PRACTICAL PHOTOGRAPHY

HOW TO CHOOSE & USE A LENS

Price 50¢

AMERICAN PHOTOGRAPHIC PUBLISHING COMPANY BOSTON, MASS

HOW TO CHOOSE AND USE A LENS

Practical Photography, No. 3

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American Photographic Publishing Co.

Boston, Mass.

1915

Stanhope Press
F. H. GILSON COMPANY
BOSTON, U.S.A.

HOW TO CHOOSE AND USE A LENS

Introductory. — The purchase of a camera necessarily involves the choice of a lens, and while few beginners in photography, whether they select their cameras for themselves or acquire them by gift, make any very logical decision as to the capabilities of the outfit they desire, the time is sure to come to every amateur when intelligent knowledge of what a lens will do is necessary. We will assume that the reader is about to buy a camera, and that he knows nothing about photography. We will endeavor to show him what a lens is, and what each type now obtainable will do. With this knowledge he can study the catalogues of lens and camera manufacturers with more confidence, and decide for himself whether the expenditure of five dollars or fifty dollars for a camera and lens making a given size of picture is best for his necessities. We may say, however, that practically every step in increased price of either lens or camera is fully justified by advance in careful workmanship, increased facility of operation, or more versatile performance, and that the higher-priced outfits in case of forced sale usually bring a greater percentage of original cost. He who begins with an outfit of limited capacity and continues in photography invariably desires a more flexible equipment. We therefore unqualifiedly advise the original purchase of the best outfit which the buyer's means will command, as the most satisfactory and economical course in the end.

In the majority of cases, the selection of one's first lens means the purchase of a camera complete and ready for use, but this scarcely limits the scope for choice, for every grade of lens may be had today on the moderate priced cameras of all makers, and only in the cheapest styles is there no choice of lens equipment. We will begin with a consideration of the simplest forms of lenses, but we must first consider the elementary principles of optics.

Light and Its Transmission. — To the physicist, light presents itself as vibrations of the luminiferous ether, a perfectly elastic medium which is supposed to fill space, and the principles of optics are deduced from a mathematical consideration of the changes of direction and velocity of these waves or vibrations when passing from one medium to another. A much simpler conception is to assume that every luminous point emits rays of light which travel in absolutely straight lines in every possible direction as long as they remain in the same medium. In passing from a rarer medium, such as air, to a denser one, such as glass, the speed of the rays is lessened, and from this fact follows the possibility of a lens, as will appear later.

That light travels in a straight line may be easily observed. Place a dark screen through which a pinhole has been pierced between the eye and a distant arc light. But one position of the screen can be found through which the light will be visible, and this is in a straight line between the eye and the light. This can be mathematically proved, as can all the facts about light and lenses which will follow, but the reader who wants such proof must seek it in more extensive treatises than this.

Pinhole Images. — If we make a pinhole in the light-tight shutter of a room from which all daylight is excluded, and place behind this a white card, we will see upon the card an image in natural colors of outside objects. Observing this, we will see that the image is inverted, the sky being at the bottom, and objects at the right outdoors appearing on the left side. This is the natural and only possible consequence of the fact that light travels in straight lines. Rays from the top and bottom of any object converge at the pinhole, cross there, and reach the card to form the inverted image. Lenses also cause the rays to cross, and so the image on the ground glass of the camera is inverted.

The Pinhole Camera. — The beauty of such an image produced in a dark room inspires the thought that it might be recorded by photography, and in fact the simplest apparatus for making photographs is a light-tight box which contains a minute opening in the centre of one end. At the opposite end a sensitive plate is placed to receive the inverted image of external objects produced by this minute opening. The nearer the plate is to the pinhole, the smaller the image of any given external object, but the larger the area of the view outside which is recorded on the plate.

The sharpness of the image produced in a pinhole camera depends partly on the fineness of the aperture, and partly on the distance of the plate from it, but mainly on the first. If the aperture could be made so small that only a single ray without thickness could pass through it, the image would be absolutely sharp. A decrease of the area of the aperture means a corresponding loss in brightness of the image, and if it is made too small there is also a lack of sharpness from the phenomenon known as diffraction, which is a bending from their course of part of the rays of light which strike the edge of the opening. This, though small in amount with a large opening, deflects an appreciable proportion of the light passed by a very small opening. In practice, therefore, the pinhole must have a fairly large diameter to produce an image bright enough to impress a plate in a reasonable time, and the practical problem is to find the mean between lack of sharpness from diffraction and that caused by too large an aperture, which allows a large number of rays from any given point to pass through, spreading out as they go and causing unsharp contours. At best the pictures made with a pinhole camera are far from sharp, and the method is curious rather than useful, though it has been much practiced in recent years, and several books have been written on the subject. There is considerable skill involved in making a successful pinhole, and those interested in the subject would find the purchase of the proper apparatus nearly as cheap as its manufacture.

Pinhole Attachments. — There are on the market several styles of pinhole attachments which may be substituted for the usual lens on any camera from which the objective is detachable. One style, selling at sixty cents, has an opening listed as No. 6 on the scale given below. A more expensive form, listing at $2, has four pinholes and an aperture for the purpose of focusing. The holes are numbered according to the system devised by Alfred Watkins on D'Arcy Power's suggestion, and called by Watkins "Watkins-Power" numbers. The complete list is as follows:

W.-P. No.	Diameter in inches	Nearest Needle No.	Best Distance for Plate
3	0.053	No. 1	40 inches
4	0.040	No. 4	20 inches
5	0.032	No. 5	15 inches
6	0.027	No. 7	10 inches
7	0.023	No. 8	8 inches
8	0.020	No. 10	5 inches
10	0.016	No. 12	3½ inches
12	0.013	No. 13	2½ inches

Using the W.-P. Number. — Multiply the W.-P. number by the distance from pinhole to plate and use the result as the *f* value of the pinhole. Then whatever the exposure would be for that *f* number with a lens in *seconds or fractions thereof* is the exposure for the pinhole in *minutes or fractions thereof.* For example, W.-P. hole No. 6 used at a distance of 10 inches from the plate is regarded as *f*:60. If the exposure, as determined by *The American Photography Exposure Tables*, or by an exposure meter, for a lens working at *f*:60 under the given conditions is 2 seconds, then 2 minutes should be given for the pinhole exposure. This system of calculating pinhole exposures is the most convenient yet devised.

Utility of the Pinhole. — As indicated in the table given above, there is a most favorable distance for the use of any given pinhole, but it is not absolutely necessary to have more than one, and a No. 6 pinhole may be used on an ordinary camera at any distance within the capacity of the bellows, with results varying very little. The pinhole camera finds a certain application in architectural photography, especially in cramped quarters, for it may be used to cover an extremely wide angle if the plate is very near the opening. The image is perfectly rectilinear. Owing to the slight diffusion and consequent obliteration of the finer detail inseparable from pinhole exposures, pictures thus made are much in vogue among workers of artistic temperament.

Refraction of Light. — The reason that we cannot get a perfectly sharp image with a pinhole is that, as it is larger than a mathematical point, the rays from any point in the object form a cone in passing through it, and continue to diverge indefinitely. We therefore need some means of once more bringing these rays back to a point, and this we do by means of a lens, the utility of which is due to the phenomenon known as refraction. As we have previously stated, when rays of light pass from a rarer medium to a denser, their speed is retarded; on the other hand, the velocity is increased in passing from a denser medium to a rarer one. When the passage from one medium to another takes place in a direction perpendicular to the surface dividing the two media, there is no change in the direction of the rays, though their velocity is changed. When the direction of the rays is oblique to this surface, the course they follow is bent or refracted. We will not go into any detailed explanation of the laws of refraction; it will be sufficient for us to know at present that when a ray of light passes from air through a piece of glass the sides of which are parallel, the direction of the ray after emerging is parallel to its direction when it entered, while if the sides of the glass are not parallel, so that it forms a wedge or prism, the direction of the ray is changed, and its course is bent or refracted away from the angle of the prism and toward its base. If we take two prisms and set them base to base, it is evident that two parallel rays, one of which passes through each prism and is duly refracted toward its base, must eventually cross, and these two prisms are the germ of the lens. Parallel rays passing through one of these two prisms would emerge with their direction changed, but still parallel, and would cross the corresponding rays bent by the other prism at variable distances from the prisms. The amount of the bending depends on the angle included by the prism, increasing as this does, and so if we have a number of very thin slices of prisms of continually increasing angles piled on each other, we could make successive parallel rays bend more and more toward the base, so that they would all cross corresponding rays from the similar prisms on the other side at a single point. Now, an ordinary lens is just such a collection of portions of prisms, for all curved surfaces made by mechanical means are composed of small surfaces joining each other at large angles, instead of being truly continuous curves. Thus we have found that by placing a lens of glass of the proper form in the place of our pinhole, we can cause the rays to come together instead of separating, and it is a matter of common experience that thereby a sharp image can be formed, instead of the diffused one produced by the pinhole.

Simple Lenses. — From the two prisms placed base to base may be derived three forms of lenses, all of which are thicker at the centre than at the edges. They are called the double convex, with two convex surfaces, the plano-convex, with one convex surface and one flat surface, and the convex meniscus, with one convex and one concave surface, but thicker at the middle than at the edges. All of these forms of lenses cause the light rays to converge until they meet upon the axis of the lens, an imaginary line drawn perpendicularly through the centre of the lens surfaces, and they are therefore called converging or positive lenses. If we assume that the two prisms are placed together point to point instead of base to base, we get the foundation for three more kinds of lenses, the double concave, the plano-concave, and the concave meniscus. All these lenses are thicker at the edges than in the middle, cause rays of light to diverge from the axis, and are called diverging or negative lenses. These six forms of lenses are all used in photography, and from them in combination all types of photographic lenses are constructed. The curved surfaces which bound them are in practice always spherical, for in the process of grinding it is mechanically easy to produce nearly perfect spherical surfaces, whereas the construction of a lens whose surfaces should be sections of a paraboloid, hyperboloid, ellipsoid, or other geometrical solid more complex than the sphere, while not impossible, would be a very expensive and laborious task. It is nevertheless probable that lenses with surfaces of this more complicated description will be produced in the future, for it seems impossible at the present time to introduce much further refinement into present day lenses that are made with spherical surfaces alone.

Dispersion of Light. — We have now seen that it is possible to make rays of light cross each other on the axis of a lens by the use of a double convex or other converging lens. It is, however, no more possible to make a perfect and satisfactory photograph with a single lens of this character than we have seen it to be with a pinhole. In order to understand the most elementary reason therefor, we must revert to our illustration of the prism. In considering this, we saw that when a ray of light falls upon a prism the ray is bent out of its course. A further observation can be made of the effect of a prism upon light. If a beam of sunlight falls upon the prism, and is bent from its course, upon leaving the prism it no longer appears as a beam of white light, but if we place beyond the prism a sheet of white paper, we will find upon it instead of white light, a band of light of different colors. In other words, the prism has split up or dispersed the beam of white light into a band of colors called the spectrum, in which the light passes by gradual change from one color to another, in the following order: violet, blue, green, yellow, orange, red. The order of these colors is always the same, and the violet ray is refracted the most while the red ray is refracted the least.

Chromatic Aberration. — A lens of course acts in the same way as the prism and separates the white rays of light which pass through it into their colored components. The violet rays therefore cross on the axis of the lens at a point nearer the lens than do the red rays. The point at which any given rays come together on the axis of the lens is called the focus of these rays, and thus in the use of a simple lens we find that the focus of the violet rays is nearer the lens than the focus of the red rays. Photographically, this is unfortunate, for the image which we see with the eye on the ground glass of the camera is composed mostly of yellow rays, which have the greatest visual luminosity, that is, affect the eye the most. On the other hand, the photographic plate is most affected by the violet rays, and when we have focused on the image formed by the yellow rays, and put a plate in place of the ground glass, the image produced by the violet rays is brought to a focus nearer the camera than the plate, and the image which we photograph is out of focus, diffused or blurred. It is possible by means of a simple calculation to find out how much it is necessary to move the plate after focusing, approximately $\frac{1}{40}$ of the focal length of the lens, in order to place it at the focus of the violet or actinic rays, as they are called, instead of at the focus of the yellow rays which the eye easily perceives, but this is a clumsy manipulation, and a simpler method has been found to obviate this difficulty. Opticians have discovered that glasses of different chemical constitution have different dispersions, that is, split up white light to different extents, and that by the combination of a positive or collecting lens, of a kind of glass known as crown, with a negative or dispersing lens of another kind of glass known as flint, of a different dispersive power, both the chemical and the visual rays can be brought together at a single point. When this has been done, the lens is said to be achromatic, and practically all modern lenses are achromatized for two points in the spectrum, one in the yellow and one in the violet. For certain purposes it is necessary to produce lenses of finer color correction than this, and lenses for three-color work, for instance, are corrected so that there is a common focus for three different points in the solar spectrum, corresponding to the three colors chosen to produce the image. Such lenses are known as apochromats.

Spherical Aberration. — If we were to separate from the solar spectrum light of a single color, and allow this to fall upon the whole surface of a simple collecting lens, we would find that the lens would be unable to bring all the rays of light of a single color to a single focus. The rays passing through the edge of the lens would be bent a little more sharply and would come to a crossing on the axis somewhat sooner than those passing through the lens nearer the centre. This property is inherent in all lenses having spherical surfaces, and is hence called spherical aberration. It may be partly corrected by using a diaphragm which will cut off the rays of light passing through the outside of the lens and allow only those striking the central portion to be used, but it is more completely corrected in practice by combining a positive and a negative lens, of opposing spherical aberrations, in such a way that one counteracts the other. Modern glasses are of such diverse properties that it is possible to correct a lens simultaneously for chromatic and spherical aberration. When a single combination has been so corrected that it will produce sharp focus, with a comparatively large working aperture, it is said to be aplanatic or an aplanat.

The Achromatic Meniscus Lens. — The simplest type of lens used in photography of any importance today is that corrected for chromatic aberration, and known as the achromatic meniscus. This is the kind of lens which is used in most of the cheap so-called fixed-focus cameras, which sell from $1 up. Certain very cheap cameras may be equipped with a simple spectacle lens, but they are of so little photographic importance that this type of lens does not need to be considered at length. The achromatic meniscus works well in bright summer sunlight, with a snapshot shutter working at about $\frac{1}{25}$ of a second and gives a reasonably well-defined image for small direct prints. This type of lens, however, though partly corrected, still has a number of defects, which make it impossible to obtain minutely sharp definition except with a very small stop, and even if such stops are provided on the camera, they can rarely be used except in the very brightest light.

Usefulness of the Meniscus Lens. — The user of a cheap type of camera almost invariably desires to get a large section of the view before him on his film or print, and for this reason achromatic meniscus lenses are usually of very short focus, thereby taking in a large angle of view. As a result of this, and the additional fact that the lens is stopped down so as to utilize only the centre and best working part of the lens, a camera of this type will give a fairly sharp image of objects from about eight feet from the camera to the limit of visibility, without any provision for focusing. Consequently such cameras are usually called "fixed-focus" cameras, a term evidently designed by some advertising man to make capital from the fact that it is not necessary to focus such cameras for ordinary landscape pictures. Probably the term "average-focus" would be a better one for a camera of this type, but whether the name be proper or not, such instruments always give fairly sharp images of objects at a reasonable distance from the camera, and answer admirably for beginners and those who do not care to give much thought to their photography. They are excellent for vacation pictures, and for those who desire to make mementoes from time to time without becoming familiar with the difficult manipulation of a better lens, and as a matter of fact, the quality of achromatic meniscus lenses sold in the United States is so high that many pictures made with such lenses compare favorably with those made with much more expensive lenses. It is an ordinary experience for an amateur who has been taking pictures with such a camera to turn out much less successful work when he *begins* to use a focusing camera with a better lens. This, however, is merely due to his inexperience with the more complicated apparatus, and as soon as he has learned to manipulate it properly, he is sure to get better results from the higher-grade outfit.

Defects of Meniscus Lenses. — The meniscus lens usually has only two aberrations even partly corrected. There are three other important aberrations of lenses, and these are not corrected in the meniscus lens. The meniscus cannot render straight lines as such when they are near the margin of the picture, and is consequently not suitable for taking pictures of buildings, though in landscape work this fault is unimportant. This defect is called curvilinear distortion. The meniscus lens also suffers seriously from curvature of field and astigmatism, two defects which will be more fully explained further on, and the cheaper grades will have some spherical aberration not corrected. All of these shortcomings render it impossible for such a lens to render the finest detail absolutely sharp even in the centre of the field, and this is even more the case at the corners. Finally, in order to make it work at all, it has to be stopped down to such a small aperture that the lens will not allow short exposures to be made, and consequently is useless under many circumstances.

Meniscus or Rapid Rectilinear? — Ordinarily the choice of a first lens for the beginner consists of deciding between two cameras of the same model, one fitted with a single meniscus achromatic and the other with a rapid rectilinear lens, a type which we will fully describe a little further on. The difference in price is usually from two to six dollars. There are a few cameras, the smaller and cheaper sorts more particularly, which are offered with meniscus lenses only. Such instruments are supplied with time and instantaneous shutters and are of the fixed-focus type. Naturally as the price is lower and the user does not need to bother with focusing, these simple cameras have been sold by thousands where the more elaborate ones have been disposed of in hundreds. It is evident that they must give good results, or they would not be so popular. Let us, then, run over the advantages of the meniscus achromatic lens and see what its field is.

The meniscus lens is seldom used for picture sizes larger than 4×5 or $3\frac{1}{4} \times 5\frac{1}{2}$ (postcard) and the focal length or distance from the film to the lens is rarely more than $6\frac{1}{2}$ inches. The stop or opening through which the light passes is seldom any larger than *f*:16, which, for a $6\frac{1}{2}$-inch lens, is $6\frac{1}{2} \div 16$, or $\frac{4}{10}$ inch. Such a stop is only of medium size, compared to the focus of the lens, and it has the advantage that it allows a good average focus to be obtained. The maker carefully adjusts the camera until it makes a reasonably sharp image of all objects from 8 feet to the far distance, and then arranges the instrument so that when it is ready for use the lens will always be at the right position to make this average focus sure. A few postcard-size cameras with meniscus lenses are, however, provided with an adjustable front with pointer and focusing scale, so that the operator can focus. Distances in feet are marked on the scale, for example, 50, 15, and 6. It is not necessary to have a focusing scale for the smaller picture sizes, such as $2\frac{1}{4} \times 2\frac{1}{4}$ or $2\frac{1}{4} \times 3\frac{1}{4}$, because the lenses of shorter focal length used for them have more depth of field and can, in accordance with optical laws, focus at once objects near and far.

Finding the Hyperfocal Distance. — The formula by which the depth of sharp field can be found is: Multiply the square of the focal length in inches by 100 and divide by the *f* number of the stop. For a 4-inch lens working at *f*:8 this would be

$$\frac{4 \times 4 \times 100}{8} = 200 \text{ inches} = 16 \text{ feet } 8 \text{ inches.}$$

The distance found by this formula is called the hyperfocal distance for that particular stop. If the lens is focused (by trial) on an object at this distance, it will be found that the depth of sharp field is from half the hyperfocal distance to the limit of vision. Thus, in the example given, the 4-inch lens will reproduce all objects more than 8 feet 4 inches from the camera with reasonable distinctness. If the smaller stop of *f*:16, which is the largest usually supplied with meniscus lenses, is used, the hyperfocal distance will become 8 feet 2 inches, and the nearest object in focus will be 4 feet 1 inch away. Camera makers, however, usually set the lens so that it will not focus objects closer than 6 feet, in order to get a better distribution of the sharpness of definition at the further distances. Any user of a camera with a meniscus lens can find its focal length closely enough for practical purposes, if the catalog does not state the focal length in describing the camera, by measuring from the plane of the film to the optical centre of the lens, which, with sufficient accuracy for most purposes, may be assumed to be at the front surface.

Stops. — Fixed-focus cameras costing more than a dollar are generally provided with three stops, which take the form of holes pierced in a metal plate which can be moved so as to bring any chosen aperture into place in front of the centre of the lens. Each smaller opening usually has half the area of the next larger, and therefore admits only half as much light during an exposure of the same length. When the speed of the shutter is unalterable (that of most snap-shot shutters, if unmarked, may be taken as $\frac{1}{25}$ second), the only way one can regulate the amount of light reaching the film is by changing the stop. If the largest stop is *f*:16, — and very few cameras with meniscus lenses are furnished with any larger aperture — the other stops are usually *f*:22 and *f*:32 and require respectively twice and four times the exposure of *f*:16. They can be used for snapshots, in the latitudes of the United States, only for subjects of exceptional brilliancy, such as snow scenes or sea views, because exposures on average landscapes require all the light which *f*:16 will admit when the sun is shining between the hours of 9 A.M. and 3 P.M.

Shutter Speeds. — The regulation of exposure by changing the size of the stop or diaphragm is supplemented by altering the time the shutter is allowed to remain open. The lowest priced cameras with shutters have a rotary shutter arranged for snapshots (or "instantaneous") and "time;" the more elaborate possess one giving "time," "bulb," and "instantaneous;" still more expensive ones provide speeds marked in fractions of a second from 1 second to $\frac{1}{100}$ second, or even up to $\frac{1}{250}$ or $\frac{1}{300}$ second, if one is willing to pay the price. However, one would find a fast shutter of little use with a meniscus lens, so manufacturers furnish only the TIB sort with this lens. The "bulb" exposure is arranged so that the shutter will remain open as long as pressure is maintained on the rubber bulb or on the flexible metal release which has now almost driven the bulb and tube from the market. The "time" exposure is arranged so that it takes one pressure to open the shutter and a second pressure to close it. A moment's thought will show that by combining different lengths of exposure with different stops, one can secure almost any desired amount of light action greater than that represented by $\frac{1}{25}$ second at *f*:16, but nothing less than $\frac{1}{25}$ second at *f*:32. The light action of the latter exposure is too short for practical instantaneous use with a meniscus lens, except occasionally in full sunlight on snow or sea.

What Meniscus Lenses Will Do. — The greater portion of the pictures interesting to the amateur in the earlier stages of his photographic career can be taken successfully with a meniscus achromatic lens. The beginner is usually most interested in photographing friends or scenes incident to vacations or holidays. Such pictures are generally made in the summer time, between 9 A.M. and 3 P.M., well within the range for summer snapshots already indicated. In weaker sunlight, good results can be successfully obtained by using a tripod and giving a quick bulb exposure with the smallest stop. In fact, if the tripod is utilized as much as possible, there are few stationary subjects which cannot be well taken with a meniscus lens. The smaller the stop, the more clear and brilliant the rendering of fine detail in the picture. The smaller the stop, the longer the exposure. These two statements mark the limitations of the lens, and show that its work is practically confined to still subjects. If the subject is not in motion, it can usually be successfully taken with a meniscus lens, as far as the single factor of exposure is concerned. There are optical defects inherent in the meniscus lens, however, which render it unsatisfactory for use on special classes of subjects. The subject limitations of the meniscus lens will be more apparent after we have considered the

Optical Defects of Single Lenses. — A single meniscus achromatic lens cannot be so made that it will render straight lines as such at the margin of the picture, or render fine detail critically sharp all over the film, or represent a flat surface as equally sharp all over. For general amateur photography these defects matter only in architectural subjects. The single lens is not suitable for taking pictures of buildings. It is too slow for making snapshots under poor conditions of lighting. It cannot, in other words, be expected to do the same work as an expensive lens. Low price, in lenses, means small aperture or working speed, with consequent limitation to stationary objects and tripod exposures if it is to be used on subjects covering the whole field of photography.

Special Types of Meniscus Lenses. — For artistic photography, some workers prefer a lens which will not give a perfectly sharp image, and so opticians have produced the so-called "soft-focus" meniscus lenses to satisfy pictorial workers. The original lens of this sort, the "Smith Semi-Achromatic," was intended to give the same quality of soft definition as the pinhole, but to possess a speed of *f*:6, thus allowing snapshot exposures instead of the prolonged time exposures of a minute or more needed for a pinhole. These lenses are partly achromatic, that is, they are constructed to bring the yellow visual rays and the blue photographic rays to nearly the same indefinite focus, though they give less halo or flare around the margins of light-colored masses if used with a yellow ray filter. They do not, however, require a correction of focus, as does a lens made with a single piece of glass, but give on the plate the same effect seen on the ground glass. Such lenses naturally cannot be used successfully with any camera which is not provided with a ground-glass screen, for the image is so soft and harmonious that it needs the most careful focusing. By employing a smaller stop, the user can secure somewhat greater sharpness of definition, but never critically fine detail. As the softness depends largely on the optical defect known as spherical aberration, it is easier to secure the precise effect one desires if the final adjustment of focus is made with the stop to be used for the exposure, for a lens having spherical aberration changes its focus slightly for each stop. The makers of these lenses now manufacture also a series of double lenses of the same type, which are much faster and can be made to give various degrees of correction of chromatic aberration and spherical aberration by stopping down.

The Use of Soft-focus Lenses. — It is somewhat difficult for one who has used only fully corrected lenses to pass to the soft-focus type, and at once master its peculiarities. A lens of this class produces pictures which are not in sharp focus but have a softness which tones down the hard outlines and minute details of objects without losing the drawing or entirely suppressing the details necessary to render textures. There is no one plane where the picture is sharpest. There is a region of focus rather than one plane, and it is possible to move the lens some little distance backwards and forwards without affecting the definition to a marked degree, yet there is just one point for each stop where the effect is most pleasing. The lighting conditions govern to some extent the stop which may be used, for there is more halo around light-colored objects in a brilliant than in dull lighting. At any stop, it is important to use the " outside focus" for firmness of drawing, for the "inside focus" tends to produce too indefinite an effect. In other words, the lens should be moved away from the plate until the image goes out of focus and then be brought back until the desired rendering of detail is obtained. Lenses of the single series have from 50 to 60 per cent correction, and therefore show more halo around the lights than the doublets of 75 per cent correction, so that they must be stopped down more to get rid of the flare or used in a duller light.

Soft-focus lenses are perhaps best fitted for home portraiture, but the full aperture has to be handled carefully, or there will be a band of halo spreading from the lights into the shadows; for example, along a white collar where it comes near a dark suit. This effect may be minimized by using a double-coated orthochromatic plate with a light yellow filter (2x) and stopping down to *f*:8. The doublets give the same effect at about *f*:5.6; in other words, they are practically twice as fast. As, however, the softening of skin texture obtained by using a large opening is often desirable, to say nothing of the saving in time, it is advisable to use light backgrounds and light draperies and to employ rather a flat lighting. If the contrast between the lighted side and the background is small, the halo becomes negligible. The shadow side should be so well lighted that the color of the flesh is quite visible in the deepest shadow as well as in the highest light. Underexposure exaggerates the flare. The spherical aberration blends the finer details without losing the form, so that minor skin blemishes disappear, and there is no need of retouching. Direct prints give the same impression of skin texture that one receives in looking at a person, for one sees the face as a whole, not as multitudinous lines, freckles, moles, pores, etc. If used with discretion, lenses of this type give results of much artistic value, but diffusion of focus alone cannot make a poor composition into a picture, and overdone "fuzziness" is a blemish rather than a merit.

Other Soft-focus Lenses. — Several other varieties of soft-focus lenses were introduced after the Smith. The Spencer Port-Land is a single meniscus lens possessing a distinctive character of its own. It gives great softness without losing the drawing, and works nominally at about *f*:4.5, though few workers can utilize its image at any stop larger than about *f*:5.6, on account of its giving a number of overlapping images. Its softness is different from that of any other lens. Then there is the Wollensak Verito, a doublet intended chiefly for portraiture and working at *f*:4. The best results with this lens are perhaps obtained by stopping down to *f*:5.6 or *f*:6. At *f*:16, the image is not very different from that of an ordinary lens. Many workers look upon this property as an advantage, as the Verito will allow them to make soft or sharp pictures at will by simply changing the stop. Yet another make in considerable vogue is the Struss, which has been used with much success by several New York pictorial workers in the short time during which it has been on the market. The great advantage of the soft-focus objectives as a class is that they allow the individual to vary the quality of the definition to suit different subjects and to express his own personality in the picture.

Curvilinear Distortion. — As we have mentioned before, a single lens cannot render straight lines as such near the margin of the picture. This defect is partly dependent on the varying thickness of the lens from edge to centre, and partly on the position of the diaphragm. If the stop is placed in front of the lens, straight lines are bowed out from the centre of the picture, producing what is known as barrel-shaped distortion; when the stop is behind the lens, the lines bow in, and cushion-shaped distortion is the result. Consequently we cannot use a single lens for architectural photography, for copying, or for any purpose where it is necessary to reproduce straight lines, especially near the edge of the picture. This defect has a very simple and obvious remedy.

Rapid Rectilinear Lenses. — When two single meniscus lenses are mounted at opposite ends of a lens tube with the diaphragm or stop between them, the barrel-shaped distortion of the rear lens is corrected by the cushion-shaped distortion of the front lens. The result is that straight lines are rendered as such, and the lens is therefore called rectilinear. The speed, or ratio between focal length and diameter of stop, is also greatly increased by this arrangement, being in fact almost exactly doubled. Most cameras of moderate price are fitted with rapid rectilinear lenses (often abbreviated R.R.). The defects of spherical aberration and curvature of the field, as well as astigmatism, are not eliminated, so the chief advantages over the single lens remain those already stated, namely, rectilinearity and greater speed. Further corrections cannot be made with only two varieties of glass, crown and flint.

To illustrate the formation of a rectilinear, let us suppose that a single lens of 16 inches focal length and a speed of *f*:16 is being used on a 5 × 7 plate. The great focal length is necessary, since the field of a meniscus lens is considerably curved and only the centre of it can be used if sharp definition is to be obtained at this large aperture. The diameter of the stop is 1 inch. If another lens exactly like the first is mounted in the front of the lens-tube, the focus of the combined lens is now approximately half that of either element, namely 8 inches, and for simplicity of statement we may assume that the 1-inch stop now has the value *f*:8. This number is found by dividing the focal length, 8, by the diameter of the stop, 1. The speed of the lens is now four times as great as that of the single lens, as shown by the ratio between the squares of the numbers: — 16 × 16 is to 8 × 8 as 256 to 64, or as 4 to 1. The reason for taking the squares is that openings pass light in the ratio of their areas, and with circular apertures the areas are in proportion to the squares of their diameters. The *f* numbers, then, are based on this ratio and express the relation between focal-length of lens and diameter of opening. Any lens marked *f*:8, for example, no matter what its focal length, is practically as fast as any other lens also marked *f*:8. There may be slight variations due to difference in color and thickness of the glass, but they are unimportant as compared with the permissible latitude of exposure. In the example given above, we have seen how a definite opening of 1 inch may be either *f*:16 or *f*:8, according to the focal length of the lens or lenses in place in the lens-tube.

Utility of the Rapid Rectilinear Lens. — A camera fitted with double or triple extension of the bellows and a symmetrical or a convertible rectilinear lens will be found a most useful general-purpose instrument. The symmetrical rectilinear is composed of two halves alike in construction and usually of the same focal length, while the halves of the convertible lens are generally of different focal lengths. The complete lens is used for all ordinary work. The halves of the lens may be used for landscape or other work containing no important straight lines, portraits, and distant objects. Lenses of this character are offered under a great many fancy names in camera catalogues; but they are all rectilinears and possess the faults already enumerated of spherical aberration at the margins, curvature of field, and astigmatism. Readers are urged to beware of putting extra money into a camera because the rapid rectilinear lens is described as having unusual corrections, for which an extra price is charged. There is made in the United States only one such lens, the Rectigraphic, of which this is true, and its superiority results from the use of three instead of two elementary lenses in each of the single combinations. Aside from this lens, if an extra price is to be paid, it is better to invest in one of the low-priced anastigmat lenses. Rapid rectilinear lenses supplied on foreign cameras are generally styled aplanats. The typical rapid rectilinear lens works at *f*:8, but it does not cover its plate with critical sharpness over the whole surface unless it is stopped down to at least *f*:10. Rapid rectilinear lenses are occasionally diaphragmed so as to work at larger apertures than *f*:8. They can be thus used for special work, such as portraiture, but cannot give good definition, as the larger opening introduces more errors.

Choosing a Rapid Rectilinear Lens. — When one is buying a camera and it is offered in two models at a slight difference in cost, the lower-priced being fitted with a meniscus, and the higher-priced with a rapid rectilinear, the choice depends on whether one is content to accept the disadvantages of the meniscus for the sake of the average-focus feature. If not, the rapid rectilinear should unhesitatingly be chosen. A good rectilinear is an excellent general-purpose lens for amateur photography. The makers can be relied upon when one is buying a complete camera, whether film or plate. The case is a little different when a lens is to be chosen from several listed with a particular camera.

Cameras fitted with a single-extension bellows, such as most roll-film and many film-pack and plate cameras, gain nothing by having a convertible lens. The symmetrical form of rapid rectilinear is usable on such instruments only as a whole. When a double extension of bellows is provided the rear lens alone can be used. The more complete instruments of folding or view style, with triple extension of bellows, should preferably be fitted with a convertible lens. For instance, in the 5×7 size a typical outfit has a focus of $7\frac{1}{2}$ inches for the doublet, 12 inches for the rear, and 18 inches for the front element. The bellows extension is 20 inches.

Value of the Rapid Rectilinear Lens. — For general amateur work, a camera fitted with a rapid rectilinear lens having a focal length about equal to the diagonal of the film or plate is very suitable. It has sufficient speed for snapshots in sunlight at all seasons of the year, and at reasonably early and late hours. When it is fitted to a film camera the focusing scale has, of course, to be relied on; and this may at first trouble the beginner. A few suggestions about focusing may be of assistance here. The common amateur sizes are $3\frac{1}{4} \times 5\frac{1}{2}$ (postcard) and 4×5 and smaller, as far as hand camera snapshots are concerned. The focal lengths of the lenses usually fitted to these sizes by makers are $6\frac{3}{4}$ and $6\frac{1}{2}$ inches. These lenses will give a good general focus when set at 25 feet, with stop *f*:8 in use. When set at 15 feet and stopped down to *f*:16, they focus everything 8 feet or farther from the camera. The only real difficulty in focusing comes when objects rather close, such as figure-studies or portraits outdoors, are to be attempted, and ordinarily one can pace off the distance, or otherwise measure it, for accurate estimation of the distance is absolutely essential.

The Shutter. — Of more importance than the lens itself, in one way, is the exposure-shutter to which it is fitted. The minimum of efficiency with a rapid rectilinear lens is obtained when it is fitted to the TIB shutter. Even then, however, it is of vastly greater efficiency than the meniscus, for the simple reason that the speed of the meniscus is such that, for snapshot work, we are always verging on the ragged edge of underexposure, whereas with the rapid rectilinear, a snapshot exposure of approximately $\frac{1}{25}$ second at *f*:8 gives full exposure not only for summer work in various lights, but also on an increased field of subjects. When, however, the shutter has time, bulb, and regulated speeds marked 1, $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{25}$,

$\frac{1}{50}$, and $\frac{1}{100}$ second, the rectilinear is capable of doing far better work. If *The American Photography Exposure Tables* are consulted, the user can soon count on getting a good picture almost every time. Considering *f*:8 as the ordinary aperture for snapshot work, the range of instantaneous speeds just given will cover all common requirements. In fact, we have seen many satisfactory pictures made with a rapid rectilinear lens set in an even simpler shutter, having T, B, and three speeds supposed to run from $\frac{1}{25}$ to $\frac{1}{100}$ second. We are of the opinion that the most generally useful shutter for the rapid rectilinear lens would be one having accurate speeds of $\frac{1}{10}$, $\frac{1}{25}$, $\frac{1}{50}$ and $\frac{1}{100}$ second.

Limitations of the Rapid Rectilinear Lens. — Although for most work the astigmatism and curvature of field of the rapid rectilinear make little difference, there are some pictures in which the poor marginal definition is a menace to success. The fault, strange as it may seem, is most likely to occur when the worker is focusing on the ground glass. The reason is that he tries to get the middle of the picture critically sharp. This is easy, for the lens is well adapted to give a considerable fineness of definition in the centre of its field. We well remember the trouble which used to occur with a $6\frac{1}{2} \times 8\frac{1}{2}$ camera, fitted with an 11-inch rapid rectilinear lens. At *f*:8, focusing near the centre, the sharpness was confined to a 5-inch circle and the rest of the plate was very blurry. Through the help of a friend, it was soon learned that the curvature of the field would have to be split. Instead of focusing on the centre, we marked on the ground-glass points about midway between the centre and the margins, focusing on them and afterwards stopping down a little if necessary. This method should invariably be adopted when a rapid rectilinear is used on a camera which allows focusing on the ground glass, for the results will thus be as good as the qualities of the lens will permit. The smaller the stop used, the less the effects of the still uncorrected errors of the lens will show.

Curvature of Field. — The rapid rectilinear lens, introduced about 1865, represents practically the limit of correction obtainable with the old glasses known as crown and flint. As we have already stated, it is still afflicted with serious optical defects, absolutely irremovable with these materials. Obviously, as the glass dry plate must be flat to be prepared on any commercially possible scale, the image produced by the lens should be in sharp focus over the whole of a large flat surface. This is distinctly not the case with the simple lens, the achromatic combination, or the rapid rectilinear. With each of these forms of lens, the image is brought to a focus on a saucer-shaped field which, of course, cannot coincide with a flat glass plate, though the use of a small stop to a large degree obviates this defect, together with many others. In the modern anastigmat this defect is almost entirely overcome.

Astigmatism. — The fifth and last of the important aberrations of the lens, the most difficult to explain and the hardest to remove, is known as astigmatism. It is not only an affliction of the artificial lens made in the workshop, but is unfortunately known by name and effects to thousands of wearers of eyeglasses, who probably have little conception of just how their affliction is caused. It is an optical defect by reason of which a lens cannot bring to a sharp focus at one time lines which run in different directions on a plane surface. The oculist's test chart contains a figure made of radial lines looking like the spokes of a wheel. The reader whose eyes are affected with astigmatism will see most of these lines sharp, but one or more blurred. So the photographic lens which is not corrected for astigmatism will render a series of lines covering the whole surface of the plate sharp in some portions of the image, and blurred in others. By racking the lens back and forth any given line can be made sharp, but some others, running in a different direction on the same part of the plate, or in the same direction on a different portion of the plate, will be blurred. The defect is due to the inability of the marginal portions of a lens made of ordinary crown and flint glass to bring to a focus in the same plane the images of lines radial to the lens and tangential to it. When one is sharp, the other will be blurred.

Mathematicians proved that astigmatism could be removed from lenses by the production of glass of certain definite qualities and a German chemist had faith that such glasses could be produced. The chemist, Schott, and the scientist, Abbe, joined hands in 1884 and founded the famous glass-works at Jena, which, with financial aid from the Prussian government, finally produced not only the single sort of dense barium crown glass of high refractive index which was necessary for the first anastigmat, but an enormous series of new types of glass of the most varied properties, which meets almost every need of the optician, and has allowed the production of lenses of qualities quite undreamed of a generation ago. In curing astigmatism, the optician has also been able to mold the other qualities of the lens almost at his will.

Advantages of the Anastigmat. — Most anastigmats are not only free from astigmatism but possess also very complete corrections for chromatic aberration, spherical aberrations of different classes, and curvature of the field. As most of these faults are well removed in the rapid rectilinear lens at a working aperture of *f*:16 or smaller, the chief advantage of the anastigmats is speed. They do not require stopping down to secure crisp, brilliant definition from corner to corner of the plate. They do not need any special precautions in focusing the image of a flat object, for the image is almost as flat as the plate, instead of being saucer-shaped, as with the simpler lenses. They require, it is true, somewhat more care than the R. R. in focusing. A very slight movement of the focusing screw is sufficient to produce all the difference between definition no better than that of a common lens and the most beautiful, minute sharpness. The margins of the picture are just as crisp and clear as the middle, even if the sharpest focus is secured at the centre. In other words, the anastigmat at full aperture gives a sharper picture than the R. R. will give unless the latter is stopped down to *f*:16 or smaller. This means that the practical, everyday, available speed of the anastigmat is from 4 to 7 times that of the rapid rectilinear, depending on the full aperture of the former. Even the lower-priced anastigmats working at *f*:8 or *f*:7.7 show this real, practical increase of speed when compared with rapid rectilinears working at the same nominal aperture. The anastigmat need never be stopped down save to secure increased depth of sharp field. This brings us to a consideration of the next step in the price of an outfit furnished with a choice of rapid rectilinear and anastigmat lenses.

Rapid Rectilinear or Anastigmat. — Reference to almost any catalogue of cameras will show that an anastigmat working at *f*:8 or *f*:7.7 is supplied for from $5 to $10 more than the rapid rectilinear lens equipment. More can be paid if one wishes a shutter with a wider range of speeds or a lens working at *f*:6.8, *f*:6.3, or faster. However as the vast bulk of amateur work is done with apertures of *f*:8 or smaller, and we may consider *f*:8 the average aperture for general snapshot work, it is worth while appraising the slower anastigmats. Should a particular camera be desired, if the makers do not offer this type of anastigmat lens, the apparatus may be bought fitted with the rapid rectilinear, and the anastigmat lens in cells may be purchased separately and screwed into the shutter in place of the glasses of the rapid rectilinear. One American lens maker offers a set ready for substitution in the shutter of any $3\frac{1}{4} \times 5\frac{1}{2}$ kodak or camera for $10. The same maker offers an *f*:6.8 lens and shutter for $20 in postcard size. Several other manufacturers offer similar opportunities to fit rapid rectilinear outfits with anastigmat equipment. The reader can easily see that price need no longer be a serious obstacle to his owning a high-grade lens.

Price, notwithstanding, remains an important consideration. The novice finds it difficult to understand why some anastigmats can be furnished with a camera for only $5 increase in price while others cost $20 to $50 more. There are several reasons for the great range of prices. Manufacturing cost is the most important. A lens with simple construction and shallow curves can be ground and polished in a very small fraction of the time required for deeper curves. The cost of mounting and testing varies tremendously for different types of construction. In every instance, the faster the lens, the more difficult it is to secure perfection, so the higher must be the price. The construction is usually more complicated, because it is difficult to correct a large aperture with a simple form of construction. These causes may make an *f*:4.5 lens, for instance, cost more to manufacture than one of a similar type working at *f*:6.3. Speed, that desirable quality which allows very short exposures, must be paid for.

Some formulas allow much more complete correction of certain optical errors than other apparently similar formulas. The older anastigmats generally retained some spherical aberration, particularly the variety known as coma, which slightly softened the image. Getting rid of coma in the latest types has been a long and costly struggle, but most makers have now produced lenses which are as finely corrected as it is possible for objectives to be. In fact, it is doubtful whether some of the present lenses can be surpassed, unless some method of economically grinding curved surfaces more complex than those of the sphere can be devised.

Although anastigmats vary in excellence, all are better than rapid rectilinears and few workers are likely to demand of even the cheaper ones more than they are capable of doing. It is only when one is doing special work, such as copying maps or plans, etc., that a minute amount of coma would interfere with the result. In general amateur and professional photography, the anastigmat will answer all purposes even if it is not perfectly corrected. To choose one is a problem which can be solved only by knowing with what apparatus the lens is to be used and what classes of work are to be attempted. We advise using some anastigmat, if possible; but the exact sort to get is something which each user must decide for himself.

The Types of Anastigmats. — In the course of time, partly to enable new manufacturers to produce lenses which should not conflict with previous patents, and partly because opticians have ceaselessly tried to improve upon prior achievements, the number of types of anastigmats has steadily increased. It may be useful for us to review some of these, especially those which have been placed upon the American market, for there are a number of anastigmats which are not sold in this country.

In the first place, it may be of interest to tell just how the first anastigmat became possible. Before the Jena glass factory was founded, there were but two kinds of optical glass, crown and flint, and from this normal glass-pair, as it is called, opticians were able to make only a chromatically corrected lens without astigmatic correction. The collecting lens in this type both refracts and disperses less than the dispersing lens. To get the anastigmatic correction, it was necessary to make the collecting lens of a more highly refractive glass than the dispersing lens, while the ratio of the dispersions was similar to that of the older glasses. Abbe and Schott made such glasses, and the combination is called an anomalous glass-pair. The achromatic lenses made from these are called new achromats to distinguish them from the old achromats. The new achromat can be corrected or over-corrected for astigmatism, but not for spherical aberration, while the case is reversed with the old achromat. The combination of an old achromat and a new achromat allows the correction of both errors, as well as distortion, and the remaining aberration, curvature of field, is disposed of by properly separating the two groups of lenses.

The Protar. — The first anastigmat was made on this basis in 1890, and was calculated by Rudolph of Jena for the Zeiss works. It was an unsymmetrical doublet, with central stop, and is still marketed as the Series V Protar, used for wide-angle work. The front combination is the same as that of a rapid rectilinear lens, while the rear half is a new achromat, the fourth glass being of the heaviest barite crown, the glass which makes anastigmats possible.

Anastigmatic Correction of the Single Lens. — The next step in the progress of the anastigmat was the production of a single lens, which was achieved by the combination of three glasses in the form of half of a rapid rectilinear in which the rear glass has been replaced by a new achromat. Rudolph immediately developed this further into a four-glass combination, which was composed of a new achromat and an old achromat cemented together. This lens, developed in 1895, is the basis of the Series VII Protars, working at f:12.5. The corrections for the various aberrations made possible by this formula are very satisfactory, so that these single lenses are excellent anastigmats of great brilliancy and crispness of definition. They are so slow that they find little favor today except in the form of sets.

Convertible Sets. — The Series VII Protar is the basis of the convertible Protar sets. Each set consists of a number of similar objectives with front stops, which may be screwed into the two ends of the lens tube, so that they can be used either singly or in pairs. A set of two elements of different focal lengths gives three focal lengths, three elements give six focal lengths, and four elements give ten focal lengths. Such a combination of like or similar halves automatically corrects distortion, coma, and some other lens errors. The double objective is therefore better corrected than the single lens, and has a much larger aperture. With such sets it is possible to photograph a given object from any point in different sizes. In combining the single lenses, it is advisable not to exceed the ratio of two to three in focal length between the elements, the lens of greater focal length being always placed in front of the diaphragm. When the single element is used, it should always be placed in the rear end of the tube with the stop in front. When two Series VII Protars are permanently combined, we get a doublet known as the Series VIIa, working at the aperture of f:6.3 instead of the f:12.5 of the single lens.

The Protar has never been surpassed as a symmetrical anastigmat doublet, with the possibility of using the halves singly. Its nearest competitors in this respect are the three-glass cemented elements of the Dagor and Collinear types. The halves of a large number of symmetrical anastigmats, especially those having elements composed of two separate lenses, cannot be used singly, because they would have to be stopped down too sharply in order to obtain a moderately useful image.

The Double Anastigmat. — While Rudolph was working out his Protars, Von Hoegh of the Goerz firm elaborated the three-glass element differently, by combining two identical elements of Rudolph's first type to form the double anastigmat, now known as the Dagor. In his opinion, his doublet lens was better corrected than Rudolph's Protar, but the elements of the Dagor are not as well corrected as those of the Protar. The effective aperture is *f*:6.8 for the shorter foci and less for the longer. This lens is probably the most successful anastigmat ever constructed. It has been made by hundreds of thousands, and as the patents have expired, it is now constructed under various names by practically all lens makers. Its maximum stop value of *f*:6.8 is nominally 50 per cent faster than that of the rapid rectilinear lens. Actually it is at least five times as fast as this lens, for the rapid rectilinear must be stopped to *f*:16 to approach it in defining power. At its full working aperture the Dagor has almost perfect flatness of field, with critical definition to the extreme corners of the plate. Half of the lens is a good landscape lens. The complete doublet used with medium or small stops is almost free from optical errors over its entire circle of illumination, and therefore can be used on plates larger than those for which it is listed, as a wide-angle lens.

Other Three-glass Cemented Systems. — Other anastigmat elements have been used by various makers. One, calculated by Von Hoegh, has long been made by Watson of London, under the name Convertible Lens, while the Zeiss Convertible Series IV is of the same type. Another invention of this type was produced simultaneously by Voigtländer of Brunswick and Steinheil of Munich, and introduced under the respective names of Collinear and Orthostigmat. These lenses not only work at *f*:7.7 to *f*:6.8, but can also be satisfactorily corrected in smaller sizes to work at *f*:5.4. As new glasses have been produced at Jena, it has been possible still further to improve this class of lenses, until one of them, the Euryplan Series Va, works satisfactorily at the high speed of *f*:4.5, about three times as fast as the rapid rectilinear at its largest opening.

Eight- and Ten-lens Double Objectives. — The Rietzschel Linear is similar to Rudolph's four-glass element, differing in the arrangement of its dispersing and collecting surfaces. In practice this and other eight-glass lenses do not surpass the six-glass symmetrical anastigmat, while the manufacturing difficulties, especially that of centering the various glasses in assembling the lens, naturally increase. For this reason opticians have not looked with favor on increasing the number of glasses, and while ten-lens systems have been constructed, the only one now on the market is the Turner-Reich. Increasing the number of glasses may increase the efficiency of the single element, but produces no improvement in the doublet in proportion to the increased expense of production. It is possible that there remains for this type of lens a great increase of working aperture, but this field has not yet been thoroughly investigated.

Triplets with Air Spaces. — In 1894, H. Dennis Taylor, scientific director for the famous English telescope manufacturer, Cooke, invented a lens consisting of three single glasses separated by air spaces, which effectively eliminated coma. This is now manufactured in two types, one working at *f*:9 to *f*:6.8, the faster series working at *f*:5.6 to *f*:4.5. The Cooke lenses, and similar ones made by Voigtländer under the names Triple Anastigmat and Portrait Anastigmat, are not convertible, but where this feature is not required it is hard to find a more satisfactory objective, as the corrections of the different series are well carried out, and the lenses are of very compact construction and light weight, especially when mounted in aluminum barrels. As the Cooke lenses are completely free from coma, they have been found of great value for photo-engraving purposes, and a majority of all lenses used in the United States for this purpose are of this type.

Heliar, Tessar, and Dynar. — Other makers soon produced types derived from the Cooke by the introduction of another kind of glass and of a collecting cemented surface. The Voigtländer Heliar was calculated in 1902 by Harting, and in this lens the zonal errors are so minimized that the lens can be constructed with the full aperture of *f*:4.5, up to a focal length of 24 inches. The Heliar is a five-glass system, containing two doublets with a single lens between, all separated by air spaces. The lens is entirely free from coma over the whole field. The Zeiss Tessar, calculated by Rudolph in 1902, contains four glasses, the rear cemented combination consisting of two glasses. The first Tessar worked at *f*:6.3, but it is now made for general use to work at *f*:4.5, and for cinematography to work at *f*:3.5. Harting states that the Tessar and the Heliar are as completely corrected as it is possible to make lenses, and considers them unlikely ever to be surpassed. They have no excessive curvatures and the spherical errors are completely removed over the whole field. The 1c Tessar covers a larger area in proportion to focal length than any other lens yet made. Harting also calculated for Voigtländer another five-glass combination, the Dynar, which works at *f*:6, and is intended for general hand-camera use. It shows the same complete corrections as the Heliar.

Four-glass Air-space Types. — The replacement of the central glass by an air space in the single combination of the Orthostigmat or Collinear type resulted in producing lenses of somewhat less complicated construction, but of very good efficiency. Such lenses have been produced by various makers in speeds up to *f*:4.5. Among them we may mention the Ross Homocentric, and the Goerz Celor and Syntor. These lenses have good anastigmatic corrections. There are many other lenses of this type on the market, but some of them, while well corrected for astigmatism, show a great amount of coma. For some purposes this is no disadvantage, but in many cases it is found necessary to stop them down strongly to overcome this defect.

Miscellaneous Types. — In addition to the many groups of lenses already enumerated, there have been marketed numerous others, from the Aldis, with two cemented glasses in front and a single one behind the diaphragm, a lens which gives a most remarkable sharpness of definition, to the air-space lenses containing many separate glasses, and cemented ones containing as many as ten elementary lenses. Some of these lenses are of the highest quality, while others are inferior. In buying lenses, one has to rely partly on the reputation of the maker and partly on the results of test exposures. The principal point of dispute between lens makers today is as to the relative efficiency of cemented and air-space lenses.

Why is there a Difference Between Anastigmats? — At this point the reader may ask, " What is the necessity for so many types of anastigmats and which is actually the best?" The only answer that can be given is that there is no best anastigmat, because with the number of variable elements at the command of the lens calculator, it is not possible in any lens to remove all the aberrations for light of all wave lengths, and for all zones of the lens. A mathematical optician must choose which aberrations he will completely remove over the whole field, and for all colors, and calculate his lens accordingly. If he is making a lens for the three-color worker, he must produce three sharp images of three different colors which will be coincident in size, and lenses of this type are called apochromatic. If he is making a lens for the process-engraver, he must endeavor to remove coma absolutely, probably at the expense of speed. For the hand camera worker, speed is the greatest consideration, but a moderately large field must be covered. For cinematography everything can be sacrificed to the production of enormous aperture, even down to *f*:1.9. Again, competition in price exists, and simplicity of manufacture must therefore be taken into account in low-priced lenses, necessitating fewer glasses, fewer cemented surfaces and shallow curves, even at some expense in corrections.

The Performance of Modern Unsymmetrical Anastigmats. — The performance of lenses seems to have reached its greatest possible height, under present conditions, in lenses containing air-spaces, such as the Cooke, Heliar, Ross, Tessar, and others. In these lenses there is such a high degree of freedom from aberration with large aperture and wide angle of view, that no practical necessity exists for improvement. Some may, however, prefer symmetrical lenses with cemented halves, because with them we have the choice of a long or short focus. Such lenses will give absolute sharpness at the edge of the plate at full aperture, and if stopped down will give complete sharpness of definition over the whole field of illumination, so that the modern universal objectives, as we may name systems working at from *f*:6 to *f*:7, are really wide angle lenses which define just as well as an astigmatic wide angle, but at a much larger opening. In this connection we may remark that if extremely wide angles are required the Hypergon double anastigmat of Goerz, which consists only of meniscus lenses with a diaphragm between, works, when focused at *f*:22 and exposed at *f*:31, over the enormous angle of 140 degrees, an angle which constructive optics can never hope to increase.

The Limit of Effective Aperture. — While anastigmats for cinematographic purposes can easily be made to give perfect anastigmatism at *f*:3.5, and satisfactory performance down to *f*:1.9, for hand camera work or any purpose of general photography, no aperture larger than *f*:4.5 is useful to the average photographer. At any larger opening, while greater rapidity of exposure can be obtained, it is not possible to obtain sufficient depth. A lens of this speed must be focused with the utmost care, and practically the only finder which is satisfactory is the camera itself. For some purposes focusing on a ground glass with a tripod would be satisfactory, but for speed work a lens of this aperture should always be used on a reflecting camera, for only with an instrument of this type is it possible easily and certainly to obtain critical focus. In general, the lens working at *f*:4.5 cannot give as great an extent of sharp field as one working at *f*:8, for even when a faster lens is stopped down to the same aperture, it is surpassed by the slower lens, because in sacrificing speed it is possible to correct astigmatism over a larger field. As to sharpness in the centre of the field, both anastigmats and astigmats may have good definition, depending on the perfection of the corrections for spherical aberrations. But certain types of anastigmats, especially the Tessar, Heliar, and Dynar, give a central sharpness which is sought in vain among the astigmatic lenses. Lenses working at *f*:3.5 are used to a slight extent by press photographers and others who believe they must possess the utmost possibility of speed.

Air-Spaces. — Some makers who produce only cemented lenses intimate that any air-space lens must be inferior because of the internal loss of light by reflection. Their opponents retort that thick cemented lenses lose as much light by absorption as the air-space lenses do by reflection. Dr. Hans Harting says, "The question of the relation of actual brilliancy in the case of cemented and uncemented lenses of the same relative opening is very often raised. Absorption depends on the kind of glass; as in the same melt various portions of glass may vary with respect to absorption, the loss of light may vary somewhat even in two lenses of the same construction and focal length. For several years I had the opportunity of comparing almost uninterruptedly for their photographic brilliancy a six-lens symmetrical objective, consisting of two halves of three cemented lenses, and an objective consisting of three single lenses. Both anastigmats of medium focal lengths have the same relative aperture, either *f*:6.8 or *f*:7.7. I was never able to distinguish a photographically measurable difference in the actual brilliancy of these two kinds of objectives representing the extremes of construction. It is true that the loss of light in the simple landscape lens is less than in the Zeiss Double Protar consisting of eight lenses. But even this difference is unimportant in picture taking, in comparison with the far greater deviations from the proper exposure in sunlight which even the most experienced photographer cannot avoid, but which are made absolutely imperceptible in the process of development." The truth seems to be that well-designed air-space objectives pass as much light as cemented ones of the same effective aperture. Under unfavorable circumstances, too many air-spaces cause general fogging of the image through scattered light inside the camera, but this fault is mainly to be ascribed to the fact that the circle of illumination is much larger than the plate covered, so that light is reflected from the inside of the bellows. The obvious remedy for this is to employ a lens hood, which will eliminate the light before it enters the camera. If bright lights appear in the picture, as in night photography, the air-space lens may show false images called ghosts, or spots of light called flare spots, but the only lens which would not show these under such trying conditions is a single lens containing only one piece of glass. These images caused by internal reflection are often so much less bright than the original that they do not appear in the photograph, though they may be visible on the ground glass. General fog ascribed to air-spaces is often due to lack of sufficient sodium sulphite in the developer, and in this case will disappear if the developer is so compounded that each fluid ounce contains ten grains of anhydrous sulphite.

The choice between cemented and air-space lenses, then, depends chiefly on the value of convertibility, adaptability to wide angle work, and smaller factors. If one is using only a film camera with single extension of bellows, the air-space type of lens is perfectly satisfactory. If one's camera has double or triple bellows extension, the symmetrical or convertible anastigmat may be preferable, as it enables one to do more kinds of work. This then brings us to

The Choice of an Anastigmat. Speed. — The first consideration is that of speed. Anastigmat lenses are offered of all speeds from *f*:8 to *f*:1.9, the latter for motion-picture work only. The higher speeds are only really available for general work in lenses of moderate focal length, for the depth of field is so small in the larger sizes that they can be used only on objects which do not move and which are nearly in one plane. This confines their use almost wholly to portraiture and copying. For general photography, the greatest speed ever useful is *f*:4.5. Lenses of this speed may be used very successfully on hand cameras in miniature sizes. Above $3\frac{1}{4} \times 4\frac{1}{4}$ they should be used only on reflecting cameras or those provided with a focusing screen, and for general photography 5×7 is the useful limit of size with this speed. With a $6\frac{1}{2} \times 8\frac{1}{2}$ plate, *f*:5.6 is about the limit, while *f*:6 to *f*:6.3 marks the practical speed for 8×10. Of course, in portraiture, photo-engraving, etc., *f*:4.5 lenses up to a focal length of 24 inches are often used. For the photography of rapidly moving objects and for general work in bad lights the *f*:4.5 anastigmats are indispensable, but the lack of depth of field and consequent difficulty of focusing render the use of the full aperture inadvisable except in case of necessity, and so lenses working at *f*:6.3 and *f*:6.8, usually spoken of as " universal " lenses, are to be preferred for general photographic work where excessive speed is not needed.

Focus. — Other things being equal, the most pleasing angle of view for probably 90 per cent of all amateur photographs is that obtained when the equivalent focus of the lens is equal to the diagonal of the plate. Most makers list anastigmats of shorter focus than this for each plate, for instance 6 inches instead of $6\frac{1}{2}$ inches for 4×5, 7 inches instead of $8\frac{1}{2}$

inches for 5 × 7, and so on. In such a case it is often better to select the next size larger. A greater focal length is of advantage from a pictorial standpoint, hence the popularity of symmetrical and convertible anastigmats, the halves of which can be used as single view lenses, if the camera has a long bellows. If, however, one intends to do only the usual types of vacation pictures, snapshots of the children at play, and an occasional out-door figure study or indoor portrait, a lens of focal length equal to the diagonal will be the best compromise, and the speed should depend on the camera and the shutter. With a reflecting camera of any size, the use of a lens working at *f*:4.5 is decidedly to be recommended because this gives the utmost possibility for speed work. When a faster lens is stopped down to the same aperture as a slower one of the same focal length, their performance is much the same, though the slower one will probably cover a larger field. The greatest disadvantage of large aperture (that is speed) is the diminution of the depth of sharp field. The nearer the object focused, the shallower the depth of field, hence the practical necessity of using a reflecting camera for an *f*:4.5 lens of moderate focal length. If, however, much portraiture in the home is to be done with any type of camera, the advantages of the *f*:4.5 lens are so great that it should unhesitatingly be chosen in focal lengths up to about 9 inches, at any rate. As a portrait lens alone, this speed is not too great in lenses of even longer focus — in fact, for this special use, there is a great advantage in using as large a lens as can be worked in the available space. For instance, a 16-inch lens at 16 feet will give better perspective than an 8-inch lens at 8 feet, though the two images will be of the same size.

Types. — The choice between the different types of lenses is very largely a matter of taste; for the rest, as already hinted, the use of a symmetrical or a convertible lens on a single-extension camera is no better than a tying-up of valuable properties which cannot be used. The user may, however, some day get another camera on which he can use the single combinations, so there is something to be said in favor of planning for the future. Otherwise, there are lenses of thoroughly satisfactory correction in both classes.

Using an Anastigmat. First Perplexities. — When one has been using a rectilinear, particularly when it has been employed chiefly for tripod work with medium stops, the first impression of an anastigmat at full opening is that it has very little depth and needs stopping down. The image, where it is in perfect focus, is so much more clean-cut and brilliant than anything ever seen before that the out-of-focus parts look distressingly soft and fuzzy. The second thing noticed is that a very minute movement of the lens is sufficient to throw the image out. If the lens has been put on an old camera, with a front which is shaky from wear, one side of the picture may be in perfect focus and the other blurred. A perfect lens must have a perfect camera. The front must be rigid and hold the lens with its axis perpendicular to the film, or the definition will be poorer than that obtained with the rapid rectilinear. When using the focusing scale, extreme care must be taken to set the pointer accurately to the required distance. An error of a few hundredths of an inch may be sufficient to make the difference between crisp, sparkling detail and a general softness which ruins the effect. Finally, one discovers that when a flat surface is focused, the detail is as good in the corners as at the centre and one does not have to split the focus, as the field is perfectly flat. This brings us to the conclusion that the lens will need stopping down only when it is necessary to increase the depth of the sharp field, not to secure covering power.

Securing the Anastigmat Advantages. — Other things being equal, an anastigmat in a poor, cheap shutter is not able to do its best work. Here we have a usable aperture of say, *f*:6.3, and a nominal $\frac{1}{100}$ second which may be really $\frac{1}{60}$. In bright summer sunlight it is necessary to stop down in order to avoid over-exposure, or conversely, we cannot take a sharp picture of athletic sports, because we lack the needful $\frac{1}{250}$ second actual exposure which a better shutter gives. Again, the low-priced shutter has no speed between $\frac{1}{25}$ and $\frac{1}{5}$ second. One is too fast for a successful snapshot at full aperture in poor light, the other too slow for the camera to be held in the hand without causing blur. The costlier shutter, however, has an accurate $\frac{1}{10}$ second which is just what is needed. In short, when you get your anastigmat, have it mounted in the best shutter you can afford, if you are not purchasing a camera fitted with a focal-plane shutter. It is well to remark that a high-grade shutter with really accurate speeds may prove a difficult tool to become acquainted with after using a cheap and inaccurate one, leading to serious under-exposure if used without realizing the fact that the speeds may be twice as great as those of the same markings on the cheap shutter. Occasionally it is an advantage to have the lens in a shutter instead of a barrel even on a reflecting camera, as the focal-plane shutter of the latter is not so well suited to give slow snapshots and time exposures as the between-lens shutter. Extra speed in the lens itself is not of much use if it cannot be made available by a wide range of shutter speeds.

Focusing. — Anastigmats being perfectly achromatic for two and usually for three colors, the image seen on the ground glass is exactly what one gets on the plate, if the latter is in register with the former. Sometimes a fine lens gives poor results, and the trouble is found to be due to the fact that the holders are not bringing the plate within a sensible distance of the same plane as the ground side of the glass. In such cases, the holders must be tested by means of a straight-edge and a wedge, and the position of the ground glass altered to correspond. Users of reflecting cameras may require special spectacle lenses fitted inside the hood in order to focus accurately. Incorrect register of the ground glass is not unknown, even in costly reflecting instruments. But when the register has been proved correct, one often has difficulty in learning to focus. The tendency is to move the focusing screw too rapidly. The difference between a microscopically sharp focus and a blur may be one of a touch of the pinion-head. Care must be taken not to focus too far back, thus sharpening the distance at the expense of the foreground and making the latter unpleasantly blurry by contrast with the extreme, needle-point definition of the background. Stopping down, however, will be needed less often than one would at first expect, as, owing to the perfect flatness of field, one can focus at any point of the picture, and then carefully divide the sharpness between far and near objects, favoring the foreground as much as possible, before putting in a smaller stop. Generally, if the plane of sharpest focus is one-third of the distance from camera to farthest object, a medium stop will give sufficient depth; but if the plane of sharp focus were placed at two-thirds of this distance, the smallest stop would often hardly suffice.

Scale Focusing. — When the camera is sold fitted with an anastigmat, the correctness of its setting should be tried by making an exposure at the exact measured distance for each mark on the focusing scale. In making these tests be sure that the front is solidly locked or drawn out to the stop, or the pointer set exactly on the mark. Should the scale prove to be incorrectly placed, adjust it by careful trial.

Hyperfocal Distances. — The greatest possible depth of sharp field is obtained when a lens is set to a definite distance for each stop. The distance is found by the formula given on page 17. Suppose a 6-inch lens works at *f*:4.5. Its hyperfocal distance for this stop is 66 feet. In the same manner, the distances for the other stops may be worked out and tabulated, a trial made at these measured distances, and a supplementary scale made for the camera. Such a scale is far more useful than one marked with conventional distances. To use it, set the pointer to the distance corresponding to the stop in use, and the depth of sharp field will extend from half the hyperfocal distance to infinity. Thus, with the lens already mentioned, the 66-foot setting will give a sharp image of everything more than 33 feet from the lens. The same lens at *f*:8 (which we consider the normal stop for hand-camera snapshots) may be set at 38 feet, and will give good definition from 19 feet to the horizon. It is by applying this rule to the *f*:16 meniscus of short focus that the manufacturers produce the so-called fixed-focus lens.

Other Points About Anastigmats. — We might write many pages on the use of anastigmat lenses without covering all the points which might arise. The owner of one, however, will learn more from using it than from reading directions. The chief advantages of the anastigmat are that its corrections have been carried out so that it condenses to a very small circle of light in the image, each bundle of rays originating in a point of the object, whether the ray passes centrally or obliquely through the lens. This circle of confusion, as it is called, should have a diameter of about $\frac{1}{100}$ of an inch in a rapid rectilinear, and only from $\frac{1}{200}$ to $\frac{1}{500}$ in an anastigmat. This means in practice that an anastigmat will give a critically sharp image over the entire plate at a large aperture.

Care of Lenses. — A fine instrument requires careful handling. When not in use the lens should be kept in a stout box, with a cap over each end, in a cool place. Dust may be removed from the combinations with a clean camel's hair brush, holding the lens up and brushing it very gently from underneath so that the dust will fall off. If a greasy film collects on the glasses, they may be unscrewed and very gently wiped with the Japanese tissue paper sold by optical and physicians' supply houses, under the name of lens paper. Rubbing must be avoided. Glass surfaces are relatively very soft. If one rubs the surface with a dusty cloth, the polish may be destroyed or the curvatures altered, ruining the lens. No other substance than lens paper should ever be allowed to touch the surfaces of the glasses. The greatest care must be exercised in taking apart and putting together air-space anastigmats. With some of these an error of adjustment of $\frac{1}{250}$ of an inch will cause considerable deterioration of the quality of the image. A lens may require recementing after years of use, or repolishing, if the softer varieties of Jena glass assume a rainbow-hued appearance. In any such case, send it to its maker for the necessary repairs.

Special Fields of Photography. — So far, we have discussed only the ordinary kinds of photography, but many prospective purchasers of a lens may wish to use it for such special fields as portraiture, copying, or enlarging. The "how to use" part is so different that it requires a little consideration.

Portraiture. — Although good portraits can be made with a simple outfit, there are certain difficulties which can be overcome only by knowing all the tricks and having a camera provided with all possible movements, inasmuch as the use of a lens very near to a subject which has considerable portions projecting forward and back of the main plane focused on may lead to poor results. Short exposures are desirable, which means using a large aperture and thereby losing depth of field. The deficiency must therefore be made up not only by tilting the camera to point down at the sitter, but also by utilizing the vertical and horizontal swings to equalize definition between nearer and farther parts. For instance, if a sharp focus is secured on the sitter's eye, with the ground glass vertical, it will be found impossible to secure sharpness in a hand resting on the lap, unless the lens is stopped down or the vertical swing is used to bring the ground glass away from the vertical plane to the place where the sharp image of the hand really lies. Similarly, both shoulders can be focused, in a three-quarter pose, only by using the horizontal swing. For these reasons a good view camera will be found the best purchase for an amateur wishing to do much portraiture. Since vertical lines seldom appear in a portrait, the ground glass may be placed in any position where it will receive a sharp image. The nearer any object is to the lens, the farther its image lies from the lens.

Copying and Enlarging. — The last statement governs the use of the lens for copying and enlarging. The ordinary camera with a single extension of bellows can be used to focus objects only up to about 6 feet. If a larger image is desired, it must be obtained through the use of a supplementary lens ("portrait attachment" or "copying lens"), or by using a camera with double or triple extension of the bellows. For instance, to copy a photograph "same size" with a 7-inch lens (about the focus of that supplied on a 3a film camera) the lens must be 14 inches from the ground glass and 14 inches away from the "copy." To secure an enlargement of 4 diameters with the same lens, that is, to enlarge from $3\frac{1}{4} \times 5\frac{1}{2}$ to 13×22, the lens would have to be $8\frac{3}{4}$ inches from the negative and 35 inches from the bromide paper on the easel. As the bellows is too short for such use, an enlarging apparatus would have to include a box behind the kodak of such length as to secure the necessary 8¾ inches' extension — or more, if smaller-scale enlargements were desired. Suffice it to say, it is useless to purchase the most universal anastigmat unless it is fitted to a camera having adequate draw of bellows. As a matter of fact, unless one confines photographic activity to outdoor hand-camera work, it will be found that two or more cameras of different sizes and capabilities are needed to cover every department of photography successfully.

Wide-angle Lenses. — A lens capable of producing a negative embracing an angle of view greater than 70° is called a wide-angle lens. Up to this angle, although it is much greater than that seen by the eye at once, the perspective is not too extreme, but above this angle, objects near the edge of the picture are much distorted, and such lenses should be used only where cramped situations render their use obligatory. A 6-inch rapid rectilinear, for instance, will work fairly well on a 4 × 5 plate, including 56° along the diagonal of the plate. If the same lens were used on a 5 × 7 plate the angle included along the diagonal would be 71°, and the lens in this instance would be a wide-angle lens for that plate. Ordinary rectilinears, however, are not well adapted to such use; a special form, made of heavier glasses and with deeper curvatures, working at *f*:16 or slower, can be bought. Cells to fit ordinary shutters and lenses in barrel-mounts are still obtainable and are useful additions to an outfit, particularly for copying or for taking interiors or other close subjects when the regular lens cannot be placed far enough from the subject to include enough of it. For instance, suppose one has a 5 × 7 camera with single extension of bellows and fitted with an 8½-inch rapid rectilinear lens. A set of wide angle cells, listed at $6, will furnish, for the same shutter, a lens having an equivalent focus of about 5½ inches. Such a lens would include 78° on the diagonal, allowing its use for small interiors. It could also be used to make a copy half the size of the original with the short bellows furnished on the camera, whereas the regular rapid rectilinear would not make one larger than ⅙ size with the same extension.

Limitations of the Old Rapid Rectilinears. — The special wide-angle types of rectilinears, of course, have all the defects of their class, with the added disadvantage of a small maximum opening for focusing. Still, if they are carefully used, they are capable of doing remarkably fine work with very small stops. It is necessary to split the curvature of field when focusing, and in interior work, to make sure that the proper depth is secured by focusing wide open on some subject only a third of the whole depth of the subject from the lens. For instance, if the interior measures 30 feet from lens to most distant wall, a point 10 feet from the lens should be chosen for the sharpest focus at full aperture and the lens then be stopped down until everything is sharp enough.

Modern Wide-Angles. — Some of the earlier anastigmats were wide-angles, notably the Zeiss Series V. Several other special forms of anastigmat wide-angle lenses have been marketed, but the symmetrical cemented double anastigmats, as well as some of the unsymmetrical objectives, answer the purpose so perfectly that they are generally chosen. For instance, a 6-inch lens which is intended for a 4 × 5 plate will cover 5 × 7 at *f*:16 and 6½ × 8½ at *f*:22 or *f*:32. In planning for two cameras of different sizes, therefore, it is not inadvisable to select for the smaller instrument a lens which will answer for use as a wide-angle on the larger camera.

Teleobjectives. — When it is necessary to obtain a large direct picture of a distant object, in order to avoid lenses of extreme focal length, with correspondingly long bellows, lens systems are used which contain a negative or dispersing lens in combination with a collecting lens. Telephoto attachments may be had for either rapid rectilinear or anastigmat lenses, and give various magnifications by varying the separations of the lenses. They greatly increase the focal length of the lens, and therefore reduce the effective aperture or *f* value, so that exposures must be very long.

Limitations of Telephotography. — It is difficult to obtain good pictures with the long exposures needed at high magnifications. The camera itself must be solidly built to obviate vibration, and the air must be as still as possible. There are, on the whole, very few days in the year which will allow successful telephotographic work. The greater the enlargement, the more noticeable is the effect of air currents in blurring the detail. The lower amplifications, 4½ to 6 times, are more likely to prove usable.

Fixed-magnification Teleobjectives.—Practical considerations, such as have been mentioned, led to the abandonment of the variable magnification and the construction of teleobjectives suitable for reflecting and hand cameras and having a fixed magnification of about 2 or 2½ diameters. In other words, these lenses give a large image with short bellows extension. One of them, the Ross Telecentric, gives almost as fine definition as an anastigmat and has a working aperture of *f*:5.4. The chief advantage, as compared with a long-focus regular lens having the same equivalent focus, is the rigidity of the short bellows. The 17-inch Telecentric *f*:5.4, for instance, has a back focus, or distance from rear lens-cell to ground glass, of only $9\frac{1}{16}$ inches. It could thus be advantageously fitted to a 4 × 5 reflecting camera which could hardly accommodate a 17-inch Tessar, for instance, even if the photographer could afford to pay for the latter. Other manufacturers brought out various forms of the telephoto objective, among which may be mentioned the Cooke Telar, the Dallmeyer Adon, and the Zeiss Magnar.

Trying a Lens. — Most workers in buying lenses are interested in those of the highest possible corrections and desire to know just how they can make a wise selection from the many varieties offered. Since the prices of anastigmat lenses have come down, the difficulty of making a choice has increased. One worker is willing to pay any sum if he can be shown that the lens is really better than some other of equal or lower cost. Another worker is strictly limited by his pocketbook, but doubts whether the price he can afford will actually buy a genuine anastigmat of good corrections and capable of doing well all the sorts of photographic work in which he is interested. The following paragraphs give, for the benefit of both classes, some methods of testing lenses, based on an article published in *The British Journal of Photography*. By trying the lenses, usually sent with the privilege of a ten days' trial by the makers, the reader can at slight trouble determine just how good they are.

Testing a Lens. — There are two distinct things which have to be ascertained about a lens before taking it into use — its capabilities and its qualities. Under the heading of capabilities are three principal points: The intensity, or, as some call it, the speed at full aperture; the relation of the circle of illumination to focal length or angle of view; and whether the image is sufficiently rectilinear for the work the lens is to be used for. Want of rectilinearity is not a defect for some work: it may even be an advantage, so we place this point under capabilities instead of qualities.

Focal Length. — To arrive at the intensity, or, as it is often called, angular aperture, we must first ascertain with some degree of accuracy the actual or equivalent focal length of the lens. There are many ways of doing this, perhaps the simplest being to focus a distant object, to mark the camera extension on the baseboard, and then to focus any object, such as a printed card, so that the image on the ground glass is exactly the size of the original. The difference between the original extension as marked and the extension required for a full-sized image is the equivalent focal length of the lens.

Focal Aperture. — The intensity is got by dividing the diameter of the largest aperture of the diaphragm into the focal length. This, however, although not difficult of accomplishment, is not quite as easy as it sounds. As in obtaining the focal length, it is not enough to measure the distance between the lens and plate with a rule, so, in measuring the aperture, it is not correct to measure the diaphragm opening with a pair of dividers. In many lenses there is a considerable convergence of the rays before they reach the diaphragm, so that it is quite possible for a lens having an actual aperture of f:6.3 to seem to have one no larger than f:7. To ascertain the amount of this convergence, we must focus a distant object upon the screen, and after replacing the ground glass by a card which has had a fairly large pinhole perforated in the centre, take the camera into a darkened room and hold a candle flame close to the pinhole. If a piece of ground glass be placed in contact with the front cell or hood of the lens, we shall see an illuminated circle, and this circle is the true working aperture of whatever diaphragm aperture happens to be in position. In a general way, we should start with the largest aperture; we may then proceed to check all the others. As it is somewhat difficult to measure the disc of light while holding the ground glass in position, it is a good plan to rule a pencil line upon it, and mark off upon that the various apertures. A better way is to place a piece of gaslight paper in the same position, and after developing, measure the diameter of the blackened circle. This gives a permanent record.

Circles of Illumination. — It is not quite so easy to determine the size of the circle of illumination with a lens unless one has access to a very large camera. With a 4 × 5 lens, a 10 × 12 camera will answer, but for lenses of over 8 or 9 inches focal length, some special device will be necessary. An optician's testing-bench is, of course, the most convenient thing for this purpose, but is hardly likely to be available. The easiest way is to fasten the lens to a fairly large front board and to fix this in a window the rest of which can be covered with a dark curtain. A child's hoop of about 30 inches in diameter, covered with tracing paper, will serve as a focusing screen, and if a scale of inches, starting with zero, in the centre, is marked on the paper, it will at once show the limits of the field. Here, again, a sheet of bromide or gaslight paper on a movable easel is preferable. The lens should be focused on infinity for this test. To ascertain the covering power for any size of plate, it is a good plan to draw a circle the size of the field of the lens, and to lay an actual plate upon it. It is then easy to see how much rise and fall is possible without any further measurement or calculation.

The test for rectilinearity should be made on the class of subject it is desired to take, as it is a fact that lenses which are rectilinear at some distances may not be so at others. We once possessed a lens which was absolutely correct on a test chart at a few feet, but which gave a perceptible curvature of the field in a church interior. The test should also be made on the size of the plate to be used, as some single lenses give practically no distortion over a moderate angle. The test should take the form of an actual exposure, as it is much easier to examine a negative than an image upon the ground glass.

Qualities of the Lens. — Before attempting to make any tests as to the quality of a lens, the camera upon which it is to be fixed should be carefully examined. The larger the aperture and the more highly corrected the lens is supposed to be, the more necessity exists for this. Most present-day cameras are very lightly built, and a slight bending of the struts or straining of the hinges will cause a lack of parallelism between the front and back which will seriously impair the accuracy of the result.

The principal defects which have to be looked for are spherical and chromatic aberrations, astigmatism, curvature of field, and flare. Besides these, the quality of the glass must be examined for specks. Faults in mounting, such as bad centering and strain through too tightly fitting the glasses into the cells, may also be present.

Spherical Aberration. — Spherical aberration means incapacity to give sharp definition at a large aperture. It arises from the fact that unless properly corrected, the rays passing through the margin of a lens have a slightly different focal length from those passing through the centre. This causes a softness of outline which is most noticeable around the highest lights of the subject, such as the white collar in a portrait or a patch of white wall in a view. It may be recognized by focusing a printed page from a good magazine, on which the ink is black and the paper smooth. If it is impossible to secure a sharp image in the center of the field without stopping down the lens, spherical aberration is present. Except in very bad cases, a sharp image can be secured when the aperture is reduced to *f*:16. Stopping down an R. R. lens may not remove astigmatism, however. A more delicate test is to use the light of a small lamp reflected upon a mercury bulb (an ordinary thermometer will do as the test object) in a darkened room, as the blurring is shown more clearly. Another way which also demonstrates the cause as well as proves the existence of this aberration is to make two stops of black paper. One is a disc about two-thirds the diameter of the full aperture of the lens, the other a disc which will fit inside the lens hood, and having a central perforation of a diameter a little larger than the solid disc. The perforated disc is placed in the hood, and any object sharply focused, the exact position of the screen being marked. This disc is then removed, and the other disc fixed on the centre of the front lens with a touch of gum or rubber solution. If spherical aberration is present, the image will no longer be sharp, but it can be made so by refocusing. If poor definition is due to other causes, such as bad centering or badly annealed glass, there will be little difference in the definition when the discs are changed. It should be remembered that for some classes of work spherical aberration is advantageous, and special means for introducing and regulating it are provided in the Patent Portrait lenses of Dallmeyer, and more recently in the Cooke Anastigmat Portrait objectives. In either of these, by simply turning one of the lens cells, a range from absolute sharpness to decided fuzziness may be obtained. The Wollensak Velostigmat Series II has a similar adjustment in the larger sizes.

Astigmatism. — Astigmatism has been already defined. It differs from spherical aberration inasmuch as it cannot be wholly removed by any amount of stopping down. It is usually present to a large extent in portrait lenses of the Petzval type, and to a lesser one in a rapid rectilinear. The handiest test for it is a cross made of two strips of black paper about three inches long and a quarter of an inch wide, pasted upon a white card. If this be focused upon the center of the ground glass, the vertical and horizontal lines will appear equally sharp, but upon rotating the camera so as to bring the image near the edge of the plate, it may appear unsharp. This may be due to curvature of the field, in which case, a sharp image can be obtained by refocusing. If astigmatism be present, it will be found that only one of the lines can be focused at a time; when the vertical one is sharp, the horizontal one is fuzzy, and *vice versa*. If the mercury bulb or "artificial star" be used for this test, the bright dot focused in the centre of the field is drawn out, on rotating the camera, into a short line, which takes a horizontal or a vertical position as the camera back is racked out or in.

Chromatic Aberration. — Chromatic aberration is a serious defect for ordinary work. A lens afflicted with it will give a sharp image upon the ground glass; but, upon taking a negative, the image of the object appears unsharp, while other objects at a greater or less distance appear sharper than they did upon the screen. This is due to the fact that the yellow rays, which are the most luminous, are those which are mainly used in focusing and produce what is known as the visual image, while the blue and violet rays, which are more chemically active, come to focus in another place. The simplest test for a lack of achromatism is to fix up a long strip of sharply-defined printed matter at an angle with the axis of the lens, the centre of the strip being opposite the lens; in a strip of two feet of length the inclination should make the nearest end of the strip about eight inches closer to the camera than the further one. It is convenient to place a couple of pins to mark the centre of the print. A column of newspaper answers well for this purpose. Then focus the line lying between the pins, and make a negative. If the line focused is the sharpest in the negative, the lens is free from chromatic error; if it be undercorrected, a more distant line will be in the best focus; if over-corrected, a nearer one. A properly achromatized lens brings both blue and yellow rays to the same focal plane, while an apochromatic one makes practically all the rays of the spectrum coincident. It is obvious that for this test the surfaces of the ground glass and the sensitive plate must fall into exactly the same plane, and for this reason it is recommended to focus upon a piece of ground glass placed in the actual plate-holder which is to be used. A trained observer can form a good estimate of the chromatic correction by a visual inspection with a telescope eyepiece, but the novice will do well to trust nothing but a photographic test.

Curvature of Field. — Curvature of field is easily discovered by examination of the image of a flat wall on which, if possible, some printed pages should be fixed. Test charts are not good for this purpose, as, being usually small, they require a longer camera extension, and this naturally increases the covering power of the lens. Consequently, a better performance can be obtained from a chart at two feet than from a wall forty feet away. If a flat object be not available any distant one, such as a weather-cock or a chimney, will serve. This should first be focused upon the centre of the screen, and the camera rotated upon the tripod until the image falls near the margin of the screen. The amount of racking-in which is necessary is a measure of the curvature of the field. In the case of some anastigmats, it is not safe merely to compare the image formed at the centre of the field with that formed at the margin, as the field frequently has a dip extending in a circular zone, after which it recovers its original flatness. We have used an expensive modern lens, which at the same aperture gave better definition at the corners of a $6\frac{1}{2} \times 8\frac{1}{2}$ plate than it did upon the 4×5 size. It is very necessary to see that the front and back of the camera are absolutely parallel, as any swing or inclination will vitiate this test.

Flare Spot. — Flare spot occurs in two forms, one being a decided disc which appears at a distance from the centre of the plate corresponding to that of any bright object, such as a gas flame or a window which may be in the field, while the other, which usually occurs in single lenses, takes the form of an ill-defined central patch of fog. The former is easily discovered by focusing a gas flame placed in front of a dark background, when, upon rotating the camera, the image of the flame and the disc will be seen to approach and recede from each other. Many useful lenses suffer more or less from this defect, which appears only under trying conditions. The other form is more difficult to detect upon the ground glass, but may be found by taking a bright sky against a dark mass of foliage. If a patch more or less circular in form is visible in the centre of the subject, it is probably due to the flare.

Mechanical Defects. — It is now rare to find lenses suffering from mechanical defects, except those due to accident. If a lens is badly centered, that is to say, if all the axes of all its components are not in the same line, the definition will be affected. This may be due to careless workmanship or to the position of the lenses having been altered by a fall. It may be detected by focusing a candle flame at a little distance from the centre of the field, and then gently rotating the lens in its flange. If the lenses are perfectly centered, the image will remain stationary; if, not, it will move in a circular direction. If the cells are separately rotated in the same way, it will be seen in which the fault is present. Another test can be made without a camera by holding the lens between the eye and a gas flame, so that a number of small images of the flame are seen inside the lens. In a properly centered lens these can be brought into a straight line, but if one or more cannot be made to do so, it shows that one at least of the glasses is displaced.

Defective glass sometimes gives rise to poor definition, and so does too tight a cell. These can be detected only with the aid of polarized light, which shows any strain, as in badly annealed or compressed glass, as dark patches. Veins in the glass may be seen by holding the lens up to a small gas or candle flame, so that the surface is uniformly luminous. The streaks will then show quite plainly. Care must be taken not to confuse them with any streaks which may have their origin in the eye of the observer. If the lens is turned, a genuine vein will turn with it, but a spectral one remains stationary. Air bubbles of any size which any manufacturer will pass, are of no importance, and may be disregarded. Being magnified by the lens, they are actually much smaller than they appear.

Choice of Focal Length. — Most cameras are furnished with a lens having a focal length about equal to the diagonal of the plate, or a little shorter. This is unquestionably the best all-around length for general amateur photography outdoors. There are, however, a great many subjects which are included in a much narrower angle of view than such a lens gives. For example, a 6-inch anastigmat on a 4 × 5 plate includes about 56° on the diagonal or about 45° on the longer side or base. The real picture, as seen by the eye, seldom includes much more than 30°, so that the print (or enlargement) may often include only a small portion of the negative. It is far more convenient, with any camera except a reflex, to use the lens with 45° angle, trimming the prints, than to use a long-focus lens which includes 30° on the base. The reason is that a short-focus lens has so much greater depth of field that it can be used successfully with a focusing scale, whereas the long-focus lens (9-inch for 4 × 5) would need more careful focusing and the use of a smaller stop to obtain similar depth. We find that a 6-inch answers well for general work if great care is taken to keep clear of the temptation to work for too large an image. If the image is too small, provided only it is sharply focused, it will stand enlarging to at least four diameters without looking at all blurred. One can often utilize a piece of a 4 × 5 negative, measuring from 1 × 1½ to 2½ × 3 inches, throwing it up to 10 × 12 or 11 × 14, and still have a picture sharp enough for framing.

Practically, then, a short-focus lens has a great advantage. The ideal way, naturally, is to have a "battery" of lenses of different focal lengths, so that when once the proper station-point for the lens has been found, a selection may be made so as exactly to fit the picture to the plate.

Focal Length and Perspective. — Strictly speaking, the perspective of the picture is determined by the point at which the lens is placed. When the decision is made to photograph a certain scene, the eye generally concentrates on an angle of about 30°. If, now, the picture is made from the position from which the view appears right to the eye, using a 45° lens, the result will almost invariably appear unsatisfactory. The principal object seems too small and too far away, and there is altogether too much of the neighborhood included in the margins. As already stated, the remedy is to enlarge the part which contains what is wanted; but most workers are inclined to go closer the next time, so as to secure a larger image for contact printing. The result is that the foreground objects appear too large and distant objects too small. If, on the contrary, one always used a 9-inch lens for a 4 × 5 negative there would be a constant incentive to move farther away from the subjects, to make sure of getting them all in. To some extent, this tendency would counterbalance the smaller "depth" of the 9-inch lens; but when larger sizes than 5 × 7 were used, it would be found, in practice, that 30° lenses would require considerable stopping down.

Readers whose interests are chiefly along the lines of artistic portraiture and landscape work will, however, find it advisable to have at least one long-focus lens. Outside of commercial interiors and exteriors in narrow streets, it is safe to lay down as a principle that the most generally useful lens for a given plate is one of a focus equal to the diagonal; for pictorial work, equal to the sum of the two sides; and for special work of a telephoto nature, one equal to twice the long side, or base. For 4 × 5, these focal lengths would be 6½, 9, and 10 inches; for 5 × 7, 8½, 12, and 14 inches.

Any one of these three focal lengths will give the same perspective if all are used from the same station-point; but the usable part of the picture will be contained in different parts of the plate. We confess to a liking for using long-focus lenses, composing the picture on the ground glass with the lens which gives the exact composition over the entire plate, and enlarging the whole plate; yet we have had exactly as good results by enlarging a part made with the 45° lens. The whole secret is knowing where to stop in advancing towards the subject.

Perspective in Portraiture. — We invariably advise that no portrait should ever be taken with the lens any nearer the head of the sitter than 8½ feet. A greater distance is advantageous, for if some part of the figure is brought nearer the lens than the main mass of the body, it will appear too large unless the station-point of the lens is far away. Amateurs, however, generally try to get very close in order to make a head of good size, and their pictures lack likeness because the features are distorted by the too-close viewpoint. If the size of the room will permit, the half of a symmetrical lens (generally of the longer focus recommended above, that is, twice that of the complete lens) will be found best for portrait work, as the loss of speed is compensated for by the better perspective and increased depth of sharp field. Even if the longer-focus lens is used at the same distance, it will give the same perspective but a larger head. When it is used from twice the distance to get the same size head, its advantage is tremendous, for the perspective is much more natural and pleasing and all parts of the figure can be focused at once without excessive use of the vertical and horizontal swings. Thus one avoids, for example, having the nearer shoulder too large and out of focus and the farther shoulder a shapeless and detailless blur.

Equivalent Focal Length. — The terms, focus, focal length, and equivalent focus, as well as equivalent focal length, are frequently met with in descriptions of lenses. The correct term is equivalent focal length, although the other three are often used. A simple lens of the double convex type, with both curves alike, has an easily measurable focal length, this being the distance from the centre of the lens to the image, when focus has been obtained on some object distant, say, 200 times the focal length. With other types of lenses, the optical centre does not coincide with the physical centre. Consequently since the distance from the centre of the lens to the centre of the image cannot be accepted as the focal length of the lens, we must find some easily measurable distance to which the focal length is equivalent. It is geometrically true that when two lenses are used under identical conditions, if they produce images of the same size their focal lengths are equivalent. If, then, a simple lens and a complex lens yield images of equal sizes, when used under identical conditions, their focal lengths must be equivalent. As the focal length of the single lens is directly measurable, the equivalent focal length of the complex lens is known immediately. Consequently, if the single lens has a focal length of 6 inches, the complex lens will have an equivalent focal length of 6 inches.

A simpler conception of this may be had, if, instead of a single lens, we visualize in its place an ordinary pinhole, whose "focal length" may be considered as the distance from the pinhole to the centre of the image. The same reasoning which applied to the single lens, applies in the case of the pinhole, and there is no ambiguity as to the path of the light rays, to confuse the beginner, if the position of the optical centre of the single lens is not entirely clear to him. For practical purposes it may be said that the equivocal focal length of a lens is the same as that of a single lens or pinhole producing an image of equal size under identical conditions.

Back Focus. — In purchasing a lens for a reflecting camera, it is sometimes important to know the back focus, or distance from the rear lens cell to the ground glass when the lens is focused for far objects, in order that we may be sure it will clear the mirror. Some anastigmats have a back focus considerably shorter than the equivalent focal length and some kinds have one considerably longer. One 6-inch lens may have a back focus of about $4\frac{3}{4}$ inches and so can be fitted to a $3\frac{1}{4} \times 4\frac{1}{4}$ reflex, but scarcely to a 4×5; while another make may have a back focus of about 7 inches for a 6-inch lens.

Circle of Illumination. — Although a lens is often chosen because it can be used as a wide-angle objective on a larger camera, it may sometimes fail to give clear negatives when used on the smaller camera. The reason is that the large circle of illumination covers the walls of the bellows, from which great volumes of light are reflected to the plate, fogging it all over. The trouble is most pronounced in focal-plane folding cameras which are not fitted with the accordion type of bellows, but present flat surfaces of considerable area acting as mirrors to cast the light on the plate. For this reason, a reflecting camera often works better with a lens incapable of covering sharply a plate more than one size larger than it is rated for; and wiseacres who think every lens should have great reserve covering power are often confounded by the superior work of what they deem an inferior lens. Many complaints that air-space lenses give foggy images are due to reflected light from the bellows. The trouble can, of course, be diminished by reblacking the camera interior with a really dead black paint and supplying a deep lens hood to cut off all scattered light, even if the hood cuts down the circle of illumination. No harm will be done so long as it does not interfere with covering the plate in use.

Focusing with the Swingback. — Although depth of field is easily secured by stopping down, users of plate cameras provided with vertical and horizontal swings have a tremendous advantage over the film-camera devotee. The swings can be used in two ways. The first, and most obvious, is to allow one to keep the back always vertical, even if the camera is pointed up or down. This movement is invaluable in architectural work, for a vertical line can be rendered as such only if the surface receiving the image is vertical. The second way, far more useful, is to allow the back to be moved to bring an image into focus without stopping down. Assuming a 6-inch lens, the image of an object several hundred yards away is formed 6 inches from the lens, but that of an object 6 feet away will lie about 6⅔ inches away. If, now, the camera is tilted down towards the near foreground object and the vertical swing is used to set the top of the ground glass two-thirds of an inch behind the point where the distant object appears on it, both images can be focused with a moderately large stop. On the contrary, if the back were kept in its normal position, the use of a very small stop would become necessary to secure a sharp image of both at once. The horizontal swing is equally useful in countless instances, particularly when near objects occur at one side and not at the other, or to focus a diagonal line, as of a procession, throughout its depth. In fact, so useful are the swings, rising and falling front, and other adjustments of a good form of plate camera, that one can get the utmost out of a lens, in a difficult situation, only by knowing how to take full advantage of every movement. The lack of adjustments is the most serious drawback of the reflex camera, as well as of the roll-film camera. Still, the use or non-use of these conveniences depends largely on the class of work one attempts, and the simplest box camera will handle a surprisingly large variety of work if intelligently used.

Supplementary Lenses. — The owner of only one camera often finds that he would like to do some kind of work for which his lens is not of quite the right focal length. For instance, to get a large head in a portrait, the use of a lens having a focal length of about 3½ feet, placed in front of the rapid rectilinear lens like a lenscap, will allow the camera to be brought to 3½ feet from the head. This results in nearly sharp focus and a good-sized head, as the supplementary lens, called a "portrait attachment," brings the image to a focus without requiring the camera front to be moved from its 100-foot position. In the same manner, lenses of greater or lesser focus can be utilized to alter the focus of the lens and obviate the need of a long bellows. Supplementary lenses are often sold in sets, consisting of portrait, wide-angle, copying, and telephoto lenses, with a "duplicator" and a cheap glass rayfilter added. By purchasing such a set, the owner of a short-bellows camera can get some of the effects which otherwise would need a long-bellows camera. Spectacle lenses can also be utilized. The rule is to place before the lens a lens having a focus equal to the distance from lens to subject. Simple lenses introduce aberrations into an optical system, so a medium or a small stop must often be used to secure satisfactory definition.

Utilizing a Curved Field. — Although curvature of field is a lens defect, it is possible at times without stopping down, to avoid the natural poor quality of definition of an uncorrected lens. For instance, when making a negative of a group of people, who can be arbitrarily arranged at different distances from the lens, their images can be brought into equally sharp focus on the plane of the plate, by arranging them in an arc of a circle, the arrangement being dictated by what one sees on the ground glass.

Table of Hyper

F Equivalent focal length	*u* Diameter of circle of confusion	*A* = *f* value of lens 1.9	2.2	3.5	4.2	4.5	5.4	5.6	6.3	6.8	7	7.7
2	$\frac{1}{400}$	70	61	38	32	30	25	24	21	20	19	17
3	$\frac{1}{400}$	158	136	86	71	67	56	54	48	44	43	39
$3\frac{1}{2}$	$\frac{1}{300}$	161	139	88	73	68	57	55	49	45	44	40
4	$\frac{1}{300}$	211	182	114	95	89	74	71	63	59	57	52
$4\frac{1}{2}$	$\frac{1}{300}$	...	...	145	121	113	94	90	80	74	72	66
5	$\frac{1}{250}$	...	...	149	124	116	96	93	83	77	74	68
$5\frac{1}{2}$	$\frac{1}{250}$	...	...	180	150	140	117	113	100	93	90	82
6	$\frac{1}{250}$	...	...	214	179	167	139	134	119	110	107	97
$6\frac{1}{2}$	$\frac{1}{250}$	...	...	252	210	196	163	157	140	129	126	114
7	$\frac{1}{250}$	...	...	292	243	227	189	182	162	150	146	133
8	$\frac{1}{200}$	...	...	305	254	237	198	190	169	156	152	139
9	$\frac{1}{200}$	...	...	386	321	300	250	241	214	199	193	175
10	$\frac{1}{150}$	...	...	357	298	278	231	223	198	184	179	162
11	$\frac{1}{100}$	...	...	288	240	224	187	180	160	148	144	131
12	$\frac{1}{100}$	...	...	343	286	267	222	214	190	176	171	156
13	$\frac{1}{75}$	...	...	...	252	235	196	189	168	155	151	137
14	$\frac{1}{75}$	...	...	...	292	272	227	219	194	180	175	159
15	$\frac{1}{75}$	...	...	...	335	313	260	251	223	207	201	183
16	$\frac{1}{75}$	...	...	...	381	356	296	286	254	235	229	208
17	$\frac{1}{75}$	...	...	...	430	401	334	323	287	266	258	235
18	$\frac{1}{75}$	...	...	...	482	450	375	362	321	298	289	263
19	$\frac{1}{75}$	...	...	...	537	501	418	403	358	332	322	293
20	$\frac{1}{75}$	...	...	...	595	556	463	446	397	368	357	325
21	$\frac{1}{75}$	...	...	...	656	613	510	492	437	405	394	358
22	$\frac{1}{75}$	...	...	...	720	672	560	540	480	444	432	393
23	$\frac{1}{75}$	...	...	...	787	735	612	590	525	486	472	429
24	$\frac{1}{75}$	...	...	...	857	800	666	643	571	529	514	467

This table shows the nearest point in sharp focus when objects infinitely distant are focused on. It is calculated from the formula $hf = \frac{F^2}{12 \times A \times u}$, where hf = hyperfocal distance in feet, u = diameter in inches of the circle of confusion or greatest allowable unsharpness of the image of a point, F = the equivalent focal length of the lens in inches, and A = the f number. This table is usually calculated for a single circle of confusion

focal Distances

A = *f* value of lens

8	9	11.3	12.5	16	18	22.6	25	32	36	45.2	50	64
17	15	12	11	$8\frac{1}{3}$	$7\frac{1}{2}$	6	$5\frac{1}{3}$	4	$3\frac{3}{4}$	3	$2\frac{2}{3}$	2
38	33	27	24	19	17	13	12	$9\frac{1}{3}$	$8\frac{1}{3}$	$6\frac{2}{3}$	6	$4\frac{2}{3}$
38	34	27	25	19	17	14	12	$9\frac{2}{3}$	$8\frac{1}{2}$	$6\frac{3}{4}$	$6\frac{1}{8}$	$4\frac{3}{4}$
50	44	35	32	25	22	18	16	13	11	9	8	$6\frac{1}{4}$
63	56	45	41	32	28	22	20	16	14	11	10	$7\frac{7}{8}$
65	58	46	42	33	29	23	21	16	15	12	10	$8\frac{1}{8}$
79	70	56	50	39	35	28	25	20	18	14	13	10
94	83	66	60	47	42	33	30	23	21	17	15	12
110	98	78	70	55	49	39	35	28	25	20	18	14
128	113	90	82	64	57	45	41	32	28	23	20	16
133	119	94	85	67	59	47	43	33	30	24	21	17
169	150	119	108	84	75	60	54	42	38	30	27	21
156	139	110	100	78	69	55	50	39	35	28	25	20
126	112	89	81	63	56	45	40	32	28	22	20	16
150	133	106	96	75	67	53	48	38	33	27	24	19
132	117	93	85	66	57	47	42	33	29	23	21	17
153	136	108	98	77	68	54	49	38	34	27	25	19
176	156	124	113	88	78	62	56	44	39	31	28	22
200	178	141	128	100	89	71	64	50	44	35	32	25
226	201	160	144	113	100	80	72	56	50	40	36	28
253	225	179	162	127	113	90	81	63	56	45	41	32
282	251	199	181	141	125	100	90	71	63	50	45	35
312	278	221	200	156	139	110	100	78	69	55	50	39
344	306	244	220	172	153	122	110	86	77	61	55	43
378	336	267	242	189	168	134	121	95	84	67	61	47
413	367	292	265	207	184	146	132	103	92	73	66	52
450	400	318	288	225	200	159	144	113	100	80	72	56

($\frac{1}{100}$ inch) for all focal lengths, but as the definition required for motion pictures or small negatives for enlargement made with short-focus lenses is much greater than that needed for portraits, the value of *u* taken for each focal length is given. If the lens is focused on objects at the distance given in the table, the sharpness will be satisfactory between half that distance and infinity.

Reducing and Enlarging Tables

All figures in table are in ins.	Reductions											
	Same size	1/2 size	1/3 size	1/4 size	1/5 size	1/6 size	1/7 size	1/8 size	1/9 size	1/10 size	1/11 size	1/12 size
Focus of lens used	Enlargements											
	Same size	2 times	3 times	4 times	5 times	6 times	7 times	8 times	9 times	10 times	11 times	12 times
3	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**
	6	4 1/2	4	3 3/4	3 3/5	3 1/2	3 3/7	3 3/8	3 3/9	3 3/10	3 3/11	3 3/12
3 1/2	**7**	**10 1/2**	**14**	**17 1/2**	**21**	**24 1/2**	**28**	**31 1/2**	**35**	**38 1/2**	**42**	**45 1/2**
	7	5 1/4	4 2/3	4 3/8	4 1/5	4 1/12	4	3 15/16	3 8/9	3 17/20	3 9/11	3 19/24
4	**8**	**12**	**16**	**20**	**24**	**28**	**32**	**36**	**40**	**44**	**48**	**52**
	8	6	5 1/3	5	4 4/5	4 2/3	4 4/7	4 1/2	4 4/9	4 4/10	4 4/11	4 1/3
4 1/2	**9**	**13 1/2**	**18**	**22 1/2**	**27**	**31 1/2**	**36**	**40 1/2**	**45**	**49 1/2**	**54**	**58 1/2**
	9	6 3/4	6	5 5/8	5 2/5	5 1/4	5 1/7	5 1/16	5	4 19/20	4 10/11	4 7/8
5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**
	10	7 1/2	6 2/3	6 1/4	6	5 5/6	5 5/7	5 5/8	5 5/9	5 1/2	5 5/11	5 5/12
5 1/2	**11**	**16 1/2**	**22**	**27 1/2**	**33**	**38 1/2**	**44**	**49 1/2**	**55**	**60 1/2**	**66**	**71 1/2**
	11	8 1/4	7 1/3	6 7/8	6 3/5	6 5/12	6 2/7	6 3/16	6 1/9	6 1/20	6	5 23/24
6	**12**	**18**	**24**	**30**	**36**	**42**	**48**	**54**	**60**	**66**	**72**	**78**
	12	9	8	7 1/2	7 1/5	7	6 6/7	6 3/4	6 6/9	6 6/10	6 6/11	6 1/2
6 1/2	**13**	**19 1/2**	**26**	**32 1/2**	**39**	**45 1/2**	**52**	**58 1/2**	**65**	**71 1/2**	**78**	**84 1/2**
	13	9 3/4	8 2/3	8 1/8	7 4/5	7 7/12	7 3/7	7 5/16	7 2/9	7 3/20	7 1/11	7 1/24
7	**14**	**21**	**28**	**35**	**42**	**49**	**56**	**63**	**70**	**77**	**84**	**91**
	14	10 1/2	9 1/3	8 3/4	8 2/5	8 1/6	8	7 7/8	7 7/9	7 7/10	7 7/11	7 7/12
8	**16**	**24**	**32**	**40**	**48**	**56**	**64**	**72**	**80**	**88**	**96**	**104**
	16	12	10 2/3	10	9 3/5	9 1/3	9 1/7	9	8 8/9	8 4/5	8 8/11	8 2/3
9	**18**	**27**	**36**	**45**	**54**	**63**	**72**	**81**	**90**	**99**	**108**	**117**
	18	13 1/2	12	11 1/4	10 4/5	10 1/2	10 2/7	10 1/8	10	9 9/10	9 9/11	9 3/4
10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**
	20	15	13 1/3	12 1/2	12	11 2/3	11 3/7	11 1/4	11 1/9	11	10 10/11	10 5/6
11	**22**	**33**	**44**	**55**	**66**	**77**	**88**	**99**	**110**	**121**	**132**	**143**
	22	16 1/2	14 2/3	13 3/4	13 1/5	12 5/6	12 4/7	12 3/8	12 2/9	12 1/10	12	11 11/12
12	**24**	**36**	**48**	**60**	**72**	**84**	**96**	**108**	**120**	**132**	**144**	**156**
	24	18	16	15	14 2/5	14	13 5/7	13 1/2	13 1/3	13 1/5	13 1/11	13

Bold figures are distances of lens from easel in enlarging, or from lens to photo being reduced in copying. Light figures are distances from lens to negative being enlarged or camera extension in case reduced size copies are being made. The outer end of lens (cap end) should face bromide paper in enlarging and in reducing should face object being copied. Distances are measured from nodal points, not diaphragm of lens, and while measuring these distances from diaphragm will give satisfactory results in many cases when enlarging with large apertures or at great distances final focusing should be done by inspection. Data not given in the table may be calculated as follows:

Conjugate Foci. — Let u = distance of object from lens, v = distance of image from lens, F = focal length of lens.

$$\frac{1}{F} = \frac{1}{u} + \frac{1}{v}, \text{ e.g., } \frac{1}{3} = \frac{1}{12} + \frac{1}{4},$$

or $$F(u + v) = uv, \text{ e.g., } 3(12 + 4) = 12 \times 4.$$

If object is reduced n times upon the focusing screen, u is $n + 1$ times the focal length of the lens, and v is the focal length plus $\frac{1}{n}$ of the focal length. Thus 12 in. photographed down to 1 in. with a 6-in. lens gives $u = 13 \times 6$, and $v = 6 + (\frac{1}{12} \times 6) = 6\frac{1}{2}$.

Rule for Copying. To find distance from lens to original. Multiply focal length of lens by the number of times of reduction, and add one focal length thereto. To find camera extension. — Divide focal length by number of times of reduction, and add one focal length thereto (see tables).

Rule for Enlarging. To find distance from negative to lens, divide focal length by number of times of enlargement, and add one focal length thereto.

To find distance from lens to paper, multiply focal length by number of times of enlargement, and add one focal length thereto.

To Graduate Focusing Scale. Camera extensions for various distances are given by the formula $\frac{pF}{F - p}$, where p is focal length of lens, and F the distance. Thus 20 ft. with 5-in. lens, $240 \times 5 \div (240 - 5) = 5.1$.

In practice it is most convenient to graduate focusing scale by trial, focusing on a test object at known distances.

Combining Lenses. To find the focal length of two lenses separated by a short distance, multiply the focal lengths together and divide by focal lengths added together, less the distance between the lenses.

$$\text{Resultant focal length} = \frac{f_1 \times f_2}{f_1 + f_2 - d}.$$

To find the focal length of supplementary lens necessary to reduce or increase the focal length of a given lens, multiply the focal length to be altered by the focal length desired, and divide the product by the original focal length less the final focal length.

$$f_2 = \frac{f_1 \times F}{f_1 - F},$$

f_1 equalling the original and F the final focal length.

To reduce the focal length use a positive lens.

To increase the focal length use a negative lens and calculate it as minus in the formula.

The focal length of a "magnifier" — to bring near objects into focus — should be equal to the distance of the object.

Diaphragm Numbers and Uniform System Numbers

f values	3.16	**4**	4.5	**5.6**	6.3	*6.8*	*7*	7.7	**8**	9
U. S. nos.	....	1	....	2	...	...	...	....	4	...
Relative exposures	....	**1**	1.25	**2**	2.5	2.9	3	3.75	**4**	5
	1	1.6	**2**	3.1	**4**	4.6	4.9	6	6.4	**8**

There are today two important scales of diaphragm numbers in use, but as both are expressed in the same notation on all modern lenses and shutters except some made in the United States, no confusion arises from this source except that some diaphragm numbers are not found in all exposure tables. On account of the latitude of exposure of all plates and films, using the exposure for the nearest number given will rarely lead one astray. The English system of marking lenses uses f:4 as a unit. It is generally replaced on American cameras by the Uniform system, in which the same unit is numbered 1. In the Stolze system, used on Zeiss and other German lenses, the unit is $f: \sqrt{10} = f$:3.16. The following table compares the three systems and gives the relative exposure times for the different stops. Opposite the caption "*f* values" are shown the *f* numbers in both the English and Stolze systems; beneath are listed the equivalent apertures in the U. S. system. The figures showing the relative exposures are computed for two systems, the unit exposures being those for f:4 and f:3.16 respectively. The exposures which bear the relation of 2 to 1 to each other are printed in boldface type.

On old lenses various other systems of markings may be found. Zeiss lenses were once marked with numbers running in reverse direction to that given above, *f* :100 being marked 1 and *f*:4.5, 512. Later *f*:50 was adopted as the unit, *f*:4.5 then being numbered 128. Old Goerz and Dallmeyer lenses may occasionally be found with numbers based on *f*:62, which is numbered 384, and the numbers run down to 3, equivalent to *f*:5.5. Still other systems may be found on French lenses, but these are so rarely seen outside of that country that it would be useless to give space to them here. For full details of the relation of stops to exposure, the reader is referred to No. 1 of this series, *The Secret of Exposure.*

11.3	12.5	**16**	18	**22.6**	25	**32**	36	**45.2**	50	**64**	71	100
8	....	16	..	32	..	64	....	128	....	256	...	....
8	10	**16**	20	**32**	39	**64**	78	**128**	156	**256**	313	625
13	**16**	26	**32**	51	**64**	102	**128**	205	**256**	410	**512**	**1024**

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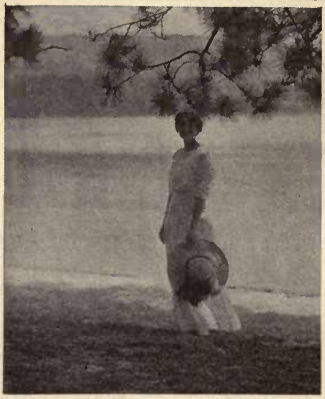

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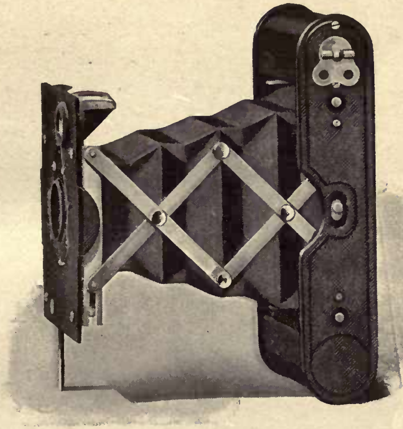

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