IV. "On a new Refractometer for measuring the Mean Refractive Index of Plates of Glass and Lenses by the employment of Newton's Rings." By G. W. Royston-Pigott, M.A., M.D. Cantab., F.R.S., F.R.A.S., F.C.P.S. Received March 19, 1876.

The instrument depends upon two principles :—

I. The distance through which an image is displaced by refraction through a plate.

II. The exquisite sensitiveness of contact-films forming the various orders of Newton's rings and the central black spot.

I. It is well known that when the index of refraction is 1·500 or $\frac{3}{2}$, an image is formed by a plate having parallel sides at a distance nearer to the eye of the observer equal to two thirds of the thickness of the plate. Indeed if t be the thickness and μ the refractive index, the displacement is generally

$$\frac{t}{\mu}.$$

If, therefore, an instrument could be devised which would with great accuracy measure the thickness of the refracting plate, and also at the same time the distance by which the image of points on its surface was displaced inwards by refraction, data could be obtained for determining the value of μ.

The instrument has assumed its present form after many constructions and reconstructions. I was led to consider this method of finding the refraction of glass by frequent accidents happening while using the fiftieth-of-an-inch objective with the microscope, which by pressure destroyed or cracked the thin glass covers generally applied to protect the objects or "slides." Now, so to speak, the observer always in such a case really examines the elevated image of the object, raised about two thirds of the thickness of this cover. By knowing, therefore, the refraction of the glass cover and its thickness, such accidents, so irreparable in many valuable objects, might be avoided. Means were sought to determine the index of refraction of such covers, frequently varying from the hundredth to the thousandth of an inch thick, an extra thickness sometimes being destructive to the most valuable objective.

Hitherto the method of finding the refractive index has been by the use of prisms made of the material in question, and employed in the form of a spectroscope.

As an example of the power of the instrument, some flint glass, nearly half an inch thick, marked B, gave on three trials

$$\begin{aligned} \mu &= 1{\cdot}6626 \\ & 1{\cdot}6626 \\ & 1{\cdot}6621 \\ \hline \text{Mean} &= 1{\cdot}6624 \end{aligned}$$

A thin glass cover about one hundredth of an inch thick gave

$$\mu = 1{\cdot}5502.$$

The optical equation for a plate of glass,

$$v = u + \frac{t}{\mu}$$

(where u is the distance of the object and v the conjugate focus), points out that when the object is on the surface, or $u=0$,

$$v = \frac{t}{\mu},$$

and consequently

$$\mu = \frac{t}{v}.$$

Upon constructing an instrument roughly the index was readily found to two places of decimals in covering-glass, viz. $\mu = 1{\cdot}55$.

The contrivance of an instrument to read to the 100,000th of an inch now seemed desirable. It was necessary not only to measure thickness, but the elevation of the image within the substance of the plate.

The well-known delicacy of evanishment of a point under a good microscope seemed to afford an exquisite test of distance.

At first the point of an advancing screw was made to touch the "plate," the screw moving in the axis of the microscope. The point was brought into focus, or rather its image. The refracting plate was now removed, the microscope remaining undisturbed. The screw was then advanced until its point again came into focus; the point now occupied the precise position just before occupied by its image. This distance was then read off and the thickness of the plate read by observing successively the distances traversed by the screw between the point of first contact and its rising to the very same position of a particle already observed on the upper surface.

II. At this point of the research it occurred to the writer to substitute a minute plano-convex lens, fixed to the end of the screw, and endeavour to produce contact-films, especially the black central spot of Newton's rings.

In order to render the colours of these rings gorgeous by reflected light, a thin piece of plate glass was fixed at an angle of 45° behind the observing objective, and a hole perforated in the tube or "body" to admit light from a lamp; the object-glass then condensed a strong light upon the film-forming surfaces, and the black central spot came out beautifully black and distinctly defined in the field of the microscope. This occurred whether air or other fluid intervened between the lens and the surface. After fixing several different lenses, I found a radius of curvature of about one quarter of an inch the most convenient for developing the rings suitably for the microscopic field of view.

For being apprised of the near approach of contact, still greater con-

venience was accorded by using a minute film of paraffin-oil, formed by repeatedly wiping the surface of the screw-lens. Contact was then heralded instantly between the two surfaces by a brilliant flash of colours. One thing appeared certain, the various colours could be produced in perpetually expanding and vanishing rings, always starting from the centre. I counted no less than thirty-two changes of colour in the central part, reckoning from the black spot of perfect contact (within the half-millionth of an inch) and the final evanescence of the last colour by slight movements of the screw.

For the purpose of illuminating the point of contact of the "screw-lens" with the plate under examination, I inserted a minute right-angled prism behind the lens. This giving totally reflected light, provided nothing adhered to the reflecting surface of the prism, afforded the means of making observations by ordinary daylight, and observing the rings of Newton, though very pale, by transmitted light.

Another great advantage of the prism-lens attached to the end of the steel measuring-screw, is the bright illumination of the contact surfaces, the contact of an opaque extremity of the screw being with difficulty ascertained.

The whole method of finding the refractive index of a thin plate of a given refractive material resolved itself, then, into the best instrumental means for advancing a fiducial visible and illuminated point truly and steadily through measurable intervals, and observing with a good microscope the precise position of evanishment in and out of focus, and determining the focal points under correct collimations.

After many trials the following form was adopted :—

A steel cylinder very accurately turned between *dead* centres (*i. e.* the centres being fixed and the object revolving between them), about 5 inches long and $\frac{3}{10}$ in diameter; upon this screw-threads (very nearly 101·3 per inch) were very patiently formed. The front part of the cylinder passes smoothly (at first air-tight like a piston) through a collar of brass, into which it had been very slowly and carefully ground (with the finest cutting-powder and oil); at about two inches of the other end was formed a screw as described, with a very exact apparatus lent to the writer by a celebrated optician.

It was found that in so delicate an operation as dealing with coloured films, touching any part of the instrument caused them to flash a new colour. It was necessary to obviate, then, all varying mechanical strain. Springs so common in micrometers to obviate "loss of time" were found to introduce, from their varying pressure, very variable errors: after a time I was compelled to abandon their use altogether.

The constant force of gravitation and dead unvarying weight was now introduced; and in order to compensate possible deviations in the true spiral form of individual threads (every one of which was carefully examined with a strong magnifying-power), a nut was formed, so as con-

stantly to embrace (unlike ordinary micrometers of the usual form) precisely the same number of threads in every measurement, so that on the average the same number of threads probably represented nearly the same distance. In the case where a spring is more and more compressed and the number of threads embraced by the nut is constantly increasing (although some compensating action may arise), the screw and parts are certainly submitted to very varying and uncertain conditions. Another source of error arose,—*shake of rotation.* Having abandoned the usual form of micrometer construction (a revolving nut with a constant change in the number of threads embraced—a plan, one would think, fatal to all delicate accuracy), the next difficulty was to insure to the steel screw absolute advance and retreat without *rotatory* shake or motion. For this purpose *slides* were also abandoned. This action, the most important part of the instrument, should now be described.

A lever is affixed to the cylinder of steel and bent at right angles; it carries an adjustable weight. This weight slides upon a flat edge formed parallel to the axis of the steel screw by a most careful process, tested by a carefully prepared spirit-level for parallelism.

On lifting the weight slightly, the lever rotates the screw through a small angle; and this lever forms a constant test of the efficiency of the screw action of the greatest sensitiveness.

A further action put into motion by a fine screw gives to the advance of the film-forming surface, or prism-lens, a movement of the millionth of an inch.

Supposing that the recording-wheels have advanced several turns, the weight and lever also advance on the smooth edge already said to be formed parallel with the axis of the screw.

The constancy of the weight preserves the screw in one normal fiducial position, as regards its liability to rotate on its axis. An error of one hundredth of an inch in the sliding edge would produce an error of the reading of less amount than the hundred-thousandth of an inch *. But the lever advances so very slowly, as the wheels rotate the nut upon the screw, that this error appears to be almost destroyed.

An arrow-head shows upon the face of the differential wheels the number of turns taken by the nut. The instrument is self-recording, and reads to four places of decimals, from the hundredth of an inch to the hundred-thousandth. Two wheels, divided into 98 and 100 teeth respectively, run in gear *at will* with a long pinion of ten leaves, carrying a wheel showing the hundred-thousandths of an inch.

The prism end of the screw passes through the ground socket; and this socket carries a small stage accurately turned and ground, furnished with stops and a spring to confine the small plate of glass, if necessary, in one

* The path of the weight on the lever would be for a complete rotation about 20 inches; the proportion of $\frac{1}{100}$ to this is 2000, and the two thousandth part of a revolution is two thousandth of $\frac{1}{100}=\frac{1}{200000}$.

position. The axis of the screw and of the observing-microscope are carefully adjusted in one line, so as to have a common collimation.

In very thin glass an objective of $\frac{1}{4}$-inch focal length has been found sufficient. For thick glass, nearly half an inch thick, Mr. Wray, of Highgate, made a beautiful half-inch with three lenses cemented together with balsam, so as to give the greatest possible penetration. The body of the microscope is about 6 inches long.

The whole instrument is placed at an angle of about forty degrees. Its accuracy depends on the weight of the toothed wheels always bearing with an equal pressure, without springs, on the back poppet of the jeweller's lathe employed to carry and work the apparatus.

It remains to say a few words on the method of using the instrument.

1. *By transmitted Light.*—The instrument is placed near a window in daylight, and the small condenser is then used to throw a light upon the minute prism, which is then reflected up the microscope. A minute drop of kerosine is placed on the prism-lens at the end of the micrometer-screw, and then wiped off. The lens is then withdrawn a little below the stage, and the plate of glass to be measured is placed upon it. The microscope is armed with a quarter-inch, a half inch, or inch objective, according to the thickness of the plate to be examined.

The microscope is then focused upon the under surface of the plate. The micrometer-wheels are set in motion. The prism-lens gradually rises into view. The instant of contact is observed by a sudden spreading out of the remains of the oil-drop. It may require several cleansings or wipings of the lens before the oil is sufficiently removed. The film expands and contracts with the slightest movement; with a little practice the eye detects the position of initial contact.

The instrument is then read.

Example.—Initial reading for a piece of "covering-glass" one hundredth of an inch thick,

$$I = 0{\cdot}0044.$$

The glass was removed and the prism-lens advanced until its surface just came into focus. The distance was then read.

$$\begin{aligned} D &= 0{\cdot}0086 \\ I &= 0{\cdot}0044 \text{ initial reading.} \\ \hline \Delta &= 0{\cdot}0042 \text{ the elevation of image.} \end{aligned}$$

Replacing the glass and again repeating the process the initial reading at the lower contact was now found not to be 0·0044, but

$$I_2 = 0{\cdot}0045 \text{ (an extra } \tfrac{1}{100000} \text{ inch).}$$

Viewing an exceedingly minute scratch on the upper surface by refocusing upon it, the reading for thickness was

$$
\begin{aligned}
\text{T} &= 0{\cdot}0163 \\
\text{Initial reading} &= 0{\cdot}0045 \\
\hline
\text{Thickness} &= 0{\cdot}0118 \\
\Delta &= 0{\cdot}0042 \text{ elevation of image.} \\
\hline
v &= 0{\cdot}0076 \text{ distance of image from upper surface.}
\end{aligned}
$$

Therefore $\mu = \frac{t}{v} = \frac{0{\cdot}0118}{0{\cdot}0076} = 1{\cdot}55$ nearly.

I obtained from Mr. Browning several square pieces of flint glass of varying density and colour, and found by a series of measurements—

	Value of μ for mean rays.
A. Clear white flint	1·537
B. Yellow and heavy	1·6626
C. Yellowish and very heavy................	1·723
D. Strong yellow, and the heaviest of them all..	1·7555

2. *By reflected Light.*—Far more interesting are the phenomena developed by reflected light, throwing the light laterally upon the inclined transparent plane within the microscope, the object-glass of which acts as its own condenser. The most beautiful colours are developed on contact, either with a film of air or kerosine.

The central spot of final contact is of a grey-black, surrounded with its well-known succession of Newtonian rings of great beauty and perfection, flashing through numerous changes of colour for each thickness of film varied by the micrometer-screw.

The instant of the formation of the black spot film (thickness 0·000005 inch) determines the place of contact, *i. e.* the fiducial point of zero, with a precision scarcely equalled by any other known method of linear measurement by optical means. It can be readily obtained with great accuracy. This important point (the zero) of the observations depends not upon a thin spider line or engraved line, but upon the formation of a bold black circular spot whose diameter is variable and dependent upon the curvature of the lens employed. Where great endurance is desired, a small plano-convex sapphire lens can be cemented to the prism at little expense.

The behaviour of minute microscopic kerosine oil-drops persistently adhering to the surface of the lens, in spite of repeated wipings, is worthy of notice.

On the near approach of the lens to the under surface of the glass under notice, the scattered drops suddenly coalesce, shooting out into a film of varying colour.

On one occasion a small oil-drop, one hundredth of an inch in diameter, appeared as a black annulus enclosing a bright thin ring of light, which enlarged on being touched by the prism-lens by the advance of the screw. It spontaneously then spread out and rapidly exhibited

within its centre a sudden display of very minute but richly coloured Newtonian rings, formed in this case by interior reflected light, although transmitted light was then being employed.

It is not absolutely necessary that a plate of glass with precisely parallel sides be used. A wedge can be manipulated if a particular spot be chosen and the wedge be most carefully adjusted to the same position by means of the stop and ledge on the stage. Less difficult, however, is glass formed into a plano-convex lens of long focus, the plane side being placed downwards, and the same point, the summit if possible, being always selected for observation: better still if a slice be cut off so as to present a secure fixing of the lens in the same position.

A variety of substances formed into plates, wedges, or lenses, with little convexity, may thus be examined, as also fluids enclosed between parallel plates.

V. "Description of a Mammalian Ovum in an early condition of Development." By Edward Albert Schäfer, Assistant Professor of Physiology in University College, London. Communicated by Dr. Sharpey, F.R.S. Received March 8, 1876.

[Plate 10.]

The opportunities which present themselves for the acquisition of the ova of Mammalia during the early stages of development, and especially ova of the period during which the formation of the blastodermic layers is proceeding, are so rare that, although the subject has been under special investigation by more than one observer, all the stages of the process of formation have by no means as yet been described; and much remains to be discovered in connexion with this phase of development alone. It seems on this account desirable to publish observations bearing upon this question, although they are limited to two or three or even to a single ovum, since it is by collecting and comparing the results which have been arrived at by different observers that there will be the best chance of coming to a definite conclusion upon a subject which involves the knowledge of every progressive stage.

I have been induced by these considerations to furnish a short description of an early developing ovum (of the cat) which came into my hands now fully two years ago, but which I had continually deferred the account of in the hope of obtaining specimens a little more in advance with which to compare that which I already had. This expectation having, however, hitherto been disappointed, I think it better to communicate the description without further delay, as it may at least serve for comparison with the statements of other observers.

In a cat which had been just killed, I noticed on opening the abdomen