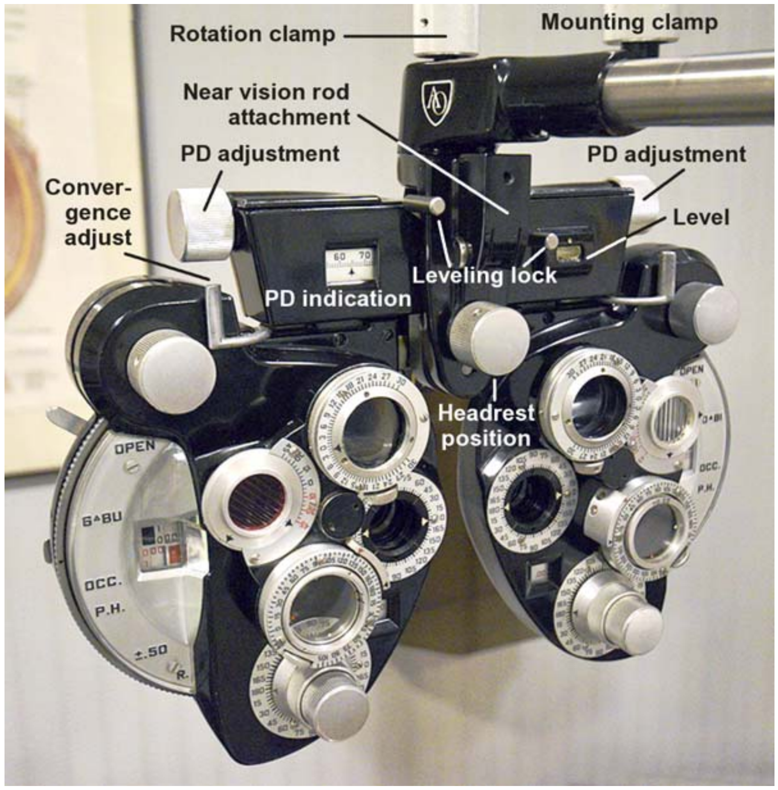

Figure 24. Positioning controls

The *mounting clamp* knob tightens the mounting "elbow" on the arm from the supporting stand.

The *rotation clamp* knob locks the left-to-right rotation of the instrument, or sets an adjustable amount of friction..

The two posts labeled *leveling lock* work a rocker arm that locks or unlocks the ability to tilt the instrument from side to side. A small level allows us to see when the unit is level.

The *PD adjustment knobs* on the left and right (they are on the same shaft; either one can be used, as is convenient) adjust the spacing between the eye ports of the two main units (the *pupil distance*, or PD). The distance set is indicated in a small window.

The knob in the center moves the headrest (not seen) back and forth so as to change the distance between the subject's head (and thus eyes) and the instrument.

The near vision rod attachment is shown folded up, out of the way. There is a clamp screw that fixes the rod into the attachment, but it is missing in this specimen. Note that, unlike in earlier models, there is no provision for moving the rod from side to side.

The *convergence adjust* levers (we see only one labeled) cant the two main units toward each other to provide convergence of the sightlines during near vision testing.

When the units are converged, the minimum workable pupil distance increases. There is an ingenious mechanism that enforces proper coordination of convergence setting and minimum pupil distance.

There are detents for the levers in both the “normal” and fully-converged positions.

7.9.9 *The corneal position sights*

This instrument has fold-up sights (much like old-style open rifle sights) on the back of both main units to allow the refractionist to confirm that the machine is positioned so the optical reference plane is at the proper distance from the corneas of the subject’s eyes. If not, the headrest can be adjusted as required to correct that. These are slightly more elaborate than those on the Model 590, but not much.

7.9.10 *Sanitary face shields*

As with the Model 590, this model had provision for attaching disposable or reusable (and presumably sterilizable) sanitary face shields which cover the part of the rear of the instrument that would touch the subject’s face.

Unlike the arrangement on the Model 590, these do not hook over a stud extending inward from the inboard side of the main units, but are wholly held in place by the flat spring on the rear (again, an extension of the spring that works the detent for the erection of the corneal position sight).

The arrangement on the Ultramatic RxMaster Phoropter is essentially identical, and a typical installation there is seen in Figure 30.

7.10 The Ultramatic RxMaster

In 1967, American Optical introduced the Ultramatic RxMaster Phoroptor series of refractors. We see a typical one in figure 2.

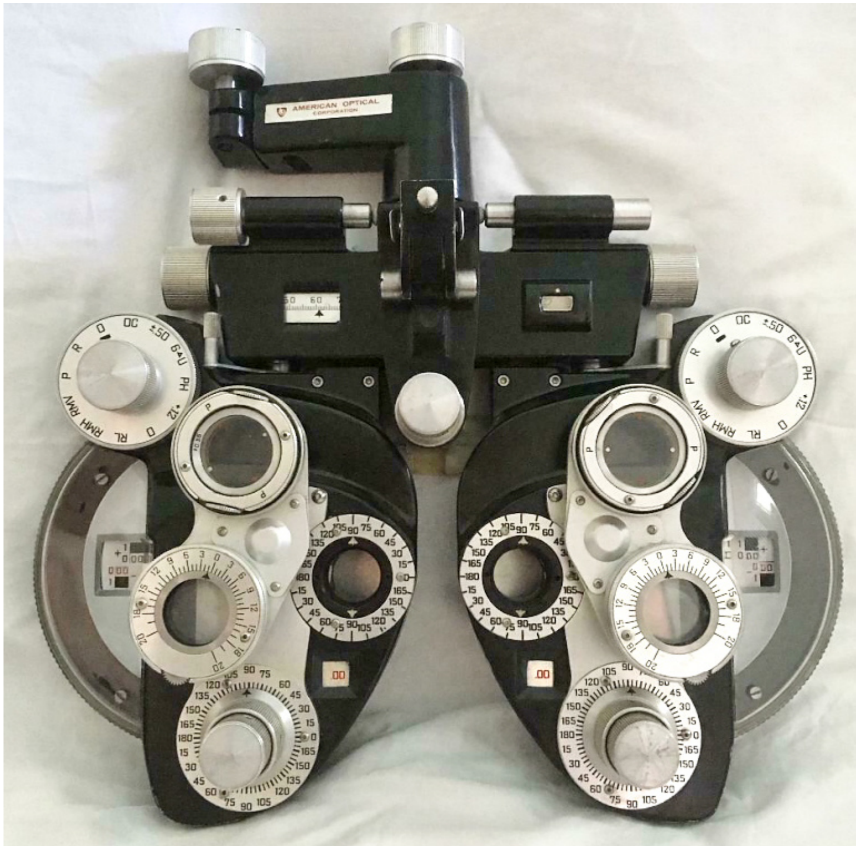

Figure 25. Ultramatic RxMaster Phoroptor

Illustrative catalog numbers are 11625 for the minus cylinder version (in the figure), 11635 for the plus cylinder version.

This is the model most of us have looked through at our last visit to the optometrist (that would have been a 11625) or ophthalmologist (who would have a 11635).

It closely follows the general design of the RxMaster, but with a number of important improvements. The two can be most easily distinguished by differences in the layout of some of the controls.

One readily obvious change is that now the auxiliary disk can be moved by a knob located in front of, and coaxial with, the (now larger) knob that directly moves the strong sphere disk.

The knob has an indicator disk on which all the “lenses” are designated. In one position (“O” for “open”) an open hole is put in place, the normal state of this disk when none of its special lenses are needed. In another position (“OC”, for “occluded”), the disk is opaque so as to block the path for that eye (while the other eye is being examined).

The repertoire of sphere lenses in the two disks is identical to that described above for the RxMaster refractor. As in that model, the lenses have a nominal diameter of 3/4 inch.

The method of control and indication of the cylinder powers, and the repertoire of cylinder lenses in the two disks, is identical to that described above for the RxMaster refractor.

The Risley prism and Jackson Cross Cylinder (JCC) units are still with us, now mounted in a two-position turret. In this model there is no Maddox rod lens in the turret. The turret is laid out as if for three lenses, but one "leg" is absent, the empty place being in front of the sight line when none of these accessories are in use.

We see the JCC unit in figure 26. Here, the "flip" of the lens is done with either of two small thumbwheels.

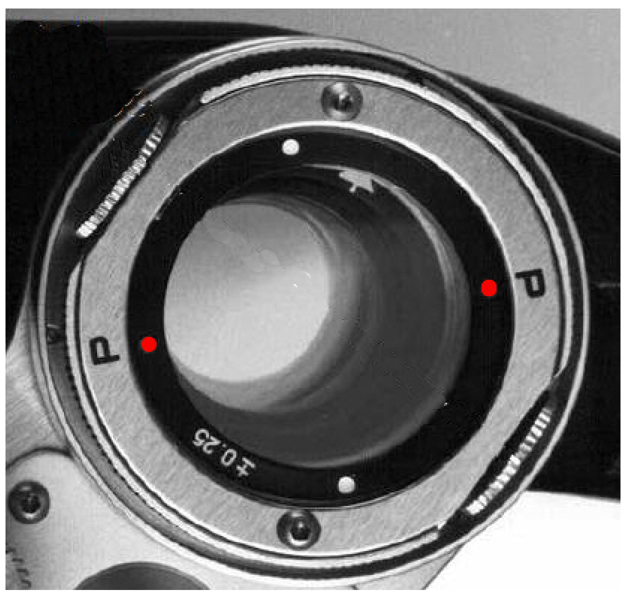

Figure 26. Jackson Cross Cylinder (JCC)

This unit differs in an important way from the JCC used in the RxMaster model. Here, the JCC unit is automatically set for the proper orientation (matching that of the setting of the cylinder axis), done by a gear train that cleverly finds its way into the turret

Actually, there are two "proper" alignments, 45° apart, used in two different phases of the test (refinement of the cylinder power and refinement of the cylinder axis). So the JCC unit can be directly rotated (thanks to a slip clutch between it and the gearing), by turning its knurled exterior, to either of those two relative positions. A detent is provided so that either of those relative positions can be assuredly located and maintained. We see this knurled exterior (on a different unit, actually) in figure 27.

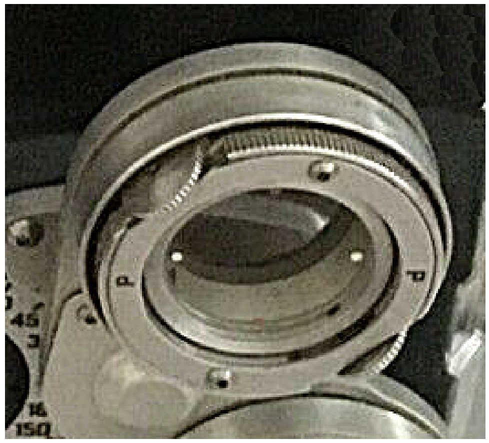

Figure 27. JCC showing knurled exterior

Note the “guard wall” around the JCC unit proper. I assume this is to prevent the unit from being turned inadvertently.

The markings “P” (“power”) are aligned with the cylinder axis for the *cylinder power refinement test*. This position is detented and is at the end of the rotation limit of the unit, so it is not hard to get this right.

Sometimes there are also two markings of “A” (“axis”) along an axis 45° from that of the “P” markings (the same as the axis of the flip thumbwheels). They are aligned with the cylinder axis for the *cylinder axis refinement test.*

But when there are no “A” marks (typical), the instructions are to align the axis of the two thumbwheels with the cylinder axis for the cylinder axis refinement test.

In any case, this position is detented and is at the other end of the rotation limit of the unit, so it is not hard to get this right.

The marking ±0.25 tells the power of the two cylinder components. It is not used to indicate the axis of either component as that is not actually needed during the procedure (the colored dots serving that purpose).

The test that would formerly be made with the Maddox rod lens as we have seen it up to now can now be made (somewhat less thoroughly) with a Maddox rod lens available among the auxiliary lenses (with two axis orientations, vertical and horizontal, on each side).

On the right eye side it is red and on the left eye side clear (said to be “white”), which assists with the test using this arrangement.

7.10.1 *Positioning controls*

In figure 28 we see the various positioning controls annotated.

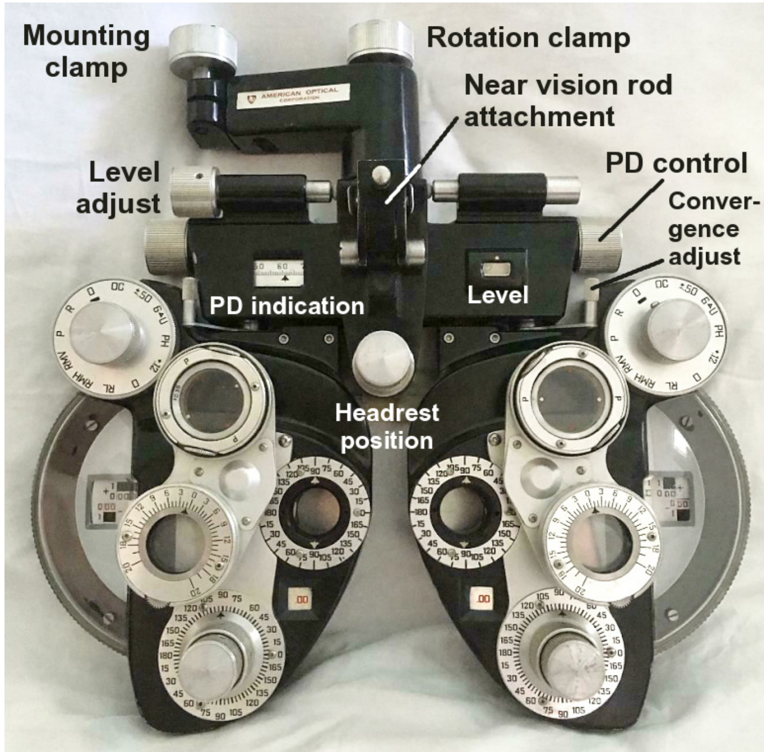

Figure 28. Positioning controls

The *mounting clamp* knob tightens the mounting "elbow" on the arm from the supporting stand.

The *rotation clamp* knob locks the left-to-right rotation of the instrument, or sets an adjustable amount of friction..

The *level adjust knob* tilts the instrument from side to side, operating a screw working against a spring plunger on the opposite side. A small spirit level allows us to see when the unit is level.

The *PD control* knobs on the left and right (they are on the same shaft; either one can be used, as is convenient) adjust the spacing between the eye ports of the two main units (the *pupil distance*, or PD). The distance set is indicated in a small window.

The knob in the center moves the headrest (not seen) fore and aft so as to change the distance between the subject's head (and thus eyes) and the instrument.

The *convergence adjust* levers (we see only one labeled) cant the two main units toward each other to provide convergence of the sightlines during near vision testing.

When the units are converged, the minimum workable pupil distance increases. There is an ingenious mechanism that avoids conflict of convergence and pupil distance settings.

The near vision rod attachment is shown folded up, out of the way. We see (not annotated) the head of the clamp screw that fixes the rod into the attachment.

7.10.2 *The corneal position sights*

Original production of this model included the rifle-sight like corneal position sights very similar to those seen on the Model 590 and on the RxMaster.

Later versions have periscope-like sights. The "periscope" feature allows the refractionist to view the corneal position indication from the front side of the instrument. We see this in context in figure 29.

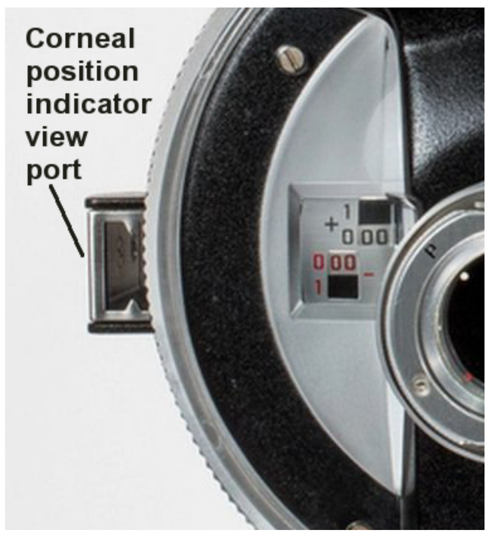

Figure 29. Periscope corneal position indicator

7.10.3 *Sanitary face shields*

As with the RxMaster models, this model had provision for attaching disposable or reusable sanitary face shields which cover the part of the rear of the instrument that would touch the subject's face. The mounting arrangement is essentially as described for the RxMaster models in section 7.9.10. Figure 30 shows a typical installation.

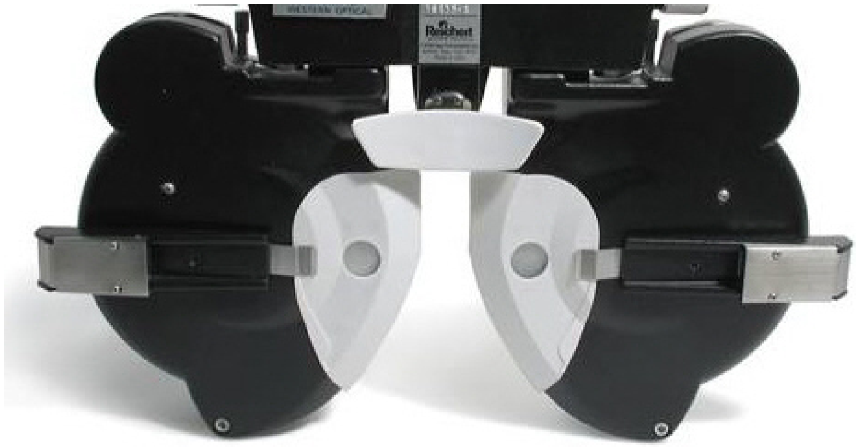

Figure 30. Sanitary face shields

7.11 Reichert, and sort-of Leica.

In 1982, American Optical sold its refractor business to Reichert (its current name is Reichert Technologies, but over the years that has varied a bit in the wake of corporate reorganization and such). Reichert continued to make the Ultramatic RxMaster Phoroptor, and has added a number of new features and modest design changes. It still offers those models at this writing (2022).

At one time, Reichert became an element of Leica, the famous maker of cameras, optical instruments, and the like, and for a while, the Ultramatic RxMaster Phoroptor was sold under the "Leica" tradename. Figure 31 shows one with the Leica logo.

Figure 31. Leica Ultramatic RxMaster Phoroptor

8 OTHER REFRACTORS TODAY

Today, several firms (*e.g.*, Topcon, Formerly Tokyo Optical) make refractors that appear to be almost exact copies of the Reichert Ultramatic Rx Master Phoroptor. Almost certainly, many of Reichert's key patents on that model have expired.

Other less-known firms also offer refractors that seem to be essentially identical to the Reichert Ultramatic Rx Master Phoroptor.

Among other things, this is a tribute to the inventors, other engineers, and industrial designers who have, for over a century now, contributed to the lineage of those now-iconic machines.

9 BEYOND MANUAL REFRACTORS

Over the past several decades, many manufacturers of optometric instruments have developed, first, manual refractors that delivered their ultimate settings digitally, then various kinds of fully automatic refraction systems. Some of these show a clear connection with the manual refractor dynasty that is the subject of this article, but I have arbitrarily cut off the story before them.

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Appendix A

The rotary cross cylinder unit

In the basic form of the deZeng No. 570 Phoro-Optometer (the 574 as well), the cylinder lens component of the corrective lens was simulated, just as in a basic trial frame, by placing loose cylinder lenses in a rotatable receptacle just in front of the receptacle for the sphere lens (for the 570) or the sphere disk unit (for the 574)..

But in the 574 a more elaborate arrangement (known as a *rotary cross cylinder* unit[8]) was available as an option. One of these units was placed in front of each eye (just in front of the sphere lens unit).

This ingenious device, invented by deZeng, has three cylinder lenses: one of power +3.00 D and two with power -1.50 D. The axes of the two -1.50 D lenses can be rotated, symmetrically with respect to the axis of the +3.00 D lens, with a small knob. The entire unit can be rotated using the that knob, which is on a long “stalk”, as a handle.

The result, at any given setting of the axes of the -1.50 D lenses, is in effect the combination of two cylinder lenses with powers of equal magnitude but opposite sign, with their axes at an angle of 90° to each other (called a “cross cylinder” lens).

The magnitude of their powers is determined by the angle between the -1.50 D lenses and is settable (over the range 0-3.00 D) by rotating the knob, and is shown on a scale.

The entire unit can be rotated (using the knob on its stalk as a handle) to set the axis directions of the plus and minus cylinder components. A second scale shows the positions of those axes.

When the magnitude is set to 0, the unit just becomes a glass window, with no refractive effect.

Imagining for example that the setting is for a magnitude of 1.00 D, with a plus axis direction of 90° and a minus axis direction of 180°, that can be shown to be equivalent to a sphere lens of power +1.00 D combined with a cylinder lens with a power of -2.00 D with an axis direction of 180°.

The cylinder component of this is just what we really want from this unit. The sphere component is unwanted, but is unavoidable. So we

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[8] Be careful not to confuse this with the *cross cylinder*, a type of auxiliary lens used for certain tests, or the *Jackson Cross Cylinder*, which is used to refine the cylinder power and axis settings.

must compensate for it by changing the power of the sphere lens section itself by the negative of the magnitude indication on the unit. And we must multiply the magnitude indication on the unit by 2 to get the cylinder power that is introduced (as a minus value). And we must consider the axis of the cylinder power to be the indicated minus axis direction.[9]

That all having to be said, this is not nearly as convenient as the "direct" cylinder lens section that was subsequently introduced with the No. 584 Phoroptor.

In 1921, when a "standard" No. 574 Phoroptor, with a stand, sold for $210.00, the cross cylinder units (No. 1110) cost an extra $20.00 each.

The instrument with one rotary cross cylinder unit was known as No. 576, and with two, No. 578. I have no idea how the refractor with one rotary cross cylinder unit would work.

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[9] This is all based on the presumption that we want the result to be in "minus cylinder" form, as seemingly was most widely used in the era of this instrument.