

# 14

## Introduction

---

**METALLOGRAPHY/MATERIALOGRAPHY COMPRISES THE OPTICAL EXAMINATION** of a material for the purpose of giving a qualitative and quantitative description of that material's structure. The structure is characterized by size, shape, distribution, density, orientation, and type of phases, as well as microstructural defects (see Fig. 1.2).

In this context, the light microscope is an important tool. In the following chapter, the basic physical principles of reflected light microscopy and the most important methods of microscopic examination will be described in more detail. In Chapter 16 a short introduction to electron-microscopy and scanning probe microscopy is given.

The optical effect of enlargement that occurs when one looks through the rounded glass of a convex lens (magnifying lens or loupe) was known to the ancient Egyptians, Greeks, and Romans. Today, a convex lens still serves as a magnifying glass for observing small objects, the useful magnification is limited to 10–15 $\times$ .

The first microscope, consisting of two lenses, was probably built by either Hans and Zacharias Jansen in about 1590 in the Netherlands or by Cornelius Drebbel around 1600. In connection with the growing significance of the natural sciences in the 19th century, microscopic observations in the fields of medicine, biology, and geology became ever more important.

H. C. Sorby in England (1864) and A. Martens in Germany (1878) were the first to prepare metallographic polished sections of steel and cast iron, examine them by microscope, and sketch or photograph their visible structure.

Microscopes used today are still built according to the old principle of a system of lenses placed together. Their essential elements are source of light, lens, eyepiece (or ocular), prism, mirror, and shutter and filtering systems.

### 14.1 Visible Light—Table 14.1—Table 14.2

Light that can be seen by the human eye is an electromagnetic light wave with wavelengths of between 350 and 780 nm. Depending on the wavelength, the human eye sees different colors (see Table 14.1).

White light consists of a mixture of all the colors in the spectrum. Light of an even wavelength is monochromatic.

When wavelengths of a particular range are missing from a beam of polychromatic light, we see a mixed color (Table 14.2).

---

TABLE 14.1—Range of Wavelength of Visible Light and Color.

---

Range of Wavelength, nm	Color
360–440	violet
440–495	blue
495–580	green
580–640	yellow/orange
640–780	red

---

TABLE 14.2—Spectral Color Filtered Out and Visible Mixed Color.

Spectral Color Filtered Out	Mixed Color
Violet	Green-yellow
Ice blue	Orange
Yellow	Ultramarine blue
Red	Blue-green

## 14.2 The Human Eye

The construction of the human eye is similar to that of a camera (Fig. 14.1). Thanks to the muscles in our eyes, the focal distance of their flexible lenses (1) can be varied to enable us to focus on any object at a distance between approximately 20 cm and infinity. The inner diameter of the iris (3) can be varied to change the amount of light falling into it. This variation produces a sharp image on the retina (2), the gray values of which are received by receptor-rods, and the color values of which are received by the cones and transformed into electrical impulses. These impulses are in turn transmitted via the optical nerve (4) to the brain where they are then processed.

For example, let us look at a 160 m (~490 ft) high tower from a distance of about 300 m (~915 ft). If we imagine two lines that extend from the middle of our eye, one to the foot of the tower and one to the top, we get what is called the visual angle. In this example, the visual angle  $\delta$  is about 30 degrees. We are not able to recognize the faces of people on the tower because the visual angle is too small for our eye to process. But if we go closer to the tower, then we can better recognize the details of the building and the people. This means that the closer we bring an object to our eye, however, thereby increasing the visual angle, the more details we are able to discern.

Normally, we are able to read the text on a page of a book from a distance of 25 cm (~10 in). This distance is called the conventional visual range, or visual range of reference. It enables us to compare the magnification data of different optical systems.

To make out the details of the individual letters on that page of text, we must decrease the visual angle. If we bring the text closer to our eyes, in order to increase the

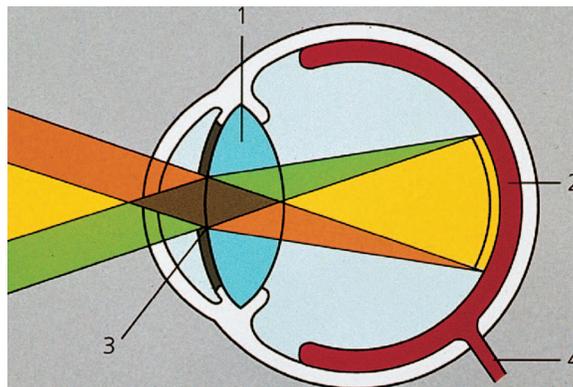


Fig. 14.1—Light path of the human eye, with lens, cornea (1), retina (2), iris (3), optical nerve (4).<sup>1</sup>

visual angle further, the text begins to blur because the ability of our lenses to adjust to the visual angle is limited.

### 14.3 Magnifying Lens and Microscope

Magnifying glasses and microscopes are optical devices that enable us to increase the visual angle between the eye and objects that are small and near so that details that cannot be seen with the unaided eye now become visible.

If we place a convex lens (magnifying glass) between our eyes and the page of text, the visual angle is increased and the details of individual letters as well as the surface structure of the paper become visible.

A magnifying glass produces an enlargement by means of a single imaging step. The object lies in the center of focus and the eye is accommodated ad infinitum. The smaller the focal point of the magnifying lens, the greater the magnification. Practically speaking, a magnification of the object of 10 up to a maximum of 15 times its actual size remains in the useful range.

By using several lenses arranged one after the other, the magnification effect can be increased considerably.

The construction of the classical microscope consists of a two-lens system. The magnification takes place in two image-forming steps. First, an enlarged image of the object is projected by the objective in the intermediate image plane. This image is then magnified by the ocular, or eyepiece.

### 14.4 Magnification

Magnification,  $M$ , as the function of an optical instrument is defined as:

$$M = \frac{\text{Visual angle with optical instrument } \delta_1}{\text{Visual angle without optical instrument } \delta_2} \quad (1)$$

or

$$M = \tan \delta_1 / \tan \delta_2 \quad (2)$$

Magnification by a compound microscope results as a product of the magnification of the objective and the magnification of the eyepiece

$$M = M_{\text{objective}} \times M_{\text{eyepiece}} \quad (3)$$