## PHOTOGRAPHIC OBJECTIVES #1: THE NORMAL LENS

The lens that typically comes with the camera is called the normal lens. Optically it is deemed normal because it is the shortest focal length that will fill the dimensions of the film size.

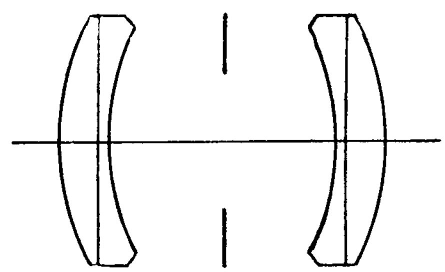
A simple positive lens will project a real image of a faraway scene one focal length away from the image plane in a circle approximately one focal length in diameter. Recall the In-Class Demonstration. To fully cover the rectangular format of the film requires a lens whose image diameter = the diagonal of the film format.

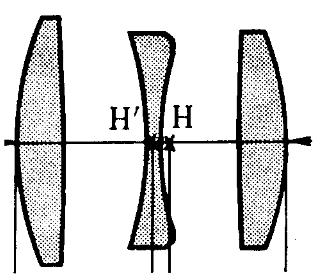
On the next page are some contemporary film formats and their horizontal, vertical, and diagonal dimensions. Notice how the focal length of the normal lens shipped with the camera is in close agreement with the diagonal dimension.

But more importantly, the perspective it affords is similar to that of the human eye regarding the same scene. A good test of this concept is to look through the viewfinder of a 35mm SLR camera equipped with a 50mm focal length lens, (the focal length normally supplied with the camera) and open the other eye. The views are similar, although the camera view will probably be slightly larger.

### THE COOKE TRIPLET

Overcoming astigmatism was the Holy Grail of 19th century optical engineers, which they accomplished with lenses they christened anastigmats. (A - Stigmatism means without a crossing; to make a negative of this negative adds another a- prefix, which converts to ana.) These designs were based on a symmetric pairing of achromats.

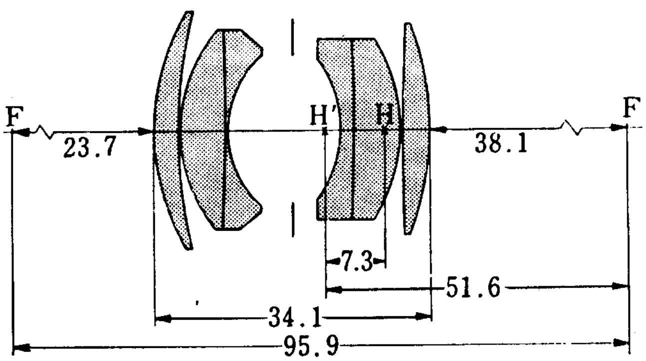




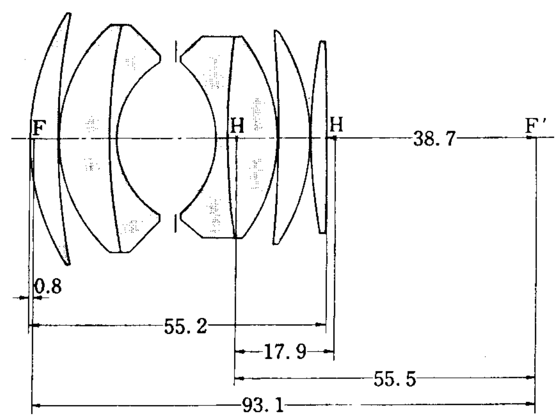

A pair of achromats means that there are four lenses to be ground, two of high index, and two of low index glass, with a high and low index face getting glued together. It is the beauty of the three element design of H. Dennis Taylor where a high index lens fits between two lower index glasses to become an achromatic system, with enough degrees of freedom in shaping the curvature of the six lens surfaces to guarantee elimination of the other aberrations.

This design is named not after its inventor but for the optical shop that Taylor worked for, Cooke of York in England. Although invented on their premises, they had no wish to manufacture it, so production was undertaken by the firm of Taylor, Taylor, and Hobson in Leicester but named in deference to its birthplace.

The drawback to the early Triplets was a relatively high f/number, like 3.5 and on up. But modern calculations have made this design speedier by splitting up the duties of each of the original three elements between 2 or 3 elements apiece, like the 50 mm f/2 amd the 55 mm f/1.2 shown below. Modern day anti-reflection coatings allow the use of the extra glass surfaces without flaring out the image.




**Optical formula of Nikkor-H Auto 1:2 f=50mm.**



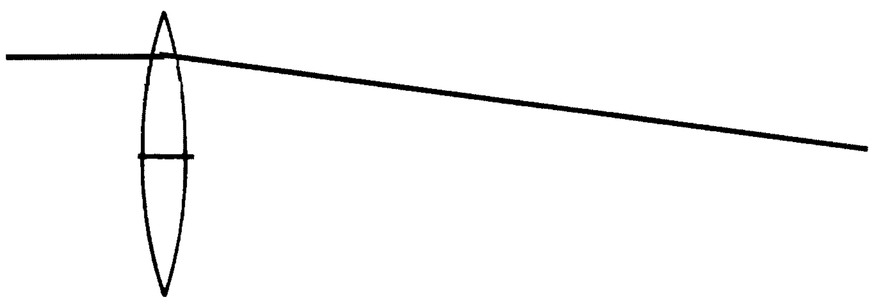

**Optical formula of Nikkor-S Auto 1:1.2 f=55mm.**

Although the 21st century normal lenses have autofocus motors embedded in their housings, the optical formula is a 19th century design tweaked to perfection! Some of the better brands are capable of 100 line pairs per millimeter of resolution!

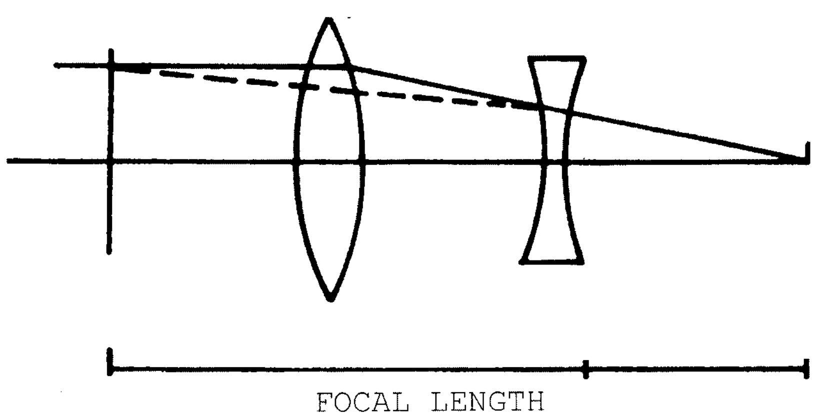
## PHOTOGRAPHIC OBJECTIVES #2: TELEPHOTOGRAPHIC LENSES

The longer the focal length, the larger the image for a given object distance, and this property can be used to make far away objects seem closer. For instance, a 1000mm focal length lens would magnify the image of an object 20X as compared to a normal 50mm lens, but that would mean the single element would have to be 1 meter away from the film plane when focussed at infinity, and moved further away for closer objects, making an unwieldy device having to be tripod mounted. Even a 200 mm focal length lens would have to be placed that far away, and racked out to 220 mm for the typical head and shoulders 1/8 magnification portrait.

A telephotographic lens, or telephoto for short, is a special optical design that is physically shorter than a single lens of the equivalent focal length. The engineering trick is illustrated here.

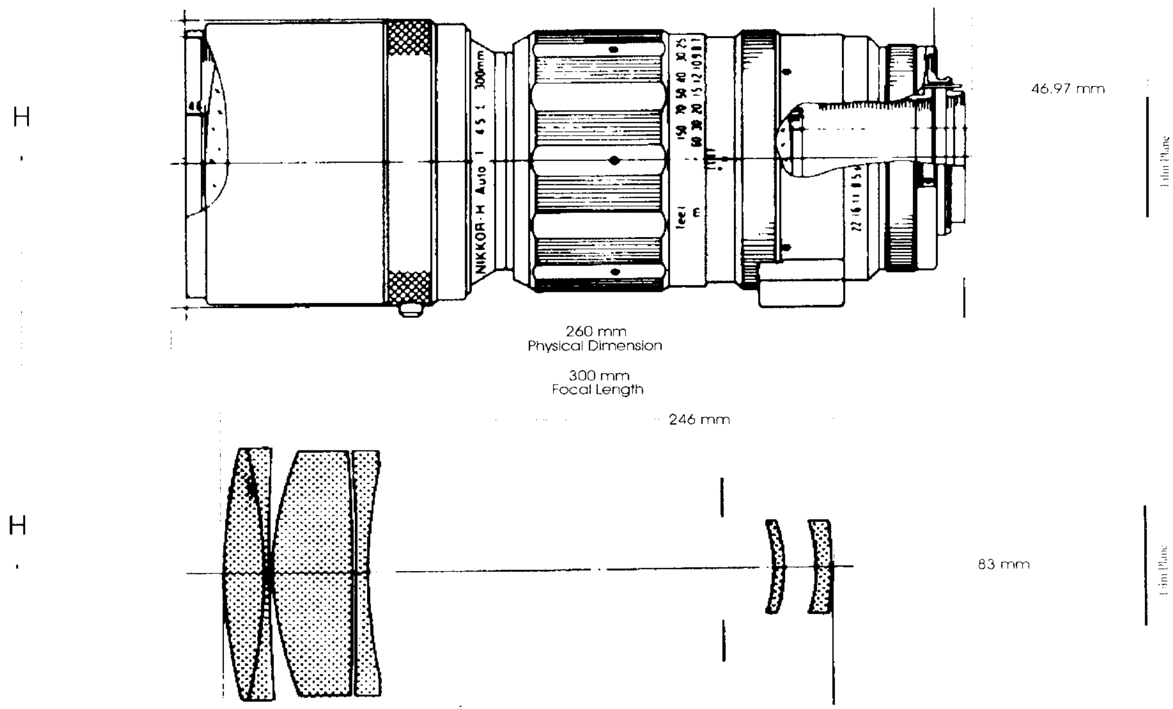


SINGLE ELEMENT ABOVE
TELEPHOTOGRAPHIC EQUIVALENT BELOW

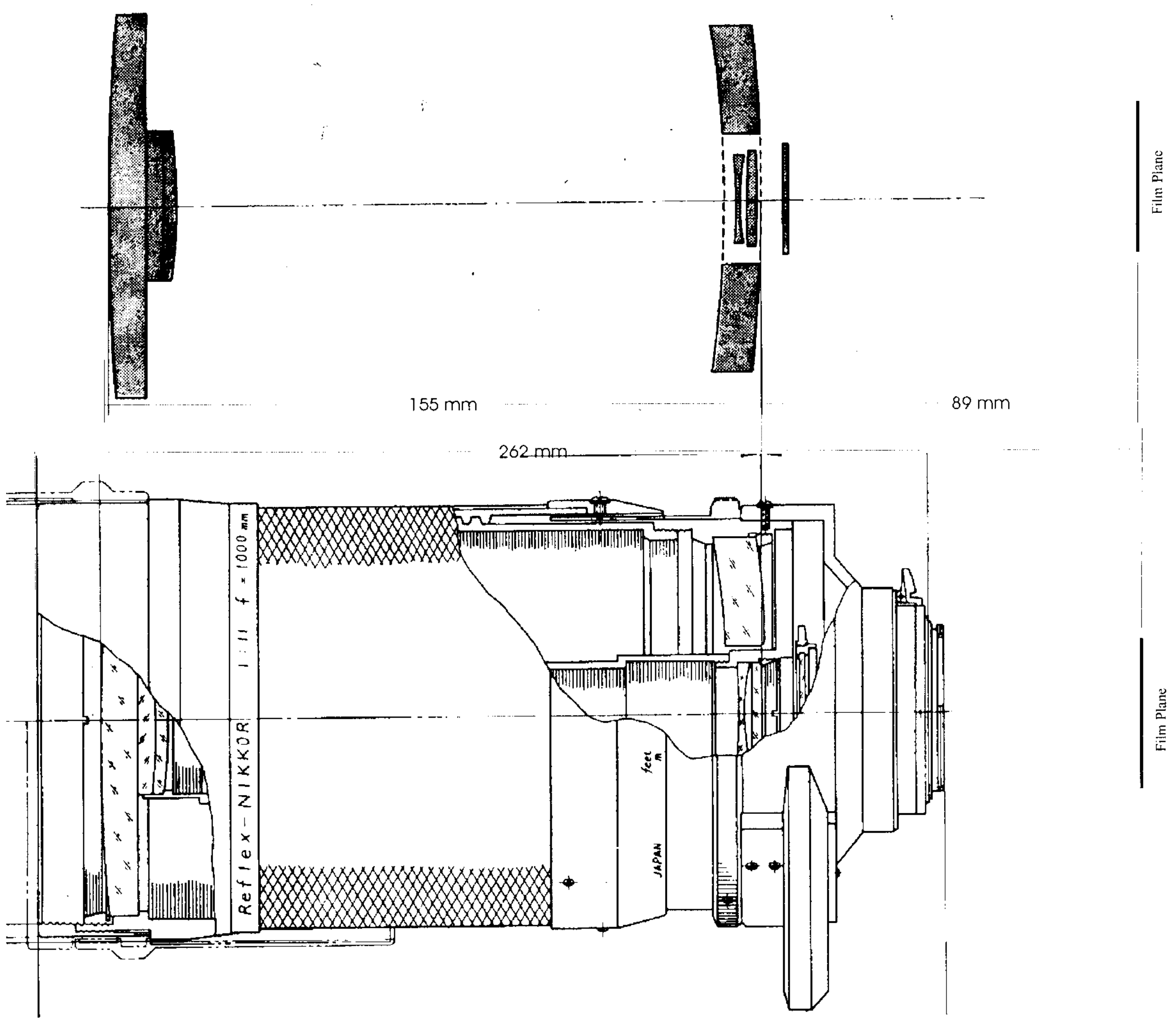



The focal length of a positive lens is lengthened by the addition of a negative lens downstream. As the converging rays of the positive lens travel through the negative lens, they are refracted outward from the optical axis. The bending power of this second lens is not so strong to not allow the rays to come to a real focus, just enough to extend its position. This lens prescription is similar to that of an achromat, but with the negative element distant from the first lens and not in contact like the achromat.

Here is a diagram of a decently long telephoto lens for a 35 mm camera. Notice that the actual length of the package is less than the equivalent focal length!




**REFLEX LENSES:** To further compact the lens package, the light path can be folded onto itself, ricocheting back and forth inside the lens tube to cut the barrel's length down by a third or more. This f/11 1000 mm focal length optic is called *catadioptric* as it makes use of both lenses and mirrors to generate an image.




1000 mm f/11 Reflex Optic

The light first passes through the front corrector plate and starts converging, then is reflected forward by the concave reflector, then back again off a convex reflector glued to the inside of the corrector plate, through a hole in the middle of the concave reflector where a negative followed by a positive lenses live, through one of the filters on the filter wheel[1], and thence onto the film.

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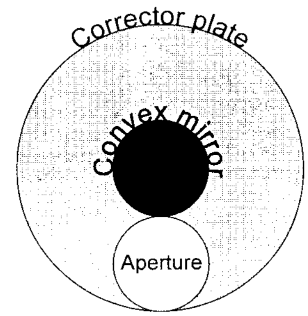
[1] Because a filter that screws on the front of the lens would have to be 115 mm in diameter a kit of the most commonly used filters (UV skylight, red, orange and yellow for deepening skies and lightening flesh tone in black and white work) would be extremely expensive. Smaller filters are installed inside of the lens unit (keeping them nice and clean!) and are rotated into position before use. Because their thickness can introduce some spherical aberration into the system and shift the focal plane, the lens is engineered to always have some filter, even if it's only a skylight filter in the optical path.

These lenses are never stopped down; there is no iris diaphragm in the center of the lens because of the convex mirror in the center of the correcting plate. To attenuate the incoming light an off-center circular aperture placed in front of the corrector plate would do the job along with increase depth of field. Usually these lenses are of moderate to slow speed anyhow, but the long focal length yields very little depth of field.



Front of Reflex Lens

Another peculiarity of this design with the center of the lens having an obstruction is that out of focus highlights will photograph as donuts! This fingerprint is a sure way to identify pictures taken with this type of lens.

**TELE-EXTENDERS:**
Since a telephoto lens is made by following a positive lens with a negative one, it is possible to extend the focal length of any photographic objective by adding a negative lens behind it.

Tele-extenders are usually designed to double the focal length of the prime objective, and are negative lenses of the proper focal length positioned appropriately so that the focusing scale of the original lens remains accurate.

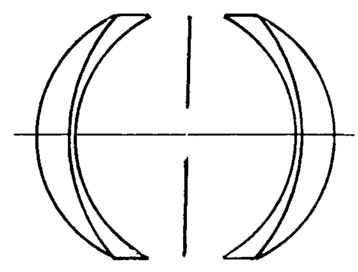
Adding more glass to an optical path may introduce new aberrations, but the big drawback is that the new working f/number of the combination is also doubled, but means only $1/4^{th}$ the light is reaching the film plane. But these are small prices to pay compared to the cost of a new lens!

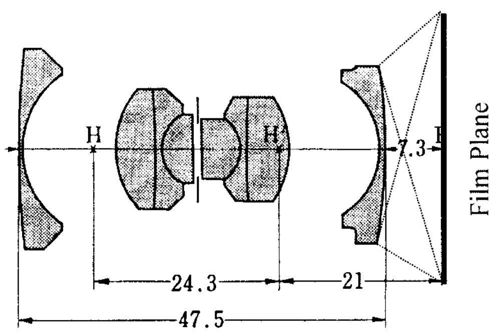
# PHOTOGRAPHIC OBJECTIVES #3:
# WIDE ANGLE LENSES

The normal lens has the shortest focal length which just fills the image format without vignetting. A lens with a shorter than normal focal length will project an image whose diameter will be smaller and the magnification is less.

The advantage to a lesser magnification is that more objects can be fit into the film format since their images are smaller for a wider field of view. But the diameter of the projected image diminishes also as the focal length decreases, and too short of a focal length might not have enough image area to cover the full film format. The trick to designing a wide angle lens revolves around projecting a real image whose diameter is larger than the lens's focal length.

Nineteenth century wide angle lenses used radically curved achromatic doublets in a symmetrical arrangement. They could have fields of view as wide as 80 degrees, but at really small openings, like f/30! This has been the basic design philosophy for wide angle lenses, with the major improvement of adding more elements to gain speed and combat aberrations.





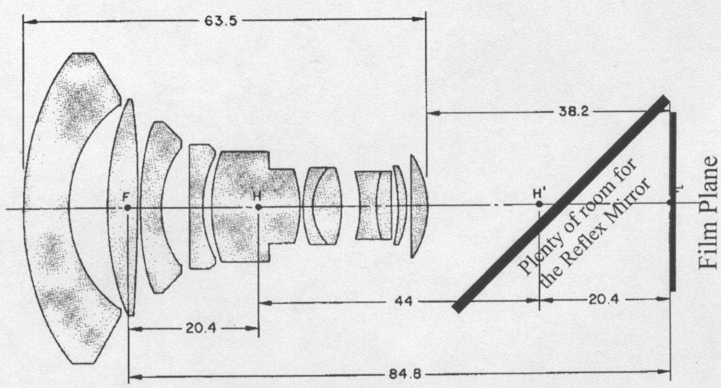
Optical Formula for 21 mm f/4

Here is an evolved design of the wide angle principle. This lens has a 21 mm focal length, and a 90 degree field of view in the 35 mm film format! Notice how obliquely the rays that form the edge of the image exit from the rear element which is a scant 7.3 mm (a little more than ¼")from the film plane!

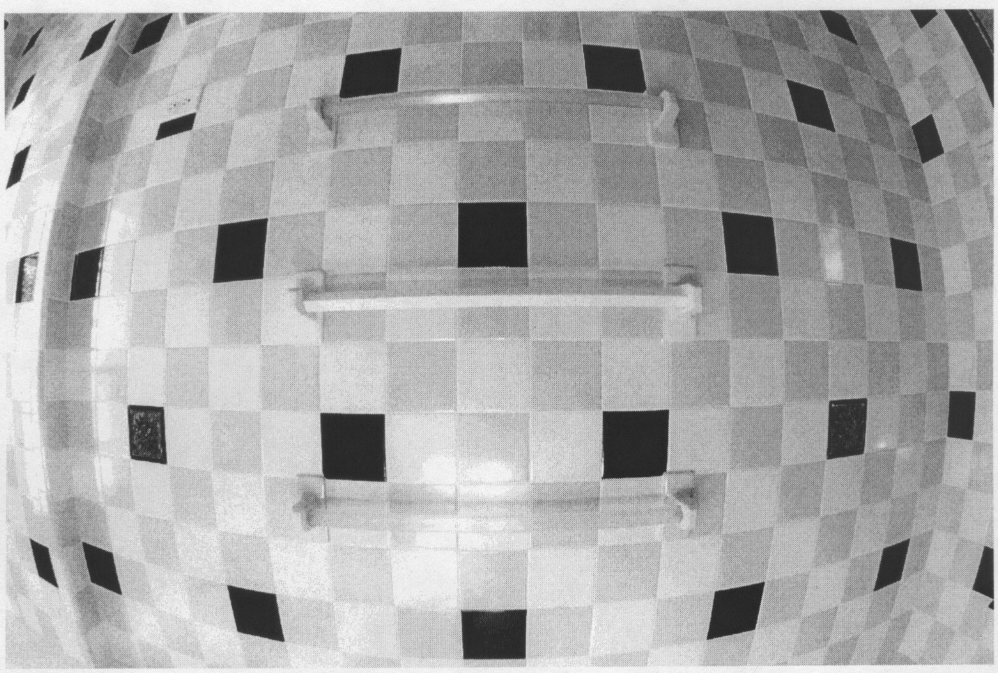
A lens with this short of a focal length could not be used in the reflex view finding mode of an SLR type camera because its elements are in the way of the reflex mirror. A different approach is taken in the design of contemporary wide angle lenses for these types of cameras, the retrofocus or inverted telephoto design, which outputs a lens whose physical dimensions are larger than its focal length!

The true telephoto design uses a negative lens behind a positive one to lengthen the focal length of the combination, which is longer than the physical package of the elements. (See the previous section, **TELEPHOTOGRAPHIC LENSES**.) Reversing their order shortens the focal length of the design and leaves a big enough gap between the rear lens element and the film plane to fit in the reflex mirror.

Another way of looking at how this design works (and how some early cinematographers cobbled together a wide angle lens and the basis for some wide angle attachments that screw on to the front of lenses) recalls what is viewed when looking through a negative lens (a minified virtual image). Use that as the first element, then follow it with a typical kind of normal lens looking through the negative one to provide a real image at the film plane.

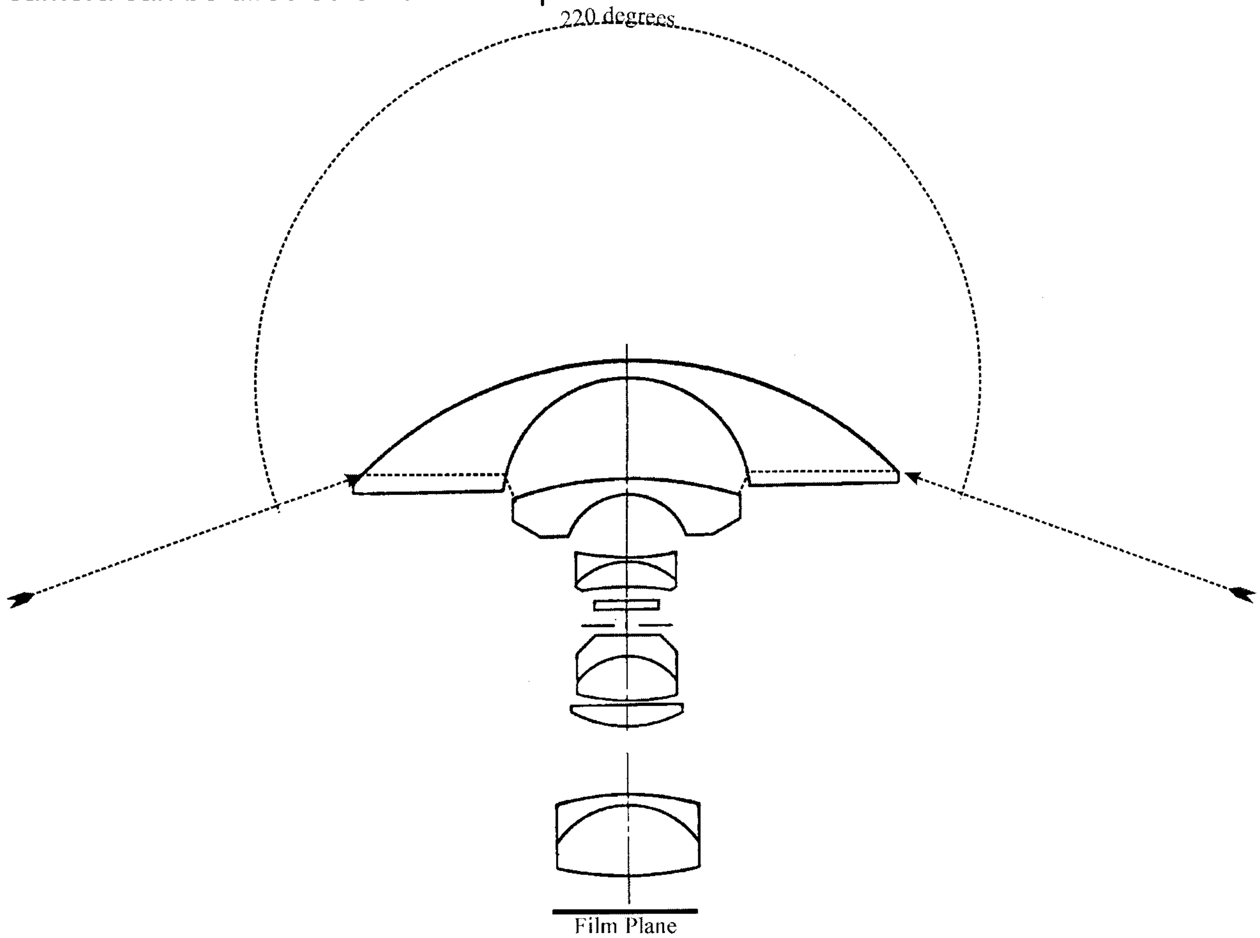


20 mm f/3.5 Retrofocus Wide Angle Lens.
Note the large negative front element and the position of H', the back focal point.



Although using a symmetric design helps eliminate distortion and curvature of field, the geometry of the short focal lengths with rapidly decreasing image size for further object points yields the familiar barrel distortion. The picture above was taken with a Minolta 18 mm f/9.5 lens, which delivers 160 degree field of view across the diagonal of the 35 mm full format.

The ultimate in wide angleness is the fisheye lens. With the radical negative front element light rays not only parallel to the film plane but even coming from behind the camera can be directed onto the film plane!




**6 mm f/5.6 Fisheye Lens** produces a 220 degree field of view in a 21.6 mm diameter image

# PHOTOGRAPHIC OBJECTIVES #4: MACROPHOTOGRAPHIC LENSES, BELLOWS, EXTENSION TUBES AND SUPPLEMENTARY CLOSE UP ATTACHMENTS

The screw thread mechanisms of most photographic lenses focus close enough to fill their format's image area with the most favorite photographic subject, head and shoulders of a person, which is a magnification of about 1/8th. To focus on an object closer than that, the image distance needs to be increased.

Spacers that fit between the camera body and the lens for most manufacturer's mounts are available to move the lens further from the image plane. By increasing the image distance, the object distance decreases, allowing the photographer to move in closer for a larger image of a smaller object.

As an example, Mamiya offers three extension tubes for the 645 camera: 11.8, 23.6 and 35.4 mm. Using the simple lens formula the working distance of the 80 mm normal lens (this distance is the longest object distance of the combination with the prime lens focused at infinity) can be calculated.

The 80 mm normal lens focuses from infinity on down to 700 mm with its built-in screw thread. At infinity, the image distance is 80 mm, as this is the definition of focal length. Solving the simple lens formula for image distance when object distance is 700 mm yields 90 mm. This gives a change in image distance of 10 mm to when the object distance goes from infinity down to 700 mm. This can be verified by measuring the extension of the lens as it is focused through these extremes of its range.

Adding the 11.8 mm extension tube gives us image distances of 91.8 for far, 101.8 for near, giving an object distance range from 622 mm to 370 mm, with magnifications of .14 to .28. (Magnification of .14 means a 100 mm sized object becomes a 14 mm sized image at the film plane.)

Running the numbers for the 23.6 mm extension tube, the image distance range extends from 103.6 to 113.6 mm, object distances of 351 to 270 mm respectively, with .30 to .42 times magnification.

Similarly for the 35.4 mm extension tube, image distance varies from 115.4 to 125.4 mm, object distance from 260 to 220 mm, magnification from .44 to .56 X.

With all three tubes stacked together, for a combined extension of 70.8 mm, plus the 10 mm that the lens racks out itself, the image distances grow from 150.8 to 160.8, the latter being twice the focal length which means the object distance is also twice the focal length for exact 1:1 object/image size! With the lens focused at its retracted infinity position the magnification is still a decent .88.

The math for using other combinations of these tubes, or in conjunction with other lenses, is, as they say in the math books, an exercise left to the reader[1]. The basic rule of thumb is that more extension lets the photographer move in closer, and the effect of the tubes is greater on shorter focal length lenses. There may be some odd combinations that don't work mechanically, or perhaps vignetting will occur, where the image is smaller than the film format, making dark corners.

These **extension tubes** or **rings** don't introduce any more optical elements into the image forming path, so the only aberrations that show up are due to the prime lens itself. Lenses can be designed to work perfectly at one conjugate distance, and performance deteriorates at other distances. Typical camera lenses are designed to work best at long object distances. Whatever happens outside this range is not necessarily a priority of the lens designer, and the addition of the extension rings to decrease object distance may show surprising image degradation.

There are lenses that are designed to work at close distances, called **macrophotographic objectives,** or **macro** for short. The conjugate distance their performance is peaked for is 1:1 life size or thereabouts, yet still deliver acceptable images in the far field.

In order for the lens to work from near to far the focusing mechanism must have a rather long screw thread arrangement. For 1:1 imaging, the lens must be extended to twice its focal length from the image plane, and in the case of the Mamiya 120 mm macro lens, this would be 240 mm, about 9½"! Just another reason why these lenses are so expensive.

A **bellows attachment** allows continuously variable image distances as opposed to the jumps of the extension rings. When collapsed to its shortest dimension, the mounting hardware adds 40 to 60 mm to the image distance, so a typical camera lens mounted on the bellows loses its ability to focus on infinity. The focusing range starts at a decent magnification, perhaps .5 or .75, and then with the bellows racked out fully the magnification might grow to 3 or 4 times life size with a normal lens in position!

There are some lenses in a camera system that do not have a focusing thread but rely upon being used solely on the bellows. These **bellows lenses** are usually the same optical system that comes packaged in the macro lens with its focusing mount. It adds an old-fashioned view camera feel to a roll film body. To feel even more retro, there

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[1] Or you can go to Mamiya.com for the particulars. If I would have went there first, I wouldn't have had to do the math! But my numbers match up to theirs quite nicely!

may not be a mechanical or electronic linkage to the lens from the camera body, so all exposure adjustments might have to be made totally manually.

On the better bellows the camera and lens mounts might move on the rails independently. Moving either one of them can deliver the proper focus. Even more deluxe are provisions to move the whole bellows and camera assembly as a unit on the tripod. Focusing could be done by moving the whole system at once, changing the object distance, which preserves the magnification ratio.

As an example, the correct lens to film distance is set for 1:1 magnification. Then the whole unit is moved closer or further from the object unit it is in focus, and not changing the image size.

A problem that occurs with either the tubes or the bellows devices is that the exposure needs to be compensated. The f/number of a lens is defined as the ratio of the image distance divided by the diameter of the lens. Usually this speed number is calculated when the lens is focused at infinity. This is the closest that the lens ever gets to the image plane, and yields the lowest f/number.

As the lens is focused on closer objects, the image distance increases, which yields an increasingly larger f/number for a given aperture size. For instance, with an 80 mm lens set at f/8 the aperture's diameter is 10 mm when it's focused at infinity. (Image distance = focal length at infinite object distance.) When the lens is focused at its closest, 700 mm, image distance is 90 mm, so the 10 mm aperture which was rated at f/8 now becomes f/9, which is less than 80% of the original intensity, or a third of a stop! By the time you focus down to 1:1 life size with this lens, the image distance is twice the focal length, 160 mm, so the 10 mm aperture now is a measly f/16! A loss of two stops!

A through the lens light meter may or may not automatically compensate for this effect, depending on whether or not the mechanical and electrical connections from the camera body to the lens are preserved. The less expensive devices probably don't, so compensation may have to be done manually in the stop down metering mode.

Light meters that look at the film while it is exposing to determine the exposure time will automatically take care of this problem. But if you are using an incident light meter at the subject plane to determine exposure for flash or flood light there will be a need to take into account the lens extension.

Exposure milestones along the way are at infinity, no compensation; at .4 reproduction ratio (100 mm object reduced to 40 mm image) one full stop compensation; at 1:1 ratio two stops. When the image is tripled life size 4 stops are necessary to compensate, and after that you are intruding into the range of microscopes.

Because it is harder to keep the aberrations under control near the unit magnification mark, macro lenses are usually of moderate speed, like f/3.5 – 4. F/2.8 is speedy for a macro.

At high magnification, depth of field for a given f/stop becomes quite shallow. The minimum f/stop is down at 22 or even 32. Be prepared for long exposure times when doing close-ups!

When non-macro lenses are used in the close up mode with bellows, especially at greater than 1:1 ratios, the preferred mounting orientation is with what is normally the output side of the lens (film side) towards the object. This is necessary because lenses are designed to work in certain focusing regions, with a normal lens doing its duty with a large object distance and a short image distance. But when the image distance becomes greater than the object distance at high magnifications, those roles are reversed and so is the lens orientation.

A different tact to moving in close is to add a supplementary lens on the front of the prime lens of the camera. They are positive lenses, and the action starts when the object is placed one focal length from the lens.

An object placed one focal length from the lens will have rays that come out parallel; Case 4, **IMAGE AT INFINITY CONJUGATE DISTANCE** in OPTICAL ENGINEERING NOTE #9 earlier in this Chapter. To capture this image formed at infinity, the prime lens is focused at infinity. As the combination is moved closer to the object to make it bigger, this close up lens moves into a Case 5 situation, **NEGATIVE CONJUGATE DISTANCE**, producing a magnified virtual image, and the prime lens needs to follow focus until it runs out of adjustment.

The close-up attachment lenses usually give their focal length not in mm but in diopters like the eye doctors. The focal length can be found by dividing the diopter number into 1000 (mm in a meter.) A #2 (500 mm) works well, picking up with its furthest focus at 500 mm, about where the close focusing ends with a typical 50 mm normal lens on a 35 mm camera. Other diopters are available, with a #10 being the strongest that can be found.

With the #2 CU Lens screwed on to a 50 mm normal lens, the closest focus is at 500 mm, and the magnification ratio is the ratio of the focal lengths, 50/500, or .1. The close focus is dictated by the close focus of the prime 50 mm lens, 600 mm. The camera is moved close enough to the object so that the close up lens forms a virtual image at 600 mm. For this image distance, the object distance is 270 mm. The

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magnification of the object by way of the close up lens is 2.2 X life size.

But following that image is the prime lens focused at 600 mm, which provides a 1/11 life size image, so the combined magnification is 1/11 X 2.2 = .2 life size, twice of the unaided lens, still respectable!

The disadvantage of using a supplementary closeup lens is the introduction of aberrations from the attachment. Stopping down and not putting important subjects in the periphery of the frame helps. The beauty of it is that all mechanical and electronic connections from the body to the lens are preserved, and there is no f/stop compensation necessary. This is one must have accessory, as it takes up next to no space in the camera bag without lightening the wallet too much!

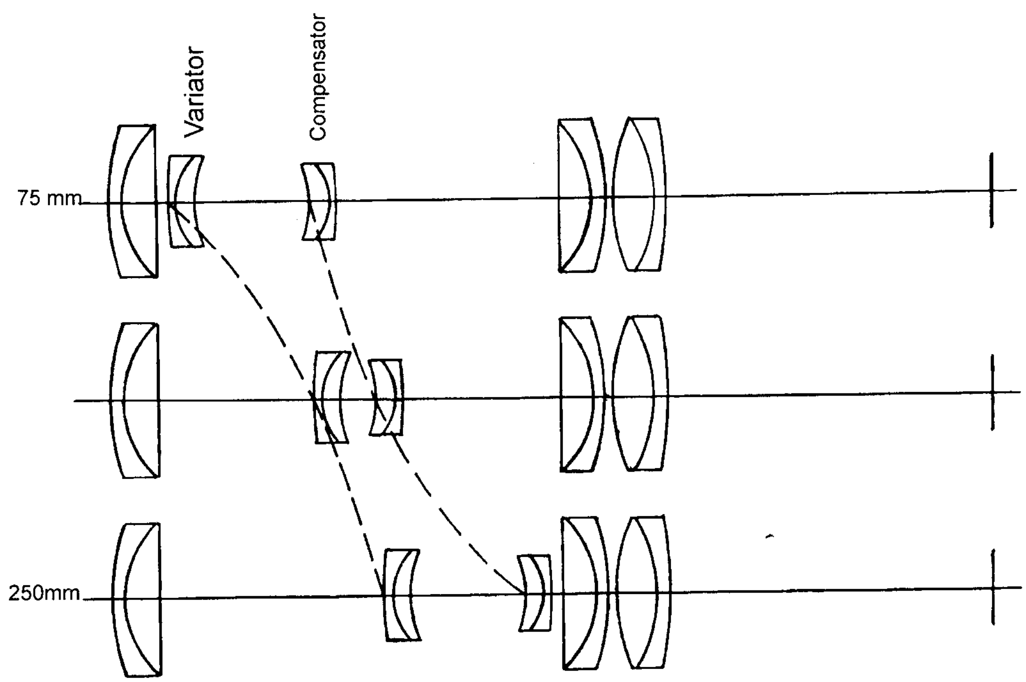
An even cheaper but quick and dirty technique to move in close to an object is to take the lens off the camera, and hold its front element against the body! It is kind of a corollary to the notion a few paragraphs above of using the normal lens backwards on the bellows attachment. The range of focusing distances and magnifications are limited, but it still can help in a pinch!

# PHOTOGRAPHIC OBJECTIVES #5: ZOOM LENSES

Combinations of lenses can produce new focal lengths. For instance, following a positive lens with a negative lens will produce a longer focal length for the combination, as in the telephoto lens prescription. Moving the negative lens closer and further from the positive one will change the focal length of the combination.

This variable focal length lens combination would vary the magnification and field of view as the relative positions of the lenses are changed, but every time the negative lens is repositioned to change the focal length, the image distance will also change and the whole assembly would have to be refocused. This type of lens is called *varifocal*, and is the type of "Zoom lens" supplied with projectors. After the size on the screen is set, then the focus is touched up.

The true **Zoom** lens has another set of optics to ensure that the focal plane does not change as the focal length varies, essential for zooming while shooting movies or video, and a big help for the still photographer. A *variator* changes the focal length, and a *compensator* ensures that the focal plane is constant.




One way to make a zoom lens. As the Variator, a negative lens, moves away from the fixed positive front element, the focal length of the combination changes. The Compensator moves in response to this focal length change to maintain the focal plane's position.

In the illustration above it can be seen that there is no linear relationship between the variator and the compensator positions. Observing the elements inside a zoom lens while zooming shows this effect in action, creating a mechanical engineering nightmare to get the lenses to move to the appropriate positions. Usually cams or slot and groove mechanisms are employed to move the interior lenses, and sometimes the front element is moved also.

There was a reluctance at first for still photographers to adopt the zoom lens, as it was thought that they could never be as sharp as a fixed focal length lens. But thanks to modern era computing as applied to optical engineering, that fear can be laid to rest.

The big disadvantage (other than price) of zoom lenses is their moderate f/#. With the amount of elements in one, scaling up the design to wider apertures would jack up the price considerably!

The size of the film format determines how ambitious the zoom design might be. For instance, for the medium format Mamiya 645 camera, only a pair of zooms, the 105 – 210 mm f/4.5 and the 55 – 110 mm f/4.5, are offered. The former is a moderate telephoto design, the latter encompasses a weak wide angle through normal ending up at weak telephoto. Their apertures are not that bright at f/4.5, and both would be considered 2X zoom power, which is the ratio of their short and long focal lengths.

Compare that offering to Canon's line up of zooms for their 35 mm format cameras, 28 in all, although there is some duplication of focal lengths incorporating minor variations, such as UltraSonic Motors, Diffractive Optics, or Image Stabilization! Their shortest **Ultra-Wide Zoom** is a 10 – 22 mm f/3.5-4.5, with a few others working in the region of almost fisheye to still pretty wide angle. They have a lot of **Standard** and **Telephoto Zooms** that encompass wide angle through normal ending up at telephoto, like 17 – 85 mm or the wide ranging 28 – 200. Most of these have rather conservative zoom ratios like 3 or 4X, although there is one that has a zoom ratio in the range of the 8 to 10 or even 12X range typical of the video or smaller format digital still cameras, the 28 – 300 f/3.5 - f/5.6. (300/28 = 10.71). The smaller the format, the easier it is to design a zoom lens that is practical to handle and manufacture. There are no zoom lenses for sheet film cameras of the 4" by 5" or 8" by 10" genres.

Some zooms have their f/number change as the lens is zoomed, for instance a 35 to 150 mm f/3.5-4.5 lens. Since the f/# is the ratio of focal length to the diameter of the opening of the lens, it can be seen that for a fixed diaphragm diameter, its f/ratio will increase as the lens's focal length increases. The position of the iris in the lens determines if this will occur.

Along with magnification variation while zooming, the perspective compression/foreshortening changes also. Shots can be lined up to get the appropriate foreground/background relationship by zooming in combination with selection of the object distance.

Cinematographers didn't like this effect in the early days of zooms, as they were used to the way perspective moved while the camera was moved in closer to or further from the subject. But the combination of zooming while moving the camera in or out can produce some very dramatic effects. As an example, there is the famous scene in Vertigo by Alfred Hitchhock where a terrified Jimmy Stewart's face is held constant in size while the camera is backed off by zooming to a longer focal length. This brings the background up to him from behind. All this happens very quickly, increasing the anxiety!

# PHOTOGRAPHIC OBJECTIVES #6:
# PROJECTION AND ENLARGING LENSES

As was mentioned in **PHOTOGRAPHIC OBJECTIVES #6: MACROPHOTOGRAPHIC LENSES**, lenses are designed to minimize aberrations for their intended conjugate distance applications. For picture taking applications, the object distance is long and the image distance is short, resulting in minification, (**CASE 1**) but for slide and movie projectors and photographic enlargers the situation is reversed, a **CASE 3** application.

Theoretically the same lens used for taking the picture could be used for projection, but this is hardly ever the case in practice. The normal lens of the camera would magnify to life size at such a short distance that the projector would need to be in front of the audience. Therefore, projection lenses are usually several times the normal focal length of the format to move the projector to the back of the room, which also helps prevent distortion.

Projectors hardly ever use fixed focus lenses, since the position of the projector is the only determining factor in the size of the image on the screen. Varifocal lenses are the status quo, and not the true zoom, as there is no need to make the lens more complicated, since once the image size is set by finding the right focal length the focus needs only to be touched up.

There is no need for an aperture in a projection lens since the projected image needs to be as bright as possible. For slide and movie projection a low f/# is of utmost importance, for the brightest possible image, even more so for movies as the light is issuing from the projector for only half the viewing time as the film cycles from one frame to the next. With the film moving, resolution is not as critical as in still projection.

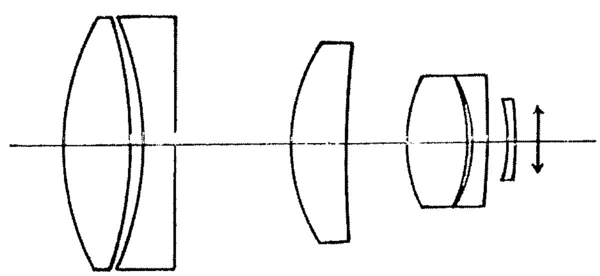


Figure 3.16. Kodak Projection Ektar $f/1$ lens.

The focusing mount is built into the projection apparatus, making the lens less expensive. Autofocusing is done by the projector, not by the internals of the lens, eliminating the expense of another device in the lens.

Kodak Carousel slide projectors offer two types of lenses, Ektanar-C and -FF lenses to combat curvature of field. The FF stands for flat field, and is recommended for slide shows where the majority of the slides are mounted between glass, so a flat object is imaged onto a flat screen.

But almost all slides commercially processed are mounted in cardboard or plastic, binding the film chip along the edges, and are not necessarily flat but are concave viewed from the emulsion side. So the -C lenses come standard, designed to image a curved object plane onto a flat screen.

Considering that a 35mm slide is roughly 1" by 1½", and the typical projection screen is at least 30" by 30" and up to 50" by 50", so to have the long side of the slide fit the screen would require a magnification ratio in the neighborhood of 30X.

Enlarging lenses are designed for smaller magnification ratios, typically from wallet size to 16 by 20, meaning from about 2X up to 16X for 35 mm format. A 50 mm lens is the default focal length for enlargements from 35 mm, and in general the normal camera focal length is the one that is necessary for enlarging that particular format. (Don't forget, the normal lens is the one whose basic image size fills the film format.)

If a shorter than normal enlarging lens is used on a negative, for instance a 50 mm on a 6 cm by 4.5 cm negative, only a circle of approximately 50 mm diameter of the negative will be projected, the rest of the image vignetted out. Using the longer focal length 80 mm lens that would be used for the 645 neg on the 35 mm neg will cover the whole negative, but the enlarger head will have to be racked up almost twice as far from the paper to give an equivalent enlargement magnification from the same negative.

As a bonus, an enlarging lens could be used as macro lens by hooking them up to a bellows. They are attached to the enlarger with what are known as "Leica threads". (A screw thread that is 39 mm in diameter, with a pitch of 26 turns to the inch. This crazy combination of metric and English units was used to discourage other manufacturers from making lenses that would fit on Leitz's popular cameras!) Never fear, you don't need to buy an expensive *tap* to cut this kind of thread into a mounting plate, just a hole big enough to let the threads fit through because the lenses come supplied with an attaching ring of the appropriate size.

Resolution is a major issue for photographic enlarging lenses, as the final print will be closely scrutinized. See the **Handout, PRACTICAL APPLICATIONS OF RESOLVING TARGETS** to see how well these lenses do.

Luckily low f/#'s are not such a high priority, although they do help when focusing. Usually the lens is used 2 or 3 stops from its largest aperture to combat aberrations, with the appropriate exposure time delivered to the light bulb via an electronic timer, having been determined by trial and error. (Photo printing papers have a wide range of speeds, and my typical exposures for 8 by 10's vary from 1 or 2" with Ilford Multigrade at f/8 to 5 to 10" with Agfa Portriga at the same magnification. Color printing papers like to standardize exposure times at something like 5" to make sure that all three layers react the same way consistently, and use the aperture to control exposure. This is not such a great idea because there is not as much fine control between the clicks of the f/stops as there is in the timer, which is accurate down to a .1 of a second.)

The two devices above are becoming closer and closer to totally obsolete, thanks to the presence of digital projectors. The lenses in these devices are similar to slide projectors, as they have similar functions and requirements. The Digital Light Processing chips are a tad smaller than 35 mm format, so the focal lengths are similar to the slide projector, but they are usually unmarked as to the true dimension and corresponding f/stop.

But a real advantage these lenses have built into them are tilts to compensate for the fact that the projectors are typically aimed at the screen from above! Something the humble Kodak Carousel was sorely lacking!