Defects of lenses
Defects of lenses

- Simple single pieces of glass do not act as perfect lenses
- They suffer from several errors, or aberrations
The objective lens

The most important lens of the microscope
The principal Aberrations are:

• **Spherical aberration**
  - caused because the surface of most lenses is made to be part of a sphere
  - easy and cheap to make
  but it is *the wrong shape*

• **Chromatic aberration**
  ‘colour’ aberration
  - caused because all materials from which lenses can be made have a different refractive index for each colour
Spherical aberration

Focus for central rays

‘Disc of minimum confusion’

Focus for peripheral rays

Focus for central rays
Correct

Incorrect

Spherical aberration

Objective with ‘correction collar’
Effect of Coverglass Thickness

Air

Coverglass

Mounting medium

Slide

Specimen
<table>
<thead>
<tr>
<th>Tubelength</th>
<th>Coverslip thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 mm</td>
<td>Unimportant</td>
</tr>
<tr>
<td>∞</td>
<td>0.17 mm</td>
</tr>
</tbody>
</table>

**Magnification:** 10x
**Numerical Aperture:** 0.4
Magnification 40x
Numerical Aperture 1.0
Oil immersion
Iris in back focal plane
Corrected for infinite tubelength
Corrected for 0.17mm coverglass
Magnification 10x
Numerical Aperture 0.30
‘Hell- und Dunkelfeld’
Suitable for Differential Interference Contrast
Corrected for infinite tubelength
Corrected for use without coverglass
The principal Aberrations are:

• **Spherical aberration**
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  ‘colour’ aberration
  - caused because all materials from which lenses can be made have a different refractive index for each colour
Chromatic aberration

Green image with large magenta halo
Chromatic aberration

The achromatic doublet

- Crown glass: Low dispersion
- Flint glass: High dispersion

- Green focus
- Red and blue focus
  - Much reduced magenta halo
Types of objective lens

• **Achromatic**
  – Chromatic aberration minimised for *two* wavelengths, and spherical aberration for *one* (usually green).
    • Relatively inexpensive
    • Adequate for routine work
    • Can give excellent results when used with green filter

• **Fluorite (‘Semi-Apochromatic’)**
  – Chromatic aberration better corrected than achromats due to optical properties of fluorite (calcium fluoride) lens elements.
    • Perform well at larger apertures than achromats
    • Simpler design and therefore cheaper than apochromats

• **Apochromatic**
  – Chromatic aberration minimised for *three* wavelengths, and spherical aberration for *two* wavelengths.
    • Virtually perfectly corrected, even for large apertures
    • Complex design, therefore very expensive
Lens Aberrations

Aberrations are minimised by careful design
…but only for certain conditions of use:

Correct matching of

• Objective
• Microscope stand
• Eyepiece

Microscope parts may seem to be *mechanically* interchangeable

But they are not *optically* interchangeable
Incorrect

Objective which *requires* compensating eyepiece, used with non-compensating eyepiece.

Note colour fringes at edges of field - red and blue images different sizes
Incorrect
Objective which *requires* compensating eyepiece, used with non-compensating eyepiece.

Purple filter emphasises colour fringes at edges of field
- red and blue images different sizes
Correct

Objective which *requires* compensating eyepiece, used with correct eyepiece.
Correct
Objective which \textit{requires} compensating eyepiece, used with correct eyepiece.

Colour image without purple filter
Curvature of Field
Most objectives have a curved field. And some are more curved than others.

Eyepieces have different fields of view - they include different areas of the primary image.

Curvature of Field

Depth of field