Introduction to Electron Microscopy

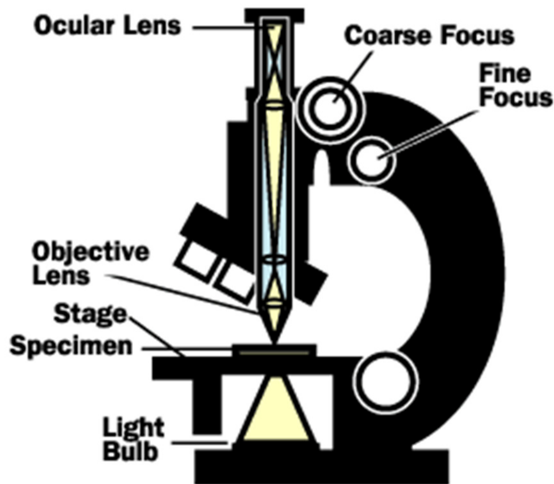

Diagram of a typical three lens compound microscope with transmission illumination.

Light microscopes were developed in the early 1600's. By the end of the century Dutch microscopist van Leeuwenhoek had imaged blood cells, bacteria and structure within the cell using a simple one-lens microscope with x300 magnification which was awkward to use. At the same time the compound microscope was being developed. This uses at least two lenses; an objective, placed close to the specimen, and an eyepiece (ocular), placed close to the eye. Such was van Leeuwenhoek's skill, however, that it was two centuries before the compound microscope could match his work. Compound optical microscopes, these days, have a maximum magnification of about x1000 and an imaging resolution of around 0.3μm for light in the middle of the visible region (λ~0.5μm). Aberrations in light optical lenses can be reduced to a minimum by grinding the lens surface to a correct shape or spacing the lenses so that their aberrations are compensated. In the absence of aberrations the limit of resolution (d) of any wave optical microscope is given by the Rayleigh criterion:-

$$d = 0.61 \lambda/(\mu \sin \alpha)$$

where λ is the wavelength of the light (or electrons), μ is the refractive index and α the illumination semi-angle. To get any improvement in resolution either λ needs to be reduced (ultraviolet region), or μ increased (oil immersion). There are two basic forms of light optical microscopes. For specimens that are optically transparent the light can pass from the source, through the specimen, and into the microscope (transmission). However some specimens cannot be made optically transparent and another type of microscope is needed where the light source is above the specimen and is reflected into the microscope (reflection).

In an ***electron microscope***, instead of using a visible light source, a beam of electrons is used. The electron beam has a much shorter wavelength than visible light which improves the imaging resolution. However electrons are unable to travel far through air without being scattered so the electron beam path in the electron microscope must be in vacuum, and electron optics suffer from significant aberrations which limit the resolution in a conventional electron microscope. There are two main types of electron microscope, ***Transmission Electron***

Microscope (TEM) and ***Scanning Electron Microscope (SEM)*** with a combined technique ***Scanning Transmission Electron Microscopy (STEM)***.

In a transmission electron microscope the electron beam passes through a very thin (<100nm) specimen and a two dimensional image of the internal structure of the specimen is recorded on a CCD camera. In a scanning electron microscope the electron beam is focused down into a spot which is then scanned across the surface of the specimen. The interaction of the beam with the sample gives rise to two main signals, secondary and backscattered electrons, which are collected using detectors and can be displayed simultaneously on a monitor (analogous to reflection optical microscopy). In a scanning transmission electron microscope the scanning beam of the SEM is used to scan over the very thin TEM specimen, and transmitted electrons are collected after the specimen using either and on axis (Bright Field - unscattered) or off axis (Annular Dark Field -scattered) detector. Multiple signals can be imaged at the same time as in the SEM.

In addition to imaging it is also possible to carry out ***microanalysis*** of materials at the nanometer scale using either ***Electron Energy Loss Spectroscopy (EELS)*** or ***X-ray Energy Dispersive Spectroscopy (XEDS)***. TEM/STEM instruments with EELS and XEDS are often referred to as ***Analytical Electron Microscopes (AEM)***.