II.—ADVANCES IN THE DESIGN OF THE INVERTED PRISMATIC MICROSCOPE.

By John McArthur, M.R.C.S., L.R.C.P., F.R.M.S.

Director of Malaria Research ; N. Borneo, Sarawak and Brunei.

Five Plates and One Text-Figure.

Twelve years ago a microscope design was published (McArthur, 1933) which introduced a completely new principle. This design was then very immature and had many weaknesses, but during the subsequent years of practical experience with the instrument, in the laboratory and field in different parts of the world, a more perfect design has been developed, which, it is found, has a number of advantages over the conventional microscope. The advances made in the design and the advantages claimed for it are summarized in the following pages.

This microscope was originally described as "a new type of portable microscope." It must, however, be emphasized at the outset that this is not now intended to be essentially a portable microscope, and that this title is inadequate. It does happen to be extremely portable, and to have other qualities of rigidity and convenience which make it the travelling microscope *par excellence,* but these are not the advantages by which it now claims attention ; and to regard it merely as a portable microscope is to overlook its greater value as a laboratory and research instrument.

Principles of the Instrument.

The chief advantages of this microscope are : its simplicity and easy handling, all the controls being operable without removing the hand from the fine adjustment knob ; its automatic focusing ; and its ability for a number of unusual activities. It is believed that it can perform anything of which the conventional instrument is capable, in some cases better, and that it can perform a number of operations of which the conventional instrument is incapable. It is, moreover, only the size of a small miniature camera.

The essential feature of the instrument is that the slide is inverted on the stage, with the objective below and the condenser above. This necessitates a prismatic system to direct the light from the inverted objective into a downward-directed eyepiece. A number of other innovations are made, but this feature is the essential part of the design, and upon this inversion of the slide most of the other improvements depend.

The arrangement of the instrument and its very small size will be appreciated from the drawing to scale and from the accompanying photographs—Plates I and II ; while the optical arrangement is illustrated in Plate III.

The Inverted Stage.

The inverted stage, illustrated in Plate IV, is made of metal, 2 inches square, supported from below by the microscope casing, of which it forms a part. It is recessed to accommodate the projecting cover-glass, and grooved longitudinally to allow the passage of the objectives from back to front.

Upon this stage the slide lies transversely, face downwards, resting upon two narrow ledges. The objectives are below, directed upwards, and mounted in a straight line on a plate, so that they may be brought into position one after the other beneath the specimen.

It would at first sight appear that such an arrangement would have many disadvantages and few advantages. For example, it might seem that the cover-glass would fall off a very wet specimen and that immersion oil would run down over the objective mount. Such, however, does not occur in practice, and while the design has certain disadvantages which will be considered later, these are trivial; on the other hand, it has enormous advantages which commend it for general laboratory use and for a number of special activities.

Advantages of the Inverted Slide.

The advantages of the inverted slide can be summarized as: automatic focusing; simplified and safer adjustment of high-power objectives; simpler adjustment of condenser and for critical illumination; erect image; simpler centring of object; the ability to examine *lying*-drop preparations and to carry out micro-dissection, staining under direct observation, and such manipulations even under oil-immersion; and a number of other unusual but useful operations.

Automatic Focusing.

Since the slide lies face downwards on the stage, the object, being on the face of the slide, lies always in the same plane as the stage. Thus the thickness of the slide makes no difference to the position of the object and focusing is automatic. Once the objective is focused for one specimen, it remains so for all specimens, except for the slight adjustment that is necessary for focusing through the thickness of a section or that may be necessary to compensate for different cover-glasses; and, since the objectives are parfocal, focus remains unchanged for any specimen and for each objective.

It is found in practice that every specimen, even under observation with the 2-mm. objective, is in focus immediately it is placed on the stage, and requires only a touch of the fine adjustment to sharpen up the focus. No coarse adjustment is necessary and only the minimum of fine adjustment is used.

Further, it is unnecessary to rack the oil-immersion objective away from the object in order to change the slide. The oil-immersion objective remains in place, in focus, ready for the next specimen.

The advantages of this are considerable. Operation of the microscope, especially with a high-power lens, becomes much more rapid and simple than with the conventional stage.

For the same reason, the possibility of damage either to lens or specimen during adjustment is greatly diminished. If the microscope is in order it is impossible to foul the slide when it is on the stage, with the objective ; and even were it possible to force the lens up against the slide, this would merely raise the slide from the stage.

Erect Image.

The inverted image of the conventional microscope, although of little trouble to the expert, is very disturbing to one not accustomed to it. With the inverted stage, however, it is very simple, by a prismatic arrangement, to produce an erect image ; and this is of value not only to the beginner but also to the expert for dissection and a number of other activities.

Simplified Centring.

A less obvious advantage, but one equally valuable in practical operation, is the fact that with an inverted stage centring is simplified.

In the first place, the slide projects over the edge of the stage and is more easily grasped and manipulated by hand than on the conventional stage. Secondly, the object can be seen by the naked eye as it lies over the objective, and can easily be positioned over the centre of the lens. This applies as much to an object under the oil-immersion lens as to one under the low- or high-power dry lenses. If desired, the object can be examined by a magnifier—the condenser, for example—while it is under focus by the oil-immersion lens.

Further, the inverted stage presents the opportunity for using a very simple but effective method of centring objects and for recording their position for future use.

This device consists, in this arrangement, of a fine line drawn transversely across the stage through the optic axis of the objective. On each side of the stage, at the point where this line meets the outer edge—which is exactly 1 inch from the midline—two other fine lines converge to form a small broad arrow.

If a slide is placed on the stage, held transversely by the mechanical stage, and an object centred in the field of view, then the point of this broad arrow coincides with a point on the slide exactly 1 inch to the side of the object under examination, in a line parallel with the edge of the slide. If a small ink spot is made on the slide exactly over the arrow-point, then whenever the slide is returned exactly transversely to the stage and this ink spot positioned over the arrow-point, the object must again be centred.

Further, by placing an ink spot eactly 1 inch lateral to any object on a slide—with the assistance of a simple template—the object can immediately be centred in the same way. If no mechanical stage is used to maintain the slide exactly transverse, then an ink spot on the arrow-point on each side of the slide will be necessary.

Improved Control of Illumination.

Since the objective is virtually fixed and moves through only a small fraction of a millimetre during focusing, the condenser also can remain always in focus, and normally requires no adjustment. Further, since the condenser is above

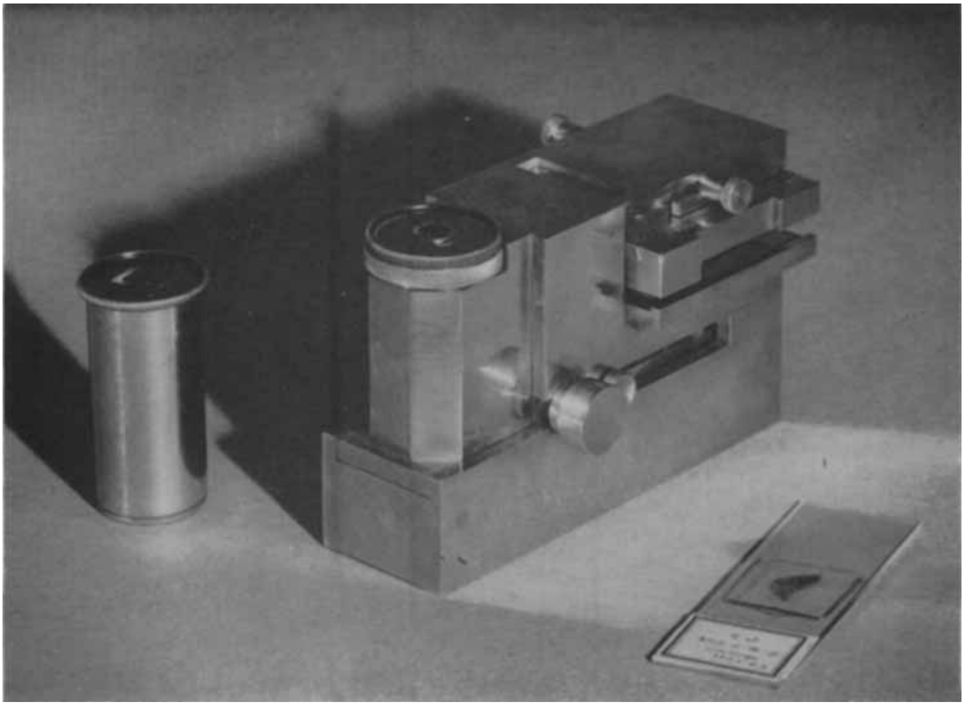

Plate I.

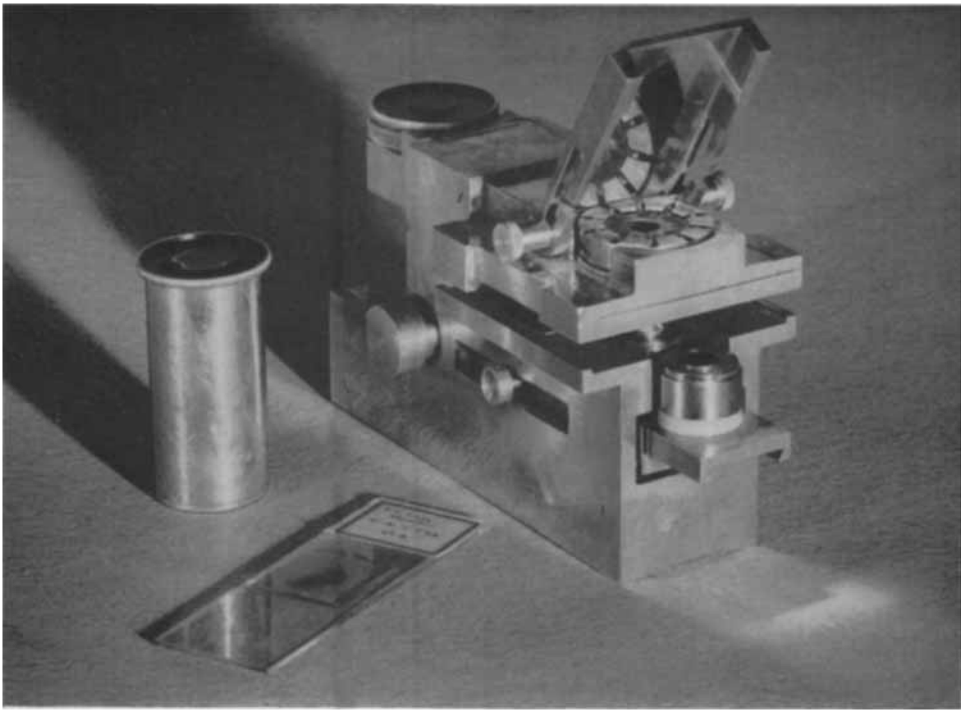

Plate II.

[*To face p.* 10.]

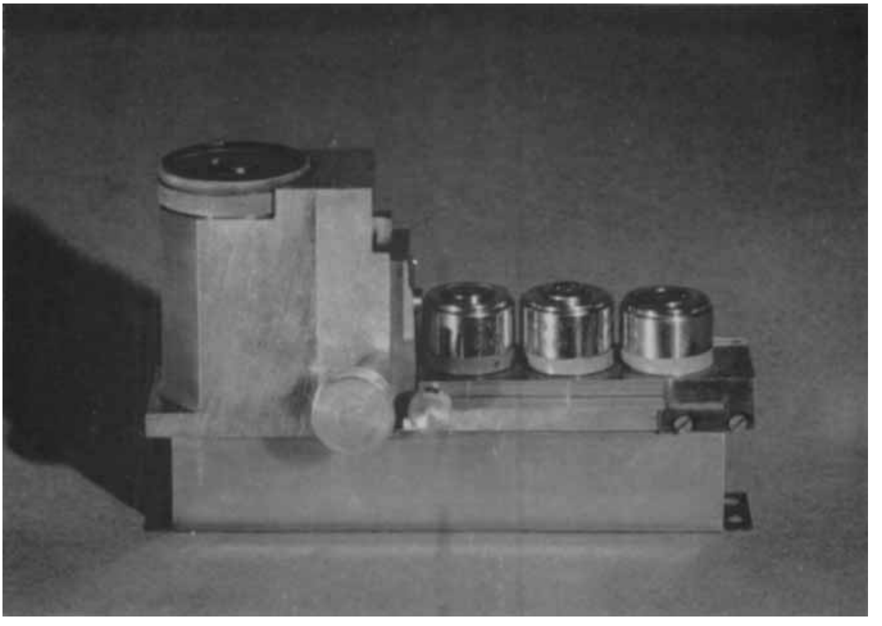

Plate III.

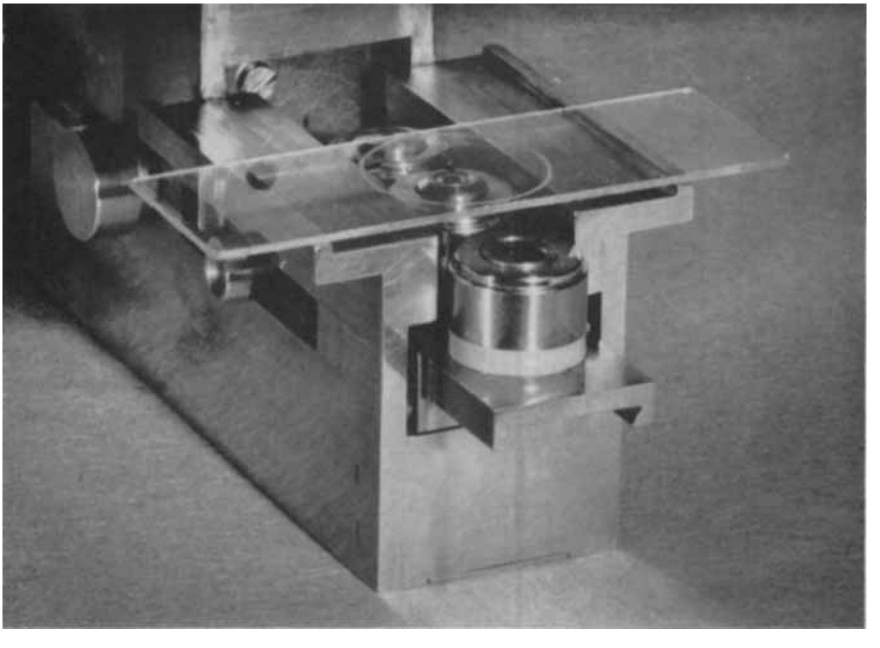

Plate IV.

[*To face p.* 11.]

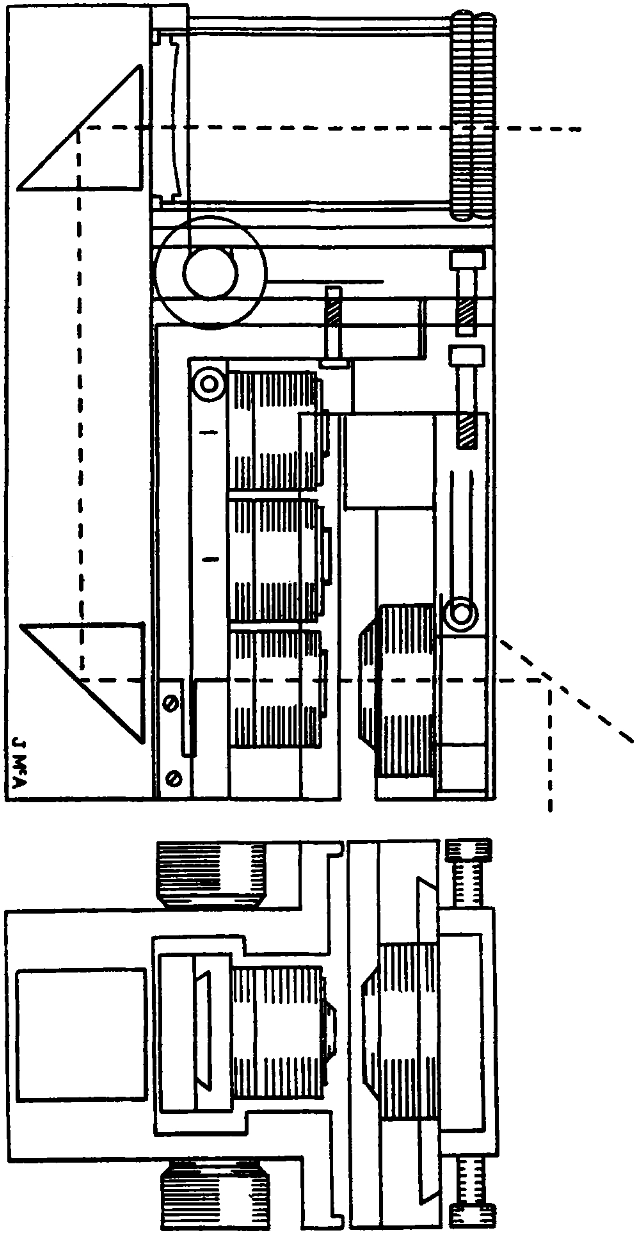

Fig. 1.—The McArthur Microscope, drawn to scale.

the object, the iris is now easily visible and accessible, and consequently in a position much more in keeping with its importance in the operation of the microscope. The removal and interchange of condensers are also facilitated.

This arrangement, with fixed condenser focus, visible iris, and convenient interchange of condenser, is more convenient for the achievement of critical illumination.

Lying-drop Preparation.

A *hanging*-drop preparation, as used in bacteriology, is not only troublesome to make but has the disadvantage that the surface under observation is curved, difficult to focus, and vibrates with the slightest movement.

With an inverted stage, a *lying*-drop preparation can be very easily made, simply by placing a drop of the fluid for examination above 3×1 inch cover-glass, and this has the advantage that the part under observation is flat, is easily focused, and does not readily vibrate.

Micro-dissection, Staining, and Other Manipulations.

With the conventional microscope, micro-dissection and other manipulations can be carried out, but with some difficulty owing to the short working length of the lens, under a high-power dry objective, but these are obviously impossible with the oil-immersion lens. Staining can be carried out to a certain extent under the cover-glass with an oil-immersion lens, but this is troublesome and its value is limited.

With the inverted stage a number of such activities can be carried out with ease, and unimpeded by the short working length of the objective or the presence of a cover-glass. A wet blood film, for example, placed *above* a 3×1 inch cover-glass and examined from below, can be observed as it dries with an oil-immersion objective, and stains or chemicals can be added or washed away immediately, and the whole effect of the reactions can be observed from the beginning in a way that opens up a useful field of work.

Similarly, with an inverted stage the sediment at the bottom of quite a large vessel of water can be examined with the oil-immersion lens ; both sides of an object, mounted on a 3×1 inch cover-glass, can be examined merely by turning the glass over ; and many other such activities suggest themselves in the course of routine work.

Disadvantages of the Inverted Slide.

It has been stated that the risks of the cover-glass falling off wet preparations, or of immersion oil running down over the objective mount do not exist in actual practice. Using even very wet preparations, such as mosquito larvæ in water, the cover-glass remains in position by capillary attraction ; and during the course of years of blood examinations, oil has never been found to run down over the mount.

The actual disadvantages of the system are that a prismatic system is used, with a small degree of light-loss, and that examination is limited to the middle part of the slide, corresponding to about half its area.

A prismatic system, however, is now widely used for inclined and binocular tubes and other accessories, so that the theoretical loss of light cannot be considered to be seriously detrimental.

With the limitation to the middle half of the slide, there is an area at each end, roughly equal to that of the label, which is normally beyond the scope of examination. It will be found, however, that in actual experience it is seldom desired to examine more than this, and it is rarely that it cannot be avoided ;

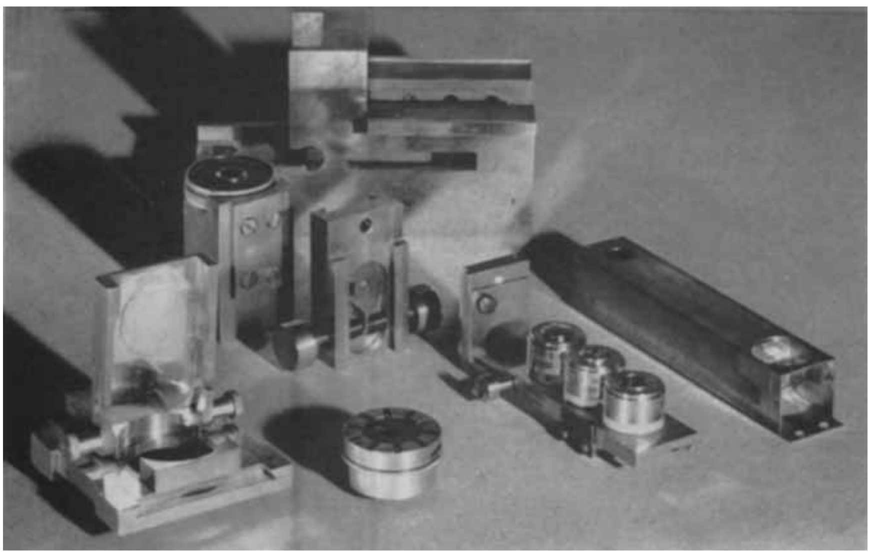

Plate V.

[To face p. 12.]

but even on these rare occasions it is possible quite simply to build up three slides together with a drop of balsam or even water, and in this way to bridge the required distance.

There are in addition certain trivial precautions which need to be observed, but which soon become second nature. For example, while it is impossible to foul an objective with a slide, it may be possible to foul an objective with a thick ring of cement ; but to avoid this soon becomes instinctive.

The Inverted Prismatic Microscope.

Several instruments, based on the principle of the inverted stage, with all its advantages and embodying a number of other improvements, have been made. The most satisfactory of these designs, that illustrated in the accompanying Plates, has given excellent service in my laboratory for several years. The component parts are illustrated in Plate V, and it is described in the following paragraphs.

This instrument carries standard optical equipment, normally 16-mm. (or 8-mm.), 4-mm., and 2-mm. oil-immersion objectives in short mounts, condenser and iris diaphragm, and standard eyepiece. Tube length is 150 mm. without the drawtube. It measures only $4 \times 3 \times 2$ inches, so that it would be possible to accommodate several dozen of the complete instrument in the wooden case necessary for one conventional type instrument. Its compactness, however, is not due to any collapsible structure. On the contrary, it is remarkably solid and free of moving parts, and its small size is entirely due to the new principle on which it is based.

This microscope is constructed entirely of fine metals, brass, manganese-bronze, and stainless steel, chromium-plated throughout to resist chemical and other corrosion. It would be possible, by the use of aluminium, magnesium, or alloys, or even plastics, to reduce the weight far below the present massive 3 lb., but for great stability and for laboratory use this weight is found in practice to be ideal, and not excessive for travelling purposes.

The instrument is kept in a chromium-plated, airtight and watertight metal case, equipped with silica gel desiccator to preserve the lenses, and measuring slightly more than the microscope itself. This case at the same time makes an excellent stand for the instrument, raising it to the correct height for normal working on a bench. The microscope can also be kept in a solid hide ever-ready carrying case, preferably strapped to the belt, either with or without its airtight metal container, for travel ; and it is one of the advantages of this instrument that it can be operated held in the hand without a bench, for field work, or can be clamped immoveably to a laboratory bench.

This microscope is a very squat, massive rectangle of solid gleaming metal, with clean lines, easy to grasp, and with no unnecessary projections. Apart from the upper end of the eyepiece, which is flush with the long, flat top of the instrument, it bears no resemblance whatever to the conventional microscope. It looks, in fact, more like the silver model of a small streamlined locomotive.

Operation.

A great deal of thought has been given to making the instrument simple and, in so far as possible, automatic, in its action. There are few movements, and every effort has been made to bring all the controls within easy reach of the fine-adjustment knob.

To make the instrument ready for use all that is necessary is to slide the dust-proof cover forwards for an inch, and then to raise it to an angle, when its inner surface is exposed as a metal illuminating mirror, beneath which is visible the condenser with its iris diaphragm.

At the front of the instrument is a horizontal slot which leads to the very unusual stage. Into this slot the slide is inserted, face downwards, and as it is pressed home it locks itself in place in the mechanical stage and can then be freely moved by the controls. It will be found on looking through the eyepiece that the object is immediately visible, without any focusing or other adjustment, even under the high-power oil-immersion objective ; and that the image is erect.

Further, a built-in electric illuminator is being designed, operated from the mains or an enclosed battery, which, it is intended, will be automatically switched on when the slide locks into place and off again when it is removed.

There is no coarse adjustment for focusing the instrument. A small degree of fine adjustment is provided, graduated in microns, but this need be little more than sufficient, for practical purposes, than to move through the thickness of the object. Even this small degree of fine adjustment is very massively constructed, and the micrometer thread of the spindle, by a new design, is in contact throughout the whole thickness of the instrument, in addition to which it bears a weight of only about 2 oz., so that wear must be almost unlimited.

All the adjustments—focusing, mechanical stage, iris diaphragm, objective change—can now be carried out without removing the fingers from the fine adjustment. For example, the mechanical stage is operated by the thumb of either hand ; a change to a higher power of objective is accomplished by sliding forward a projecting knob with the middle finger of either hand. It is hoped even to incorporate the automatic delivery of a drop of immersion oil to the objective by the pressure of the thumb. The condenser requires no focusing, as it is in permanent focus, and the iris diaphragm, visible to the eye, is adjusted by *rotating the eyepiece*, to which it is directly coupled.

The method of objective change has two advantages. In the first place it is simpler to centre the objectives in a straight line on a plane surface than on a rotating nosepiece, so that centring should be more accurate. Of more practical value than this, however, is the fact that it is not necessary to look at an objective mount in order to know what power is in use, as this is known to the touch of the finger by the position of the control knob.

Although the condenser always remains in correct position, it can readily be removed and interchanged with any one of a series of illuminating units—spot lens, achromatic oil-immersion condenser, dark-ground illuminator, and so on—with the same simplicity as changing an eyepiece, since all the series of units are mounted in standard R.M.S. eyepiece fitting.

The monocular eyepiece may be replaced very simply by a binocular eyepiece without disturbing the specimen under examination ; and since the eyepiece tube has no relation mechanically with the fine adjustment, an unlimited weight of accessory apparatus can be mounted on the eyepiece without disturbing the adjustment of the microscope.

The mechanical stage is built upon a principle demonstrated a good many years ago—the use of rotating friction wheels—but a principle which was abandoned owing to the undue wear on the materials then available. It is believed that this very satisfactory system may now be practicable using modern friction materials which were not available previously.

The mechanical stage is graduated on one side in inches and on the other in millimetres, and is recessed on each side to expose the small arrow engraved on the stage for centring and permanently recording the position of an object on the slide.

Centring the object is carried out as described previously for the inverted stage : (1) by observation through the eyepiece in the conventional way ; (2) by examination of the object directly, after removing the condenser ; (3) by examining the object, magnified by the condenser ; (4) by placing a dot in the correct position on the slide, exactly over the arrow-head on the stage ; (5) by reference to the vernier on the mechanical stage ; and (6) by the rather cumbersome method of encircling the object with a ring drawn on the cover-glass. Centring is no more difficult with the 2-mm. oil-immersion objective than with the low power.

Finally, an attachment is being designed for photomicrography, whereby a 36-mm. camera can be incorporated in the instrument without interfering with routine work. When an object is seen which it is desired to photograph during the course of ordinary observation, this camera can be operated by simply pressing a button, and the work can then be continued without more than a moment's interruption. The advantages of 35-mm. film are already demonstrated in its ability to render detail, in colour or monochrome, with much more rapid exposures than can be used for larger negatives ; and the arrangement described has the additional advantages of great rigidity and simplicity of operation, without adding greatly to the small dimensions of the instrument. The complete apparatus for photomicrography should not be more than 6 inches high.

Experience under Working Conditions.

The instrument described has proved its ability under actual hard-working conditions for several years in a number of parts of the world. It has been used in some of the most highly equipped research laboratories and hospitals, and again under the most primitive of conditions. It has been used in an open boat on the Atlantic ; in an African dug-out canoe ; in camps in many places ; in native huts in the wilds of Borneo and elsewhere ; and in planes over Europe and Asia. It has been carried across by breeches-buoy from a relieving lifeboat, and taken long distances on horseback and foot. Through all these it has shown its ability to stand up to rough treatment, to be as inconspicuous and trouble-free as a miniature camera, and at the same time to carry out excellent work.

For critical laboratory work it has proved its value in its rapidity and ease of operation, its versatility, its capacity for critical work, and its ability for the unusual operation described. It was used in the field and the laboratory for the identification of scores of thousands of mosquito larvæ, for the examination of thousands of mosquito dissections, and tens of thousands of blood films in North Borneo, and was instrumental in discovering the mosquito carrier of malaria in that land.

The model used in Borneo not only proved its value in this way as a travelling and a research instrument, but showed its ability to be smuggled past Japanese guards and used in a Japanese prison camp in a way which would have been impossible with any other microscope. It is believed finally to have been blown up by a bomb after its ultimate confiscation by the Japanese. Unfortunately no trace of the instrument could be found after a week's excavation under tons of rubble, but it was felt that had it been so found, it was so massively constructed that it would have stood every chance of surviving.

As an illustration of its ability to stand up to punishment, it has been run over by both wheels of a motor-car without injury.

Thus, with this instrument, which is capable of the highest quality of work, it is possible for the student to examine his slides in a bus or tube-train ; for the busy medical practitioner to do a blood count or a " differential " at the bedside or in his car ; for the tropical medical research man to examine a blood film while standing in a native village or sitting in a canoe ; and for the biologist to examine specimens by a forest pool, in a train, or in a plane just as well as in his laboratory.

The chief advantages of the instrument, however, lie in the laboratory, where, by its ability for critical and specialized work, it is claimed that it challenges the position of the well-established conventional instrument, which has remained essentially unchanged in form for several centuries.

REFERENCE.

McArthur, J. (1934).—" A New Type of Portable Microscope." J. Roy. Micr. Soc. **54**, 182–5.

DESCRIPTION OF PLATES.

Plate I.—The McArthur Microscope, rear view, with mirror closed.
Plate II.—The McArthur Microscope, front view, mirror open for use.
Plate III.—The McArthur Microscope, optical parts (8 mm., 4 mm., and 1·8 mm. objectives, eyepiece, drawtube, and prismatic light tube).
Plate IV.—The McArthur Microscope, front view of inverted stage, with condenser iris and mechanical stage removed, illustrating automatic focusing.
Plate V.—The McArthur Microscope, showing component parts : casing ; mirror, condenser arm and mechanical stage ; condenser and iris diaphragm in eyepiece fitting ; prismatic light-tube ; objective holder ; focusing mechanism ; and drawtube.

Note.—The original instrument, having been captured by the Japanese, has been lost. The instrument illustrated is unfortunately still incomplete, and does not yet incorporate controls for the mechanical stage, nor is the eyepiece yet coupled to the iris diaphragm to control its aperture.