AEDg reserve
Apr 2. '97
(To be returned)

Compliments of the Author.

11-11-36
Have just received
Galley proof of this
with a lot of halftones
from my early current
sketches and
photos, for Sci. Am.
book just coming out
on Amateur Astronomy
Ingalls, editor.

Atmosphere, Telescope and Observer.

A. E. DOUGLASS.

1954 ~~Oct~~ 25-26, 1954 this
was largely described in
conference at Lowell Observatory
Flagstaff called by Dr Albert Wilson
& including Dr E H Carpenter
from here and Johnson of L.O.
and Zwicky from Palomar

Reprint from POPULAR ASTRONOMY. June, 1897.

ATMOSPHERE, TELESCOPE AND OBSERVER.

A. E. DOUGLASS.

It is a matter of importance and significance that so little has been done in recent years upon planetary detail by telescopes of great size. The strenuous effort to produce instruments of enormous power and perfection has resulted in telescopes of remarkable light-giving capacity, which have a true motion and are all that could be desired in convenience, but which do not show improved definition. There is no difficulty at all in assigning poor atmosphere as the cause of this because with the exception of the Lick Observatory, the Harvard Observatory in Peru and the two stations of the Lowell Observatory no effort of any moment has been made to place large instruments in locations directly selected for their astronomical qualities.

The thirty-six inch of the Lick Observatory was in a sense the pioneer in this hunt for good surroundings but on account of the great size of the glass and the lack of comparison observations in even better latitudes it was impossible to estimate with any precision the relative importance of atmosphere and instrument.

The Harvard expedition to Peru was more successful. There, Professor W. H. Pickering, having at Cambridge, U. S. A., observed Mars through one opposition, was able to declare at once the superiority of the atmosphere. For the same reason he could indicate the difference between Cambridge and Flagstaff; the fact that for certain measurements of the satellites of Jupiter he habitually used a power of 1305 is sufficient evidence of the steadiness of the air at the latter place. Professor Pickering was unquestionably the first to intelligently appreciate the great importance of seeking a good atmosphere.

The result of our own experience in studying planetary detail has been to regard the atmosphere as of the first importance, the energy and the intelligence of the observer as of the second and to put last of all, the instrument, provided it gives a fair amount of light; but we find that the value of the instrument increases in an atmosphere that is reasonably near perfect. These conclusions are derived from the continuous use of large telescopes in Peru, Massachusetts, Arizona and Mexico.

The atmosphere then is a factor of prime importance in the definition exhibited by large telescopes and its study becomes of corresponding consequence. Every astronomer knows that good seeing is not a matter of clouds, that the definition does not become superb merely because the atmosphere has become clear and perfectly transparent; on the contrary a certain amount of haze sometimes improves the seeing. Most astronomers have become aware of this fact and more correctly judge the seeing by means of the "steadiness" of the air. This is estimated chiefly from the twinkling of stars. Hardly one or two have gone beyond this and investigated the cause of twinkling and found the means for making direct observations upon the quality of the atmosphere for fine work.

There are three media through which the light from a distant heavenly body must pass before being interpreted by the students of astronomy. And upon each of these three, Atmosphere, Telescope and Observer, it is our purpose to make some remarks, describing certain details of each that have come under our observation. Through the discovery of certain methods of studying directly the conditions of the air for astronomical work and the vast importance of obtaining favorable conditions, the larger and more important portion of this paper is devoted to the description of the origin and character of those methods. Taken in its entirety this treatment of the three topics is introductory to the study of the selection of Observatory sites.

The Atmosphere; Its Currents.

Every posseesor of a fair sized telescope has at hand a means whereby he may study the more obscure atmospheric conditions which accompany good and bad seeing and, at least in some cases, determine whether bad seeing is due to local conditions which may be evaded by moving a few miles, or to general conditions which may require a large change in latitude to correct. The means consists simply in placing the eye directly in the focus of the objective and watching the streams of air pass by overhead.

These currents were first noticed in this way by the writer, at the Harvard College Observatory station at Arequipa, Peru, in 1892. That Observatory is situated on the bank of a canyon-like river valley which drains some large plains lying fifteen miles to the north and at some five thousand feet greater altitude. In the early night, if the sky is clear, the air becomes cold in the bottom of this valley and begins to flow gently downward. Soon it attains considerable velocity, spreading out over the more open valley below. Some hours after midnight its volume is such that it overflows its confines and submerges the Observatory producing a sudden lowering of temperature and an immediate destruction of the seeing.

The movement could be felt as a fresh steady, chilly breeze coming from the mountains to the north. By means of the objective it could be seen as a set of fine parallel north and south lines moving swiftly from north to south. This effect of lines moving longitudinally is of course the effect always produced by an uneven surface passing rapidly across a small field of view, as, for example, the appearance of the ground between the rails when one stands on a swiftly moving train and looks down between the cars. The absence of any such appearance in the objective previous to the arrival of this midnight wind amply proved the the connection between these moving lines and the descending breeze.

This connection between the streams of air and lines across the objective was subsequently verified by an experiment tried on the great Yerkes lens when it was undergoing tests at Alvan Clark's manufactory. A lighted lamp held before the objective produced a very conspicuous series of them rising across the field. Any owner of a telescope can make a similar test by pointing on a star at low altitude and, while receiving the image of the star directly on the eye, having a lighted lamp or lantern held beyond the objective.

Beginning in September, 1894, the writer made observations upon atmospheric currents in the 18-inch Brashear lens at Flagstaff. It was found that the direction of the currents and roughly their heights and velocities could be obtained. This discovery seemed to chiefly concern meteorologists and the results of the observations up to the end of the following December were discussed with especial reference to that subject in an appropriate magazine (*American Meteorological Journal*, March, 1895). From January 1 to April 3, 1895, observations were made at Flagstaff on every clear night and the astronomical importance of such work became more apparent. Since that time observations have been made whenever practicable and tests on artificially produced currents have verified the conclusions already reached.

One of the most striking instances of the use of these observations, was the discovery of the reason why some of the east winds at Flagstaff gave good seeing and others bad. When the seeing was good the currents seen through the telescope came also from the east but when the seeing was bad they did not do so at all. Instead, they came from the north or northeast and the mountain range extending from ten miles due north to about six miles east, northeast was shown to be responsible both for the change of direction in the surface movement and the very bad quality of the stream which was passing by at considerable altitude overhead. It seems probable from this that neighboring mountain ranges are not good.

The examination of the atmosphere by means of a lens is nearly the same operation as the test of a lens for ascertaining its correctness of form. In the ordinary test on a bright star the expert looks for the unchanging irregularities in the illumination of the objective; such irregularities belong to the objective because they are unchanging. In examining the atmosphere the observer notes the variable irregularities of illumination which must belong to the atmosphere because they do vary. He will see several kinds of variation in the illumination. The first, and one which is most familiar to us, is twinkling. This is most conspicuous with a very small lens—with the naked eye, for example—but on trial it has been seen nearly always in field glasses, very frequently in a three-inch lens, often in a six-inch and once or twice in an 18-inch glass. It was once suspected in the 24-inch.

Different Kinds of Currents.

In a large telescope there is one form which is called the "ordinary" current, which is almost invariably seen. It consists, as described, in light and dark lines passing the lens longitudinally, varying in density, in rapidity of motion and in distance apart. Frequently—in some localities nearly always—there are two ordinary currents moving across the field, quite similar in appearance or, more rarely, quite unlike. Often also, when one current is conspicuous a branch will begin to form, first having a direction nearly parallel to the main current and then gradually turning until it attains an angle of as much as 45°, when it suddenly ceases.

The form which is called "mottled" impresses one as something different but I am inclined to think that it is the ordinary current with a less rapid motion, for the reason that I have seen an ordinary current decrease in speed and become mottled. The fact which most strongly suggests its being a different kind, or at least having some special cause, is that it often causes the seeing to grow much worse. It is, however, always slow of movement and has the appearance of light and dark globules scattered over the lens. A similar appearance may be produced by pointing the telescope on a star at low altitude with or against the direction of motion of the most conspicuous current, thus reducing its apparent motion—a fact which verifies the idea that it is a slow form of the ordinary current.

There is another form, not at all common, which has certain similarity to the mottled but which arises from a different cause. It may be called "vibration" or "vibrating effect" and consists of light and dark globules upon the field that appear to pulsate without any marked change in position. I think however from carefully watching them that this form is the result of two nearly equal currents of the ordinary form crossing rapidly at about right angles. When this is visible in a large instrument the lens of a small telescope appears to twinkle; and this is certainly one cause of twinkling to the naked eye—the crossing of the currents. The mottled form when moving very slowly could, I believe, produce the twinkling but the ordinary form moves too rapidly to allow the naked eye to perceive the variations of light it receives. Twinkling then, usually means that there are two currents passing overhead in different directions, whose waves are farther apart than the diameter of the lens in use.

One form remains to be described; it is the "floating" or "syrup" form. It resembles in appearance the curved streaks produced by stirring syrup and water together and is very variable in its motion seeming to float in the air above the objective. It is the most persistant of any of the forms, having been absent only once or twice out of some hundreds of observations. In order to see this current distinctly it is sometimes necessary to decidedly change the focus of the eye which fact suggests a very strong refractive power in the current. The waves are almost universally close together, long and irregular in form and have a tendency to suddenly start off with a rush in any chance direction.

The mottled and floating forms are the only ones which show their actual outlines in the air. It is probable that the shape of the waves in the ordinary form of current is similar to that of the mottled form; it is certain that it is not merely a longitudinal wave, because the variation it produces in the position of a planet is almost always equal in all directions. Both mottled and floating wave-shadows cast by electric lights on the sides of houses are often quite evident.

Methods of Seeing the Waves.

The first and most direct mode of observing the atmospheric currents is by placing the eye in the focus of the objective. The currents cast, as it were, their shadows on the objective and as all the light is concentrated in the focus, the eye can, without changing position see all the irregularities in illumination which take place over that area, that is, in the cylinder which extends from the lens to the limits of our atmosphere in the direction of the star. In the case of a planet of sensible diameter this volume is a truncated cone with its smaller end at the objective, instead of a cylinder. These differences of illumination are not real shadows but are condensations or rarefactions of light equal currents of the ordinary form crossing rapidly at about right angles. When this is visible in a large instrument the lens of a small telescope appears to twinkle; and this is certainly one cause of twinkling to the naked eye—the crossing of the currents. The mottled form when moving very slowly could, I believe, produce the twinkling but the ordinary form moves too rapidly to allow the naked eye to perceive the variations of light it receives. Twinkling then, usually means that there are two currents passing overhead in different directions, whose waves are farther apart than the diameter of the lens in use.

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The currents of course are usually observed at night but they may be seen in the daytime by using a small diaphragm at the focus to exclude the greater part of the light of the sky. By day they are extremely handsome and are characterized by an excess of the syrup form.

A difference is produced by the object at which one looks. The ideal object is a star in which the contrast in the waves reaches a maximum; in fact at times the little irregularities become so conspicuous that it is difficult to distinguish the more important main currents. A planet with a diameter of less than 30″ shows nearly everything in a fashion convenient for observation but a large planet like Jupiter has often failed to show certain fine currents at all, or with difficulty, and has made coarse ones appear fine. This depends on the height of the current and is due directly to Jupiter's great diameter, as will be explained below.

Features of Atmospheric Currents.

Direction.—The apparent direction in the telescope has to be reduced to the horizontal direction so as to name the point of the compass from which the stream is coming. It is usually sufficiently accurate to hold a pencil so that it may be seen by the eye not at the focus, placing the pencil in the general direction of the current and then considering where it would intersect the horizon if extended.

Size.—This is also observed with the eye in the focus, and may be found by dividing the diameter of the objective by the number of parallel streaks which appear to cross it. This is a rough method but it gives all the accuracy required and is easily done. Such estimates should be made on a star or small planet and if at low altitude a rough correction should be made to find the size of the waves if they had been in the zenith.

Rate.—The motion of a current passing such a small field is very difficult to estimate except in the roughest way; the words "swift" or "slow" are usually sufficient to indicate what is seen. I have attempted to make a more careful measure of the rate but have been very uncertain about it as I had nothing with which to verify my results. Slow currents should always be mentioned.

Conspicuousness.—This is one of the most important notes to make as the seeing is directly dependent upon it. I have as yet been unable to form any direct standard of conspicuousness and it therefore becomes purely a matter of experience. It should always be remembered that the diameter of the object viewed makes a difference in the relative conspicuousness of different currents.

Constancy.—This refers either to continuousness of existence or steadiness of direction; usually the two go together, a current inclined to shift its direction being rarely permanent. This, however, does not apply to the floating form which is always changing direction and yet is practically permanent.

Height.—This is a difficult feature to observe because a scale has to be put on the sliding tube and the eyepiece run out until the particular current comes in focus. Owing to the extremely small portion of the lens which receives the graduations of light from a particular wave the focus is usually very indefinite—one has simply to do the best he can. The distances actually obtained are those of the points of convergence of light both above and below the waves, produced by the refraction in their slopes. Upon moving the eyepiece outside the principal focus the first focus reached is that of the highest system of convergent points which has anything like good definition; the next focus corresponds to the next lower set, and so on. If the refraction is such that one set of points would occur below the level of the telescope its distance behind the lens may be found by moving the eyepiece inside the principal focus (just as distances above the lens are found by the extension of focus). It is probable that only one set above and one set below the waves are sufficiently definite to produce foci. If the altitude of each of these sets is obtained, the altitude of the wave system must be half-way between them. I have attempted to verify this conclusion by actually comparing the distance apart of these two "principal" convergent planes as obtained by the change in focus and as obtained by the separation of the waves and their refractive power deduced from the vibration of the image in the focus.

The tabulated results are as follows:

Date 1895.	Altitude Wave-System.	Waves to convergent planes. By Focus.	By Vibration.
	feet.	feet.	feet.
Jan. 9	10,000	6,600	2,900
Feb. 19	14,000	11,800	10 500
Mar. 17	9,000	4,800	5,600

And on artificial waves,

Apr. 24	290	18	83

The observations of April 24 were made upon artificially produced waves at a distance of 300 feet, through a 6-inch telescope pointed upon an artificial star at a distance of 450 feet. The correctness of the distance obtained by change of focus, exhibiting an error of only three per cent, is quite satisfactory and that indicates, as I had previously decided, that the chief trouble in this method of obtaining wave-heights is not in the focus but in estimating the amount of vibration due to a particular wave-system. This explains, I have no doubt, the disagreement in the last two columns, in two out of four cases above and yet this estimation is of importance because often we have to depend for the altitude of the wave-system solely on the altitude of one convergent plane and the estimated vibration and size of waves. In making such observations I believe it is best to observe the lower limit of the upper convergent plane and the upper limit of the lower plane, when possible, and the maximum vibration that can be attributed to the system. The observed distance from wave to wave has to be divided by two to give the separation of adjacent slopes.

A correction must be made for the apparent altitude of the star in use, since the quantity obtained is a function of the distance of the waves from the objective. If the waves give good contrast and definition, this method is capable of considerable accuracy and might be applied to obtaining the height of well-defined and brilliant clouds. I have tried it on a terrestrial object which had a measured distance of 8.6 miles, with an 18-inch objective, and obtained the result of 8.5 miles. It is well to note also whether a current seen without the eyepiece, shows more distinctly by throwing the eye out of focus.

Seeing.—Of course a record is always kept of the seeing but in this connection more precision is desirable. It is not enough to judge merely from experience, especially since we have the good and definite scale of seeing devised by Professor W. H. Pickering which has already been published once in connection with this subject and which I give below in a slightly modified form, derived from, and therefore adapted to, a 6-inch telescope.

With sufficient power (100 to 150 to the inch) the star image consists of a large central disk and a series of rings.

Seeing 12.	Disk well defined, rings motionless, image motionless in field. Perfect seeing.
Seeing 10.	Disk well defined, rings motionless, image moving in field.
Seeing 8.	Disk well defined, rings complete but moving.
Seeing 6.	Disk well defined, rings broken into dots and lines but still traceable.
Seeing 4.	Disk well defined, no evidence of rings.

Seeing 2. Disk and rings in one confused mass, constant motion, no increase in size.
Seeing 0. Disk and rings in one confused mass, violent motion, image greatly enlarged (for example to twice the diameter of outer ring).

This scale of seeing changes with the size of the objective, but it may be made complete by noting, in addition to the appearance of the stellar image, the character of its motion. In fact the ideal scale of seeing is one that depends solely on the motion of a stellar image such as would be obtained by a telescope of extremely long focus and very minute aperture. Perhaps some day when photographic plates are more sensitive, this observation will be made by photography; to-day it can be done by turning on a bright star, like Sirius, putting a very small diaphragm over the objective and setting the two micrometer threads at one or two seconds of arc apart and watching the motions. Practically Professor Pickering's scale with a few notes on the motions of the planet or star is at present a less difficult form to give the observation.

Having directly compared a 24-inch with a 6-inch in the use of this scale, I find the 24-inch wholly unequal to exhibiting many gradations of seeing which are of common occurrence. As nearly all observatories have a 6-inch telescope, or one of about that size, or can diaphragm a larger instrument, I recommend the universal adoption of the above scale and aperture as the standard. By the present addition of seeing, 12 and the motion of the image in the field, the scale is made to cover those changes in seeing which are only of consequence in the use of enormous apertures under remarkably favorable atmospheric conditions.

Similar Phenomena.

In order to understand the subject better let me cite a few familiar cases of the same or similiar phenomena. The most ordinary instance is met with in sunlight upon shallow water. There, beneath each rising wave, the light is condensed, while beneath each trough the light is enfeebled. At a certain depth depending on the character of the waves the contrast between the crest and the trough is most marked. Upon going deeper the difference decreases leaving finally only light and dark patches. I conceive the waves in the air to be very similiar in their action though having a different origin and with an extremely slight refractive power.

Other very familiar examples are to be seen in the wavy motion of objects seen across a desert, across the top of a hot stove, or over a camp fire. I have often seen atmospheric waves upon the sunlit sill of an open window when the difference between the inside and outside temperatures was very great. They show at night on the sides of white houses which are not too far from a brilliant electric light.

A less well-known case is that of shadow-bands or wave-shadows at the beginning and ending of a total eclipse of the sun. The reason that shadow bands are not always visible in sunlight is perfectly simple and exactly the same as for the fact already mentioned that certain atmospheric currents do not become visible when viewing Jupiter. Each point on a light-giving disk casts its own set of shadow waves. When different points can be far enough apart for their respective shadows to overlap each other, an even illuminated surface results. That is what happens ordinarily with the Sun and Moon, and even with Jupiter. At the moment of a total eclipse however when the visible part of the Sun is greatly reduced they show, presenting undoubtedly an erroneous wave-form because the source of illumination is a line or thin crescent instead of a point or small circle. In the shadow bands of April 16, 1893, they were in the form of slightly curved wave-crests moving in a direction perpendicular to their length. This direction of motion would imply great similarity to waves on water but we were left in some doubt as to the cause of this coincidence because their length was also roughly in the same plane with the visible crescent of the Sun. They were observed at an altitude of nearly 4000 feet above the sea. At sea-level they were at the same eclipse observed to be longer and perhaps less well-defined.

The absence of shadow bands of great size suggests that a large telescope can usually present to view all existing currents.

Causes of the Current Phenomena.

The causes to which these phenomena are assigned have already been suggested but not as yet distinctly discussed by themselves.

These so-called waves are lines of irregular refraction in the air due to non-uniform density. The irregularities in density are due, I am convinced, to irregularities of temperature. The ease with which change of temperature may cause them in comparison to change of pressure may be observed in the following way. Wave a large, strong fan violently backward and forward in front of the lens when the telescope is pointed on a bright star; with great care the lines of pressure may be seen, resembling the curved wave that follows the tip of an oar in the water. Then try the bare hand in front of the objective, and the lines showing the movement of warm air from the surface of the skin are at once apparent.

The general cause of change in temperature so far as I have traced them are given below.

Convectional currents.—These seem to produce chiefly, and perhaps only, the syrup form.

Settling of cold air at night.—This settling occurs in valleys or level plains when there is not too much wind. I do not know its effect in an absolutely quiet air but in valleys where it can have a downward motion it is productive of extremely bad seeing, with very conspicuous and rather small waves.

Mountains or Hills.—The experience at Flagstaff, already cited, indicates that when standing well up above the horizon they have a bad effect on winds passing over them.

Snow.—A Flagstaff experience similarly indicates that snow is extremely deteriorating. In each of these cases the size of the waves was merely a good average—neither large nor small.

Cloud Condensations.—This theoretically should cause changes in temperature, and clouds, especially moist clouds, actually cause changes in the appearance of the currents, making them coarser for the time being. It is difficult to say what is the cause of the coarse or fine currents but it is possible that it depends on the humidity of the air.

Streams of Air at Different Temperatures.—This does undoubtedly produce local changes of temperature, sufficient to cause bad seeing but is obviously a difficult matter to study. In a very local way it may be investigated by a thermometer. I have been able to detect a rise of 2 F. at some distance to the leeward of a house; which shows how very bad a large city must be and the necessity of placing large instruments at considerable distance from them. In fact the population of a region is a factor worth considering in locating an Observatory.

Remarks upon the Floating Form.

There is a very marked difference in this form between day and night. By day it is extremely conspicuous and full of movement, at night it is often difficult to distinguish. It always moves about in the way that smoke does in a draughty room; it is very similar in appearance to the intense heat lines produced by a lighted lantern in front of the objective, or to the lines about the hand under similar conditions; it requires a great extension of the focus to bring it into view with the eyepiece. From these facts I conclude that it takes its origin in the layer of comparatively calm air that exists between the surface of the Earth and the lower great stream overhead. It is in this layer that the main convectional movements occur by day. That I think is the reason of its greater conspicuousness and activity during that time. With a large planet like Jupiter it perhaps shows less change than the other forms, indicating thereby a low elevation.

It does not seem to exist in the telescope tube because it shows no association with the outline of the lens nor have I ever seen the entire lens vibrate, which would sometimes happen if there were currents of any consequence within the tube. Elaborate means have sometimes been taken to prevent movement of air within the tube but after trying to see real evidences of such movement and failing I am forced to conclude that none exist.

It is more difficult to say whether any of this current comes from the dome but so far as I have observed I am inclined to think not. For the comfort of astronomers in cold weather it would be well worth trying to heat the dome, preventing the exit of any hot air near the tube by a rubber-cloth curtain which would hang down inside the shutter entirely filling it, and be tied around the end of the telescope. By watching the currents of this character one could easily tell if the heating did any damage at all to the seeing.

The floating form is the one most commonly seen without telescopic aid or in very small glasses such as surveyor's transits. Over dry ground, especially in tropical countries, its effect may usually be seen at midday with the naked eye. Owing to the source of light being an area instead of a point, no variation of illumination is produced, but the object becomes disturbed and distorted through the refractive power of the air waves. As one minute of arc is roughly the smallest angle visible to the naked eye under ordinary conditions of illumination we may easily put the refraction of these waves at 5′ to 20′. Of course it must be constantly exceeding even these figures when the conditions are particularly favorable.

Effects of Currents on Seeing.

The immediate dependance of the seeing upon the atmospheric currents is a continuous experience. With an increase in the number of the currents the seeing at once grows worse, and the direction of the current may have a large effect, some being habitually bad and others always good. The cause of such difference is to be sought for in local topography or in general climatic conditions. The conspicuousness of a current is its most directly influential feature as it is a direct result of the refractive power of the waves and upon this depends the vibration of the object in view and its consequent distinctness of outline and detail.

The refractive powers of the various telescopic forms of waves, are as follows: The ordinary form rarely exceeds 1″ or 2″, while its usual amount is much less, say 0″.3. The mottled form has an average of about 1″ and goes up to 8″. The floating form has usually a low refractive power at night but when very bad may reach up to 10″. The ordinary form which is caused by the settling of cold air at night sometimes considerably exceeds this even reaching 25″, and that due to snow not infrequently comes near it. These figures are derived from observations on the motion of Mars in the focus and are given from a brief examination of a large number of observations. There is so much variation in the recorded amount of vibration that these figures can only be regarded as general approximations.

The average characteristics of waves of the ordinary form observed in Arizona and Mexico (each at an elevation of about 7000 feet above sea level) were as follows: direction, westerly; size, 1½ inches, and rate, roughly 10 miles per hour. The average size of the floating form was about ½ inch.

The Telescope; Its Apertures.

Bearing in mind the foregoing facts in regard to the constant presence of air waves which are only a few inches apart and have a measurable refractive power it is no difficult matter to deduce the conditions under which certain apertures become preferable.

It is easily a matter of observation that, making allowance for the variation in brilliancy of the apparent field when the eye is in the focus, the atmospheric currents are precisely the same in telescopes of different apertures at the same time and place. This is of course what should be expected. But different apertures do change the character of the seeing; and this also is what we expect. Conceiving the waves to consist of crests and valleys as the waves on water, we see that the refraction takes place on the slopes between these and that two adjacent slopes refract in opposite directions. If we take the distance from crest to crest as d and the mean amount of refraction in each slope as r seconds we shall find that in a telescope with an aperture of ½ d or less the image in the focus will oscillate through a distance of 2 r. If the aperture of the telescope is d we would see in succession, if the waves were all of perfect form, first a haziness of the planet, then a displacement of *r* seconds in one direction, then a haziness followed by a displacement of *r* seconds an the other side of its original position, then a haziness as at first, and so on; the haziness in each case being due to the presence of two slopes at once before the lens. If the aperature were 1½ *d* there would be alternations of haziness with these displacements of *r* seconds, the displacements themselves being not entirely free from haziness. With further increase of the size of the objective displacements would for a time exist but become more and more hazy until at last they would cease, leaving the planet perfectly steady but blurred.

Such is the effect of using different aperatures. As a matter of fact we rarely have such simple conditions in actual experience. We have a given telescope and usually three series of air waves which may be all of different sizes. By a big diaphragm we can get rid of the blurring effect of the largest set. By medium and small diaphragms we can improve successively the bad effect of the other series but in doing so the light is enormously decreased. We may summarize this matter of aperture by saying that the smaller the aperture the more bodily motion and less confusion of detail; the larger the aperture, the less bodily motion and the more confusion of detail. This leads us directly to the aperture required for certain classes of work. For seeing planetary detail we should use a small aperture unless the seeing is at its very best. On the other hand for micrometer work when steadiness of the image is required we need a large aperture. On one occasion after taking a large number of diameters of Mars and assigning weight to each measure, I found that the agreement of the readings was almost inversely proportional to the assigned weights. I then remembered that I had judged the weights according to the distinctness of the limb and detail. Upon changing my criterion to the steadiness of the image in the field, the weights then become of real use in judging the relative value of different measures. Of course there is a limit to which this increase of aperture may be carried for the planet may become so ill-defined that micrometer measures are worthless. One has to tell from experience when this limit is reached.

Good seeing then, apart from transparency of the air, consists of two factors, steadiness and definition. In a given atmosphere these factors vary with the aperture, one being improved at the expense of the other; either one may come from a superior atmosphere. Let no one therefore be deceived in attributing to his atmosphere what is really due to the relation between the diameter of his telescope and his class of work. For an accurate record of the quality of the seeing I earnestly recommend observers to use the scale already given.

Eye-End Diaphragms.

It is usually rather inconvenient to put on and take off diaphragms, so it is worth remembering that to a large extent the same effect may be produced by using small diaphragms over the eyepiece which cut down the pencil of light entering the eye and so reduce the affective area of the objective. For a given diaphragm the amount of reduction varies with the focal length of the eyepiece. These eyepiece diaphragms have been tried by the writer to great advantage.

This idea of placing obstructions between the eyepiece and the eye has a further use. The field of light about a very bright star is largely due to chromatic aberration, the impossibility of bringing all colors to the same focus. Through the refractive effect of the atmospheric currents and sometimes through the projection of opaque objects into the circle of the lens (for example, tin-foil separating the glasses) this field, consisting of many concentric rings, is divided off into series of rays. In searching for faint companions to bright stars these rays are extremely objectionable and anything which will help to get rid of them will be of value.

The objectionable field light produced by any given point in the objective lies almost entirely across the focal image in a line parallel to one joining that point and the centre of the lens. Therefore by placing across the objective or behind the eyepiece bars of suitable size all the field light may be cut off in a line parallel to that bar without making any very great loss of light. Experiments may be made in this line by merely thrusting a knife-point in front of the eyepiece.

The Observer; Optical Qualities of the Eye.

Aperture has another effect on the seeing which is of different kind, namely, physiological. It principally concerns observers of planetary detail and doubtless has frequently been explained by them.

All the effects of this kind observed, vary with the size and brilliancy of the pencil of light entering the eye. The first imperfections noticed are motes which float about and persist in coming upon the planet which is under examination. They can also be seen against a clear blue sky. They often have the appearance of minute twisted hairs and sometimes show signs of a cell-like structure—a fact which is more than suggestive because they undoubtedly are the remnents of cells floating in the liquids which fill the parts of the eye-ball. When they come upon the planet they may be disloged by a quick motion of the eye to one side, but that is only for the moment as it seems to stir up a commotion and others quickly follow. With these as with other imperfections to be mentioned, their maximum conspicuousness belongs to a certain intensity of light. With very bright sources of illumination they do not interfere; yet their range is very great and I know of no possible way of getting rid of them. To the naked eye they are perhaps a little less likely to appear under faint lights because the pupil is enlarged and they must be very close to the retina to throw any distinct shadow. In telescopic work their probability of appearing is inversely proportional to the square of the diameter of the pencil of light which enters the eye and they are therefore less likely to appear with low powers. High powers have the further disadvantage that they greatly reduce the apparent light of the planet and often render the motes more conspicuous in comparison. From their apparent size when projected on Mars I infer that their real size within the eye is between one and two one-thousandths of an inch.

Another region in which imperfections occur is the outer surface of the eye. These become visible when the pencil of light entering the eye is extremely minute and of the proper brilliancy, by the casting of their own shadows, as it were, on the retina and the absence of enough light from other parts of the pupil to drown them. With extremely high powers they begin to appear and it need hardly be added that high powers show more of the imperfections of the eyepieces for a similar reason. These imperfections in the eye are extremely small and consist usually in streaks or drops of moisture, bits of dust and lines of compression, probably on the cornea.

Lack of correctness in the curves of the refracting surfaces of the eye is another source of trouble. Such general imperfections as myopia or astigmatism can be fairly well corrected by glasses but there may easily exist in many eyes somewhat more local irregularities of curve which glasses cannot help and which therefore spoil the definition of the eye. It is a well known fact that some observers prefer high powers and some low. It seems possible that one cause of an instinctive preference for a high power may be certain local imperfections in the surfaces of the eye because, if fairly large, these imperfections interfere less with the small pencil of light emerging from high-power eyepieces than with the larger pencils from low-power eyepieces. For persons with eyes defective in this way there is a real advantage in using high powers.

But perhaps the most harmful imperfection in the eye is the lack of homogeneity within the more dense transmitting media, either the lens or membranes, probably the former. Under proper conditions the lens (presumably) displays irregular circles and radial lines, the whole resembling a spider-web structure. Under actual tests this structure is so very prominent that we wonder how the eye is able to give such good definition as it does. No optician could ever sell a lens so badly made except for the coarsest usage; in proportion to its size it has the imperfections one finds in the lens of a bull's eye lantern.

A most simple and instructive method of examining ones own eye is by taking two double concave lenses from a pair of opera glasses and looking through them at a candle some ten feet distant; by holding one lens near the eye and moving the other backwards and forwards the illumination may be adjusted to produce the best contrasts. In the experiment the pupil is seen as a circle of light and, if the candle is bright enough, concentric interference rings may be seen at its edges. After a few trials the motes in the eye, the irregularities in density in the lens or membranes and the drops and streaks of moisture left by the eye-lid may all be seen. It is probable that irregularities of the refracting curves such as spherical aberration and astigmatism can also be made evident by this device. In spherical aberration the center should appear brighter or fainter than the edges, while in astigmatism there should be a bright or dark band across the center from side to side in a direction depending directly on the line of astigmatism. It is possible, however, that spherical aberration could be produced merely by throwing the light into the eye in this unaccustomed manner just as it may be produced in a telescope by reversing the lens. Minute local errors may be seen as light or dark spots and the semi-permanent effects of holding the lid closed by force for a moment, impresses one with the fact that such usage of the eye is very bad for its power of definition.

One might guess at the errors of curve quantatively but if sufficiently large they can be actually measured by using a telescope, micrometer and artificial star. Let the micrometer be illuminated from one side and put a very small stop on the telescope so that the emergent pencil shall be very small. Under these conditions the entire pupil will receive the light from the threads but only a very small part of it will receive the light of the star. By passing the pencil of light through different parts of the pupil the error of any one point with regard to the whole may be obtained. It is possible that this usage of the telescope combined with a slight spherical aberration in the eye, is sometimes a cause of the "parallax" attributed to eyepieces. By carrying this process to an extreme one might even measure the refraction in those minute permanent marks in the eye which become evident upon careful examination. These marks are about one one-hundredth of an inch apart, so that a pencil of light as small as one two-hundredth of an inch would be required for measuring them.

Contrast.

This is a subject but little understood although it is of great importance in research upon planetary markings. The elementary fact is that high powers greatly reduce contrast; when one changes from a low to a high power the light parts of the planet become correspondingly fainter but the dark parts seem to become lighter; a perfectly black marking, however, such as the shadow upon Jupiter of one of its satellites, remains practically unchanged in good seeing. In an experiment for testing the effect of illumination on contrast, eyepieces were placed in the 24-inch telescope and its 6-inch finder so that a magnification of about 200 diameters was produced in each. Jupiter was examined and although work in the 6-inch would have proved more difficult owing to the greater conspicuousness of imperfections of the eye no especial difference in contrast for the larger markings could be perceived. The same result was obtained upon trying a power of 750 in each instrument. It was therefore concluded that illumination and probably the size of the spurious disk and the size of the emergent pencil have practically no effect on contrast within a large range but that magnification has. Illumination however, does effect color contrast, for the greater the illumination, the more brilliant and conspicuous are the colors.

No doubt the chromatic aberration of a lens (its scattering of light in a large field about the focus) has much to do with contrast; for the scattered light from each point on a planetary disk helps to reduce the contrast on all other parts of the disk within a certain distance. If we consider for a moment the image in the focus it is apparent that this destruction of contrast will be the same in two lenses of the similar curves and equal ratio between the aperture and focus, no matter what the actual aperture be; but it is also evident that diaphragming a given lens will reduce scattering and tend to aid contrast, or, to express it differently, long focus lenses should be beneficial to contrast. We conclude, then, that, as well as improving the seeing, diaphragming may improve the contrast provided the disk is not decreased too much in brilliancy, and that diaphragming a large telescope is better than using a smaller instrument of shorter focus.

Seeing of course has an effect on contrast because the refraction in the air waves causes a spreading about of the light from the object in view. Dust on the lenses causes loss of contrast for a similar reason. But under given conditions of seeing the marked effect of a change in power cannot be due to seeing because there is no relative change in the size of the object under examination, the atmospheric waves and the lens.

Apparent contrast, then, is a function of the size of the impression on the retina. The only explanation that suggests itself is this: The part of the retina most sensitive to slight contrast is the "yellow spot" which is also most sensitive to definition. It is quite likely that after a faint marking becomes large enough to be seen at all it will show maximum contrast when its retinal image holds a certain relation in size to the yellow spot. For markings of different densities it is possible that this dimensional relation changes.

The eye has considerable power of adapting itself to contrast occurring in different intensities of light in a manner entirely independent of the size of the pupil. This has often been exemplified in the experience of visitors looking at Mars, when the emergent pencil was much smaller than the pupil of the eye; at first they see nothing but a glare of light but after looking sometimes for fifteen minutes the glare diminishes and markings begin to appear. This is a certain power of adaptation which I have never seen mentioned before. After much practice that first glare becomes less and less noticeable and the eye becomes more sensitive to the particular range of contrast sought. That in fact is the training required by the eye to discern planetary detail and for different planetary bodies which present different degrees of contrast and different intensities of light, the training has to a certain extent, to be undergone afresh in each case.

It is a result of this training helped, perhaps, by some natural difference in eyes that two observers may find contrast more marked and detail easier in entirely different intensities of light. This point is best exemplified by the fact (very familiar to ourselves) that of two observers examining Mars on alternate nights one saw extensive and intricate detail in the light regions of the planet and the other observed numerous markings in the dark parts, but that for the entire opposition neither one saw much of importance in the other's region. The sequel is interesting, for during the opposition just passing each one has made a special and continued effort to train his eye for markings in the other intensity of light and so far succeeded that each has corroborated the other's previous work. This corroboration was not due to prejudice but to perseverance.

He will greatly benefit work in planetary detail who constructs an apparatus for increasing contrast. The polariscope has been tried with success upon clouds in our own atmosphere because it darkens the background of the sky. In astronomical work we need some medium which, without spoiling the definition, will cut off all the light which comes from the delicate gray-green or blue tones of planetary markings.

Observer.

The observer has already been mentioned as ranking very high in order of importance. It is not merely that the best observers of planetary detail are able to recognize what they see and draw it but it will be noticed that they have been very diligent in working often on unpromising material and amidst discouragement from other laborers in the same field. To everyone at first view all fine planetary work seems almost impossible and that is why all those who do not pass through this first stage discredit results that are finally proven to be of the greatest value. If one would see something he must persistently and persistently keep at it, picking up bits of detail, little by little, even though the seeing seems bad and the object difficult, always and only with the stern determination to see something if that something exists. The final pleasure of seeing his disjointed observations take shape in one consistent whole, is his reward.

Lowell Observatory, Mexico, April 2d, 1897.