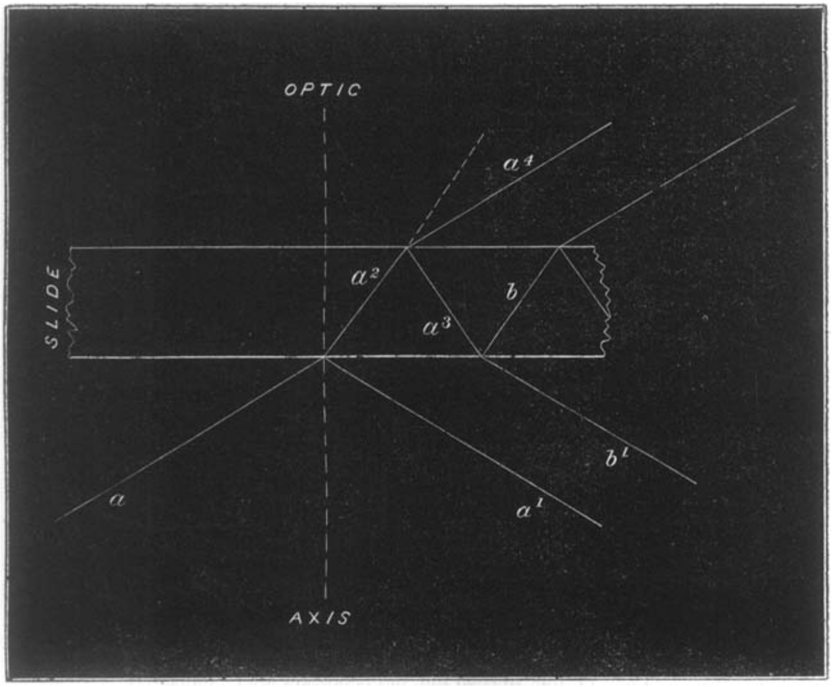
III.—*Note on a New Paraboloid Illuminator for use beneath the Microscope Stage. Also Note on the Resolution of Podura Scale by means of the New Paraboloid.*

By James Edmunds, M.D., M.R.C.P. Lond., &c.

(*Taken as read before the* Royal Microscopical Society.)

The glass paraboloid, known as Mr. Wenham's, is so useful an accessory that no microscope is complete without it; and, for dark-ground illumination, with dry-front objectives up to a considerable angle of aperture, the results are excellent. But with high powers of large angular aperture and with immersion fronts, the Wenham paraboloid introduces fog, while it fails to give a dark background. That these radical defects are inseparable, not merely from the Wenham paraboloid, but also from all our present contrivances for oblique sub-stage illumination, will be obvious to everyone on considering the following diagram.



Assuming that, by means of Wenham's paraboloid, a long focus objective, or other contrivance, a pencil of light be successfully thrown upon the under surface of the slide at an angle of 60°

from the optic axis, we get the following results. The ray *a* is in large part reflected from the under surface of the slide, as *a* 1, and the proportional magnitude of *a* 1 will increase in a great ratio as the obliquity of *a* itself augments. The reflected ray *a* 1 falls into the spherical hollow of the paraboloid, or upon sub-stage fittings, and in considerable part is reflected back into the slide at low angles. *a* 1, therefore, is not merely lost, it is detrimental by fogging the illumination. *a* 2, on entering the slide, undergoes refraction, and, assuming a low index for the slide (1·5), it will be seen by a simple geometrical construction or by reference to the table of sines that it reaches the upper surface of the slide with its obliquity reduced to about 35°. Its achromatism also will be damaged in proportion to the thickness of the slide. At the upper surface of the slide *a* 2 undergoes a second division into *a* 3 and *a* 4, *a* 3 being reflected back in the slide to its lower surface, where it splits into *b* and *b* 1. *b* 1 passes out below, falls upon the sub-stage fittings, and, in part, returns into the slide at low angles to add to the detrimental effects of *a* 1. *b* goes on repeating the results produced by *a* 2, and at each cycle in its course, throws a ghost image into the field.

Returning now to the remainder of the original pencil *a* 4, it will be seen that it passes out through the upper surface of the slide; and the ray, thus reduced in obliquity, weakened in power, and damaged in colour, enters any object which is optically continuous with the slide. Otherwise the ray undergoes a second refraction, and strikes the object or cover-glass at the original angle of 60°. Thus in any case the ray which enters the object is enormously weakened in power, and is more or less chromatized, while the illumination of the field is damaged with fog and with ghost images. And if the obliquity of the original pencil be made greater than 60°, the drawbacks all increase in a great ratio.

While working at difficult objects with high powers, it seemed to me that all these disadvantages might be got rid of, and our command of oblique sub-stage illumination made perfect by the new paraboloid of which I now submit a description, and which, having been constructed for me by Messrs. Powell and Lealand, has fully answered the expectations which were raised by optical and geometrical considerations.

A paraboloid lens of glass, free from veins and from colour, and of the lowest obtainable refractive index, is made. The apex of the lens is cut off at a point, one-twelfth of an inch below its *latus rectum* or internal focus. The whole surface is brought to an optical polish. The lens is set with its base left clear as far as possible, and with a flat shoulder projecting about one-fiftieth of an inch below its face, so that diaphragms may be adjusted to work against this shoulder, close beneath the base of the lens, without abrading its surface. By an arrangement which it would be difficult to make clear without diagrams, any combination from a set of central disks, peripheral zones, and revolving shutters can be so placed beneath the lens, as to admit light in any or every azimuth, and at any or every angle, and the light may come through a stage of any depth, from a simple plane mirror. In short, a splendid pencil of pure unrefracted light may be easily converged upon an object placed at the focus of the lens, if only the object be made optically continuous with it by means of a fluid or cement which is optically homogeneous with the lens.

If the lens be adjusted with a central disk stopping out from its base only such light as would pass directly through the upper plane surface, and sunlight be thrown up, the action of the lens is demonstrated with great splendour. The plane top throws back all the light by total reflection, and remains itself perfectly black, when viewed from above. But, if there be dust resting upon the plane, each particle becomes brilliantly luminous where the light from beneath impinges, and if, for the purpose of demonstration, the top be smeared with wax, or have tissue paper gummed on to it, there is seen a brilliant circle of light surrounding a sharply defined central black disk, about a fourth of an inch in diameter.

On placing upon the top of the lens a plate-glass slide one-sixteenth of an inch thick—fine tissue paper having been gummed on to the upper surface, and a drop of glycerine used below to cement the slide to the paraboloid—a central focus of intense white light is seen on the tissue paper. On lowering the paraboloid, but not sufficiently to separate the film of glycerine, this brilliant focus spreads into a small circle with a central black spot—the tissue paper having been raised above the focal point. If in place of the tissue paper there be cemented on to the slide a hemisphere of glass, and, by the stage movements, the centre of the plane surface of the hemisphere be located at the focus of the paraboloid, then all the light which reaches the focus diverges again and passes out through the hemispherical surface at a few degrees above the horizon without refraction. Here, while the eye in every azimuth at that angle receives a brilliant picture of the sun, no light whatever is received by the upper portion of the hemisphere. If the optical continuity between the slide and the paraboloid be broken by lowering the paraboloid until the film of glycerine be separated, the image of the sun instantly disappears, all the light being then thrown back out of the base of the paraboloid.

I find that the glycerine film makes the slide optically continuous with the top of the paraboloid, and at the same time acts as a perfect lubricant, allowing the slide to travel over its surface in any direction as if it were perfectly free, and without damaging its optical continuity with the lens. By lowering or raising the lens also the film of glycerine may be so far thickened or thinned out, as to give ample range of focal distance between the reflecting surface of the paraboloid and the object. Thus, by very simple management, an object under Powell and Lealand's twenty-fifth, sixteenth, or new immersion eighth of 140°, may be bathed in light until it glows with luminous radiance upon a perfectly black background. By slight alterations in focussing, or in centring the paraboloid, the light upon the object may be made converging or diverging, or it may be instantly extinguished. By extremely small inclinations of the plane mirror beneath, the paraboloid is made to act as a powerful prism, and the object may be bathed with a pure broad band of monochrome, from black-red through a brilliant luminous green, on to blue, and black-violet.

Amphipleura pellucida, in this pure white light, shows like a transparent three-edged file floating in black space and glowing with its own radiance. On slightly inclining the mirror, the diatom becomes black-red or disappears. On the tenderest possible further alteration of the mirror, the diatom stands out as luminous as before, but in splendid green with its cross-markings in black; as the inclination of the mirror is increased, the diatom becomes pure blue, then violet and hazy, and then again invisible. On slowly restoring the mirror to its original position, the diatom travels backwards through the same phases, but its cross-markings only come out well between the bright blue and the low green, and they are most distinct where the low blue merges into splendid green. Other objects such as *Navicula rhomboides*, which are in themselves prismatic, of course add their *quota* to the grand play of colours produced by the prismatic action of the parabolic lens. Such objects as give coloured images from illumination by pure white light may generally be viewed in red, green, or blue separately, by inclining the mirror or by focussing the objective. Taking the pure luminous green as the best image, the red comes out on shortening the focus of the objective, the blue on lengthening it. Moreover, these prismatic images, and the well-known diffraction bands, may be developed so splendidly by the paraboloid, that their images will probably become as useful for the measurement of extremely delicate objects in the field of the microscope, as Newton's rings have proved elsewhere for calculating magnitudes infinitely too small for mechanical measurement.

Bacterial fluids have been the despair of microscopists. Under the best modern immersion objectives, many important specimens give only a foggy, impenetrable field, in which dim spheroidal forms start into view only to fade out again and be lost in fog. If the new paraboloid, tipped with glycerine, be inserted into the substage, and gently racked up until its glycerine suffuses the under surface of the slide and spreads out so as to render the lens and the slide optically continuous, we get a new view of bacterial fluid. On looking into the microscope, the field is seen—clear as a glass tank in which thousands of minute fish are disporting themselves. Just as, in the heavens, a mass of nebula is resolved by the great reflector into a universe of stars, so, in the field of the microscope, an unweighable particle of foggy fluid is transformed by this paraboloid illuminator into a limpid pool tenanted by myriads of atomies. These atomies, if they have any theories of the future, must be thinking that a final conflagration of the universe has commenced. Observers may watch them as, on a summer evening, with soft white clouds behind and pure sky in front, boys look into a clear pool and see the life of the frogs and the minnows. Immeasurable in their minuteness, these atomies gyrate upon the field, and from point to point they urge their way with vast activity. Some of them appear like winged creatures, others are furnished with whorls of cilia, and some are seen as amœboid masses lazily digesting particles of solid matter.

Blood and saliva also may be seen as new objects. If fresh transparent blood-serum with a few corpuscles shaken out of the edge of the clot be viewed, the serum is seen filled with a nebulous haze of points, as is mote-laden air in a sunbeam or in the electric light. Isolated corpuscles appear as lenticular or flattened spheroidal masses of pale red amœboid matter. Other corpuscles have massed themselves into large rouleaux—not nummiform, but like rouleaux of dried figs—their exterior outlines showing as if their whole surface were self-luminous, the septa persisting and the corpuscles being easily separable. On pressure, the corpuscles fuse into large amœboid masses, and may be again broken up into corpuscles of various sizes, some small, some large, but not otherwise distinguishable from the original corpuscles. It may be that blood-corpuscles are formed mechanically by the capillaries through which the blood with its amœboid matter is continually being lashed, and that their continual re-coalescence is prevented by some modification of their exterior which is produced by the action of the serum. If this be so, the size of the corpuscles in various animals will prove to be a measure, in some simple ratio, of the calibre of their capillaries. I have just examined some blood taken from a gentleman dying of malignant pustule of the upper lip, and for whose treatment I have met Dr. Gomer Davies, of Bayswater, several days in consultation. The blood was drawn by myself twelve hours before death from a puncture in the cheek near the local disease, and was venous in colour. The tube was of Bohemian glass, heated to redness in a Bunsen burner, then drawn out and hermetically sealed. The points were broken off immediately before drawing the blood up into it, and were again at once hermetically sealed. Six hours afterwards I broke open the tube and examined the serum with some loose corpuscles. Upon this specimen I have based the description given above. I regret that, owing to the absence of sunlight at the critical time, and my own want of a heliostat, I could not get light enough to define the character of the nebulous points in the serum, or to determine the question as to their motility. Certainly, however, this serum contained no moving forms such as would ordinarily be recognized as Bacteria. The serum was quite free from that mere chylous milkiness often seen in blood drawn soon after a full meal.

Salivary corpuscles show up magnificently as spheroids of all sizes floating in a sky intrinsically dark, but lighted up by tracts of "milky way," and flecked with masses of heavy greyish-white cloud. The corpuscles, instead of being distorted by foreshortening into mere disks, appear as self-luminous spheroids, like moons, their nucleolar matter distinctly visible inside the sphere, and each one giving an image free from distortion by its own lenticular action on transmitted light. The "milky way" is like the opaline haze of the blood-serum, but not uniformly diffused through the field, and consisting of spheroidal particles rather than points, some of the spheruloids approaching in size and character to the corpuscles which alone are ordinarily seen. The heavy clouds are "epithelial scales," appearing, however, not as scales, but rather as irregular dodecahedral masses, and each one revealing from within a microcosm of its own.

In using a balsamed object with a very fine dry sixteenth by Powell and Lealand, no light whatever comes up through the cover except that which is seen in the microscope by the radiance of the object itself—the background remaining a soft black. With their new immersion eighth or sixteenth the appearance in the microscope is exactly the same, but the drop of water before the lens glows with horizontal radiance so as to become a sparkling and conspicuous object at many paces distance.

The first lens made for me by Messrs. Powell and Lealand was cut so perfectly as to answer exactly to the theory of its design. But this lens being calculated for a slide one-sixteenth of an inch in thickness, of course only gives light up to an angle of about 80° —a large belt of surface below the *latus rectum* having been cut away. These gentlemen are now making for me a second lens with the apex cut off at a point only one-fiftieth of an inch below its *latus rectum*, and, with such a lens, objects may be illuminated with light nearly up to their own horizon. But the mounting must be such that the object with its vehicle, slide, and subjacent film of glycerine, must come within the thickness of one-hundredth of an inch so as to allow a second hundredth of an inch in vertical sub-stage movements, for the purpose of altering the focus of the paraboloid when it requires to be exactly centred to the optic axis. If light beyond this angle be required, a third lens may be constructed with its apex cut off just below the *latus rectum*, and, upon the face of such a lens, a particular object may be set in glycerine or balsam, or may be merely attached to the surface. By stopping out light from the base with a central disk equal in size to the top plane, *plus* a peripheral zone, wide enough to stop out all rays which will not reach the focus at a sufficient angle, it is clear that an object may be drenched with unrefracted light converging upon it at practically 90°, and from as large an arc of its own horizon as may be determined by the use or disuse of the revolving shutters beneath. By cutting off the apex between the *latus rectum* and the *vertex*, then turning out through the top plane a lenticular cavity—its surface being a portion of a small sphere, and its centre of curvature located at the focus of the paraboloid—pure unrefracted light, considerably beyond the angle of 90° even, may be converged upon an object set near to the focus. The cavity may be occupied by gelatine, balsam, water, castor oil, or other medium in which it is desired to set the object, the refractive index of the medium being of no consequence in this construction; and a very high power might be brought to bear upon an object carefully set for a special investigation if covered with a small disk of thin glass. Or an object uncovered, or dry, might be supported near the focus of the paraboloid by a loose wad of curled hair or other material, the image of which would not blend with that of a delicate object. Possibly, by such a paraboloid, the illumination of an object may be made to reach the point where it could be taken up from above the stage by a fine parabolic Lieberkuhn or other reflecting appendage to the objective. Four such lenses would form an exhaustive series, and only one set of diaphragms and sub-stage tubing would be needed.

It is important that the glass of the lens be of very low refractive index, and that the optical media between its top plane and the object be as nearly as possible of the same refractive index as the lens—otherwise in using light at nearly 90° from the optic axis of the microscope slight differences in refractive power between the paraboloid, the cementing fluid, and the slide will come into play at the junction surfaces and deteriorate the illumination.

I fear lest in submitting this description I have occupied too much space. But I find, practically, that these new paraboloids go as far beyond the Wenham paraboloid as the Wenham paraboloid goes beyond the spot lens. In amount of light, in purity of colour, in freedom from fog and from ghost images, in range of azimuth and of angle, and in mechanical adaptability to every microscope, they are unexceptionable. They fill a gap in our illuminating appliances which, of late years, has been increasingly felt, and they lift the microscopic objective to a new level. They are, moreover, if well made, as manageable in practical work as they are perfect in optical principle. So far as I am aware, no previous appliance has ever converged upon an object unrefracted high-angled all-round light, so as to make it appear in the field of our best modern immersion-objectives as a brilliant shadowless picture floating in black space, like a star in the field of the reflecting telescope. In any case, those who have more time and ability than myself for microscopic manipulation will give to this appliance such welcome and development as it may deserve.

Note II. On the Resolution of Podura Scale by means of a New Paraboloid Illuminator.

By James Edmunds, M.D., M.R.C.P. Lond., &c.

(*Taken as read before the* Royal Microscopical Society.)

I have a large and finely marked Podura scale mounted upon an ordinary slide, and covered with ·003 glass. Placing this upon the new paraboloid, I find that by the aid of Powell and Lealand's twenty-fifth, sixteenth, and new immersion-eighth—working the scale up to about 2500 diameters under careful illumination from a white sunny cloud—the markings are, at various stages of the amplification, resolved into beautiful plumules or featherlets which appear to be exactly analogous to the scales upon the wing of a moth or butterfly. Each plumule stands out distinctly in fine definition, and is beautifully lighted up all round as if from above, while one looks down between the plumules on to a blue-black hyaline membrane from which the plumules spring—all the rest of the field being bistre-black. One can also see that the serrated margin of the scale is due to the overlapping of the ends of the plumules. This test-scale measures nearly the $\frac{1}{400}$ inch in extreme breadth, and fully the $\frac{1}{125}$ inch in length without the pedicle. The "test-scales" only differ from the other scales in that the featherlets are more finely developed, and I find that I can show the featherlets on almost all the scales irrespective of size. The rounded ones have their featherlets more like hairs, and they are often disposed in a vorticose manner, whereas the elongated test-scales have fully developed featherlets mostly disposed in a direction parallel to the long axis of the scale, and therefore not shadowing each other so much in the picture formed by transmitted light.

At one or two points where my scale has been blistered by the focus of the paraboloid, or has in some other way been damaged while under this work, the bare membrane of the scale can be seen, and on the black field some torn-off plumules may be distinguished. When I first observed the abraded portions of the scale, it appeared