Eyepiece Collimation of Binocular and Trinocular Microscope Heads from Leitz' "Black Era"

Introduction

These maintenance notes describe basic do-it-yourself eyepiece collimation of binocular and trinocular Leitz microscope heads from Leitz' "Black Era" that ended in the early 1970's. These heads with an improved and modern binocular head design became a success when introduced to the microscope market in 1913 by E. Leitz, Wetzlar. The heads are known as "Jentzsch heads" after their inventor the German physicist Felix Jentzsch. One disadvantage with the early head designs was that the mechanical tube length (170 mm) changed when the head's interpupillary distance was adjusted. Later a remedy was introduced by providing *both* eyepiece tubes with length adjustment mechanisms that could be used to compensate for these tube length changes.

The heads from this period differ in features, appearance, and technical design, but the eyepiece tubes and how they are attached to the heads are virtually identical (Figure 1.) Therefore, generally the same collimation procedure can be used with them all.

Figure 1: Three different (but similar) Leitz binocular/trinocular microscope heads from the "black era".

What is collimation?

Somewhat simplified, one could say that collimation (a.k.a. optical centering) is the act of bringing into line the optical axes of all optical components, from the illumination through to the eyepieces, with the goal to make them to coincide into one common optical axis. Collimation of the entire microscope is

primarily done at manufacturing to optimize the optical performance of the microscope before it is released from the factory. Re-collimation may later be needed after maintenance/service, replacement of certain components, or when the microscope has been subject to harsh treatment.

These maintenance notes cover only basic re-collimation of the eyepiece tubes on the microscope's binocular/trinocular head. Such re-collimation is highly recommended (well, required actually) every time after an eyepiece tube has been removed from the head, typically to clean and lubricate a seized diopter adjustment or a seized interpupillary distance adjustment. Accidental bumps and shocks to the microscope head during routine use are however probably the most common causes to eyepiece miscollimation.

A more serious kind of miscollimation (which is much more difficult to remedy and best left to professional repair) happens if the prisms in the head become misaligned. The heavy prisms are cemented to thin sheet metal brackets (Figure 2) which makes them particularly sensitive to shocks. This is something to be aware of when buying a used "excellent condition" microscope head on an online auction. Careless packaging combined with brutal shipping conditions is hardly a recipe for a satisfying purchasing experience.

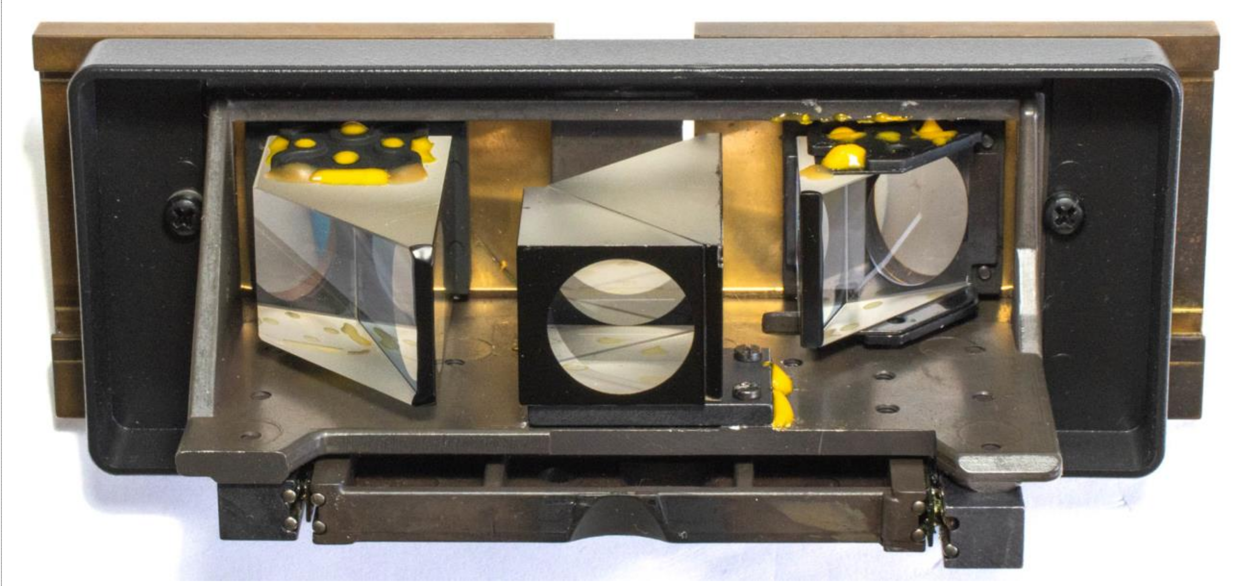
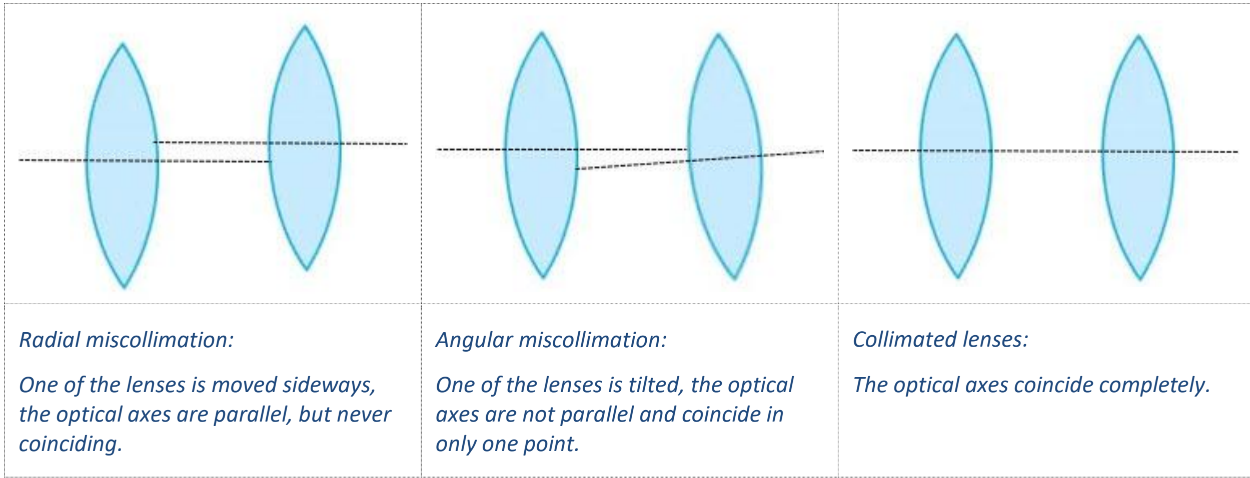


Figure 2: Prisms in the inside of a more recent Leitz microscope head. At manufacturing the heavy prisms were meticulously aligned and positioned in the black sheet metal brackets with yellow cement.

Miscollimation

Generally, optical components can be miscollimated in two ways; through radial miscollimation (a.k.a. offset or centering miscollimation), and through angular miscollimation (a.k.a. yaw) (Figure 3.) The optical paths are certainly more complex in a binocular/trinocular head than in two simple lenses, but the general concepts still are the same.

Rotation of the optical axis is a third kind of miscollimation that specifically may affect binocular/ trinocular heads. It happens when one of the eyepiece prisms has become rotated by accident (for example, due to failed efforts to repair or align the prisms inside of the head) or by a blow to the head. Prism rotation is challenging to remedy and outside of the scope of these maintenance notes.



Radial miscollimation:	*Angular miscollimation:*	*Collimated lenses:*
One of the lenses is moved sideways, the optical axes are parallel, but never coinciding.	*One of the lenses is tilted, the optical axes are not parallel and coincide in only one point.*	*The optical axes coincide completely.*

Figure 3: Illustration of miscollimation. The figures show miscollimation involving two convex lenses, but it applies to any optical components, including prisms. The dotted lines (………) represent the optical axes of the lenses. And of course, miscollimation can be both radial and angular simultaneously.

How do we perceive miscollimation?

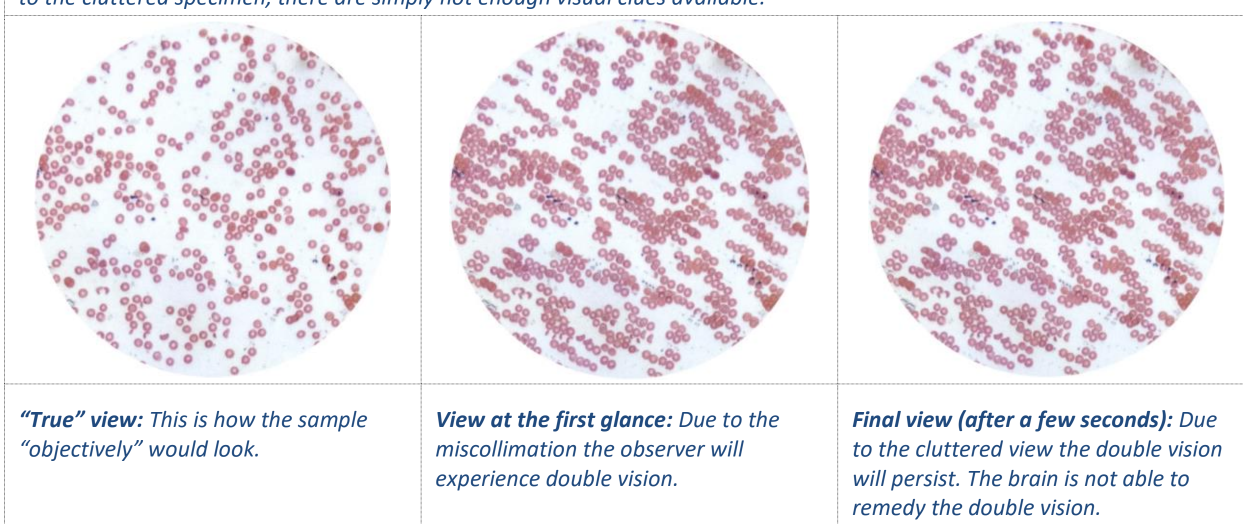
Double vision is the telltale sign that a microscope head needs re-collimation.

There can of course be different degrees of miscollimation in a binocular/trinocular microscope head. Serious miscollimation inevitably reveals itself by the unpleasant experience of double vision in the microscope. The human brain can however automatically compensate for *smaller* miscollimations without us even noticing. That adaptation can happen within a few seconds but comes with a cost - fatigue eventually sets in with difficulty to concentrate and a feeling of visual exhaustion. Furthermore, the brain relies on visual clues in the observed object. Therefore the brain may manage its magics in a view with only one distinct item (Figure 4), but completely loose it if we switch to a cluttered object, like a dense carpet of red blood corpuscles (Figure 5.)

Figure 4 (below): How the brain can compensate for a slight miscollimation when the observed specimen provides distinct visual clues (a single worm egg). Both eyes receive almost the same image, the only difference is a slight shift sideways due to the microscope head's miscollimation. Thanks to good visual clues the brain can align the images.

"True" view: *This is how the sample "objectively" would look.*	***View at the first glance:*** *Due to the miscollimation the observer will for a short moment experience double vision.*	***Final view (after a few seconds):*** *The brain brings the double vision into one succinct image.*

Figure 5 (below): How the brain may fail to compensate for a slight miscollimation when the observed specimen is cluttered (human blood at low magnification). Both eyes receive almost the same image, the only difference is a slight shift sideways due to the microscope head's miscollimation. Although the shift is small, the brain still can't manage to align the images. Due to the cluttered specimen, there are simply not enough visual clues available.

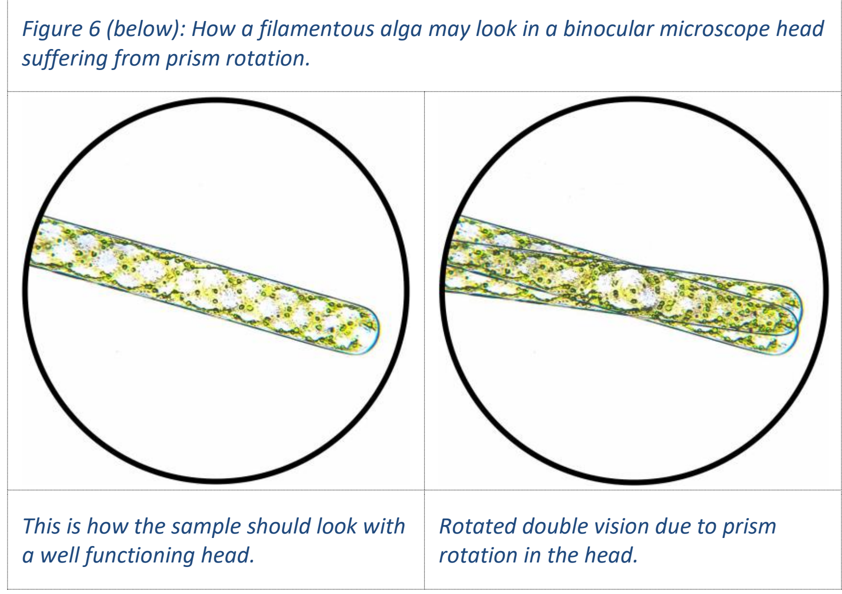


"True" view: *This is how the sample "objectively" would look.*	***View at the first glance:*** *Due to the miscollimation the observer will experience double vision.*	***Final view (after a few seconds):*** *Due to the cluttered view the double vision will persist. The brain is not able to remedy the double vision.*

The takeaway is that even though we may not experience any double vision in the microscope, we still could suffer from visual fatigue due to minor eyepiece miscollimation. So, for a pleasant and productive microscopy experience it makes sense for an amateur microscopist 1) to be able to diagnose the presence of miscollimation, and 2) to be able to fix it, at least in less serious cases. "Less serious" should be emphasized. Serious collimation remedies, like changing the prism alignment inside of the head, are difficult and risky endeavors that require expensive equipment in the hands of a skilled microscope service technician.

Prism rotation was briefly mentioned in the previous section. Figure 6 shows how a microscope view may be affected by prism rotation. It is very difficult (almost impossible) for the human vision system to compensate for this type of miscollimation. Trying to change prism alignment inside of a microscope head without the required knowledge and equipment can easily cause prism rotation that could be difficult to remedy.

Figure 6 (below): How a filamentous alga may look in a binocular microscope head suffering from prism rotation.



This is how the sample should look with a well functioning head.	*Rotated double vision due to prism rotation in the head.*

A miscollimation illusion

As an aside, sometimes one can perceive an interesting side-effect of the brain's ability to compensate for miscollimation. If the observed object has a very regular pattern the visual system can sometimes be

tricked into creating a double vision, *even though there actually is no real miscollimation*. This is an optical illusion and can, for example, happen with a stage micrometer grid (Figure 7.)

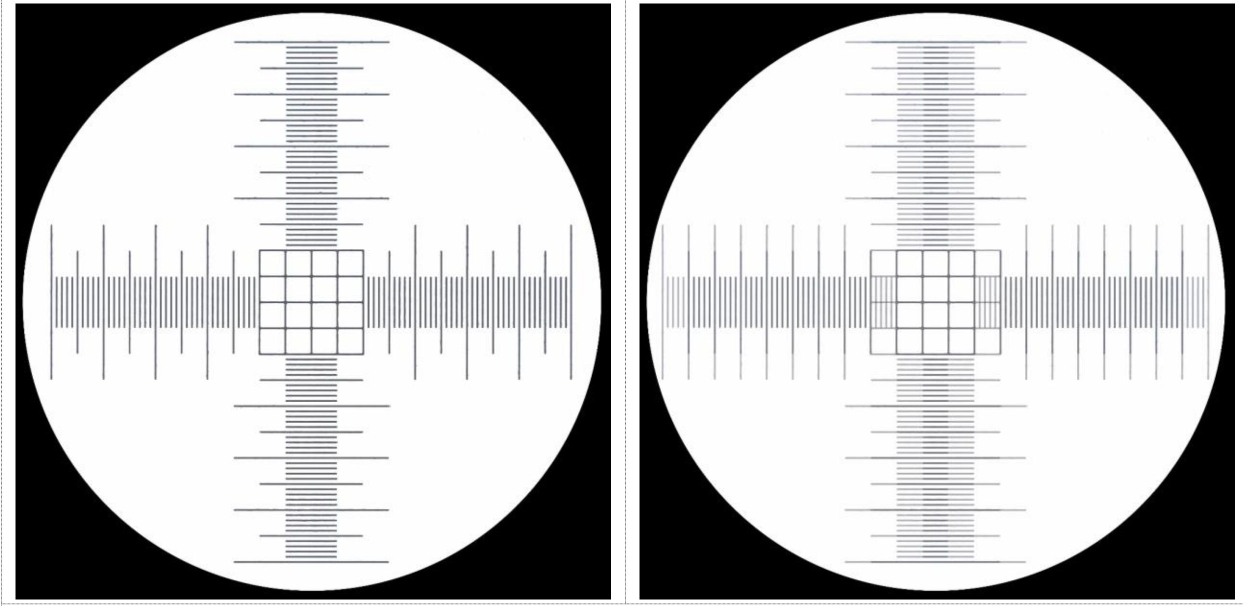


Figure 7: The regularly spaced lines in a stage micrometer grid in a well collimated microscope (left image) can sometimes mislead the brain's visual system to create an optical illusion that appears as double vision (right image.)

What probably happens is that the observer first focuses on the grid in the middle. Then the brain's visual system kicks in and tries to make sense of the two images provided by the eyes. But in the hurry, the regularity of the grid's squares may trick the brain to align the images wrongly, perhaps by one square off to the side as in Figure 7. Because most of the lines in the grid still overlap, the brain locks to that view and makes it difficult to change consciously, even though the observer may realize that it is an illusion.

Here is a suggestion for a way to overcome the illusion: Look away from the microscope and look at something far away (e.g., out through a window) for a few seconds. Return to the microscope, but this time avoid looking at the center of the grid – look instead at the upper end of the vertical scale.

Screws and screwdrivers

The screws that hold the eyepiece tubes to the microscope head require a screwdriver with a thin tip to fit into the narrow screw drives, and a rather slim shaft that is of sufficient length to reach the screws in the constrained space along the sides of the eyepiece tube.

Some non-routine equipment

Stage micrometer (a.k.a. object micrometer). A stage micrometer is an object glass with etched/printed measuring scales and/or other patterns on the surface. Affordable stage micrometers of different designs can be purchased online. The micrometer must have a distinct middle point, and preferably also a graduated scale both horizontally and vertically. Figure 8 shows the microscope view of one common design that is useful for our purpose. The center point of the grid will be our aiming point for the collimation, and the scales will help to provide a semi-quantitative estimate of any miscollimation.

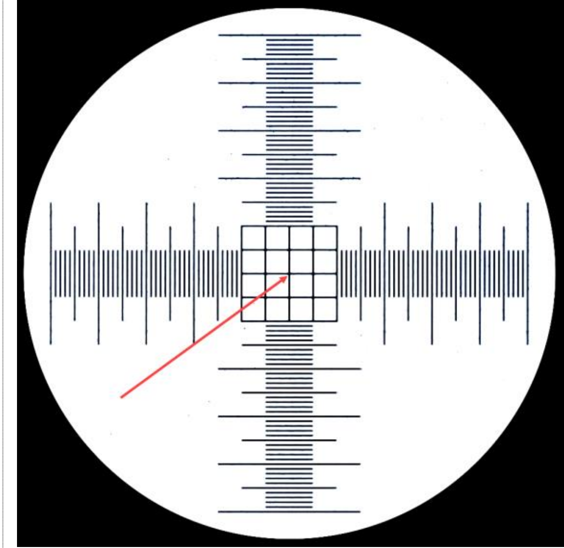


Figure 8: Graduated crosshair on a stage micrometer. This is a typical view using a 10x microscope objective and a 10x eyepiece. The width of the image is 1 mm, and each fine division of the graduated scale measures 0.010 mm. *The red arrow added to the image points to the center point of the stage micrometer.*	*Figure 9: Focusable Leitz Periplan eyepieces with internal crosshairs. The image shows two identical eyepieces with different focus settings on the adjustable eye lenses.*

<u>Focusable eyepiece with a crosshair</u>: This is like a regular microscope eyepiece but with an internal crosshair disc and an eye lens that is adjustable for setting the focus on the crosshair (Figure 9.)

During the collimation procedure the eyepiece will be moved back and forth between the head's eyepiece tubes (and the phototube, if the head is trinocular.) Therefore, it would be highly desirable to have the crosshair very exactly centered in the eyepiece. Unfortunately, one will find that such centering seldom is perfect. The crosshair centering can be checked in a microscope as follows: In a microscope with a 10x objective align the stage micrometer's crosshair so it overlaps with the center of the eyepiece's crosshair, and then rotate the eyepiece 90°, 180° and 270°. The center of the eyepiece crosshair should remain in exactly the same position relative the center of the micrometer crosshair. If the crosshair center moves, it indicates poor centering. The good news is that the eyepiece still can be used, but then some precautions must be taken to ensure that the crosshair always is used with the same orientation. This can be accomplished by putting a mark on one side of the eyepiece barrel (notice the faint + sign on the upper eyepiece in Figure 9) and then making sure that the mark always is oriented in the same direction when the eyepiece is moved between the head's eyepiece tubes. (Notice that the mark is on the eyepiece barrel and not on the narrower barrel of the focusable eye lens – the latter may turn and change its position as the focus is adjusted on the crosshair.)

Unfortunately, eyepieces with crosshairs are somewhat difficult to obtain (although only one is needed.) Probably (and with some judgment) an equivalent eyepiece from another manufacturer than Leitz could be used because for our purpose the eyepiece doesn't need to be perfectly optically compatible with the objective.

When purchasing a used focusable eyepiece make sure that a crosshair is included.

Simple collimation screening

This is just a simple and subjective check of the microscope head's collimation without the use of an eyepiece crosshair or a stage micrometer (only a suitable object glass specimen is needed, see below.) The screening can be useful to do after having purchased a new (used) microscope head, or even out in the field when assessing a used microscope before buying it.

Prepare an object glass with a specimen comprising a clutter of small particles like, for example, a blood smear (as in Figure 5), a yeast cell suspension, pollen, or mushroom spores. Set the microscope up with a medium objective (for example, 10X), with proper illumination, and focus for both eyes. Locate an area in the specimen with many evenly spread-out small identical corpuscles, but without any eye-catching features that would stand out as visual clues.

Go away from the microscope for a minute, or so; this is to let your brain's visual system forget any adaptations it may have done to compensate for miscollimation. Leave the microscope as it is, with the object still illuminated.

Go back to the microscope and observe the specimen. Note your immediate impression, whether the view starts with double vision, and then how long it takes for the brain to merge the double vision into a single image. Does it feel comfortable or difficult to maintain a sharp view? Or is it not possible at all to get rid of the double vision?

The best outcome is that you effortlessly and immediately get a nice and sharp view. This tells you that your eyepieces are well collimated, or at least that any miscollimation is not too serious.

A different collimation screening procedure is described in *A Practical Guide to Binocular Collimation*, by Ron Green. To sum this up, focus on the edge of a glass slide, then slowly withdraw your head from the microscope eyepieces until the single image separates into two. The line formed by the edge of the slide must continue to be straight through both eyepieces. See the description in the article for the details.

Summary of the (full) collimating procedure

1. Setup the microscope with a 10x objective and focus it on the stage micrometer.
2. Use the stage's XY controls to position the stage micrometer crosshair at the chosen collimation reference point.
3. Insert the crosshair eyepiece into the eyepiece tube that needs adjustment. Slightly loosen the screws that attach the eyepiece tube to the head and slide the tube horizontally and vertically on the head (Figure 10) until the eyepiece crosshair overlaps with the stage micrometer crosshair.
4. Tighten the screws of the eyepiece tube.
5. (If applicable, move the crosshair eyepiece to the other eyepiece tube and repeat the adjustment.)

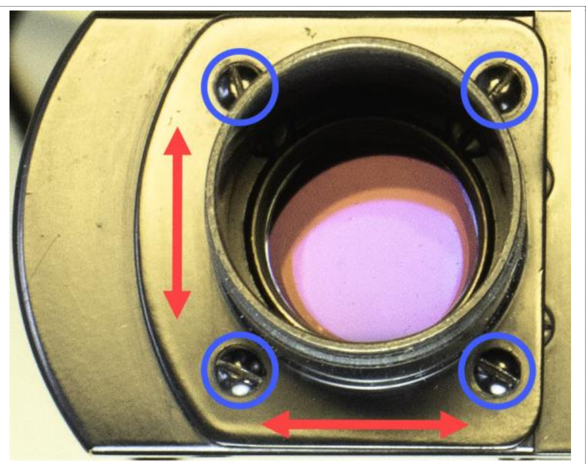


Figure 10: The left eyepiece tube on a binocular microscope head. The eyepiece tube is attached to the head by four screws (with blue circles in the image) in the tube flange. After loosening these screws, the tube can be slightly moved sideways and up-and down on the head as the red arrows indicate. (The length of the arrows is exaggerated and should not be taken as an indication of the actual available range of the tube movement.)

Establishing a plausible reference point for the collimation

If you have found out that your eyepieces are miscollimated, then you need to decide which of them it is that has been bumped out of collimation and which of them that is OK. Should you adjust the right eyepiece tube until it aligns with the left eyepiece, or should you adjust the left eyepiece tube until it aligns with the right eyepiece? Or do you need to adjust both eyepiece tubes? Is there any objective criterion to determine the best position (the *collimation reference point*) into which the eyepieces should be adjusted? Yes, there is. The criterion is to align the optical axes of the eyepieces with the optical axis of the objective. By doing that, the eyepieces' field of view will become properly centered above area where the objective provides optimal sharpness and flatness as illustrated in Figure 11 and Figure 12.

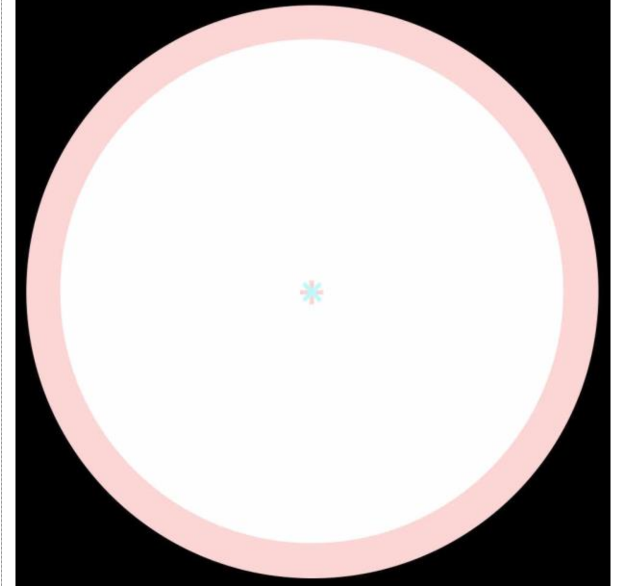
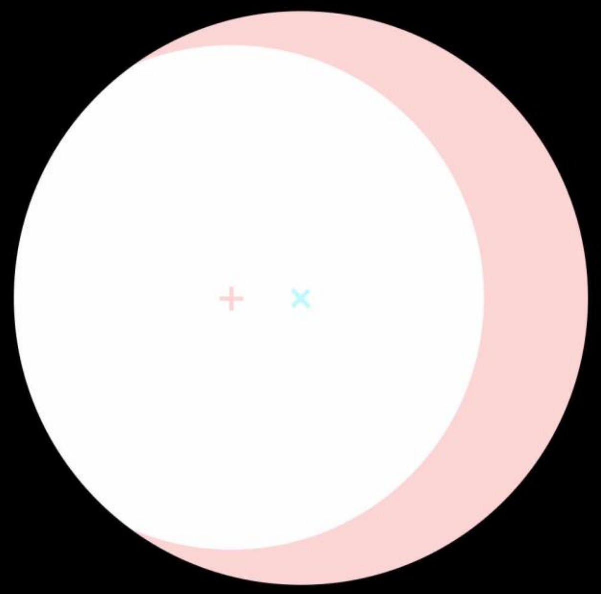
	

Figure 11: Drawing of the microscope view when the eyepiece is well collimated with the objective. *The white area represents the objective's optimal field-of-view, i.e., the area where the objective provides the best image quality (regarding sharpness and flatness.) The pink area at the periphery indicates where the image quality starts to be inferior.* *The pink cross (+) in the middle of the image indicates the objective's optical axis, while the light blue cross (x) indicates the eyepiece's optical axis. Both optical axes coincide, which means that the objective and the eyepiece(s) are well collimated.*	*Figure 12: Drawing of the microscope view when the eyepiece is poorly collimated with the objective.* *The eyepiece's optical axis (x) has moved sideways away from the objective's optical axis (+). Therefore, it appears as the high-quality image area has moved to the left and is now partly outside of the eyepiece's field-of-view. The pink area with inferior image quality is now more dominant and conspicuous.*

Unfortunately, locating the optical axis of the objective requires special equipment (and knowhow) which is out of reach for us amateurs. But all is not lost, there are a few indirect routes that may guide us:

1. Prior knowledge about which of the eyepiece tubes it is that may have been knocked out of collimation. Then this eyepiece tube would be the one requiring adjustment. This is probably not a common scenario, but could occur if you, for example, needed to remove and service only one of the eyepiece tubes because its diopter adjustment had seized due to old, hardened grease.
2. If the head is trinocular (i.e., includes a phototube, Figure 13 and Figure 14) it seems reasonable to assume that out of the three eyepiece tubes, the phototube should be the one that most reliably has retained its collimation with the objective's optical axis and therefore should serve as the collimation reference point. The reason is that the phototube has a simpler optical path and a more robust mechanical design than the eyepieces. Therefore, we would start by putting the crosshair eyepiece into the phototube (with the help of a suitable eyepiece adapter, see Figure 14), and then we would mark that position as our collimation reference point by moving the stage until the stage micrometer aligns with the eyepiece crosshair. Finally, we would switch the crosshair eyepiece over to the other two eyepiece tubes and have each of them moved until they are nicely aligned with the stage micrometer. The phototube is fixed on the head and can't be moved sideways, which means that its collimation can't be adjusted in the same way as the (binocular) eyepiece tubes.

3. Put another microscope head (that has the same microscope mount, and preferably one you trust is well collimated) on the microscope (don't move the stage, it is important to preserve the collimation reference point by keeping the position of the stage micrometer fixed) to get a "popular vote" on which of the eyepiece tubes you need to move for collimation. The verdict is in if three of the eyepiece tubes yield overlapping crosshairs, while the fourth is astray.

If none of these cases are applicable, you will need to arbitrarily decide to make one of the eyepiece tubes the reference point for the collimation, or alternatively you could opt for a compromise and decide to establish the reference point in the middle between the current eyepiece tube centers. In the latter case you would then adjust/move each eyepiece tube the same distance but in opposite directions.

It should be emphasized that the collimation adjustments that can be done by adjusting the position of the eyepiece tubes are quite marginal (not more than 1 mm) and will therefore not lead to any serious deviations from the collimation with the objective. So don't worry too much if you are not able to collimate with the objective. After all, what matters is that you get the eyepieces mutually collimated.

Figure 13: Trinocular microscope head (on a Leitz Ortholux microscope.)

Figure 14: Trinocular microscope head with an exploded view of the phototube parts. From the bottom to the top: Trinocular head with 38 mm phototube, eyepiece adapter (38 mm → 23.2 mm), eyepiece.

Make a collimation record

It is a good idea to establish a basic collimation record to document the collimation efforts. The record may prove invaluable if sometime in the future you need to redo or undo the collimation.

Identify not only the head undergoing collimation, but also the microscope used, the objective, the stage micrometer, and the crosshair eyepiece. Describe briefly how the collimation reference point was chosen. Record how far each eyepiece tube was moved and in which direction (use the stage micrometer's scale interval marks to estimate the distance.) Record the result of the final collimation check, i.e., the collimation state "as left".

Collimation procedure

Remember to record all adjustments, decisions and actions performed.

1. Setup the microscope with the microscope head that will be checked for collimation, a suitable low-to-medium magnification objective (10X is suitable), and a stage micrometer. Set the head's interpupillary distance setting at the midpoint (typically 65 mm) and turn the eyepiece tubes' diopter adjustment(s) so the rims of both tubes extend to the same height. Put the crosshair eyepiece into the head's left eyepiece tube but leave the right eyepiece tube empty. If you have put a mark on the eyepiece barrel (like the + sign on the upper eyepiece in Figure 9) make sure it always points in the same direction. Turn the focusing collar of the crosshair eyepiece until the crosshair is sharp. Adjust the illumination and set the microscope's focus on the stage micrometer's center point (whether that is a grid, a crosshair, or any other design with a defined center point.)

2. Turn the eyepiece so the crosshair lines are parallel with the micrometer scale. Move the stage until the stage micrometer's center point is exactly below and overlapped by the left side eyepiece's crosshair (Figure 15.) The position of the stage with the stage micrometer should now be considered as a <u>temporary</u> collimation reference point. Be therefore very mindful not to bump the stage or change its position after this step – even the lightest touch of the stage can shift the stage micrometer and thereby jeopardize the collimation.

3. Move the crosshair eyepiece from the head's left eyepiece tube to the right eyepiece tube.

4. Record how far away the eyepiece crosshair is from the center point of the stage micrometer. Use the stage micrometer's scale to determine how much the eyepiece crosshair deviates from the micrometer's center and record it. This can conveniently be done by using cartesian coordinates (e.g., "Right tube miscollimation: X = +0.07 mm and Y = -0.04 mm", see Figure 16.)

5. Decide if the miscollimation needs correction. If affirmative, proceed with the instructions below.

6. Chose the collimation reference point according to the guidelines in section "Establishing a plausible reference point for the collimation".

7. Move the stage to position the stage micrometer's center point exactly at the chosen collimation reference point. This is easy if the reference point coincides with the eyepiece crosshair at any of the left or right eyepiece tubes (see point 2 above) but requires counting micrometer scale bars if some intermediate reference point has been chosen. Once the stage micrometer has been aligned with the reference point it is important to make sure that the stage isn't inadvertently moved.

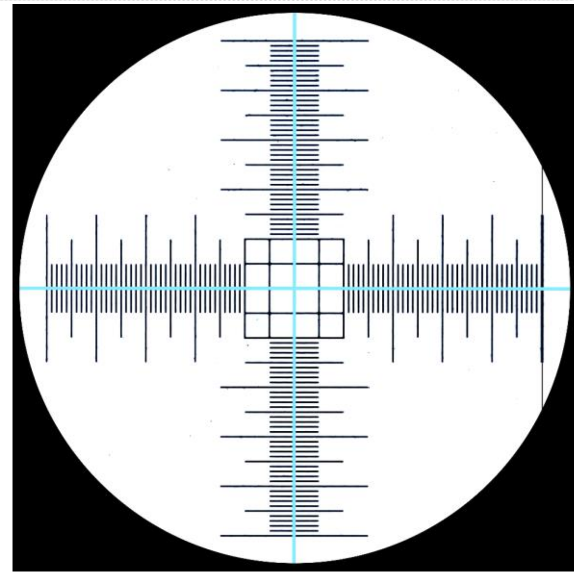
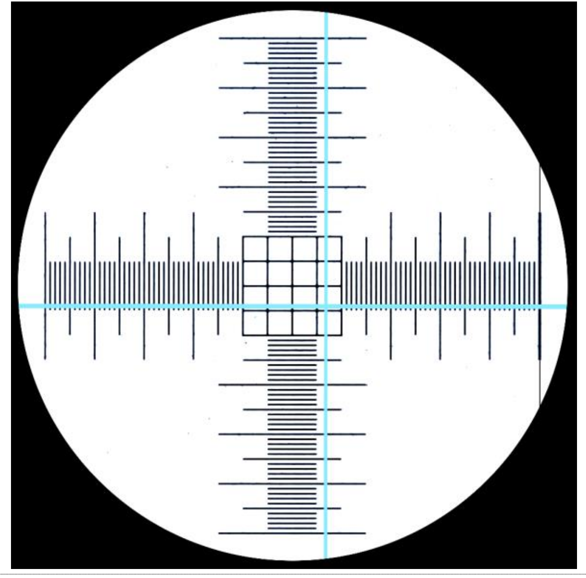
	

Figure 15: The stage micrometer's (black) center point positioned exactly below the left eyepiece's crosshair (blue).	*Figure 16: The view after switching the crosshair eyepiece from the left to the right eyepiece tube. The image shows a miscollimation X = +0.07 mm and Y = -0.04 mm as expressed by cartesian coordinates.*

8. Put the crosshair eyepiece into the eyepiece tube that needs collimation adjustment.

9. Loosen slightly the screws (Figure 10) that hold the eyepiece tube to the head. Adjust the screws to hold the tube enough firmly attached so the tube doesn't slide downwards due to its weight, but still loose enough to allow the tube to be pushed vertically and horizontally. It's a delicate balance, and it may help doing the initial settings with only two of the screws, preferably two that are diagonally positioned. Slide the eyepiece tube on the head until the eyepiece crosshair coincides with the stage micrometer's center point. Carefully tighten the screws in very small increments, while all the time checking that the crosshair still overlaps the micrometer's center point. An annoyance is that the eyepiece tubes tend to slide out of position every time the screws are tightened. Practicing this operation helps.

10. If applicable (if the chosen collimation reference point doesn't coincide with one of the eyepiece tubes), repeat steps 8 and 9 with the crosshair eyepiece in the other eyepiece tube.

11. Check that the collimation was successful as per points 2, 3 and 4 above, and repeat the collimation procedure, if necessary.

What if the collimation fails?

The collimation adjustments we can do by moving the eyepiece tubes sideways are limited by the play allowed by the screw holes in the flange of the eyepiece tubes. This necessarily means that the adjustments that can be done will be relatively marginal. If, for example, the head's prisms have been brutally bumped into miscollimation one may experience that the available adjustment range is insufficient to achieve collimation. In abused microscope heads one can sometimes see that the cement that holds the prisms aligned in the head has been cracked (Figure 17.) Sometimes the cement cracks can be repaired, but it should still be expected that it could be difficult to recreate the original prism alignment.

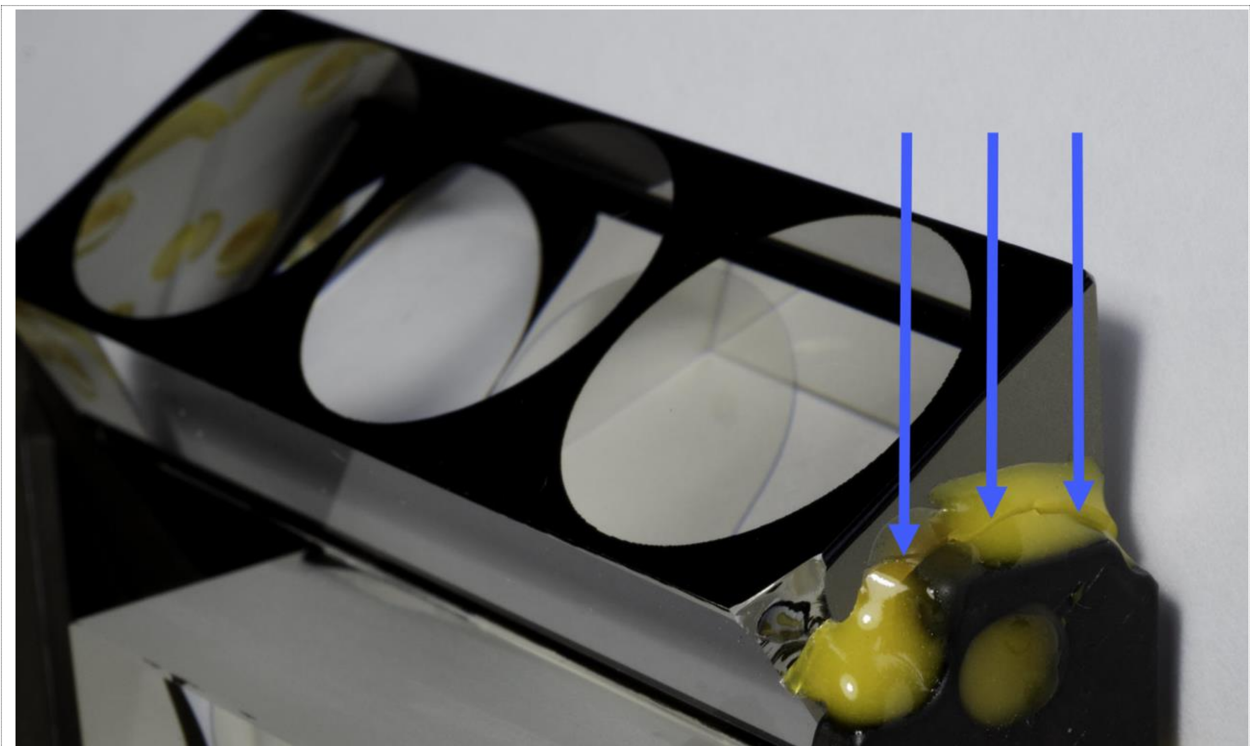


Figure 17: Prisms where the cement has been cracked due to rough shipping conditions. The arrows point to the crack in the yellow cement.

Below are a few suggestions for what can be done if you fail to achieve collimation according to the procedures in the previous section. Note that items 3. through 6. are risky undertakings and should be classified as hacks rather than reliable remedies.

1. Send the head (with the microscope) for professional collimation. This may be expensive, and may require shipping (with all caveats…)
2. Surrender to the circumstances and buy a new (used) head.
3. If the eyepiece tube can't be slided all the way towards the desired reference point, one remedy is to try to slide the other eyepiece tube to "meet" with the first tube where it stopped. Start by tightening the tube flange screws to lock the first tube in the stopped position. Make this position the new collimation reference point by repositioning the stage micrometer so its center is exactly below the crosshair of this tube. Switch the crosshair eyepiece over to the other eyepiece tube, loosen that tube's holding screws, and try to move the tube to get it aligned with the new collimation reference point. With some luck it can be moved enough to reach the new reference point and then be locked by tightening the screws.
4. Increase the play of the eyepiece tube's screw holes by drilling or milling them. The screw holes can be enlarged by drilling or extended in any desired direction by careful milling. The larger holes can then be covered by suitable washers to allow for easy adjustments with the original screws.
5. Change the inclination of the eyepiece tubes by experimenting with putting shims under the eyepiece tube flanges. Shims of various thicknesses can be made from thin copper wire strands or cutouts from plastic film. A disadvantage is that unevenly placed shims may allow for dust penetration into the head.

6. Changing the alignment of the prisms in the head. As mentioned earlier, it is difficult to get this right with a high risk of causing permanent misalignment. It could of course be tried as a last resort (and perhaps as a learning experience.)

Periodic re-collimation?

Inadvertently bumping into the microscope head or the eyepiece tubes can easily cause miscollimation. Such accidents probably happen more often than one would like. Therefore, it may be good practice to check the eyepiece collimation periodically. I'll leave it to you to decide how often.

References

A Practical Guide to Binocular Collimation, by Ron Green, revised in 2008, first published in the Micro Miscellanea newsletters No 64 (2006) and No 65 (2007) of the Manchester Microscopical and Natural History Society. (This reference has some useful and practical information about binocular head collimation.)

Thoughts about diy collimation of a compound microscope, by Paul James. (This reference doesn't specially cover microscope eyepiece/head collimation but has some good information about general collimation of other microscope parts.)