ADJOURNED DISCUSSION IN LONDON.

April 21st, 1920.

The Royal Microscopical Society held a special meeting on April 21st, 1920, in the Rooms of the Society at 20, Hanover Square, London, W., in conjunction with the Optical Society and the Faraday Society, to discuss the papers presented to the Symposium which dealt with the "MECHANICAL DESIGN AND OPTICS OF THE MICROSCOPE."

Professor John Eyre, President of the Royal Microscopical Society, who was in the Chair during the first part of the proceedings, opened the Discussion with the following remarks :—

The object of our meeting this evening is not to initiate a fresh discussion on the microscope, but to continue the work which was commenced at the Symposium held in January last. The volume of communications which was simply poured upon the Symposium was so great that it was impossible to discuss more than a very few of them, and, indeed, many papers were only presented in abstract, but in order to correlate the views of all the workers in this branch of science, we are arranging a series of short meetings in which specially selected papers can be discussed, and the results of the discussion recorded for publication. During the course of the evening my two confreres, Sir Robert Hadfield, President of the Faraday Society, and Mr. R. S. Whipple, President of the Optical Society, will each take the Chair for a period, in order that the members of their Societies may feel that they are adequately represented.

The Chairman then called upon **Mr. J. E. Barnard** to give a GENERAL SURVEY of the subject (*see* page 37), after which abstracts of the following papers, read at the original meeting, were presented by their respective authors:

THE MECHANICAL DESIGN OF THE MICROSCOPE.

(*a*) *General.*

PROFESSOR F. J. CHESHIRE, C.B.E., "The Mechanical Design of Microscopes."

MR. CONRAD BECK, C.B.E., "The Standard Microscope."

MR. F. W. WATSON BAKER, "Progress in Microscopy from a Manufacturer's Point of View."

MR. POWELL SWIFT, "A New Research Microscope."

(*b*) *Metallurgical.*

DR. W. ROSENHAIN, F.R.S., "The Metallurgical Microscope."

PROFESSOR CECIL H. DESCH, D.Sc., "The Construction and Design of Metallurgical Microscopes."

MR. E. F. LAW, "The Microscope in Metallurgical Research."

MR. H. M. SAYERS, "Illumination in Micro-metallography."

(*c*) *Petrological.*

DR. J. W. EVANS, F.R.S., "The Requirements of a Petrological Microscope."

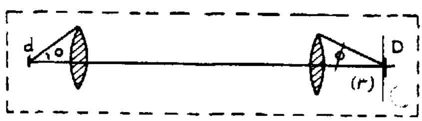
Sir Robert Hadfield, F.R.S., in taking the Chair during the reading of the metallurgical papers, said:

I do not intend to take up much of your time, but should like to say in a few words how very gratified I feel to see this important gathering continuing the work we tried to do a couple of months ago. We then had something like 40 papers presented, and as, of course, it was quite impossible to do more than touch upon the fringe of the discussion of them, I may also add that out of that large gathering in the Rooms of the Royal Society we have had a continuation of the same work in the cities of Sheffield and Glasgow. That will show you that we did really stir up not only the metropolis, but also the north and the far north. As I am taking the Chair during the reading of the papers in the metallurgical section, I would like to say how very important we find the microscope as regards metallurgical operations and investigations. My friend Mr. Barnard has said that we do not think sufficiently of resolution and that we are rather too fond of magnification. I still have a little feeling for magnification, but cannot help thinking that we shall, aided by resolution—the double resolution of the microscope and our own resolution—find out improved methods of handling steel. That is a matter I am specially interested in. The more one studies the structure of iron and steel, the more fascinating it becomes. To use an illustration in which I have been concerned very much during the war, *i.e.*, the production of the large calibre armour piercing shell, we could not really have obtained a shell of the requisite quality without the use of the microscope. When one considers that the 18-inch gun carried a projectile with a muzzle energy of 150,000 foot-tons, one can imagine the tremendous stresses which occur when that shell is suddenly brought to rest by the armour attacked, and yet it must not break. Out of those war researches are proceeding further investigations which will apply that information to the arts of peace, and I do not think it will be found that we have wasted our time. We in England were not behind, but we wanted stimulating a little, and a great deal of investigation work was carried out during the war which would not have been done otherwise, because in times of peace the money could not be found.

DISCUSSION.

Commander M. A. Ainslie, R.N.: With regard to design, the principle of the optical bench seems to me exactly the principle needed in order that you may build up in bits the apparatus you want for any particular research, so that everything may fall naturally into alignment. Each piece of apparatus should be on a separate saddle of its own. I would even have the eye-piece on a separate saddle, with a separate coarse adjustment of its own; this may sound revolutionary, but I believe it to be perfectly sound. Then, again, I think we ought to have a longer range to the draw-tube; as a rule, it is quite insufficient, especially when high power dry objectives are in use. An ordinary dry 3 mm. objective requires a change of about 20 mm. in the tube-length to compensate for a change of .01 mm. in the thickness of the cover glass; and although objectives of lower power are less sensitive, objectives of low power and large aperture are not very easy to obtain.

With regard to the size of illuminant required in photomicrography, whether of metals or of other objects, this is settled by a very simple relation. If d be the diameter of the light-source, and D that of the illuminated area on the object slide, and if θ be the



angle made with the axis of the extreme ray entering the optical system and ϕ that of the extreme ray falling on the object, the latter being supposed in a medium of refractive index μ, then we always have

$$d \sin \theta = \mu D \sin \phi,$$

which is, of course, merely the well-known "optical sine law"; it really amounts to saying that the product of the diameter of the light-source into the N.A. of the collecting lens is equal to the diameter of the circle of illumination on the object, multiplied by the N.A. of the condenser. You cannot get away from this relation; it settles once for all the diameter of the illuminated field, and it is true for any optical system whatever between the light-source and the condenser.

If you are going to use a metal filament lamp, you are confronted with one of two things; either you are going to project an image of the filament on your object, or else you are going to project this image into the plane of the objective aperture, filling it irregularly; a state of things which Professor Conrady long ago showed to be incorrect. The diameter of the filament is far too small, having regard to the relation I mentioned just now; and of course one does not want an image of the filament on the photograph.

With regard to the intensity of the arc, what decides the exposure is the intrinsic brilliancy and not the total power of the arc. As to the heating effect, I have used a 25 ampere arc within

1¼ inch of one of the solid glass rods supplied by Messrs. Beck, for half an hour at a time, without the slightest damage to the glass, and I am inclined to think that this "bogey" of the danger to your collecting lens is somewhat over-rated.

Mr. C. Beck: Has Commander Ainslie tested the amount of light lost by absorption from glass to glass. Is it 75 per cent.?

Commander Ainslie: Yes, of course, a great deal of light is lost. It was a question of the capability of the glass to withstand heat. It is a question of the size of the illuminant. I have seen a piece of ground glass as the source of illumination instead of the crater of the arc itself.

Mr. Maurice Blood: You can use a large collecting lens.

Commander Ainslie: But you will not get more light, because it is the intrinsic brilliancy of the light that counts.

Dr. R. Clay: The feature that pleases me most in the microscopes that Mr. Beck has shown is the provision that he has made by which one can start with a simple form and gradually build it up. I have been advocating this for some time, and I am very glad to see it is accomplished here. That a student who has not too much money can commence with an inexpensive instrument and add to it as he goes along, and as he feels the necessity for and understands the use of improved apparatus, is a very great advantage.

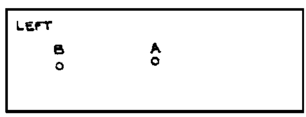
I was very much interested in Commander Ainslie's formula connecting the area illuminated by a substage condenser and the aperture of the condenser. I think it is one of the most important things that has been brought forward during this Symposium, because there is quite a lot of nonsense talked about the illumination of microscope objects, and that formula puts the whole in a nutshell. I was also interested in the paper on the illumination of metallurgical specimens, as I think it is possible with a prism that I devised some time ago for another purpose to give the 50 per cent. illumination that has been asked for in that paper.

Mr. W. R. Traviss: I should like to mention that it is over 35 years ago since I introduced to Messrs. Swift and Son a microscope on the lines of the one that the last speaker has said he would like to see, viz., an instrument that could be commenced in a small way and gradually built up as time goes on.

The simplest form had a firm tripod, of which the toes of the legs were cork-filled to give firmness. The stage was a cut-open form recommended by the late Dr. Dallinger and Mr. E. M. Nelson. The coarse adjustment was made by the body sliding in a cloth lined fitting. The screwed holes for the attachment of the limb or arm to the stage were made a standard distance from the optical centre, so that a coarse adjustment with rack and pinion movement could be exchanged. The side edges of the stage were grooved for the vertical movement of a mechanical stage or roller sliding bar which could be easily slipped on and off. The under-stage tube was fixed to a plate; this could be replaced by a centering motion, rack and pinion sub-stage. The sliding draw-tube could be replaced with a rack and pinion draw-tube divided into mm.

Another addition which is added to a small portable microscope, and would be useful to all plain stage microscopes, whoever the maker might be, is a very simple and efficient finder, and is standardised as follows:—

Each maker has a 3 × 1 in. piece of metal 1 mm. thick. At equal distances from the ends and sides is made a small hole (A) 1 mm. diameter, and another hole the same size, made exactly 1 in. distance from the centre hole and equal distance from the sides (B), thus:—



When an instrument is assembled and completed ready for sale the above plate is placed on the stage of the microscope resting against the sliding bar or mechanical stage, or a mechanical square; then with a 2/3rd or 1 in. objective the hole A. is brought into the centre of the field of the eye-piece; the metal 3 × 1 is held firmly by the stage springs or clips, and a small sharp drill is passed through the hole B and a few twists given, which will make a drill mark on the stage. This is then filled in with Plaster of Paris, thus giving a white dot over a black stage.

Now suppose we have a scattered slide, and some part (or parts) has some object of special interest which one wishes to find quickly at some future time—all that is needed when the object is squarely on the stage is to make an ink dot on the slide exactly over the white dot on the stage. Other dots can be made if needed, and marked A, B, C, etc. Then for the future all that is necessary is to place dot A, B, or C over the white dot on the stage, and the desired part is in the centre of the field of the eye-piece.

With regard to Dr. Evans's paper, he has specially mentioned crystals, but I do not think any instrument is so efficient for examining minute crystals as the one introduced by Mr. Allan B. Dick. In this instrument you can introduce a minute crystal on the cross wire, and it does not alter its position at all.

Dr. J. W. Evans: No one appreciates more than I do its valuable qualities, but it is impossible to apply the methods devised by Professor Beck for the study of interference figures to a microscope with rotating nicols, at any rate without very considerable modification, and in the second place the small upper Bertrand lens cannot compare in convenience and effectiveness for the examination of the interference figures of minute objects with a Beck lens placed above the eye-piece, in conjunction with a diaphragm placed in the focus of the latter.

Col. J. Clibborn: We have heard to-night an immense amount of detailed information as to what is desirable, but nobody has suggested yet the means by which we may attain our object. I do not think there is any doubt that what is desirable is that we should, at all events, have one standard microscope which will fill the conditions that have been mentioned. We should at all events have one pattern—it is possible that we may require other patterns—but we at any rate require one pattern of standard microscope, because it is only possible to manufacture in very large quantities. These instruments cannot be manufactured cheaply, even in large numbers, unless you have suitable machines, and the question is how are we going to arrive at this condition of things. I do not think it can be done by separate manufacturers, because it is not possible that the patterns will all agree. The manufacturers might all join together and form a combination, and perhaps it might be done in that way, but I think the best way is what I suggested 12 months ago, namely, that a Committee should be appointed of the ablest men interested in the question, inside and outside the Society, to devote themselves to the design of the standard microscope. It should undergo as much criticism as can be brought to bear upon it, and then we should endeavour to get an instrument made and tested. If we do not, I am perfectly certain that the manufacture of the microscope will leave this country and go to the Continent.

Dr. J. R. Leeson: An important question is that of price. I have been trying for four years to fit up my little laboratory with microscopes, but I cannot get them; at least, if I can get them I cannot find the heart to pay for them. Scientists are not rich people, and if you are going to popularise the microscope, you must have an instrument that is within the reach of the ordinary individual. If you do not, then the trade will again leave this country.

Dr. R. Mullineux Walmsley: The last speaker and the last speaker but one have referred to matters with which I have been somewhat associated through the British Science Guild. A Committee has been proposed here to-night, but I would like to inform the proposer that the work he suggests has already been done. The British Science Guild first of all invited well-known users of microscopes to schedule their requirements. Having collected and collated these schedules, we asked the manufacturers to join the Committee and tell us whether it was possible from their point of view to produce microscopes which would fulfil their requirements. Eventually by the combination of the scientific men who were using the microscopes and of the manufacturers, we drew up and published specifications for three or four standard instruments for different purposes. We were in the middle of the Great War at the time, and the object was to see whether manufacturers would consider placing such instruments on the market, when peace came, with such added modifications as the progress of time might render desirable The question of price was not overlooked, although I do not know that the prices we put down in 1917 can be held to at the present time.

The evidence of the work is on record, both in the *Journal of the British Science Guild* and the Royal Microscopical Society, and I fancy that the manufacture of both instruments exhibited to-night were to some extent influenced by the specifications prepared by the Committee.

Mr. Conrad Beck said that the standard instrument made by his firm was made to the specification of the British Science Guild Committee, but the larger one, made by Messrs. Swift, was quite a different matter. The latter was more of a special research type. He certainly welcomed the suggestion that a small sum of money should be put up to assist in manufacturing microscopes. But what was meant by a small sum? In some instances upwards of £20,000 had been spent in tools and machinery; Messrs. Watson and his own firm had each expended an enormous amount of money on machinery and tools which it was hoped in course of time would be found advantageous to microscopical work, and if a small sum meant something of this nature it was an excellent proposition.

Mr. Watson Baker: The microscope which our firm has made according to the specification of the British Science Guild is not here to-night, but I am glad to take this opportunity of saying that we should welcome any members of the Royal Microscopical Society to our works to see exactly what is being done.

I believe that Col. Clibborn himself would be pleased to see that microscopes are being made by machinery in a manner not hitherto done in this country. It has taken us 12 months to put up a new building and make the necessary tools, but we have accomplished it, and if British users could be induced to visit us and see what we have done and what it has involved, we should be very pleased.

Mr. Perkins: I was struck by the remark of Professor Desch in his paper when he said that microscopes wear because of the bad material of racks and pinions. I have found in a fairly long experience of microscope repair that sometimes the German slides are softer than the English slides, so that does not, in my opinion, account for the fact that the English microscope wears quicker than the German. It has always seemed to me that the English makers, in spite of their undoubted ability, overlook the fact that if you want to reduce wear on the slides of a microscope, they must bear properly upon each other. It is no good putting in slides which bear at points, as in Fig. 1. Wear very quickly takes place at those points and develops a shake, and you get a loss of stability, such as Professor Barnard spoke of. The closest analogy I can put forward is an ordinary bearing. If, for argument's sake, the inner bearing is much smaller than the outer (Fig. 2), you get point metal to metal contact and quick wear. If, however, it fits as in Fig. 3, the lubricant stops in in an unbroken film, and you get long and efficient wear. I have seen microscopes 20 years old which have no shake in them and still fit perfectly all over. Then, again, the weakness of design of the usual spring fitting is another point which in my opinion English manufacturers have always overlooked. If you spring at four corners, like *a*, *b*, *c*, *d* (Fig. 4), the fitting E has got to be a very fine fit, and also the fitting F, but directly you start springing E you distort F at once. I have seen it; I have spent hours over it worrying about it, but English makers are

FIG. 1.

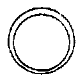


FIG. 2.

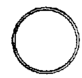


FIG. 3.

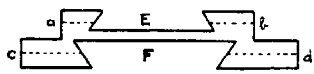


FIG. 4

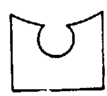


FIG. 5.

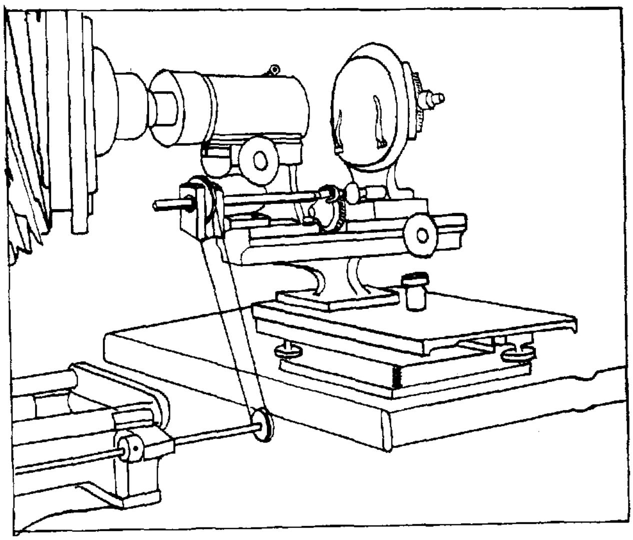
gradually waking up to the fact that you have got to have your slides in a springless chunk of metal, something like that shown in Fig. 5, so that when you do the screws up, the chunk of metal remains as it was and does not distort. Again, how can you efficiently remove the grinding material from the springing slots, which is another obvious source of wear.

Mr. Beck: Was the microscope 20 years old which you referred to German or English?

Mr. Perkins: It was German. I am not saying that I have not seen an equally good English instrument 20 years old, but I am speaking of English instruments as a body. Another point is that English makers must now see to it that they have an efficient system of inspection. The Germans have a very efficient system of inspection, and English makers must see that nothing leaves their factories which is not perfect. When you have got to that point, but not before, then success is assured.

Mr. Harold Wrighton: It fell to my lot to prepare the photomicrographs which were shown in the paper given by Sir Robert Hadfield and Mr. T. G. Elliot at the Symposium. These photographs were taken on a Zeiss-Martens horizontal machine. In order to obtain them I found it necessary to alter radically the long distance fine focussing adjustment. Even in the best patterns of photomicrographic apparatus the design and efficiency of this long distance focussing fittings seems to receive very little attention. Possibly a description of the new arrangement may be of interest to some gentlemen who have a similar Zeiss-Martens outfit.

The arrangement shown in the accompanying sketch was made in the works at very small cost, and has proved very satisfactory. The short metal rod which fitted into the socket on the focussing rod has been replaced by a longer rod, $\frac{1}{4}$ in. square in cross section. A $1\frac{1}{2}$ in. pulley wheel, turning on flanges, is mounted on a bracket at the corner of the microscope base. A square hole through the pulley wheel is just large enough to allow of very slight play between the wheel and the square rod. As the square rod will pass along through the pulley wheel, horizontal traverse of the microscope stage is not interfered with. A long rod is mounted in brackets screwed



to the base, which carries the camera. This rod has a $\frac{3}{4}$ in. pulley wheel at one end, which is connected by cord to the other wheel. At the other end is a 2 in. milled brass head, for turning. The two grooved wheels over which the cord passes are milled inside the grooves, thereby preventing slip. The arrangement as made to dimensions given above further reduces the speed of fine adjustment by one half. The main advantage is that, owing to slight play between wheel and square rod, any slight torsion produced whilst turning the rod can ease itself when the hand is removed, without turning the fine adjustment and disturbing the focus.

Another matter, referred to by a previous speaker, is the lack of contrast in most metallurgical specimens as compared with a biological section. This is one of our difficulties, and, as a matter of fact, most of our photomicrographs show considerably more contrast than is actually present in the specimen.

Mr. T. Smith: I would like to have spoken on the optical side of the discussion, but there is one matter I will refer to. We have been given some figures by Commander Ainslie based on a displacement of 1/100 mm., and some further results on a basis of the same magnitude, with the displacement along the axis, may be of interest.

I have worked out some figures relating to a 2 mm. objective, N.A. = 1.4, which gives perfect definition when used properly. With the object displaced 1/100 mm. from its proper position, I find that the marginal rays, instead of converging to the paraxial image point, get farther and farther away from the axis. This indicates how accurately it is necessary to focus at high magnifications. Therefore I would like to suggest that manufacturers of apparatus for high power work and particularly for ultra-violet microscopy should pay special attention to the problem of adjusting the specimen accurately in relation to the objective. Particularly when short wave-lengths are being used, as in ultra-violet microscopy, is this necessary if much time is not to be wasted in taking useless photographs.

The Chairman: We now proceed to the discussion of the OPTICS OF THE MICROSCOPE, and I will ask MR. WHIPPLE, President of the Optical Society, to take the Chair.

Mr. R. S. Whipple: I think that at this stage of the proceedings we ought to congratulate Messrs. Beck on the fact that they have been able to produce a standard microscope and that they have been able to keep their promise to produce it this month. As a manufacturer I know the difficulty of keeping a promise of this kind, and it is greatly to their credit that they have been able to keep to time. As a manufacturer, I also know some of the difficulties involved in the production of a new instrument. They have covered the foot of the stand with ebonite. To do this is in itself an achievement; they have introduced this ingenious geometric arrangement for holding the objectives, another considerable achievement. Thus in this apparently simple looking article there are a number of mechanical achievements—I venture to say great achievements—which a few years ago would have been regarded as impossible. I think, therefore, that it is not right to pass from the mechanical side of the microscope without expressing our indebtedness to them for what they have done so far, and to wish them and other English microscope makers every success in the future.

Abstracts of the following papers were then presented:—

THE OPTICS OF THE MICROSCOPE.

PROFESSOR A. E. CONRADY, "Microscopical Optics."
DR. H. HARTRIDGE, M.A., "An Accurate Method of Objective Testing."
MR. H. S. RYLAND, "The Manufacture and Testing of Microscope Objectives."
MR. F. TWYMAN, "Interferometric Methods."

DISCUSSION.

Mr. Conrad Beck: I have been greatly interested in the Hartridge test for microscope object glasses. Whether the graphs that you get are any value or not, it is impossible to say. I should not at present like to express the slightest opinion; all I can say is that I was interested to find that the graphs which we took in succession one after the other with the same object glass were fairly consistent, which, considering the conditions under which these observations are made, is rather remarkable, because one is using an extremely small portion of the object glass at one time. The principle is that by the use of a small diaphragm you are illuminating a small zone of the object glass, and the numerical aperture of the portion you are illuminating is very small. I did not expect that our results would agree, because of the extremely inferior image produced with such a small portion of the object glass being used at one time. In discussing this matter with Dr. Hartridge, he pointed out that his microscope was not nearly sufficiently rigid for the purpose. The matter has been considered by my firm, and they came to the conclusion that there was no microscope sufficiently rigid for the purpose, and consequently for the last eight weeks we have been designing an instrument which I am proposing to make for my own personal use that I hope and think will be the most perfect microscope stand ever made. I shall show it to the Society as soon as it is made. Those who use the microscope for general work may consider it too elaborate and expensive for ordinary purposes, but I am not sure. It will have some features about it that will make it unusually rigid. Its construction is an interesting engineering problem, and whether anybody will ever order a similar one may be doubtful, because the cost will be very great.

There is one point made by Dr. Hartridge in his paper which I think is an obvious error, and if it were pointed out I think he would admit it. The method of testing the object glass is only a test to see whether the light from a lens is going to one point. It is not a test of the sine condition. That must be carried out as a separate test, and I am bound to say that my own impression is that when the Hartridge test is worked out and his method of calibrating and plotting out has been done, we shall find we are testing an important, but not by any means the most important, correction on an object glass. The important points about an object glass, apart from achromatic corrections, are firstly, that the light from the whole object glass shall go on to a point, and secondly, that the focal length of every zone in the glass shall be the same, and it is this latter point that the sine condition guarantees. Mr. Hartridge's test has some analogy to the Hartmann test; it measures the lateral shift of the uncorrected rays instead of the longitudinal error.

Commander M. A. Ainslie, R.N.: I should like to concentrate attention on the subject of the condenser. Professor Conrady refers to the incorrect position of the iris diaphragm; this is certainly most marked, but there are one or two points to be considered in this connection. There is no reason why the iris diaphragm should not be placed between the top lens of the condenser and the next lens, or perhaps a little lower down; at any rate, much higher up that it is at present. The diaphragm could be very well worked by means of a bevel wheel and a pinion coming out radially; the only thing against this is that the stage is so thick. It would be quite impossible on the standard instrument here shown, but if we were to return to the "horseshoe" type of stage designed by Nelson, it could be done perfectly easily. Presumably, however, the exit pupil of the objective is in the neighbourhood of its upper focal plane; as a general rule I fancy it is rather lower down, but the position does not seem to be constant, even in objectives of the same type. *If the obliquity of illumination* at the margin of the field mentioned by Professor Conrady is to be avoided, the iris will have to be in the back focal plane of the condenser; if that is the case, no lateral movement of the condenser will affect the position of the image of the iris-aperture in the back lens of the objective, and it will be impossible to judge of the centering by looking down the tube.

Again, I think that both opticians and users of the microscope are content with too little in connection with the performance of the condenser; and I should say that the objection that the slide is composed of "window glass" introduces another "bogey." The area involved is always small, and if an oil immersion condenser is used, the surfaces of the slip cease to exist optically. At any rate, with a first rate modern achromatic condenser, such as the Watson "Parachromatic," it is possible, when the light source has a screen extending half way across it, to focus with such sharpness an image of the edge of this screen on the object that one row of dots on, say, *Pleurosigma Angulatum* shall be in full light and the next in "full darkness"—and this with an N.A. in use of not less than 0.7. This means that it is possible to get sharpness of the order of $\frac{1}{50,000}$ of an inch. But this is only done on one condition, and that is that the distance of the light-source is carefully adjusted to the thickness of the slip; as carefully as we adjust tube-length to the thickness of the cover glass. This point is almost universally avoided by the text-books, and I want to bring it forward as strongly as possible.

Mr. T. Smith: With regard to increasing the resolving power of microscope objectives, there is little doubt that the numerical aperture, as it is ordinarily understood, can hardly be increased with advantage, but there is considerable prospect of obtaining increased resolving power by using shorter wave-lengths of light. There are very considerable difficulties at present in the way, but I see no reason why they should not be overcome, although an extraordinary amount of experimental work will be involved. It is necessary to know the properties for such light of a very great variety of materials. Where we already possess some knowledge of the behaviour of certain materials with regard to ultra-violet light, this information must become much more precise than at present before it can be considered adequate, and I should like to see some definite encouragement given to researches of this character, because they can hardly fail to lead to results of value to the microscope user. Coming now to objectives and their design, it seems to me that this subject has never been investigated systematically, but that new objectives have generally been a further development of old designs on known lines. I should like to see systematic investigations undertaken, so that we may know what prospect there is of effecting real improvements in the corrections. For example, in a high power objective we have a lot of lenses placed very close together, though I am not aware of any thorough investigation which justifies adherence to this arrangement. There are obvious difficulties in the way of large separations; nevertheless, there would appear to be some decided advantages to be gained. At present with apochromatic lenses the curvature of the field is due to the properties of the transparent materials we employ. In general they have very similar properties as regards relative dispersion, and this imposes very severe limitations on what can be achieved; but these limitations no longer hold if the lenses are well separated, and it is possible that material improvements may be effected by radical alterations in the type of objective. There would be difficulties in doing this with objectives for ordinary use, but they would hardly apply at all for a special instrument required to give very great magnification, such as the metallurgists ask for, and I think these investigations might very well be made in regard to objectives for this particular purpose. In fact, I think we want to see a very great deal more of the design and manufacture of objectives for special purposes instead of expecting one objective of a given focal length to do any and every job. It ought to be realised more generally that an objective of high resolving power differs markedly from a so-called universal objective like a photographic anastigmat. A microscope objective of large N.A. is necessarily a very poor instrument for any conditions but precisely those for which it is designed. There are many other points to which attention might be called, but it must suffice now to mention one. A great deal has been said about the variation in the definition given by similar objectives made by the same firm from similar glass, which ought therefore to be identical in performance. I want to suggest that a possible contributory cause may be insufficiently accurate centering of the surfaces. I do not think that investigations have ever been carried out on methods of getting surfaces centered to an extraordinary degree of accuracy, yet a very high degree of accuracy is obviously required in a microscope objective. I have seen photographic lenses under examination with the interferometer, and these have shown marked irregularities in the wave front towards the periphery of the lens. When we seek the highest possible resolving power, it is the periphery of the lens that is all important, so I think we want to see, among other things, an investigation into methods of getting surfaces centered, not twice as accurately as we do them at present, but perhaps 10 or even 100 times as well. If any manufacturer were able to effect such an improvement, he would probably find that his lenses would realise a much more uniform standard of excellence than those produced at the present time. I very much hope that in some of the directions I have indicated the National Physical Laboratory may be able to give assistance to our own manufacturers.

Mr. J. E. Barnard: Mr. Smith has just referred to the question of investigation by the use of radiations of short wave-length. I should have hesitated to bring the subject up again had it not been that Professor Conrady also referred to it in his paper, and by a curious chance he has dropped into a not unusual error. He says that the limitations of the work are in part laid down by the opacity of bodies to ultra-violet light. When you get down to the dimensions with which we are dealing in a microscopic object which is at or beyond the ordinary resolution limits, opacity is almost non-existent. Sir George Beilby has shown that very thin metal films are almost perfectly transparent, and yet metals are the most opaque of substances. Latterly I have been endeavouring to photograph by means of ultra-violet light some exceedingly small organisms, some of which are beyond the limits of resolution, and the difficulty has been that with any wave-length I have at present available, the organism is transparent. The radiations pass completely through, and I am unable to get an image of any description whatever. So that to say that the limitations of the work are largely governed by the opacity of small bodies is not in accordance with practical experience or theoretical expectations. It may possibly arise if we use radiations of much shorter wave-length than those at present available, but in that case we shall be working with a microscope *in vacuo*, and I do not think it is a point which is likely to arise in practice for some time to come, although it may, and probably will, arise at a later stage.

Mr. L. C. Martin: I was interested in the description of the Hartridge test for the microscope objective, but I should like to say that it is not often, I believe, that a man testing a microscope objective wishes to know the aberration to any great accuracy, but rather whether the microscope objective is sufficiently good for the purpose. Therefore a somewhat easier quantitative test is to be desired. At the present time I have been doing a certain amount of work as a sort of preliminary study of the star test, and I think that possibly the so-called Rayleigh condition of less than one quarter wave-length a speedy test of the aberrations of a microscope objective.

Professor Conrady remarks in his paper that the fulfilment of the so-called Rayleigh condition of less than one quarter wave-length difference of optical paths between paraxial and marginal rays in good telescope and microscope objective, has been demonstrated by the Hilger interferometer. It is easy to understand that, imagining a perfectly spherical mirror in the interferometer and a means of controlling the position of such a surface to correspond with any particular focus of the test lens, such a perfect demonstration could be given. It is not easy to understand, however, when we consider that the errors of the surface of a mirror, which may be of the order of $\frac{\lambda}{4}$ or even more, are doubly important in such a case, and that the position of the test focus has to be obtained by trial. It is only when we consider a fact which was hinted at by Lord Rayleigh in 1879, and worked out by Professor Conrady in his paper on Star Discs, viz., that the effects of spherical aberration can often be countered very completely by changes of focus (or in mathematical language that we can partly balance the terms of the fourth and higher orders in the aberration expression by a change of the coefficient of the second order), that we can realise that the indications of the interferometer are trustworthy even to the extent previously indicated. It is necessary to bear in mind, however, that there is nothing magically sensitive in the interferometer tests as compared with star tests, for example, if these are performed with the maximum of care. Those who expect them to give tremendously sensitive results far excelling all other tests are doomed to disappointment.

Mr. Beck: Will you explain to us whether a quantitative measurement is obtained in the star test. The star test has been in use with the microscope objective ever since the achromatic microscope objective was known, in the form of a minute mercury globule reflecting a small source of light which makes practically an artificial star.

Mr. Martin: The work I have been doing is in a very unadvanced stage, but I hope it will be possible to obtain a rough estimate of the variation of the spherical aberration.

Commander Ainslie: I had the curiosity to test a low power objective on the well-known Wassel method, and it was easy to obtain (by this particular method of the extinction of the two sides of a zone simultaneously, with a screen), numerical values for the different foci of the different zones. I was only using a low power objective, an half-inch apochromat, and it would be difficult with high powers, unless, perhaps, an auxiliary telescope is used.

Mr. T. Smith: Mr. Beck said that the Hartridge test would not give coma. May I suggest that it is quite easy to get coma by plotting the spherical aberration for two somewhat different magnifications. From these numerical values, the deduction of the coma is quite easy.

Professor Eyre, in bringing the discussion to a close, said :

The time has now come when I must close the meeting. It is very difficult at the end of an evening o this character to sum up with anything like precision or to offer an opinion that has any value on the work that has been presented. There is, however, one outstanding feature, namely, that workers are willing and anxious to state their requirements to the manufacturers, and I think we have evidence that the manufacturers on their side are willing to do all in their power to help meet these needs. We cannot expect perfection at once. As Mr. Watson Baker has said, it has taken quite a year to get his factory and the machinery ready. It has been the same with all manufacturers and I do trust now that the necessities of the workers have been placed clearly before the manufacturers that we shall soon reach a stage when we shall have an instrument of our own manufacture, not only for home use, but one which will also enable us to capture the world's trade in microscopes.