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An Optical Arrangement for Getting Simultaneous Records of the Refractive Index and its Derivative for Stratified Solutions

HARRY SVENSSON

The Laboratories of LKB-Produkter Fabriksaktiebolag, Stockholm, Sweden

In a recent article[1], the author gave a survey over the different methods which have been used for recording the concentrations in cells with stratified solutions. These methods could be subdivided into two main groups, one of them being characterized by giving direct records of the concentration (by way of refractive index or light absorption), the other by giving records of the concentration derivative with respect to the position in the cell. In a comparison between the relative merits of the two groups of methods, it was found that both the concentration function and its derivative are very useful and that it is not possible to give one kind of record the absolute preference. On the contrary, the ideal method of observation should give records of both functions simultaneously.

To carry out such combined records in practice, it was said in the same article, would be easier if both records were based on the same optical principles. Since it did not seem possible to modify available derivative methods to give the integral function, it was instead tried to modify an integral method to give the derivative.

It has now been found, however, that a suitable combination between the inclined slit arrangement, which gives a record of the derivative, and a modification of the Rayleigh interferometer recently developed by Philpot and Cook[2] and the present author[1] can be carried out by very simple means if one starts from the optical system of the inclined slit method.

To make this clear, let us compare the optical systems of the inclined slit arrangement and the modified Rayleigh interferometer. Fig. 1 shows the optical components of the former arrangement and Fig. 2 those of the latter, both

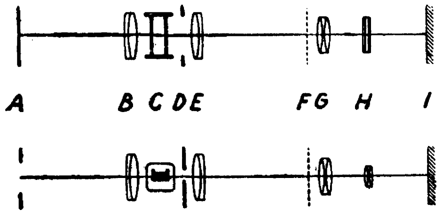
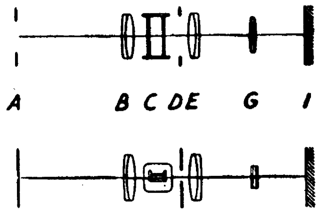


Fig. 1. The diagonal slit arrangement. Upper figure: elevation; Lower figure: plan.



Rig. 2. The interferometric arrangement according to Rayleigh and Philpot. Upper figure: elevation. Lower figure: plan.

systems being shown in plan and in elevation. In Fig. 1, A is a horizontal slit illuminated by light which is not necessarily monochromatic. The lenses B and E give an image of the slit in the plane F, where the inclined slit is situated in such a position that it crosses the image of A. Between the lenses, the light runs horizontally, one portion through and one beside the cell C. The diaphragm D has a lateral dimension equal to twice the breadth of the cell plus the thickness of the cell wall. The lenses G and H form together an astigmatic optical system with different focal powers in plan and in elevation. In plan, this lens system gives an image of the plane F, consequently also of the plane A, whereas in elevation the lenses give an image of the cell C. Thus, the vertical coordinate on the plate is related to the vertical coordinate in the cell, and the horizontal coordinate on the plate is related to the horizontal coordinates of the planes A and F.

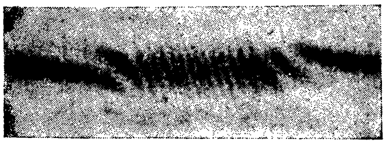
In Fig. 2, the interferometric arrangement, A is a vertical slit illuminated by monochromatic light. The lenses B and E give an image of this slit on the plate I. Between the lenses, we have parallel light, one portion passing through and one beside the cell C. The diaphragm D has a lateral dimension equal to twice the breadth of the cell plus the thickness of the cell wall. The cylindrical lens G with a horizontal axis brings, in elevation, the cell C into focus on the plate I, while, in plan, it does not alter the focusing of the slit A.

A comparison between the two optical systems reveals that the following properties are common to both:

1) in plan, an image of the illumination slit is formed on the plate;
2) in elevation, an image of the cell is formed on the plate.

On the other hand, we find the following differences:

1) the inclined slit method requires a horizontal illumination slit, while the interferometric method requires a vertical slit;



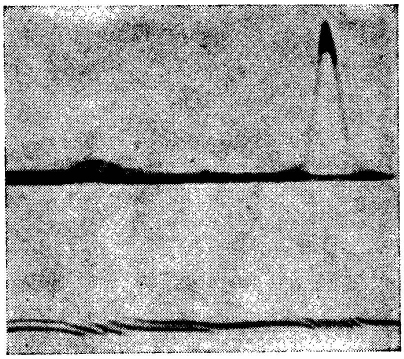


Fig. 3. Exposure from an electrophoresis experiment using combined diagonal slit and interferometric observation. Both patterns show the presence of three concentration steps. To the right: the whole picture; above: the right-hand portion of the interferometric pattern in greater magnification.

2) the inclined slit method requires a twofold focusing of the illumination slit, first to the plane of the inclined slit, then to the plate, whereas in the interferometric method a direct focusing from the illumination slit to the plate is possible;
3) the inclined slit method does not require monochromatic light, while the interferometric method does.

It is remarkable that, although the optical system of the inclined slit arrangement is unnecessarily complicated for the Rayleigh-Philpot-Cook interferometric arrangement, it is yet useful for it since it is characterized by a simultaneous focusing of the illumination slit and the cell, in plan and in elevation respectively. These properties are the necessary and sufficient conditions for interference. Consequently, when an inclined slit set-up is to be completed with an interferometric arrangement, nothing need be altered except the slits and the light source if this is not already monochromatic. *If the horizontal slit is replaced by a vertical slit, and if the inclined slit is removed, the result will be an interferometric arrangement according to Rayleigh and Philpot-Cook* *. This conclusion has been verified experimentally.

It follows from the above that simultaneous records of the refractive index and its derivative can be obtained by using one horizontal and one vertical slit in the plane A, Fig. 1, side by side. Since these slits are brought to focus on the plate when viewed from above, we will then get the two records side by side there. The inclined slits used hitherto, however, are not suitable in the combined procedure because their mechanical constructional details cut off the light from the vertical slit. It is necessary to construct a new diagonal slit which also carries a vertical slit in order to let the interfering light pencils through.

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* Added in proof: This fact was discovered independently by Dr. G. Kegeles in June, 1949 (personal communication from Dr. L. G. Longsworth).

Double slits according to the above requirements have been constructed and placed in the planes A and F, Fig. 1, respectively, in ordinary electrophoresis experiments. Fig. 3 shows an exposure from such a run. Instead of measuring the areas of the peaks in the derivative diagram, one can count the number of fringes and measure the fraction of a fringe displacement within the same region in the interferometric pattern. On the other hand, the derivative pattern is more suitable and convenient for localizing the concentration steps and for resolving the different steps from each other. Since the cell magnification is the same in both patterns, it is very simple to pass from one to the other.

Fig. 3 is of considerable interest from the point of view of resolving power of the two methods since it offers a direct comparison and since it includes one refractive index gradient just on the border of the resolving power. The resolution of the diagonal slit method was studied theoretically by the author [3] with the result that a refractive index change of $18 \cdot 10^{-5}$ could still be measured with some precision in a 25 mm cell and with a wave-length of 5000 Å. It was pointed out, however, that this figure did not make full justice to the method chiefly because a refractive index change that can still be measured with some precision is far greater than the least perceptible change, the latter quantity generally being adopted as the definition of resolving power. Labhart and Staub [4] payed attention to this fact; nevertheless, they considered an interferometer more sensitive than the diagonal slit arrangement.

When a gradient curve obtained by the inclined slit method is compared with the corresponding interferometric pattern, one must not forget that the former is the derivative of the latter and that every differentiation is necessarily accompanied by a considerable loss of accuracy. Consequently, the two diagrams should not be compared until the interferometric pattern has been differentiated or the inclined slit pattern integrated. No doubt the interferometric pattern looks much more accurate, but it would be superficial immediately to conclude that it really is.

Hansen [5] concluded from purely theoretical reasoning that the resolving power of the *Schlieren* method, of which the diagonal slit method is a modification, is the same as that of interferometric methods. Taking practical considerations into account, however, he found the interferometric methods to be somewhat superior. Fig. 3 seems to strengthen this view. The very small refractive index gradient in the middle of the pattern gives a displacement of almost one fringe, which corresponds to a refractive index change in the cell of $1.8 \cdot 10^{-5}$. This gradient is just perceptible in the derivative pattern, hence the resolving power of the diagonal slit method is found to be roughly $2 \cdot 10^{-5}$ for the green mercury line and for a 25 mm cell. However, in the interferometric pattern this gradient is more than just perceptible; it can still be measured with some precision since even fractions of fringes can be estimated. Thus the addition of an interferometric diagram to the inclined slit pattern not only increases the convenience of the evaluation. It also enhances the accuracy.*

SUMMARY

It has been shown that an inclined slit arrangement can be transformed into a self-recording interferometer according to Rayleigh and Philpot-Cook simply by replacing the horizontal illumination slit by a vertical slit and by removing the inclined slit. Accordingly, simultaneous records of the refractive index and its derivative can be obtained side by side with the same cell magnification by using vertical slits beside the horizontal and inclined slits. It has further been shown that the resolving power of the diagonal slit method is roughly $2 \cdot 10^{-5}$ for the green mercury line and for a 25 mm cell, which corresponds to the displacement of one fringe in the interferometric pattern. The possibility of measuring displacements smaller than one fringe increases the accuracy of refractive index measurements.

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* Similar conclusions are drawn by Dr. L. G. Longsworth in a recent investigation of the Philpot-Cook arrangement applied to electrophoresis (*Anal. Chem.*, in the press).