THE

ABERRATION OF THE FIXED STARS

AFTER THE WAVE THEORY

From

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Explanation and Disposition.

Under the term "aberration," two different processes are almost always combined in the writings dealing with this subject; first, the delusion which we are subject to by the direction of the ray owing to the motion of our point of view, and which are quite comparable is that which we fall in a fast-moving carriage or railroad over the direction of the pouring rain; secondly, the real change in the direction of the ray, which also causes the movement of the earth as well. The former may be called the physiological, the latter the physical part of the aberration. The confounding of these two different effects under the concepts of aberration, by aberration being understood to mean the total, apparent and real change in the direction of the ray caused by the earth's motion, has been nothing less than favorable to the treatment of the object. Even the consideration of the expediency and sharp limitation of concepts in every terminology would suffice to find the combination of two processes, which are related only by common origin, but incidentally different, not very advantageous. But it also adds that those two parts of aberration are of very different difficulty of treatment.

In the case of the physical part, or the real changes in the direction of the reflected or the refracted ray, insofar as it is a consequence of earth-movement, one must presuppose a dependence on the translatory or flowing motion of the Aether, even if one arrives posteriori to the knowledge, that this flow is indifferent to the appearance. One recognizes therefore immediately that the treatment of this effect must appear far more difficult than that of the physiological: the delusion, which we expire when using a telescope with reticle, or even a diopter with visor opening and crosshair. In the latter respect, it is merely a question of determining the size by which the crosshair is removed from a ray passing through the visual tool at a given speed and parallel to the axis. If this size is the same while the length of the axis is being traversed, the deception about the true direction of the ray is evidently the same, and we easily recognize that this deception is quite independent of all modifications in the construction of the eyes, the refraction so it does not matter at all. We may also make a remark of this physiological effect, the correctness of which is evident to the point of triviality, but which, however profound and fruitful it may seem at first glance, will in a sense provide us with the key to the whole of aberration.

For it is clear that when two rays of originally arbitrary different directions pass the thread plane of a telescope in the same direction, the illusion caused by their earth movement over this their final direction is the same for both of them and the same Proportional to the vertical component of the earth's motion This sentence now provides us with the logical disposition of our treatment in the following way.

If we apply it to the most numerous, indeed everyday cases of astronomical observations in which a ray is brought into the axis of a telescope by reflection, experience shows on the incontrovertible that the part of aberration, for which above designation: *physiological aberration* was chosen by which the change of direction corresponding to the reflection of the ray is changed by as much as the physical aberration, but in the opposite sense; for the experience made and made thousands of times is just that the sum of both changes is zero. However, there are fewer observations that the same compensation also occurs when a ray is brought by refraction in a different direction from its original direction.

This remark, essentially pronounced by Fresnel in other words, thus gives us a property very important to the theory of aberration, the way in which the physical aberration is altered when the ray is deflected by refraction or reflection, or what appears to be quite the same is the influence of the earth's motion on the refraction and reflection. Since we obtain this by way of experience, independently of any hypothesis about the translatory motion or flow of the Aether, we have at the same time gained an experience of the latter. On the basis of the propositions according to which the refraction and reflection are explained in the wave theory, it follows that the influence of the earth's motion on reflection and refraction is just as it should be when the Aether, both of the medium and of the world space would be quite free from translatory motion, or rather, as if merely the partition of the refracting or reflecting media were moved, without being accompanied by translatory movement of the Aether. We conclude that either the Aether is really at rest or that its translational motion has no effect whatsoever on the appearance. In this dilemma, we find the former assumption reprehensible for various reasons, so we have to decide according to experience, for the second; but we are also able to prove that the latter, that is, the independence of the physical aberration of hypotheses about the translatory motion of the Aether, is in harmony with the fundamental doctrines of wave theory, but we will not refrain from doing so to note that this independence extends only to those phenomena which, like the present one, have only to do with the position of wave planes and their normals. In the diffraction phenomena, for example, in which other conditions are still decisive, one cannot assert the independence of the phenomenon from the translatory motion of the Aether; It is also known that Fizeau's acumen in the diffraction phenomena has recognized a means of measuring the translatory motion of the Aether itself and certain hypotheses of Fresnel which we will cite later.

Here we still come across the practically important question of whether the aberration constant depends on the instrument or not. Fresnel adheres to this by attempting to set up a theory about the experiences that existed in his time. These were simply the conclusion that the speed of light, closed by Delambre from the eclipses of the first Jupiter satellite, was very close to that of Bradley's Constant. It could be deduced from this that an effect to be expected from the glass thickness of the lens, as will be elaborated in more detail below, will not be revealed until then, because of this effect; if present at all, revealed itself only in a very small size, which was still hardly accessible to the observations of fixed stars at that time. Let it be immediately stated here that, for the reason just given, in a telescope of medium dimensions, as used for transit observations, the aberration constant must be found to be greater than the Delamhre's by nearly 0",20.

As the practical astronomer knows, the newer and best observations of fixed stars give on average the aberration constant very close to 0",20 greater than Delambre's value 20",255. It will be developed below a formula, according to which the constant for a somehow composed lens from the refractive indices, glass thicknesses and radius of curvature can be calculated in sharpness.

Fresnel negated the dependence of aberration on the means by which a telescope is constructed, partly

To a great degree of confidence in the observations of fixed-matter observations available at that time, but partly also by inclination to see the simple behavior of aberration in the theory of emissions also noted for the wave theory. For this reason, he has also escaped the remark that the translatory motion of the Aether, if it conforms to the hypotheses it establishes, nevertheless remains irrelevant to the size of the aberration constant.

It can be seen from the foregoing that the separation of concepts in the theory of aberration, the separation of that part which consists in a delusion of the direction of the ray, of that which gives rise to a real directional motion induced by the motion of the earth in the case of reflection or refraction. Changing the mirrored or refracted beam is of undeniable value. Through this approach a well-stabilized harmony comes into the theory of aberration, which can now be treated rationally according to wave theory, as it is the case for any other discipline of higher optics. So long as optics does not consist of the integrals of the most general differential equations of the motion of an elastic medium, with regard to the extension of the optical means and all arbitrary movements in it, as a tree can develop from a nutshell, so long are the strictness of the justification of optical sentences, and thus the aberration of certain defects. No one, however, will seriously assert claims to a rigor that is too ideal for the flourishing of the natural sciences; i.e., require that all theoretical considerations of higher optics and aberration theory be postponed until perhaps future times have succeeded in integrating those most general equations. Lamé himself once remarked at one point in his well-known theory of elasticity that it would be a mistake to believe that one could write analytic optics entirely in the style of analytic mechanics, in which case the latter always first. the whole theory can be set up and nothing needs to be left to the experience, as last to substitute the arbitrary constants. In analytical optics can only be a convenient change to advance between theory and experience. Incidentally, it can be said of the theory of aberration that it enters its circumstances, which perhaps dispenses entirely with the most general solution, in much the same way as one often disposes of the knowledge of the general integral in order to ascertain a definite integral becomes. The specific discussion of each item will also cover this in more detail.

An appendix contains observations on a transit instrument in which the ray of light had to pass through a long column of liquid to test the aberration constant.

I.

The optical illusion caused by Earth's motion, or Bradley's fixed-star aberration.

Assuming that, for some reason, a ray of an infinitely distant object is brought in the direction of the axis of a telescope, and in that direction passes through the telescope at a velocity v', an image of the object would coincide with the crosshairs; if the earth has no motion perpendicular to this direction, and we would then say without delusion that the direction of the beam with the telescope axis is parallel. If, on the other hand, the earth has a motion perpendicular to the axis, which may correspond to the velocity *g*, then it moves away during the time *t*, which the beam uses, to go through the length of the telescope to the thread plane, the crosshairs of the size *gt* from the point of the thread plane where the picture comes to pass. Our immediate judgment, then, erroneously writes one of his rays different direction, because we do not see the image in the crosshairs. The magnitude, by which the direction of the ray apparently differs from the telescope axis, evidently expresses by $\frac{g}{v'}$, whereby we have equated this small arc with its tangent. This delusion, this is what one used to understand by Bradley and in the emission theory under the aberration of the fixed stars and expediently, even after the introduction of the wave theory, was to understand this name alone. If you throw, as often happens, with the aberration too the real changes of direction, which are to be assumed because of the earth's motion and the currents of the Aether, make the investigation of even the simplest cases extremely difficult. If, on the other hand, we put aside for the time being the reasons why the ray in the telescope has assumed its true direction and the velocity of propagation v, we may consider the above approach to the emergence of Deception, introduced by Gauss in the *Theory of Motion of Celestial Bodies*, that is, at a time when the emission theory still maintained its rule, without further reference to the wave theory transfer. For in wave theory we know nothing less than in emission theory what we must understand by the direction of a ray. We know that this is always the normal to the wave surface, here wave plane, which connects the Aether particles the same phase. Nor are the concepts of the speed of propagation of the waves a reproach of clarity; contemplation therefore loses nothing of its precision and rigor, unless someone misses the proof that under the influence of the earth's movement and all possible currents of the Aether, waves and equally regular wave surfaces in the telescopes are still possible are, however, which proof we cannot fulfill without the integration of the most general equations of Aether movements. We exclude the possibility of this regularity, despite the proximity of the earth, from ongoing experience; cannot even consider the requirements of a barren hypercriticism here.

Thus, choosing the Gaussian approach, we find the law according to which the optical illusion or the physiological part of the aberration is directed, first considering the usual case in which v', the velocity of the waves in the interior of a telescope whose velocity in world space v is not different. In this simplest case, the apparent inner ray is extremely close to the rectilinear unbroken continuation of the apparent outer, between object and

Objective lying part, and therefore corresponds to the arc $\frac{g}{v'}$ or $\frac{g}{v}$ at the same time to that angle through which the telescope axis or the entire telescope must be rotated to bring the image of the object in the reticule, i.e., of the aberration to be measured, with which latter we in the Astronomy always have to do. If v', the coherence of the light in the interior, i.e., between the objective (the effect of which we can disregard for the moment) and the filaments, which differ from the velocity v between object and objective, so would those two, the outer and the inner direction of the apparent ray, because of the transition at the inner means of refraction, no longer be parallel. Let a be the small angle which the external ray apparently makes with the axis of the telescope, or the aberration to be measured, α' the angle which is apparently formed by the direction of the ray within the axis, is obvious

$$\frac{sin\alpha}{sin\alpha'} = \frac{v}{v'} = n \,,$$

if n represents the refractive index of the internal agent against the external, in short, against the world-space. Sufficiently close, always can be set

$$(A) \quad . \quad . \quad . \quad . \quad \alpha = n\alpha'$$

It is, however, as shown above, $\alpha' = \frac{g}{v'} = \frac{gn}{v}$, therefor

$$(B) \quad . \quad . \quad . \quad . \quad \alpha = n^2 \frac{g}{v}$$

From this it is seen that if the telescope were filled in the long of its focal length with a medium to which the refractive index n belongs, the aberration to be measured would thereby be increased in the ratios of n^2 to 1. The occurrence of the square of n is the consequence of the relation valid in wave theory

$$v' = \frac{v}{n}$$

while in very substantial contrast to this the emission theory ascribed a greater velocity of the ray to the more refractive medium and; instead of as above, put:

$$v' = nv \,.$$

According to the emission theory, you would have more

$$\alpha' = \frac{g}{v'} = \frac{g}{nv}\ ;\ \ \alpha = n\alpha' = \frac{g}{v},$$

and in this latter case, therefore, aberration would be independent of the instrument. Completely different, as we have seen, demanded the wave theory, so those who wanted to know the older and simpler law with Fresnel and for the latter had one more. to accept a special process which compensates for the effect of the greater density of the internal means upon the aberration. Fresnel attributed such an effect to the translatory motion of the Aether inside the telescope. Of the hypotheses in this regard of him, however, the first one has a high probability for itself. It is consistent with Fizeau's well-known experiments on the displacement of diffraction fringes produced by running water. But as regards the effects expected of them on the direction of a ray, it will be shown below that they cannot exercise such, that therefore, according to the wave theory, a dependence of the aberration constant on the means of the instrument must remain because even all the safe determinations of aberration and a recent experience speak quite clearly for such dependency.

Even if the lens does not, like a column of liquid placed inside the tube, cancel out the equality of the apparent direction of the inner ray with the outer one, rather, based on Gauss's doctrine of the principal points of a lens, it will cause both directions to be parallel. However, due to the fact that light travels slower through a glass layer than through air or through empty space, it has a small modifying effect on aberration. The same can, from their smallness, from the numerous observations of Polaris and other fixed stars, which modern astronomy has employed for the purpose of ascertaining the constant of aberration.

For this reason, a prism with total reflection, as it is regularly used in transportable transit instruments, must also have an influence, and indeed a rather important one, which is neglected in any reduction claiming sharpness should be.

II.

Evidence from the observations that earth movement also changes the true direction of a reflected ray

In the foregoing we have seen that the direction of a ray coming from an infinitely distant object inside the telescope (which latter direction is always to be regarded as the final direction crucial to the immediate measurement) deceives when the earth makes a motion perpendicular to it this direction has. It is this physiological effect entirely not to be confused with the *real* directional changes that the earth's motion produces in addition, when the ray is deflected by reflection or refraction, and which can be proved by the following discussion. The cases in which the beam is first brought into the telescope connected to a measuring apparatus by reflection are among the everyday of practical astronomy. Let's take as the first and the simplest example a sextant measurement of the distance between two stars A and B. We aim the telescope at A and then bring by reflection the image of B also into the crosshairs; in other words, we give that rays of both stars a *common final direction*. Therefore, even after the deduction of the first section, we have a *common*, that is, *equal*, aberration of the two rays, and should accordingly reduce the observations with the same correction, and indeed with the aberration of A, if we want to proceed rationally. But it will, like every astronomer white, so reduced, as if the direct beam of B had been caught in the telescope. For this procedure, practical astronomy has as justification only experience, which teaches that nevertheless correct is obtained. Thus, the apparent incorrectness of the process is rendered harmless by another effect, and this other effect is the effects of earth's motion on the direction of the reflected beam. After that, the sextant measurements justify the conclusion:

> that there is an influence of the movement of the earth on the reflection, and that the position of the mirrored ray is changed by the same by as much as the aberration is changed by the reflection, but in the opposite sense.

The magnitudes involved are very considerable, and therefore evade neither the sextant, in which the aberration of the deflected ray may be different from that of the direct, much less other perfect instruments which are on the principle. However, the correctness of the sentence just set out from observations on transits and universal instruments with broken ones is even more unequivocal axis. Here, the deflection which the direct beam experiences by the total reflection of the prism mounted in the axis of the telescope is always 90°. If the direct ray reaches the maximum of the aberration, then the illusion about the closing direction in which the threads are passed becomes zero, and vice versa. In the conventional reduction method, we always count on the aberration of the direct ray, instead of the aberration of the perpendicular direction. Nevertheless, the result of the observation is found to be correct, in consequence of the effect given on the true direction of the deflected ray, which renders the incorrectness of our method harmless. To give yet another example: one of the most common operations, but at the same time a very high degree of accuracy is usually sought and achieved, is the observation of the beam reflected from the mercury horizon. In general, the aberration of the direct beam is reflected from that of the

Its final direction be very noticeably different. Again, the rational reduction of aberration would require that the final direction be attached. If we arrive at a correct result for the position of the mirror normal, as we know, differently, then the reason is that by neglecting the influence of the earth's motion on the true direction of the mirrored beam, we make a mistake of just opposite influence.

A special case makes this even clearer; the direction of the direct beam coincides with that of the earth's motion, the reflected beam is perpendicular to it. Accordingly, the aberration would be zero for the direct beam, whereas for the direction of the reflected one would be Aberration or deception of about 20", by what magnitude apparently this latter direction appears opposite to the mirror normal or the zenith, so one would expect, according to the usual reduction method, in which only the aberration of the direct ray is taken into account, the location of the mirror normal is found to be false by 10". This does not, however, the case has the reason given above.

The summary treatment of aberration, to which Fresnel already drew attention on the occasion of the first substantially correct interpretation of the Arago experiment to be mentioned below, also causes the opinion expressed here and there that in the case of reflection or refraction, for example in the case of the application of the artificial horizon occurring dilemma in terms of aberration, simply decide by thinking of the horizon with the telescope in conjunction. This fiction is obviously allowed; but it is not permitted to conclude that the aberration is now, of course, as usual, to be redressed, because now we have to deal with a single telescope, of a slightly different construction than usual. It is overlooked that this apparatus asked for two different optical axes; by merely ignoring this circumstance, the question as to which of the two one can count the aberration cannot be decided.

In the case of refraction there is also the experience, first made by Arago, that the fixed-star observations made by an achromatic prism provide correct points when calculating the illusion or aberration as if it had occurred in the direct ray. This is apparently about the deception that takes place a faulty reduction, since only the final direction of a ray can be subject to deception. The fact that regardless correct points will irrefutably show that the motion of the earth here, in addition to the deception, still causes a real variation in the refraction and that this variation compensates with the apparent effect. It is only to be greatly regretted that these so important observations of Arago, so far as the author is aware, have not been published anywhere, whence it may be explained that different authors differently refer to the arrangement of these experiments. Therefore, we want the cause of the experiments, the general arrangement to the same and the result can be led, as happens in the commemoration on Fresnel:

"There is a very simple way of noticeably altering, if not the absolute velocity of a ray, at least its relative velocity; it is to observe it during its annual course, when the earth is directed towards the star whence this ray emanates, or towards the diametrically opposite region. In the first case, it is as if the speed of the ray were increased by all that of our globe; in the second, the change has the same numerical value, but the primitive velocity is diminished. Now no one is ignorant that the speed of translation of the earth is comparable to that of light, that it is the ten thousandth of it. To observe at first a star towards which the earth is moving, and then a star which the earth flees, is to have operated on spokes whose velocities differ from one to five thousandths. Such rays must be unevenly refracted. The theory of emission provides the means of telling in numbers how much the inequality will rise, and we can see that it is much greater than the small errors of the observations. Well, specific measures have completely denied” "the calculus: the emanated rays of stars, in whatever region they are located, precisely experience the same refraction."

The same observations are made in the highly recommended book by Hoek, *Astronomical research of the Utrecht Observatory*, first edition (of the influence of earth's movements on the fundamental phenomena of optics used by astronomy), there page 36 described. The author has never succeeded in finding the observations himself, and the research of others does not seem to have been happier in the relationship. The author has seen the result of those observations, as long as it states only that the refraction of the Earth's motion is not directly perceptible, confirmed by his own observations, which are somewhat similar to the Aragoians. But as the purpose was quite different from that of studying the influence of the motion of the earth, the conclusion of them is less compelling, as being from Arago's attempts made only in the above regard; however, their publication will take place at the appropriate opportunity.

III.

About the influence of the movement of the partition of two media.

It may sometimes be of great use to examine the processes which, in an abstract case, never to be offered by nature itself, would be expected according to a definite theory; because it is very common that the natural and an abstract arrangement have the same effect brought forth. An example of this kind is offered by the important propositional doctrine or the doctrine of potential, which states that two homogeneous spheres attract each other as if their whole mass were united into their centers. The case being compared with is obviously an abstract, since in nature infinitely small volumes with finite mass; so, bodies of infinite density do not occur. In the applications of the doctrine of potential, it is also known that it is always possible to find a distribution of magnetism on the surface of a magnet which completely replaces the effect externally, and so many examples could be cited where the comparison of the theory of potential nature with an abstraction, if you want, with a fiction, great advantage granted. In a similar way, we assume here too that the partition of two means can be moved so that the wave formation in both means is not altered at all, and every wave plane or surface of the same phase is the same in space in both means, only by motion The partition directly affected, retains position and can continue undisturbed up to the generally inclined to the same partition wall. There is even a special case, a grandeur, where nature itself grants this possibility, when the two means of sealing become infinitely close. If the two media are different in relation, then in reality it is one movement of the partition surface also accompanied by translational movement of the Aether. By choosing the term partition, instead of reflecting or refracting surface, we just want to suggest the demand that one should abstract from such physical consequences and the level to which the waves of both media continue, at different times different situation, with in other words give a parallel shift. If such occurs in the direction of the wave progression, it is clear that the speed of the wave is *relative* to the same direction is reduced to the partition. In general, this *relative* velocity of the waves against the partition will be reduced by the component of the movement of the partition falling in that direction, a quantity which, of course, differs in both means, owing to the difference in the directions of the ray. The refraction, which suffers a wave of homogeneous light at the partition of two means, and likewise the reflection depends on the velocities of the waves against the partition wall off. Let φ be the angle which the wave plane in the one means, in which the momentum progresses at the absolute velocity, forms with the partition, φ' the angle between the wave plane and the partition in the second mean, for which we mean the absolute velocity of the tails spread equal to v'. If the partition were at rest, then v and v' would at the same time be velocities against the partition, and one would have the known relation

$$\frac{sin\varphi'}{sin\varphi} = \frac{v'}{v}$$

from which the angle φ' determines, if we consider φ as given. If, on the other hand, the divisional surface has a motion g equal to the earth, which forms the angle N with the normal to this surface, going against the direction of the ray, then the angle to be sought for the second mean will no longer be as in the case of rest; one will rather have the previous one

1. $$\frac{\sin(\varphi'+\delta\varphi)}{sin\varphi} = \frac{v'+g\ cos(N-\varphi'-\delta\varphi')}{v+g\ cos(N-\varphi)}$$

where $\delta\varphi'$ means the variation produced by the movement of the partition and always to be treated as a very small first order quantity, which is the consequence of the movement of the partition.

A similar but simpler formula is obtained for the variation of the reflection. One can spare their particular derivation, or apply the above briefly very briefly, if one notices that the reflection can be regarded as a special case of refraction, in which the speed of light in the second mean v' is negative and becomes equal to -v. The mirroring formula for the case of the quiescent partition would thus also be written:

$$\frac{sin\varphi'}{sin\varphi} = -\frac{v}{v} = -1$$

It supplies the angle φ' in the fourth quadrant of the nature of the case. On the other hand, under the influence of the specified movement of the partition one will receive

$$\frac{\sin(\varphi' + \delta\varphi')}{-sin\varphi} = \frac{-v + g\ cos(N - \varphi' - \delta\varphi')}{v + g\ cos(N - \varphi)}$$

or, if φ', as is usually done for a better overview of type equation here, is counted symmetrically with φ from the incidence heater and all higher-order terms are immediately omitted

2. $\frac{\sin(\varphi'+\delta\varphi')}{\sin(\varphi)} = \frac{v-g\cos(N+\varphi)}{v+g\cos(N-\varphi)} = \frac{1-\left(\frac{g}{v}\right)\cos(N+\varphi)}{1+\left(\frac{g}{v}\right)\cos(N-\varphi)}$

The variation $\delta\varphi'$ caused by movement of the specular surface becomes hereafter

3. $\delta\varphi' = -\frac{g}{v}[\cos(N-\varphi)+\cos(N+\varphi)]\tan(\varphi) = -\frac{2g}{v}\cos(N)\sin(\varphi)$

It is now easy to show from this size that it is equal to the difference in aberrations for the direct beam, and less so for the reflected beam. For the former is evidently the same $\frac{g}{v}\sin(N-\varphi)$ the latter $\frac{g}{v}\sin(N+\varphi)$, and the difference is the same

$$-\frac{2g}{v}\cos N\sin\varphi$$

as it should be proved.

Considering the method of counting φ', the same compensation between physical and physiological aberration, which we have come to know in the previous section as the most unequivocal result of astronomical experiences, follows from the assumption that the reflecting surface without producing translational movements of the Aether, it can be carried along by the earth, and if, under this assumption, the position of the reflected ray is derived from the naturally completely given direction of the direct one. The fact that in nature the movement of the divisional surfaces of two means of different density is not possible under such circumstances does not give any value to the value and usefulness of what has just been found, as we shall see below.

In the previous section already, in the preliminary examination of a liquid filled inside diopter or telescope, we had opportunity to the difference between the apparent distraction from the direction of the ray in a medium as would be perceived by an eye placed in such means, from the aberration which one would measure on the instrument. It was the aberration of the angle around which the instrument had to be rotated in order to move from setting to the apparent ray to the true ray. For the proof to be given, that even with every refraction which the direct ray suffers, the variation of the aberration is equal to the variation of the refraction with opposite sign, we must always pay strict attention to this difference. Our proposition applies precisely to the aberrations to be measured and is presupposed in this case that its final direction to be measured again passes through a medium of the same density as that of the direct ray. In other words, it is presumed that the aberration of the refracted ray would be measured at its extension, i.e., near the direction of the direct ray, directed to the former and to the object. Whereas for the aberration of the direct ray the indicated difference disappears, on the other hand the apparent aberration of the refracted ray must be multiplied by the factor

$$tan\varphi' cotan\varphi$$

be reduced to the one to be measured. For while retaining the name chosen above, this factor is the ratio of associated increments $\frac{d\varphi'}{d\varphi}$, as is the relation $\frac{sin\varphi'}{sin\varphi} = \frac{v'}{v}$, so $d \cdot \frac{sin\varphi}{sin\varphi} = 0$ corresponds to.

Obviously, in the manner indicated, one obtains the rotation required by the instrument in order to guide a crosshair placed in the direction of the direct ray from the apparent backward-refracted ray to the true backward-refracted ray.

Thus, the aberration of the different paths of the ray is so predicated, and the statement made above applies not only to every single transition to another means, but also to every repetition of this process, and therefore also, when the beam has been deflected by a prism of any composition. At the same time, it corresponds perfectly to the experience which has been made in this respect, and which likewise could only refer to the aberration to be measured.

One may also make the general remark that the aberration to be measured is greater than the apparent one, when the crosshairs and the axis of the measuring apparatus fall into the denser medium, but smaller when this axis lies in the thinner mean.

Equation 1 yields without difficulty, always neglecting the higher powers of the very small quantities $\frac{g}{v}$ and $\frac{g}{v'}$:

4. $$\delta\varphi' = \frac{g}{v'}\frac{sin\varphi'}{cos\varphi'} \cdot \cos(N-\varphi') - \frac{g}{v}\frac{sin\varphi'}{cos\varphi'} \cdot \cos(N-\varphi)$$

This expression for the variation of the refraction $\delta\varphi'$ suffered by the earth's movement can be further transformed as follows:

$$\delta\varphi' = \frac{g}{v'}\ sin\varphi'\ cosN - \frac{g}{v}\frac{cosN \cdot cos\varphi \cdot sin\varphi'}{cos\varphi'}$$

or, here for $\frac{sin\varphi'}{v'}$ its value $\frac{sin\varphi}{v}$ is substituted:

5. $$\delta\varphi' = \frac{g}{v} \cdot \frac{cosN}{cos\varphi'} \cdot \sin(\varphi - \varphi')$$

If the movement of the partition is perpendicular to its normal, or if the direction of the earth's motion falls into this partition itself, then N = 90 ° and $\delta\varphi'$ = 0. But in the same case the physiological aberration is in the refracting medium:

$$\frac{g}{v'}\ cos\varphi' = \frac{g}{v'}\frac{v'}{v}\frac{sin\varphi}{sin\varphi'}\ cos\varphi' = \frac{g}{v} \cdot \frac{sin\varphi\ cos\varphi'}{sin\varphi'}$$

If we reduce by multiplication by cotan φ tan φ' to the aberration to be measured, then this becomes equal

$$\frac{g}{v}\ cos\varphi$$

which latter apparently is the aberration in the direction of the direct ray. The difference between the two aberrations is therefore zero.

If equation 5, N = 0 is used, that is, the case that the earth moves in the normal itself, then for this case

$$\delta\varphi' = \frac{g}{v}\,\frac{1}{cos\varphi'} \cdot sin(\varphi - \varphi')$$

But then it has the direction of φ' the aberration

$$\frac{g}{v'}\;sin\varphi' = \frac{g}{v}\;sin\varphi\;;$$

This is again as before, with the factor cotan φ tan φ' to reduce the aberration to be measured; so, she will

$$\frac{g}{v} cos\varphi\; tan\varphi'$$

The aberration of the direction of φ, however, is the same

$$\frac{g}{v} sin\varphi$$

and needs no reduction. So, we have as an expression of the difference in question:

$$\frac{g}{v} cos\varphi\; tan\varphi' - \frac{g}{v} sin\varphi = -\frac{g}{v} \cdot \frac{1}{cos\varphi'} \sin(\varphi - \varphi')$$

and the same here is equal to the variation of the refraction with opposite sign.

The movement of the earth will therefore be successful in *every* direction, since every movement can be divided into the two mutually perpendicular directions.

The same result can easily be applied to the second refraction in a prism, in which the ray from the denser medium passes again into the thinner one. Let us then denote the aberration in the direction of the direct ray with I, that of the ray once refracted with II, that of the twice-refracted ray in which it leaves the prism, with III; Thus, through the mediation of II, III, we can compare with I, which comparison gives the same result for III-I, which we give for II-I, a result which is in complete agreement with the experiences, including the so-called Arago experiment.

The reader easily sums up that although our proof has been given without regard to dispersion, or for homogeneous light, it can readily be translated to compound light and the action of an achromatic prism.

IV.

Some remarks on the previous section and the conclusion to be drawn therefrom on the influence of the translatory movement of the Aether.

The immutability of the sum of the physical and physiological aberrations for each direction into which the ray passes through reflection and refraction, must not be mistaken for another proposition, frequently made on the same occasion, which states that aberration is quite independent of them Means that meet the telescope. This latter proposition is quite unacceptable not only for theoretical reasons which we will develop below, it also contradicts experience; Therefore, we want to prevent by some remarks the confusion of the two sentences. In the first theorems confirmed by the observations, the invariable sum of the physical and physiological aberrations, for the different directions, which sum is generally different from zero, is determined by the position of the axis which serves for measuring, and moreover the nature of the breaking media, which are in this axis. That sum is therefore unchangeable with the direction, but not in other respects. Earlier we have already considered the case that in the entire length of the limited measuring axis of a diopter with a visor aperture and reticule, or even a telescope with reticule, a column of liquid of refractive index n is turned on; We found the aberration magnified by a ratio of 1 to n^2, and this magnification would apply to all directions which we may give to the ray by refraction or reflection in such an arrangement. In Arago's experiments, the reduction with the ordinary aberration constant and applied for the direct beam, instead of for the deflected, applied to a correct

Results because the measuring axis was in a mean of the refractive index 1. In the other case, if this remedy had a greater impermeability, one would have to apply a greater aberration constant.

The assumption about the translatory motion of the Aether, from which the formulas of the previous section have been derived, certainly does not correspond to nature, and yet all previous experience agrees entirely with it. This perception must lead us to investigate whether it is not possible, for a reason to be taken from the nature of the wave theory, that any translatory movement of the Aether, which must accompany the change of a body from a density that surpasses cosmic space, has no effect on the direction of a ray, and only the movement of the refracting and reflecting surface itself plays a role. In a later section we will show that this neutrality of the translatory or entrainment motion of the Aether is a very close and quite necessary consequence of a major principle of wave theory.

Those experiences which show the influence of the earth's motion on the direction of the broken ray, offer yet another opportunity worthy of another not unimportant remark. By Newton, the fundamental theorem has been introduced into the optics, that with the same breaking the media the deflection of a ray or its breakability is bound to the color. One speaks therefore of the refraction of the red light, or the yellow, the violet, etc. The same relation has been adopted unchanged by the wave theory, only the wave theory distinguishes the colors also according to the oscillation numbers and the wavelengths which correspond to the different colors in the free Aether or in the world space. The Newtonian theorem of the correspondence between color and retractability therefore also expresses the wave theory in the form that it says that the refraction of a ray is bound to its wavelength. The correctness of this relation can certainly be said to be beyond doubt, as long as it is not the eye or the light source has a speed comparable to the speed of propagation of the light. Doppler has already pointed out that the color of a ray must undergo changes through each of the two movements. If the eye, reduced to an optic nerve and thought to be without refraction, is brought closer to the source of light, this obviously results in an increased frequency of the waves passing through it; It seems to the eye that the duration of oscillation is shorter than in the case of rest, and it would therefore be, for example, red transformed into orange. A similar happens when the light source approaches the eye through its motion; for every wave later emitted by the light source has a shorter path to the eye than any of the preceding ones. The epochs of the arrival of these waves in the eye thus appear compressed, the frequency of the waves thus also increased in this case, and therefore the duration of oscillation abbreviated. Now, the question that is very interesting for astronomy is to raise the question: is Newton's theorem, which is certainly set up without any regard to such relations of motion, extend to that color which results under the effect of motion? As you can see, this question is divided into two parts; because what is said about the movement of the eye or the earth does not necessarily have to take place for the light source. The author refers here to the very part in order to dedicate a special treatise to him, the more difficult one.

Let us confine ourselves here to the question: is it indifferent to the wavelength of a colored ray, or not, whether the color of the same comes about with the assistance of the earth's motion, and the above sentence of Newtonian optics can be applied to it in any case?

If we want to answer it with the help of an experience, then the experiment of Arago gives us the material for it. What we have already concluded from this is that the movement of the earth exerts a significant influence on the direction of the refracted ray, which of of the same order, as that very remarkable quantity, which we simply call aberration. The following consideration, however, presents itself further. If the direction of the refracted ray, which reaches our eye with a certain color, were determined in a manner wholly independent of the mode of color, according to Newton's theorem, then it is easy to recognize that the direction of the broken beam could not be affected by the earth's movement. For the previously ultra-red ray, which appears as Roth only under the influence of motion, would then have the same distraction, ie refraction, as would come to a light originally red and without motion. The same can be said of every part of the spectrum. Now if the prism is achromatic, as in Arago's experiments, i.e., if all colors emerge in a common sense, then obviously this common direction cannot be different from that which would have taken place without motion; there would be no effect of earth movement on refraction, either direct, or indirect, detectable. However, Arago's experience undoubtedly points to such a conclusion, and it turns out that Newton's proposition cannot be extended to those colors in which the earth's motion is involved. Likewise, the ordinary correspondence between color and wavelength ceases to be strict. But you can also make this latter clear by very simple considerations.

The wavelength is the distance between two Aethereal particles in the ray, which are in the same phase; The passive eye, receiving only the impression of light and color, will evidently be able to change nothing in the distance of the Aether's particles from the same phase. Or, according to a related approach, imagine a partition between two equally dense media, if one wishes, a plane set by the free Aether of the world-space itself, to which the ray should be perpendicular, in motion. Such a movement evidently does not require any training which would make our judgment more difficult, we can therefore, say that the ray for an eye behind this partition is no longer of its original color, since the frequency of the waves in the partition and for the eye is different than in the state of rest. Nevertheless, the wavelength will be unchanged. Consider also many plates provided with undulating elevations, wherein the interval of the waves should correspond to the wavelength of the different types of light. If these plates, one after the other, are pulled under an absolutely stationary pin at a speed equal to that of all, so as to produce a tone, it is obvious from the height of the plates, and from the known speed with which to place the plates under the pins slid on the interval of waves on each plate can close. This is the same conclusion as the optics so common in color from the color to the wavelength. But it is only permissible if the pencil, in the optics of the earth, does not itself have a movement. For, evidently, this latter movement will influence the height of the sound, without, however, in the least changing the intervals of the waves.

We conclude, according to the preceding considerations, that Newton's principle of the same color, equal refraction, or the equivalent principle of the wave theory: the same color, the same wavelength, is not extended to the colors arising with the participation of the Earth's motion may be. However, the incorrectness in measurements on the solar spectrum cannot be noticeable because, as we know, the earth's orbit is almost circular, so that the earth almost always maintains the same distance from the sun.

Those who regard that old principle as an axiom which grants no exception, as a proposition with which the wave theory itself stands and falls, find themselves in the most tangible embarrassment if they are to explain the fact lying in Arago's experiment. So says, for instance, Billet (*Traite d'Optique Physique,* Tome 1, p. 85.)

"Movement of the eye.

"In relation to color, the results are analogous to the previous ones. There is, however, this difference already reported

"(§ 41), that the lengths of the waves outside the eye are no longer modified, and it becomes necessary to decide first of which of these two circumstances, the number of waves or their external length, depends on the color. This difficulty can be solved other than by experience. In fact, it is not the outer waves, but the inner ones formed in the vitreous humor, that must be preoccupied; but the movement of the eye affects the length of these last waves. But it happens that, when they become more numerous, they are at the same time shortened, and optics does not offer on this point the same division, as acoustics. It will not be forgotten, moreover, that the influence of the movement of the eye is different is less active than the preceding one. As to the influence on direction, we have sufficiently studied it under the name of aberration."

Again, we encounter the idea that under all circumstances, as often as the perceived color corresponds to a larger number of oscillations, the wavelength must be shortened. Under this idea, the explanation of Arago's experiment attempted on this (in the following section of the book) must necessarily suffer greatly.

If we see the principle that has become so general: the same color, the same wavelength, the same wavelength, the same refraction, with the result of Arago in a radical contradiction, which cannot therefore be eliminated, our view shows that the change originating from the earth's motion the color does not entail a change in wavelength, with the experience gained thereby in full harmony. For if the increase in the number of oscillations preserves the greater wavelength of the lower frequency of oscillation, nothing else than to attribute to the waves an altered velocity against the partition, and the reader can easily convince himself that the changes become the same as those already given to the formulas of the previous paragraphs Basically laid. Those formulas are quite in line with Arago's experiment.

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V.

The Fresnel Hypotheses and Their Role in Aberration Theory.

Fresnel's theory of aberration, which has exerted the greatest influence on the views of astronomy on questions of aberration theory, is found in the ninth volume of *Annales de Chimie et de Physique*, developed in a letter from Fresnel to Arago. Let us take the letter here, to make remarks in the passages which seem to us to be particularly important, and to get to know Fresnel's view exactly. The entrance refers to the much mentioned Arago observations:

"By your beautiful experiments on the light of the stars, you have shown that the movement of the terrestrial globe has no appreciable influence on the refraction of the rays emanating from these stars. This remarkable result cannot be explained in the system of emission, as you have observed, that by supposing that the luminous bodies impart to the molecules of light an infinity of different velocities, and that these molecules do not affect the organ of sight with only one of these velocities, or at least between very close limits, and such that a ten-thousandth more or less is more than enough to prevent sensation. The necessity of this hypothesis is not one of the slightest difficulties of the system of emission; for what is the vision? At the shock of the luminous molecules against the optic nerve? But this shock would not be insensitive by an increase in speed. In the way they refract in the eyeball? But red molecules, for example, whose speed would have been diminished even by one-fiftieth, would refract even less than violet rays and would not leave the spectrum, which presents the limits of vision."

It is not Fresnel's own view, but rather Arago's, as has long been recognized, based on an incorrect interpretation of the experiment: "that the movement of terrestrial globe has no noticeable influence on refraction rays etc.“ This mistake in Arago's is corrected by Fresnel with such great care that a not very attentive reader can easily be led to believe that Fresnel parts are the Aragoean view. The continuation of the letter further explains below. It is then called:

"You have engaged me to examine whether the result of these observations could be more easily reconciled with the system which makes light consist in the vibrations of a universal fluid. It is more necessary to explain it in this theory, that it must apply equally to terrestrial objects; for the speed with which waves propagate is independent of the motion of the body from which they emanate. "

This last sentence has the character of an occasional utterance, which probably has not preceded any actual examination of the question in question. It is well done, not to add too much weight to such occasionally expressed opinion, even if it comes from a Fresnel. The reader will easily recognize why the Arago's experiment cannot provide a useful contribution to answering the question of the influence of the movement of the light source. The average refraction for different regions of the sky will always be the same, despite any individual differences of the stars. To recognize the latter requires many observations, a different choice, and a different arrangement than Arago has made. Incidentally, without any danger to our present subject, the view that the movement of the light source has an influence on the refraction may be for the time being perversely eroded.

Fresnel then continues:

"If we admit that our globe imprints its movement on the Aether with which it is enveloped, it would be easy to see why the same prism always refracts the light in the same way, whatever the side from which it arrives. But it seems impossible to explain the aberration of the stars in this hypothesis: I have not been able at least to conceive this phenomenon so far as by supposing that the Aether passes freely at "across the globe, and that the velocity communicated to this subtle fluid is but a small part of that of the earth; do not exceed one hundredth, for example.

As extraordinary as this hypothesis seems at first glance, it is not in contradiction, it seems to me, with the idea that the greatest physicists have made of the extreme porosity of bodies. One can ask, in truth, how a very thin opaque body intercepting light, it happens that it establishes a current of Aether through our globe. Without pretending to reply completely to the objection, I will remark, however, that these two kinds of movements are of a nature too different to apply to one what is observed relative to the other. The luminous movement is not a current, but a vibration of the Aether. It is conceivable that the small elemental waves in which light is motted through the bodies may, in some cases, find themselves in discordance when they meet, because of the difference of paths traveled or unequal delays they have experienced in their walk; which prevents the propagation of vibrations, or denatures them in such a way as to deprive them of the property of illumination, as well as that in a very striking manner in black bodies; while the same circumstances would not prevent the establishment of a stream of Aether. The transparency of the hydrophane is increased by the wetting, and it is evident that the interposition of the water between the particles, which favors the propagation of the luminous vibrations, must on the contrary be a little more an obstacle to the establishment of a stream of Aether; which demonstrates the great difference that exists between these two kinds of movements.

The opacity of the earth is therefore not a sufficient reason to deny the existence of a stream of Aether interpenetrating molecules, and we can suppose it to be porous enough for which it communicates to this fluid only a very little part of his movement.

With the aid of this hypothesis, the phenomenon of aberration is as easily conceived in the theory of undulations as in that of emission; for it results from the displacement of the telescope while the light traverses it: now, according to this hypothesis, the light waves not participating substantially "to the movement of the telescope, which I suppose directed to the true place of the star, the image of this star is behind the thread placed at the focus of the eyepiece of an amount equal to that which traverses the earth during the light goes through the telescope."

This latter is exactly the view of *Theoria motus corporum coelestium*, art. 118; it gives the great advantage of showing that the aberration of the refractive fluid of the eye does not depend on using an instrument with a crosshair.

"It is a matter of explaining now," it’s called then, "in the same hypothesis, how the apparent refraction does not vary with the direction of the light rays in relation to the earthly movement."

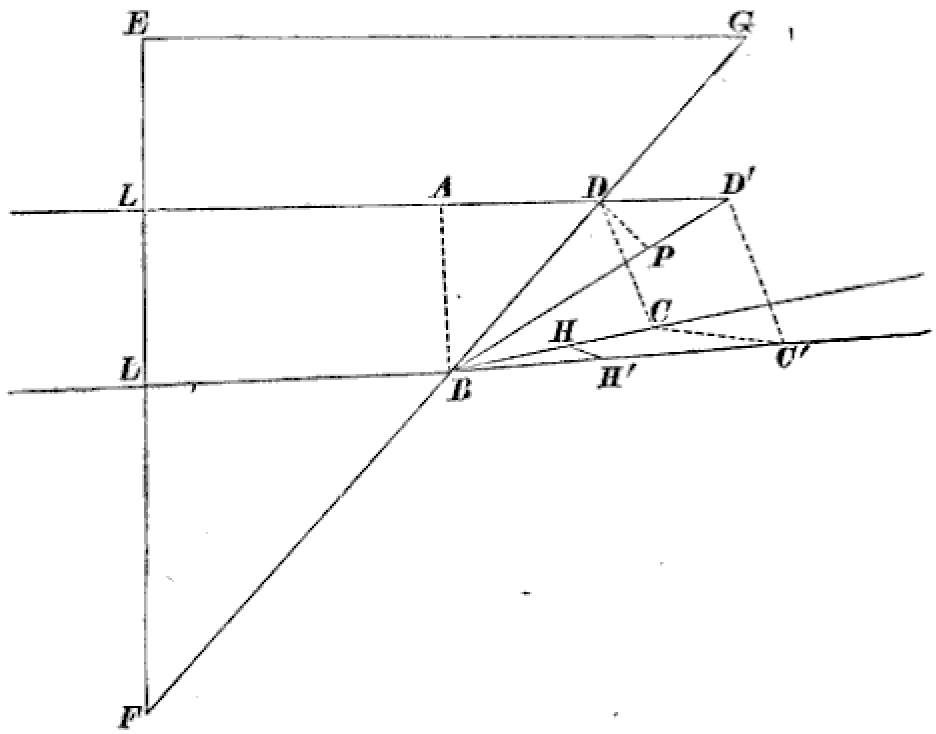

Fig. 1.

"Let EFG, Fig. 1, a prism whose side EF is supposed perpendicular to both the ecliptic and the incident rays, which are thus in the direction of the terrestrial movement: if it can influence their refraction, it is the case where this influence must be the most sensitive. I suppose they move in the same direction as the prism."

"The rays, being perpendicular to the surface of entry, do not experience any refraction on this side of the prism, and one has to consider only the effect produced by the second surface. Let LD and LB be two of these rays which meet the exit surface at the points D and B. Let BC be the direction taken by the ray LB when leaving the prism, in the case where this prism is stationary. If from point D a perpendicular is lowered on the emergent ray, and by point B, BA is led perpendicularly to the incidents; the light must traverse AD at the same moment as BC: this is the law which determines the direction of the refracted wave DC. But the prism being driven by the earth movement, while the light travels through the interval AD, the point D moves; which, increasing the difference of the paths traversed in the glass by the two rays LD and LB, must change the angle of refraction. FG representing the position of the emergence surface, when the incident wave arrived at A B, D' is the point where the radius AD attains this surface and leaves the prism. Let BC' be the new direction of refracted rays. The perpendicular D'C' will be that of the emergent wave, which must satisfy the general condition that AD' is traversed by light at the same time as BC'. But to determine the ratios of length of these two intervals, it is necessary to calculate the variation which the movement of the prism brings in the speed of the light waves which traverse it.

If this prism carried along with it all the Aether that it contains, the whole medium that serves as a vehicle for the waves thus sharing the terrestrial movement, the speed of the light waves would be that which they should have in the medium supposedly immobile, increased the speed of the earth. But the case in question is more complicated; it is only a part of this environment which is carried by our globe, which constitutes the excess of its density on the surrounding Aether. The analogy indicates that when only a part of the medium is moving, the speed of wave propagation should be increased only by the speed of the center of gravity of the system."

It is certainly true that if we have a right at all with Fresnel to accept means of greater or lesser optical density, the moving optically denser

Means its greater tightness must be preserved in some way. If we assume no hypotheses about metaphysical probability, we can imagine that the visually denser body carries with it all the Aether contained in it. It would then, in the place of the space which he leaves in his movement, create a complete emptiness, whereas at the place in which the body enters, all the Aether previously situated there would have to be displaced. On the other hand, suppose that the Aether contained in the body does not take part in the movement at all, then a surplus would arise in the space left every time; on the other hand, at the newly occupied place, not so much Aether would be as the body needs as a more visually dense one. In both hypotheses, it would require a second movement of the Aether to establish the normal state, and therefore metaphysically far less likely than the assumption that every optically denser body carries with it only that excess of Aether to which it owes its greater density. This is the hypothesis that Fresnel puts forward and discusses further at once. However, much we must agree with this assumption, which is supported by certain very ingenious experiments by Fizeau, so little, in contrast to it, is it possible for us to recognize that this translatory movement has an influence on the principles of wave theory to exercise the phenomenon of aberration. The reasoning of this view of the author can be found in the following sections; but the essence of this dissenting opinion can be briefly stated that Arago's experiment is also explained by any other assumption about the translation of the Aether, as long as it does not cause any other change in the degree of tightness than that caused by the partition. Leakage changes, however, would cause new partitions and then gain influence.

Now let us return to the development of Fresnel, whose order of thought we have already anticipated in the preceding.

“This principle is evident for the case where the moving part is half the middle; for, by relating the movement of the system to its center of gravity, considered for a moment as fixed, its two halves move away from each other with equal velocity and in opposite directions; it follows that the waves must be delayed in one direction as much as accelerated in the other, and that they have only the ordinary velocity of propagation relative to the center of gravity, or, which amounts to the same, that they share his movement. If the moving part was the quarter, the eighth, the sixteenth, and so on. in the middle it would be easy to show that the velocity to be added to that of propagation of the waves is the fourth, the eighth, the sixteenth, etc. from that of the moving part, or even the speed of the center of gravity, and it is clear that the theorem being true for all these particular cases, must be in general.

This being done, the prismatic medium being in tension equilibrium with the surrounding Aether (I suppose, for simplicity, that the experiment is done in a vacuum), we can consider the delay of the light in the prism when is motionless, as resulting only from a greater density; which gives the means of determining the density ratio of the two media; for it is known that it must be the inverse of that of the squares of the propagation velocities of the waves. Let d and the wavelengths of the light in the surrounding Aether and in the prism, Δ and Δ’ be the densities of these two media; we have the proportion: $d^2 : d'^2 :: \Delta' : \Delta$; from where $\Delta' = \Delta \cdot \frac{d^2}{d'^2}$, and therefore $\Delta' - \Delta = \Delta(\frac{d^2 - d'^2}{d'^2})$. Such and the density of the moving part of the prismatic medium. If we represent the space traveled by the earth during the duration of a luminous oscillation, the displacement of the center of gravity of this medium during the same interval of time, which I take for unity, or the speed of this center of gravity to:

$$t \cdot \left(\frac{d^2 - d'^2}{d^2}\right).$$

Therefore, the waving length of in the prism carried off by the earth will be equal to $d' + t\left(\frac{d^2 - d'^2}{d^2}\right)$.

By calculating, with the help of this expression, the space AD' (Fig. 1) traversed by the ray AD before its exit from the prism, one can easily determine the direction of the refracted ray BC'. If we compare it to that of the same radius BC, in the case where the prism is stationary, we find for the sinus of the angle CBC', neglecting, because of the smallness of t, all the terms multiplied by its square and the higher powers, the expression:

$$\frac{t}{d'} sin.\, i \cos.\, i - \frac{t}{dd'} \cdot sin.\, i \sqrt{d'^2 - \mathrm{d}^2 \sin.^2 i}$$

where *i* represents the angle of incidence ABD.

I suppose that, by any point H of the radius BC, we lead a line HH' parallel to the ecliptic, and equal to the space traveled by the earth during the time used by the light to go from B to H'; the optical axis of the telescope with which one observes the target being directed according to BH, the light must follow the direction BH 'to arrive in H' at the same time as the wire of the telescope trained in the terrestrial movement: gold, the line BH' coincides precisely with the direction BC' of the ray refracted by the prism carried away in the same movement; because, for the value of sin HBH', we find the expression:

$$\frac{t}{d'} sin.\, i \cos.\, i - \frac{t}{dd'} \cdot sin.\, i \sqrt{d'^2 - \mathrm{d}^2 \sin.\, i}$$

Thus, one must place the telescope in the same direction as if the prism were motionless; whence it follows that the motion of our globe must have no sensible influence on apparent refraction, even when it is supposed that it only communicates to the Aether a very small part of its velocity. It can be ascertained by a very simple calculation that it must be the same for reflection. Thus, this hypothesis, which gives a satisfactory explanation of the aberration, does not lead to any consequences contrary to the observed facts."

Do not overlook that Fresnel says: “whence it follows that motion of our globe must have no sensible influence on *apparent* refraction, etc.” Arago, on the other hand, as his words clearly show, expresses the influence of the Earth's motion on the *real* direction of the refracted ray as denied by the experiment.

Fresnel expresses his almost diametrically opposed opinion in the expression of apparent refraction.

The last section of the important letter, to which we have little to say, is:

“I will end this letter with an application of the same theory of experiment proposed by Boscovich, consisting in observing the phenomenon of aberration with glasses filled with water, or with another fluid much more refractive than air, for ensure that the direction in which a star is seen may vary because of the change that the liquid brings in the march of light. I will first remark that it is useless to complicate the result that we seek by aberration, and that we may as well determine it by aiming at an earthly object as a star. Here, it seems to me, is the simplest and most convenient way to experience.

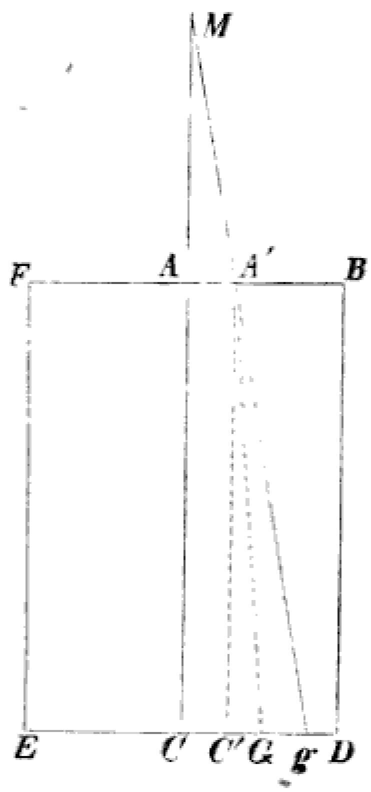

Fig. 2.

Having attached to the telescope itself, or rather to the FB DE microscope (Fig. 2), the focal point M, situated in the prolongation of its optical axis CA, we would direct this system perpendicularly to the ecliptic, and after having made the observation in a sense, we would return it end to end, and we would make the observation in the opposite direction. If the terrestrial movement moved the image of the point M in relation to the wire, we would see it, in this way, sometimes to the right and sometimes to the left of the thread.

In the system of the show, it is clear, as Wilson has already remarked, that the earthly movement must not change the appearances of the phenomenon. Indeed, it follows from this movement that the ray starting from M must take to pass through the center of the objective, a direction MA' such that the space AA' is traversed by the globe in the same time interval that the light uses to travel MA', or MA (because of the smallness of the speed of the earth relative to that of light). Representing by v the speed of light in the air, and by t that of the earth, we thus have: MA: AA' :: v: t, or $\frac{AA'}{AN} = \frac{t}{v}$; it is the sin of incidence. v' being the speed of light in the denser medium contained in the telescope, the sinus of the angle of refraction CA'G will be equal to $\frac{t}{v'}$; we will therefore have $C'G = A'C' \cdot \frac{t}{v'}$; from which we draw the proportion: C'G: A'C' :: t: v'. As a result, the eyepiece wire C' placed in the optical axis of the telescope will arrive at G along with the light ray which has passed through the center of the lens.

The theory of undulations leads to the same result. I suppose, for simplicity, that the microscope is in a vacuum. d and being the velocities of the light in the vacuum and in the medium contained in the telescope, we find, for the sinus of the angle of incidence AMA', $\frac{t}{d}$, and for that of the refraction angle C'A'G, $\frac{td'}{d^2}$. Thus, independently of the displacement of the waves in the direction of the terrestrial movement, $C'G = A'C' \cdot \frac{td'}{d^2}$. But the speed with which these waves are driven by the moving part of the medium in which they propagate is equal to $t \cdot (\frac{d^2 - d'^2}{d^2})$; therefore, their total displacement Gg, during the time they use to cross the telescope, is equal to:

$$\frac{A'C' \cdot t}{d'} \cdot \left(\frac{d^2 - d'^2}{d^2}\right);$$

so:

$$C'g = A'C' \cdot t \cdot \left(\frac{d'}{d^2} + \frac{d^2 - d'^2}{d'd^2}\right) = A'C' \cdot t \cdot \left(\frac{d^2}{d'd^2}\right) = A'C' \cdot \frac{t}{d'}$$

We thus have the proportion: C'g: A'C ':: t: d'; consequently the image of the point M will arrive in *g*, at the same time as the wire of the micrometer. Thus, the appearances of the phenomenon must always remain the memes, regardless of the way in which one turns this instrument. Although this experiment has not yet been made, I have no doubt that it confirms this consequence, which is also deduced from the system of emission and that of the undulations."

The experiment projected by Boscovich, with some insignificant but advantageous modifications, such as substitution of chemically pure turpentine oil for water, carried out by the author with all caution, has not yet confirmed Fresnel's latter conjecture. On the contrary, this experiment, like other experiences collected by Fresnel, seems to indicate that the aberration constant depends on the means by which the telescope is constructed.

VI.

Reason for the proposition that for the position of the mirrored or refracted ray, only those translatory movements of the Aether which change the partition of the agent are of influence.

In discussing Fresnel's letter, the author was not allowed to withhold his own dissenting opinion if he did not want to renounce the purpose of this writing. So much as one may consider it probable that the entrainment of the Aether proceeds according to the hypothesis made by Fresnel, so little will one fail to appreciate the strength of the following reasons, which show that such an abstraction of direction the rays still must remain without influence. Imagine what the wave theory understands by the direction of the ray: the normal to the wave surface. This surface is always defined as the surface which connects the particles of equal phase, and in our case, because of the extraordinarily great distance of the light source, is a plane. The direction of a ray is always determined by the Aether particles of the same phase, and the generation of a ray of definite direction is to be regarded as the total effect of all Aether particles lying in the region of wave propagation. But since this total effect as such is independent of the place occupied by the individual branches of the Aether or the individuals, it is independent of the translatory motion of the particles. In order to fix the concepts, we choose the consideration of a very specific case. A diopter is in the length of its limited measuring axis, i.e., between visor opening and reticle, filled with a strong refractive medium of refractive index n. A ray falls in its true direction together with this axis, to which in this concrete case the motion of the earth should be perpendicular. Thus, for the ray, the maximum of the aberration would be, and therefore, if, in Fresnel's view, the aberration should remain the usual α, instead of $n^2\alpha$, as a result of the translational motion of the Aether, then this effect of the translatory motion on the direction of the Beam to be the largest. But in this case, there is obviously no such effect at all; for as the particles of the Aether are transferred here in the wave-plane itself, another, which has the same phase, moves in the wave-plane to the place which an Aethereal particle has left with the wave-phase which is in common with the wave-plane; the phase is varied everywhere in the wave-plane by the size zero, and therefore neither the wave-plane nor the direction of the ray has been changed. The beam thus passes through the axis of the diopter in the same direction, and (since there is no translatory motion in the direction considered in the considered case) also with the same speed as if the translatory motion of the Aether were not present at all, and only the crosshairs were moved. One must therefore by no means expect to see the aberration constant reduced to ordinary value despite the more refractory medium.

The component falling in the direction of the beam is indifferent to the aberration. But in relation to these it may be remarked that, if it were present, and a change in phase occurred as a result of the translational motion, it would not be zero, but constant, everywhere in the wave-plane. For the direction of the ray, this would be as indifferent as the insertion of a plane-parallel-glass would be, or as it is the epoch for which the light source has begun with lights. Whatever direction the motion of the earth may have, and in what proportion the Aether may take part in it, such an appearance as the direction of the ray will not be affected by it. Only such movements can influence the changes in tightness or, like the movement of the partition, give a different position to the interface between two different leaks. Since the density changes can be counted under the category changes of the partitions, we may say so briefly *that the direction of the ray, independently of the translatory motion of the Aether, is varied only by the movement of the partitions of the medium.*

This principle, which hitherto has been laid down by no one, which seems to follow with necessity from the nature of the wave-theory, gives an understanding of a series of experiences which stood abruptly next to one another, and seems all the difficulties mentioned in the beginning of Fresnel's letter remove. We have already emphasized that it can also be regarded as an empirical proposition derived from Arago's experiments; we will get to know other experiences in the following sections.

But for the important principle still an example

To remember, we remember the well-known origin of the rainbow. Here, too, we have, as far as the position of the center of the rainbow is concerned, a total effect of all the raindrops, which fall in the extension of the arch. It is easy to see that the location of the center is determined only by the direction of the rays of the sun, whatever the speed of the raindrops themselves. If, for example, the rain suddenly ceased at one point in the arch, and it was just as sudden at one of the very distant parts, this would be mechanically equal to an extraordinarily large movement of the raindrops. But still only the intensity ratios would be changed; the position of the center of the arch, dependent only on the direction of the sun's rays refracted in the drops, reflected in this process into individual colors, that is, an overall effect independent of the location of the individual drops, will certainly not be changed. For it is evident that an aggregate effect, which is independent of the place, is also independent of what produces a change of place, of movement. The same thing that could be said here of the total effect of the raindrops can apparently also be asserted by the total effect of the Aether particles, consisting in the production of wave planes.

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VII.

Dependence of the aberration constant of a telescope on the glass thickness of the objective.

The same thing that applies to a diopter filled with a strongly refracting medium will also find application to such a modified telescope. For each of the rays, which is collected by the objective and refracted by the foci, follows the same direction as if the Aether in the telescope were free of translation through the earth, the average of all these rays, the location of the image, will likewise not be affected by translation. Fresnel sees this image as a real object, as is often done in dioptric investigations and generally allowed. In this case, however, this view leads us crazy; a real object would, however, be able to be brought into motion by the earth in a certain proportion, but not a virtual object or a mere picture, especially since the role of producing it does not always fall to the same but always to other and other parts of the Aether.

Therefore, we can not only expect that a column of fluid, mounted in a telescope, will greatly increase the aberration of the telescope; even the effect of the glass thickness of the objective, in which the light waves propagate more slowly than in the cosmos, will no longer allow us to regard the aberration constant as independent of the instrument. We now want to investigate this influence for a simple lens.

Let d be the average value for the thickness of the lens,
f whose focal length,
D is the distance of the threads from the inner surface of the lens,
a the distance of the second principal point from the inner vertex of the lens,
r the radius of curvature of the external,
r' that of the inner surface of the lens, both positively calculated, if the surface is convex against the object,
g is the velocity of the earth in the component perpendicular to the ray,
v the speed of light in world space,
v' the speed in the glass,
n the refractive index of the glass variety.

In Figure 3, let H and H' be the two principal points, F the place where the image is formed, F' the place occupied by the crosshairs when the rays falling in the axis of the lens reach point F. The light needed

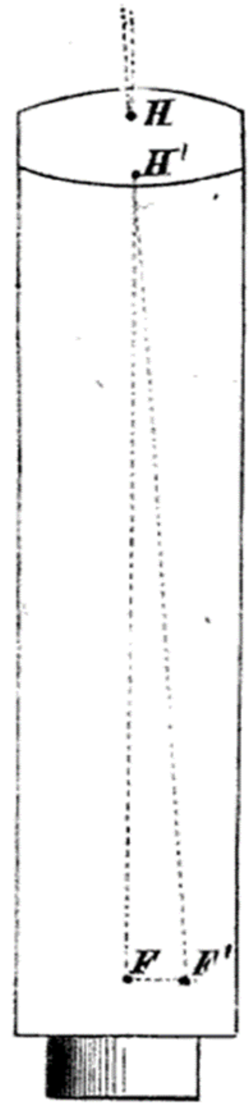


Fig. 3.

the time $\frac{d}{v'}$ to go through the glass thickness of the objective, and

the time $\frac{D}{v}$ for passing through the inner empty space between lens and reticle.

So, it is at all $\frac{D}{v} + \frac{d}{v'}$ the time left to the crosshair to make its motion FF', which is the cause of the aberration, and thus

$$FF' = g \cdot \left(\frac{D}{v} + \frac{d}{v'}\right).$$

But the aberration is the angle F H' F' at which we the tangent may be set equal to the bow. We therefore receive for the aberration in this case

$$F\ H'F' = \frac{g\left(\frac{D}{v} + \frac{d}{v'}\right)}{D + a}.$$

Considering that $v' = \frac{v}{n}$ we also set the Delambre aberration α for $\frac{g}{v}$ and for a its expression known from Gauss dioptric investigations

$$\frac{a}{d} = \frac{r'}{n(r' - r) + (n - 1)d}$$

For example, we still understood $\Delta\alpha$ to be the increase in the aberration constant caused by the objective thickness:

$$F\ H'F' = \ \alpha + \Delta\alpha = ((\frac{D + nd}{r'd}) \cdot \alpha)/(D +$$

If we now develop, neglecting the square and the higher powers, the very small quantities $\frac{d}{D}$ and $\frac{d}{r'}$,

whereby in the awful expression for the small quantity $\Delta\alpha$ we can simply put *f* for *D*, one obtains:

I. . . . . $\Delta\alpha = \left\{n^2 - \frac{r'}{r'-r}\right\}\frac{d}{f} \cdot \frac{\alpha}{n}$

a formula by which to calculate the effect of each lens, knowing the curvature radius and refractive index. α or the value of the aberration constant which follows from the velocity of light in world space, is, as is known, equal to 20",255, according to Delambre.

The Formula I. can also be used for an achromatic objective; for without any noticeable error one can assume that the total effect of the lenses of such an object is the sum of the effects of the individual lenses. However, for this case one must remember that *f* no longer imagines the focal length of the single lens, but the equivalent or resultant focal length of the objective, since in the previous development *D* and the *f* that closely matches it mean essentially the removal of the filaments from the objective.

Let us also consider the case of a column of index *n*, of length *d* and of parallel planes limited in a telescope of the focal length *f* turned on. The greater optical density of the medium of the column will make it necessary to remove the threads from the objective if the image is still to be formed in the filament plane as required for observation. According to dioptric theorems, this necessary extension of the telescope is the same for the mutual distance of the two main points of the column, that is, since the radii of curvature of the end faces of the pillar, to which the dioptric prescriptions for lenses are applied, are infinite

$$\left(1-\frac{1}{n}\right)d\,.$$

The effect of the objective, as already known, set aside here, the ray becomes the time

$$\frac{d}{v'}+\frac{f+\left(1-\frac{1}{n}\right)d-d}{v}$$

or

$$\frac{d}{v'}-\frac{d}{nv}+\frac{f}{v}$$

or finally

$$\frac{nd}{v}-\frac{d}{nv}+\frac{f}{v}$$

necessary to reach the crosshairs. Because of the earth's movement, this makes the movement during that

$$\frac{g}{v}\left(nd-\frac{d}{n}+f\right).$$

In order to deduce the angular value corresponding to this linear displacement, it is only necessary to notice that the insertion of the column does not change the reduction from the linear value to the angle value *h*; for the factor of reduction remains the same as long as the convergence of the rays remains the same. It is easy to see that the rays after their passage through the column have the same motion as before. Therefore, each thread interval has the same angular value as if the column had not been inserted and the threads had their usual distance from the lens. Thus, we find the arc corresponding to the above displacement, that is, H. the aberration at turned column, dividing by *f*, and it becomes in this case

$$\alpha + \Delta\alpha = \frac{g}{v}\left(1 + \frac{nd}{f} - \frac{d}{nf}\right) = \alpha\left(1 + \frac{nd}{f} - \frac{d}{nf}\right)$$

or

II. . . . . . $\Delta\alpha = (n^2 - 1) \cdot \frac{d}{f} \cdot \frac{\alpha}{n}$.

In order to show the perfect agreement of this Formula II with what we have found for the aberration of a telescope or diopter completely filled with a denser medium, let us now deduce this special case from the generality of Equation II.

Since *f* represents the focal length of the objective in the usual sense, the distance of the filaments from the objective is, when the telescope is filled with a denser medium of index *n*, by the amount

$$d \cdot \left(1 - \frac{1}{n}\right)$$

to magnify. So, we have, since the whole space between objective and threads should be filled

$$f + d\left(1 - \frac{1}{n}\right) = d$$

so

$$d = nf.$$

Equation II, therefore, provides for this special case

$$\Delta\alpha = (n^2 - 1)\,\alpha$$

or the aberration constant which then belongs to the apparatus

$$\alpha + \Delta\alpha = n^2\alpha,$$

exactly coinciding with the earlier results. Formula II. is therefore valid for columns of any length; she does not merely find her practical application if, as the author has done, the Boscovich-suggested fundamental attempt to compare theory and experience, will also serve to ascertain the magnification of the aberration constant which accompanies this in every telescope broken axis mounted prism for total reflection. The path that must be traveled by the beam in the prism can be very close to the channel.

leg be equated to the base, and this size is to substitute for d in formula II. To show just how significant the prism can affect the aberration, the bill for a small T. L. Ertel Transit instrument of the Göttingen Observatory may already find a place here. At the 21st line aperture and 18-inch focal length of the objective, the eligible dimension of the prism is close to 10 lines. The refractive index will be very close to 1.60. Thereafter, in this example II.

$$\Delta\alpha = (2{,}56 - 1) \cdot \frac{10}{216} \cdot \frac{20{,}255}{1{,}6} = 0'', 91\ arcseconds$$

It will certainly be admitted that an expected increase in the aberration constant of 0",91 or 0",06 in time is a circumstance worthy of note, especially on occasion of sharp length determinations by the telegraph, in case one does at the stations to be compared, instruments of very unequal construction should have been used.

VIII

Difference between Delambre's and Struve's aberration constants, derived from the theory.

It is known that the more recent determinations of the aberration constant, among others that of Struve, give this constant at near 0”,20 greater than that found from Delambre's investigation of the eclipses of the Jupiter’s first satellite in accordance with Römer's method. The author has already expressed his view in No. 1583 of the Astronomical News that this difference, despite Fresnel's hypothesis, can be explained by the objective effect, on which occasion he already indicated the basic features of his aberration theory to the view that this difference is brought about by the slower reproduction taking place in the lens of the objective, and that, as far as the side of experience is concerned, it is possible to know more closely.

But if this proof is to be of general importance for the theory of aberration, we must have indications that the difference in question is very probably due not to errors of observation. As regards the aberration obtained from fixed stars, there is the extremely slight probable error of the provisions of Struve, Peters, Lundahl, v. Chr. Lindenau, Richardson, some guarantee that none of these provisions will be flawed at 0 ",20, despite the smallness of this size. We want to cite the provisions that seem the most reliable to us, from them, considering the probable failure to derive the aberration constant, which we may attribute to a medium-sized telescope.

Aberration for v. Lindenau	20,4486	Probable error	=	± 0",0318
Aberration for Struve	20,4451	Probable error	=	± 0",0111
Aberration for Peters	20,4255	Probable error	=	± 0",0175
Aberration for Lundahl	20,5508	Probable error	=	± 0",0433
Richardson (Troughton's Circle)	20,505	Probable error	=	± 0",043
Richardson (Jones Circle)	20,502	Probable error	=	± 0",049

With respect to the probable errors, one obtains from them the constant of aberration for fixed stars

20",4489 with the probable error of ± 0",0122.

This value is as good as completely consistent with Struve's aberration, which has long been used for such reductions. We must note, however, that according to our theory each telescope has a slightly different aberration, that these variations may amount to a few hundredths of arc seconds by a certain average. The number just found can therefore only be cited as the most reliable average for now, but only for straight telescopes, for broken ones, one must assume the aberration still considerably greater, as has already been shown above.

Let us now turn to the Constant of Delambre, which is known to be 20",255 so 0",192 smaller, and the

The assumption is that the light takes 493.2 seconds to go through the radius of the earth's orbit. The difference between 0 and 192 between the two types of determinations may at first glance seem to us a size which is difficult to guarantee even in the case of fine means. However, we must take into account that it corresponds to a change of 4.58 time seconds in the light time determined by Delambre. Although, unfortunately, Delambre has not communicated his accounts extensively in any way, which at the time was much less common than today, though we know just as little, what were the instruments of the observations of the eclipses of the first Jupiter satellite of 1660 to 1802, an error of such magnitude is not very probable in such an application of the Roman method. For the disappearance of this satellite in the shadow, or its emergence from the shadows, has a duration of only a few seconds, and is for every reasonably useful telescope, i.e., for such a one, which can show the satellite even in a moderate approach to the disk of Jupiter, a pronounced phenomenon. Also, the imperfections in the theory of the system of Jupiter may have had very little effect on the time of light found, since the observations span over a century. But the strongest argument in favor of Delambre's determination is that Delambre did it twice, the first time using 500 eclipses of the first satellite, the second time from more than 1,000 observations. The result of both investigations was almost identical about the time of light. In his panels Delambre makes the following statement:

“I determined the factor 493",2 by more than a thousand eclipses of the first satellite. I had employed only five hundred in this research, in my first Tables; but these new calculations have not given any sensible correction, and my new Tables of the equation of light are” the same as the first ones; I only changed the distribution a bit."

It therefore does not appear justified to eliminate the correspondence between the two main types of determination and their results of the Struve and Delambre constants, which is lacking in the conventional theory of aberration, by assuming an error of the required magnitude in the latter. In general, it is always very unfortunate to explain unexpected differences due to observation errors that might have occurred; One should resort to this interpretation only in the utmost emergency. But such a case is certainly not the case here; for only according to the old theory is there a difference between Delambre and Struve; after the new one both are in the most perfect agreement, as we now wish to show.

At the end we need only apply the formula I of the previous section to a telescope of medium dimensions. Above all we need an average value of the ratio $\frac{d}{f}$, or the glass thickness of the objective to the focal length. In order to obtain such, author has made measurements on five telescopes of the Göttingen Observatory, whose focal lengths are between 4 and 6 Paris feet (more precisely, the largest of the focal lengths is 2020 millimeters). The ratio varies between $\frac{1}{103.4}$ and $\frac{1}{131.0}$. It resulted for the individual telescope:

at the 6-foot Merz. . . . . . $\frac{d}{f} = \frac{1}{103,4}$ = 0,00967,

at the 4-foot Heliometer . . . . . . $\frac{d}{f} = \frac{1}{104,0}$ = 0,00962,

at the 5-foot Tubus von Steinheit . . . . . . $\frac{d}{f} = \frac{1}{113.8}$ = 0,00879,

at the 6-foot Transit-Instrument . . . . . . $\frac{d}{f} = \frac{1}{125.9}$ = 0,00772,

at the 5-foot Meridian-Circle-Telescope . . . . . . $\frac{d}{f} = \frac{1}{131.0}$ = 0,00764.

The mean of these numbers will by no means be compared with the average value of other such telescopes, as may be useful for aberration studies, may be significantly different. Instruments of smaller dimensions, which usually also have a somewhat more significant glass thickness, are not considered here and have therefore not been considered in the measurements. It now turns out to be mean

$$\frac{d}{f} = 0,00869$$

In relation to the distribution of this thickness on the crown glass and on the flint glass lens, the average glass thickness of both lenses can be set the same, as at least in Fraunhofer's objectives. A slight difference in the relationship, as the reader will easily recognize, is almost unnoticeable in the resulting effect of the two lenses, in that what the flint glass lens lacks in thickness benefits the crown glass lens, and vice versa each of the two lenses

$$\frac{d}{f} = 0,00434$$

Since it is forbidden to consider obvious considerations of taking apart the objective of the above achromats and examining their curvature, the author chooses two combinations of Prechtl's Practical Dioptric, close to four-footed telescopes, to extract the remaining material.

FIRST COMBINATION

Radius of the front surface of the crown glass lens = 31,519 Par. inches

Radius of the back surface of the crown glass lens = 10,212 Par. inches

Radius of the front surface of the flint glass lens = 10,396 Par. inches

Radius of the rear surface of the flint glass lens = 55.476 Par. inches

Refractive index for crown glass = 1.528

Brechungs-Index für Flintglas = 1,616

So, we have:

Δα for the crown glass lens = $\left(1{,}528^2 - \frac{10{,}212}{41{,}722}\right) * 0{,}00434 * \frac{20{,}255}{1{,}528} = 0``, 1202$

Δα for the flint glass lens = $\left(1{,}616^2 - \frac{55{,}476}{45{,}080}\right) * 0{,}00434 * \frac{20{,}255}{1{,}616} = 0``, 0751$

General effect . . . . = 0“,1953

With this combination you would have the following aberration:

20",255 + 0",1953=20", 4503

SECOND COMBINATION.

Radius of the front surface of the crown glass lens = 41.800 Paris inches

Radius of the back surface of the crown glass lens = 16.638 Paris inches

Radius of the front surface of the flint glass lens = 16,972 Paris inches

Radius of the rear surface of the flint glass lens = 75.653 Paris inches

Refractive indices as before

Here according to Formula I:

Δα for the crown glass lens = $\left(1{,}528^2 - \frac{16{,}638}{58{,}438}\right) * 0{,}00434 * \frac{20{,}255}{1{,}528} = 0“, 1179$

Δα for the flint glass lens = $\left(1{,}616^2 - \frac{75{,}653}{58{,}681}\right) * 0{,}00434 * \frac{20{,}255}{1{,}616} = 0“, 0719$

Overall effect . . . . = 0“,1898

With this combination you would get the aberration constant

20",255 + 0“,1898 = 20“,4448

Is obtained.

It can be seen from these examples that the Delambre Constant agrees perfectly with the Struve's if one applies the effect of the objective lens only to the former, according to this new theory.

Some time ago, when the author first stated in a motivated way, that Fresnel's hypotheses about the abstracting of the Aether in the remedies left untouched the effect of the means inside a telescope, and that, therefore, the difference between Struve's and Delambre's aberration was due to such objective action In his estimate, the influence of the radii of curvature of the lenses was neglected by him. This latter consists mainly in the displacement of the second principal point, as the derivation of formula I reveals; he can become very noticeable.

ATTACHMENT

Execution of the experiment proposed by Boscovich of the observation of stars by a column with liquid, which is mounted inside a telescope.

The first version of Boscovich's experiment must be referred to in the appendix to the preceding treatise, since it is only the beginning of a series of experiments intended to study aberration and to give a more complete examination of the theory. The apparatus produced for this purpose, of which a drawing and a brief description are supplied here, is to be attached to a small transit instrument of Ertel, which is in the possession of the Göttingen Observatory; However, this instrument has been used by the author himself and by other astronomers for telegraphic length determinations, which did not permit postponement, for almost a year, and only during a brief interruption of a few days in these works was it permitted Boscovich's attempt to hire at least once. With the arrangement made, the theory demanded such a significant increase in aberration that the expected uncertainties of observation could not greatly distort the result, and that a single attempt of that kind would at least be either quite likely, or very likely unlikely to make.

With no slight tension regarding the result became so preliminary, and until the instrument quite this examination, adjusting the apparatus and putting it into use once. The result confirms to the author deductions, or rather, adds something significant in probability to what the comparison of the two aberration constants with the effect of the objectives taught. Incidentally, it goes without saying that the one-off appointment of such a fundamental attempt cannot be enough to form a definitive judgment.

Here follows the description of the, on the workshop of Dr. Ing. Meyerstein, apparatus which has proved itself very well in the essential points, and which will therefore be retained by the author for the continuation of the experiments.

Fig. 4 shows a broken-axis transit instrument in which a glass cylinder closed with a liquid and filled with a liquid, closed by the plane-parallel glasses p and p', is in contact with this liquid column, which communicates with the side of the telescope The auxiliary tube, which extends beyond the column in length, serves both to fill the column and to absorb the bubbles, which is evidently necessary, for if the column were not always completely filled and the fluid had a free surface, one would The plane-parallel plates p and p' are fastened by a screw-threaded metal socket, as shown in the drawing, near the two ends of the column the socket is replaced by the screws c and c', but in different ways at both points, at c the socket is in one double ring, so that compass suspension can be made and the column's axis can be moved freely, while the point of the axis located at the center of the rings remains at rest. In this device, the axis can be moved horizontally and vertically by the correcting screws at c', without creating a damaging tension in the socket. Thus, the axis, or the normals to the plates p and p' can be made to closely match the objective.

The lens of the telescope is in a special,

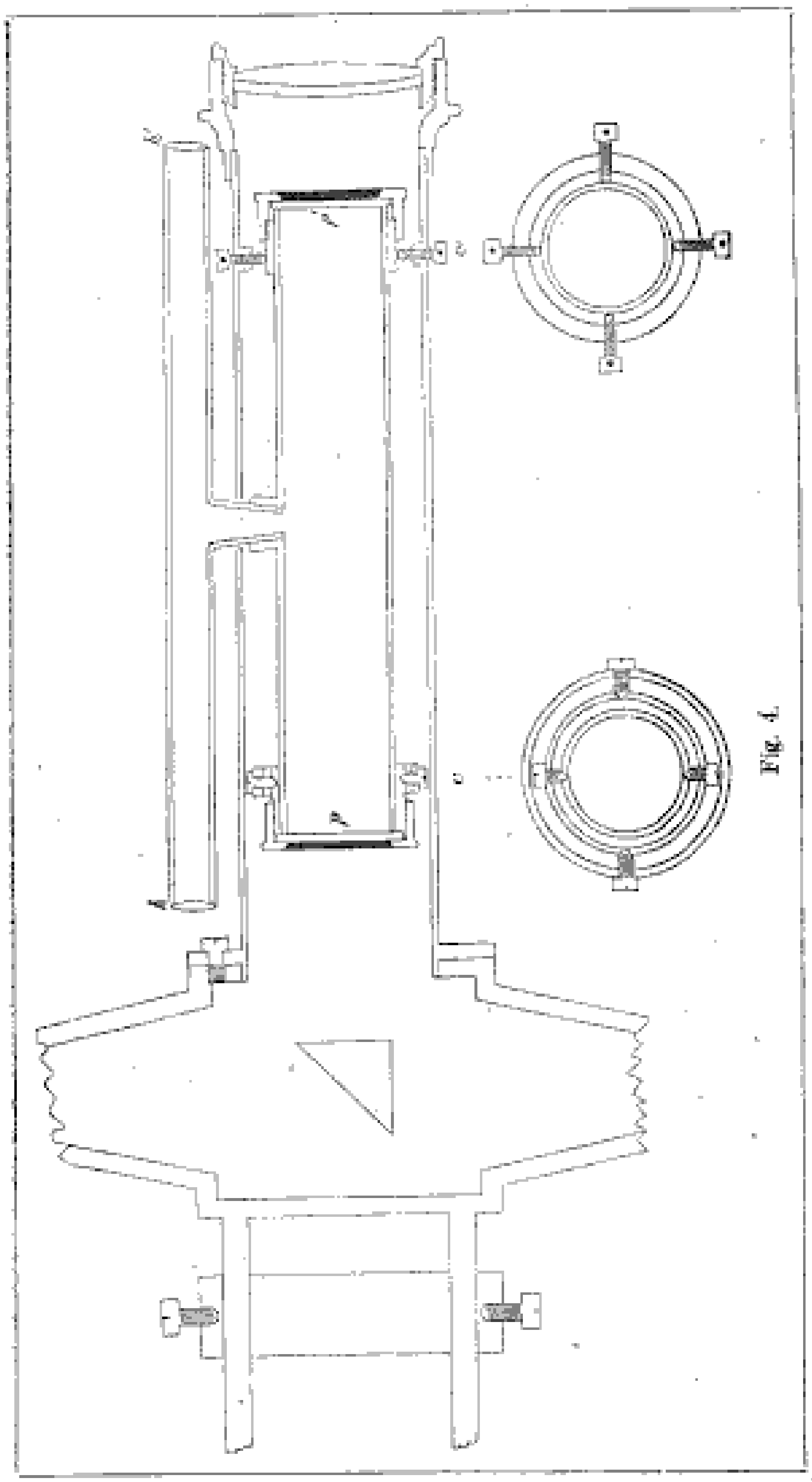


Fig. 4.

rather long and very short and secure guidance, so that, depending on the refractive index of the liquid to be applied, the lens can be removed from the filaments by the quantity $d\,(1\ -\frac{1}{n})$ mentioned in the seventh paragraph. At the eyepiece end, there was not enough room for maneuver; the arrangement made here has also proved to be satisfactory, since a variability in the collimation of the telescope axis, perhaps to be provided for it, was quite unnoticeable.

The usual parts of a transit-instrument, for instance the mounting of the prism is known to than that they need to be included here and in the drawing.

It is very natural to substitute, for the water proposed by Boscovich, which has only a moderate refractive index, the carbon disulfide which is distinguished by the power of its refracting power. In fact, a telescope filled with carbon disulphide all its length would have to increase the aberration to two and three times its usual amount, and therefore, at first glance, hardly any arrangement may seem more advantageous. On the other hand, he soon raises serious reservations, the most important of which is to draw attention to the strong dispersion of that liquid. Namely, the quantity $d\,(1\ -\frac{1}{n})$ on which the focus correction of the instrument depends is obviously not the same for all colors because it varies with the value of n. It would therefore, in order not to make this circumstance disturbing emerge, the length of the column must choose lower in carbon disulfide, as with other media, whereby the whole advantage would be lost again. However, one must take care of this before starting the experiment; It is possible, by the way, that in practice, this evil is not so much noticeable. For the present, chemically pure turpentine oil was preferred; this liquid is characterized by low color dispersion with very considerable refraction, therefore, all rays keep very close the same union width and it can even for a very long column will receive a very good, in every respect correct picture. In addition, the turpentine oil has a low specific gravity and an extremely high degree of transparency, which both come well here.

Instead of a liquid, glass has probably been proposed; but it is known that it is very difficult to produce a homogeneous glass column of some length, and certainly the experiment with glass would be extremely costly.

Incidentally, the arrangement of the experiment followed here is based on a very simple consideration. If one determines instruments modified by the intervention of a liquid column, observations of fixed stars, and the pace of a clock in the sun, then it becomes no longer possible with the instrument obtained by a common instrument on the same objects at least not when the modified instrument is based on the ordinary aberration constant.

The difference will be most pronounced when one observes the sun at noon and stars at midnight, because in the former the aberration is in the negative, in the latter in the positive maximum. Thus, a perfectly accurate clock will almost seem to precede twice the amount of aberration magnification, assuming the usual reduction; however, if the clock really does rush, then its advance is found to be greater than it actually is by the amount just indicated. Thus, a second observer, who determines the passage between the two epochs on a meridian instrument of ordinary institution, belongs to the employment of the experiment according to this method. In assuming this role, the assistant of the Göttingen Observatory, Mr. Borgen, observed in the experiments below the same objects on Reichenbach's meridian circle telescope, which the author at the same time was observing on the transit instrument with liquid column. The latter, with a telescope of 21 par. Lines aperture and 18 inches focal length, was at 50 times

Magnification suitable to give the state of the clock to a small fraction of a second, as had been shown at least in the length determinations. But in order to become almost completely independent of legitimate errors, only objects in the same parallel were compared, at noon the sun with all known precautions, at midnight stars in parallel with the sun, as on the day of the experiment β and δ Herculis. It seems that this arrangement does not concern the exact knowledge of the instrumental corrections, but only their possible changes, and that one is convinced that changes in the course of the clock, which one finds, do not change the composition of the instrument Owe origin. The changes in collimation error and azimuth could be tested and measured on a mire, and had shown a high degree of immutability earlier, as well as during the trial. The inclination of the horizontal axis of revolution was less constant, but not to the extent that the reliability of the observations would have suffered.

It is easy to see that in the case of the described method, in which absolute time determinations are dispensed with the modified instruments, one also becomes completely independent of all irregularities of the course, since the same objects are observed on both instruments. For this reason, it is equally valid whether the objects are well known in their Rectal ascension; i.e., fundamental stars are or not; every star is usable, which is clearly visible.

According to Dioptric principles, a column of eight inches in length could still be expected to have a perfectly good picture, as proved. Not only was the picture satisfactory in terms of sharpness, it was also surprising that, although the lens was dimmed down the column for the smaller diameter, except for about 15 par. Lines of aperture, δ Ursa Minor, in the institutions, for approximate orientation, minute without any difficulty could be observed. So great was the transparency the pillar that even the fine thread of the Mire was clearly visible. Afterwards, however, this transparency suffered a noticeable loss through a small, easily eliminable, evil state of the apparatus. In the adjustment of the column, the density of the end of the column had at least suffered to the extent that a very small quantity of the liquid had found an exit, and by temporarily forming a very fine precipitate on the plates closing the column made it difficult to observe weaker stars. This was already evident in δ Herculis, a star of the fourth magnitude, and later compelled to take the apparatus apart to thoroughly eliminate this defect.

We know of no error source in the given procedure, which could falsify the result. Everything will therefore depend on how exactly you see, d. H. how exactly one can observe the threads of entrance (the instrument has 16 threads, nearly symmetrical to an ideal middle thread), and further, which is the size by which the influence of the column of liquid is expressed. From the picture we have already said that it is quite good, and this corresponds to the agreement of the reductions on the middle thread, of which we here as a sample those of β Ursa Minor, a slowly going through the field circumpolar star, which was used for orientation, want to lead.

β Ursa Minor O. C.

$14^h\ 58^m\ 52^s{,}61$ time of day

52,63

53,08

52,41

52,75

52,56

53,62

52,67

53,38

52,48

53,22

52,91

53,03
51,86
53,07
53,16

Mean: $14^h\ 58^m\ 52^s,84$ time of day.

The largest deviation of a thread from the mean here is 0^s, 98 in the parallel of the star, so only about 1/4 second in the equator. Quite corresponding to the other culminations, such. As the two sun edges, which, like all passages, were obtained on all 16 threads.

The question of how great the influence of the liquid column must be, we can easily answer, at least very approximated, according to the Formula II of Section VII; The author is unable to determine the exact dimensions at this time, as the instrument is not available because of provisional use elsewhere.

It is close enough for this first comparison:

d	=	8	Paris Inches
f	=	18	Paris Inches
n	=	1,47	

So, the expected $\Delta\alpha$

$$= (1{,}47^2 - 1) \cdot \frac{8}{18} \cdot \left(\frac{20'', 255}{1{,}47}\right) = 7'', 098.$$

To these effects we can still add the glass prism rated at 0",91 (that of the lens is already in the yearbook Constant 20",1451). The magnification of the aberration constant will thus amount to

7",11 + 0",91 = 8",02.

We must now calculate how much this increase diminishes the right ascension of the Sun, which is magnified by the two comparative stars, β Herculis and δ Herculis, the former of which was just south of the parallel of the Sun and the other almost exactly as far north. The day of the observations was 1867, June 12. It can be calculated with Struve's aberration; the apparent right ascension of the named objects as follows:

Θ	*RA*	=	5^h	20^m	$42^s,70$
β Herculis			16	24	32,48
δ Herculis			17	9	36,48

The passages obtained at Reichenbach's meridian circles are to be compared with these places in order to have the course of the clock. On the other hand, according to known rules, we obtain the following terms, which had to be applied to the column of liquid, in order to give a course which agrees with that.

Θ	*RA*	=	5^h	20^m	$42^s,70$	-	$0^s,58$	=	5^h	20^m	$42^s,12$
β Herculis		=	16	24	32,48	+	0,55	=	16	24	33,03
δ Herculis		=	17	9	36,48	+	0,59	=	17	9	37,07

The comparison of the sun with the mean of the two stars, therefore, is the magnitude of $1^s,15$, by what amount the observations with the column of liquid would make the advance of the clock too strong, when compared with the sources of the yearbooks, i.e., with the ordinary Constant reduced. If we really do this in this way, then we find in fact the following for both instruments:

Meridian circle, observer: Börgen.
Leading between Θ and β Herculis $1^s,65$
" " Θ " δ Herculis 2,02
Transit instrument, observer: Klinkerfues.
Lead the same $2^s,94$
" " " 2,78.

The lead is thus found to be too strong on the latter instruments by $1^s,025$ on average, while the theory put forward 1^s, 15 required. If, on the other hand, one takes the modified right ascension given above for the modified instrument, one must, according to the same theory, obtain the ratio on the average as well as on the first instrument.

In this reduction you get for the passage on Transit instrument:

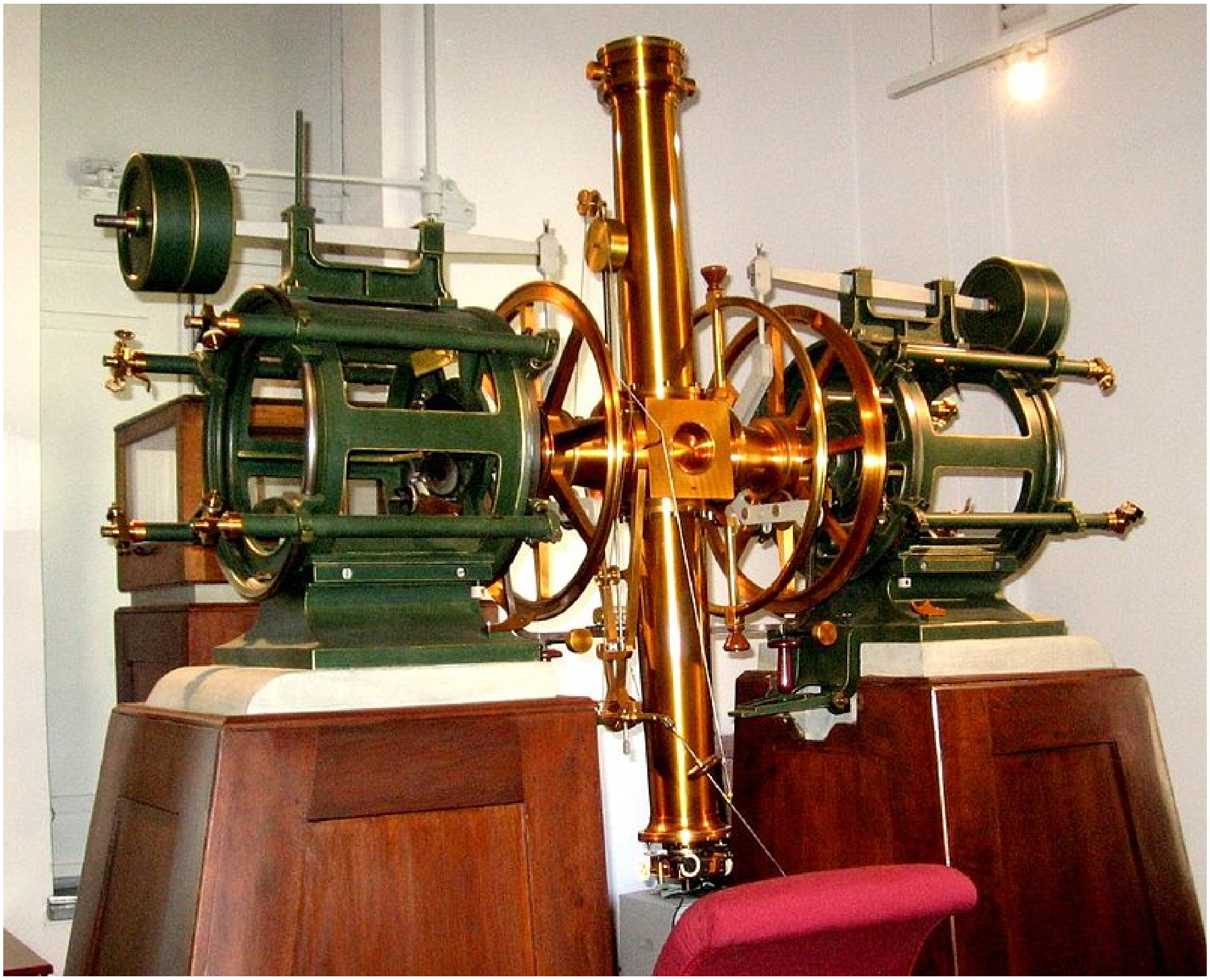
From	Θ	to	β	Herculis	$1^s,81$
"	Θ	"	β	"	1,61
				on average	1,71

while the same course was found by ordinary means equal to 1^s,83.

We do not want to ascribe these individual attempts to a decision, but at least this experience also leans on the side of the view that the aberration constant depends on the instrument, despite the translatory movement of the Aether in and out of the telescope. The opposite view can not only by no means cite any empirical evidence taken from experience; according to the wave theory, the reasons given for this cannot be regarded as valid. In this essay, the author believes that he has substantiated this latter claim to what he set himself as his main task.

TRANSIT INSTRUMENT

Representative of the transit instrument of Ertel used by Klinkerfues which was in the possession of the Göttingen Observatory



Meridian circle at the Kuffner observatory, Vienna, Austria, built by Repsold & Sons, Hamburg, 1886. Note the counterweights, the short, green cylindrical objects at the outer top of the mechanism, and the four long, thin, microscopes for reading the circles.