Ray Optics
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(9h-12h)

19 december 2008
duration: 3h

Documents and calculator authorized

RAY OPTICS EXAM

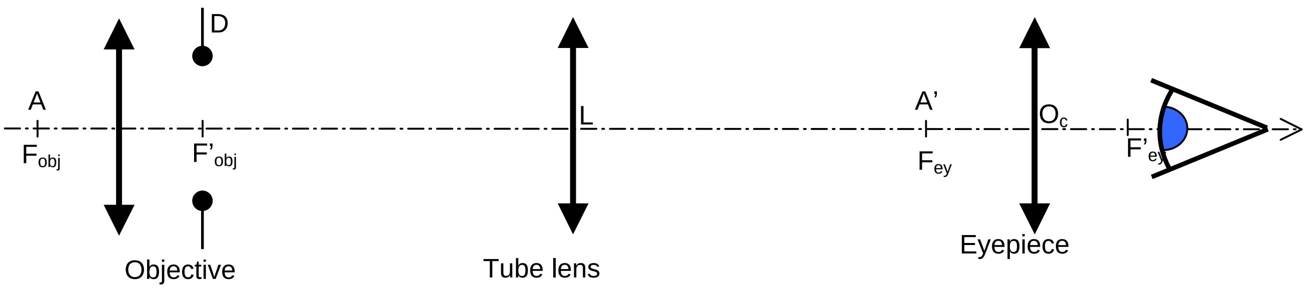
Simplified study of a research microscope

The microscope objective used here makes an image at infinity. It is thus coupled to a tube lens to form a real image that can be observed with an eyepiece or on a CCD detector.

In this problem, we will approximate all the lenses as thin lenses. We will thus always be in the paraxial approximation. We will also assume that the observer is emmetropic (i.e. looks comfortably at an object located at infinity).

A- First design of the microscope

- The transverse magnification of the microscope objective associated with the tube lens has an absolute value of 10.
- The focal length of the tube lens is 200mm.
- The distances $F'_{obj}L$ and LF_{ey} are equal to 200 mm in this first design.
- The aperture stop of the microscope is located in the second focal plane of the objective. Its diameter D is 10mm.
- The eyepiece is a single lens with a focal length of 25 mm.



1. What is the focal length of the microscope objective ?
2. Where is the entrance pupil of the microscope ? Calculate the numerical aperture of the microscope objective (in the object space).
3. What is the (commercial) magnification of the eyepiece?
4. What are the power and (commercial) magnification of the whole microscope ?
5. What is the angular size of the image for a 5µm object?
6. What is the transverse resolution limit (in the object space) due to diffraction ?

7. What is the transverse resolution limit due to the eye's resolution? (take 2 minutes of arc as the naked eye's resolution limit)
8. What is the depth of field in the object space if the observer can accommodate from infinity to a distance of 250 mm ?
9. What are the position and diameter of the exit pupil of the microscope?
10. Make a drawing of the whole microscope (from the object plane to the exit pupil) with scale 1: ½ along the optical axis and scale 1:5 in the transverse direction (use the longest size of the page for the optical axis).
11. Draw a bundle of rays passing through the whole microscope for an object on axis, with the largest aperture authorized by the aperture stop.

<u>Study of the field of view :</u>

We want the bright field of view in the object plane to have a diameter of 2 mm.

12. Draw (in a different color) a bundle of rays originating at one edge of the bright field in the object plane and passing through the whole microscope (still with the largest possible aperture).
13. Determine the minimum diameters for the objective lens, the tube lens and the eyepiece so that the bright field is indeed 2 mm in diameter in the object space.
14. Calculate the bright field in the image space of the microscope.

<u>Second part of the problem : new design for the tube lens</u>

15. To reduce the required diameter for the tube lens, we decide to bring that lens closer to the objective lens. We want to use a tube lens with a diameter of 20mm. What must be the maximum distance between the objective lens and the tube lens so that the bright field of view is still 2 mm in the object plane ?
16. We choose to place the tube lens at 100mm from the second focal point of the objective lens ($F'_{obj}L$ = 100 mm). Of all the following characteristics of the microscope : *Power, Magnification, Numerical aperture (in object space), Exit pupil diameter, Exit pupil position,* only one has changed compared to the first design. Which one? Calculate the new value.
17. Has the depth of field changed ? Explain why.
18. Make a new drawing of the whole microscope (same orientation of the page, same scales as in the first part). Draw the bundle of rays originating at an object point on axis and with the largest aperture.
19. Draw (in a different color) a bundle of rays originating at an object point off axis, on the edge of the bright field (still 2 mm diameter in the object plane), and passing through the whole microscope with the largest aperture.
20. Determine the minimum diameter for the eyepiece lens.
21. What is the bright field diameter in the image space? Is it different from the first design?

<u>Third part: observation on a CCD camera</u>

Instead of observing with the eyepiece, we want to record the image on a CCD matrix. That detector has 512*512 pixels. Each pixel is a 20µm*20µm square.

22. What is the resolution limit (in the object space) if we place the CCD detector directly in the second focal plane of the tube lens?
23. We want the resolution to be limited by diffraction (same value as in the first part). Suggest one possible design using an extra lens between the tube lens and the detector. What will then be the field of view in the object space (assuming the diameter of that extra lens is not limiting)?