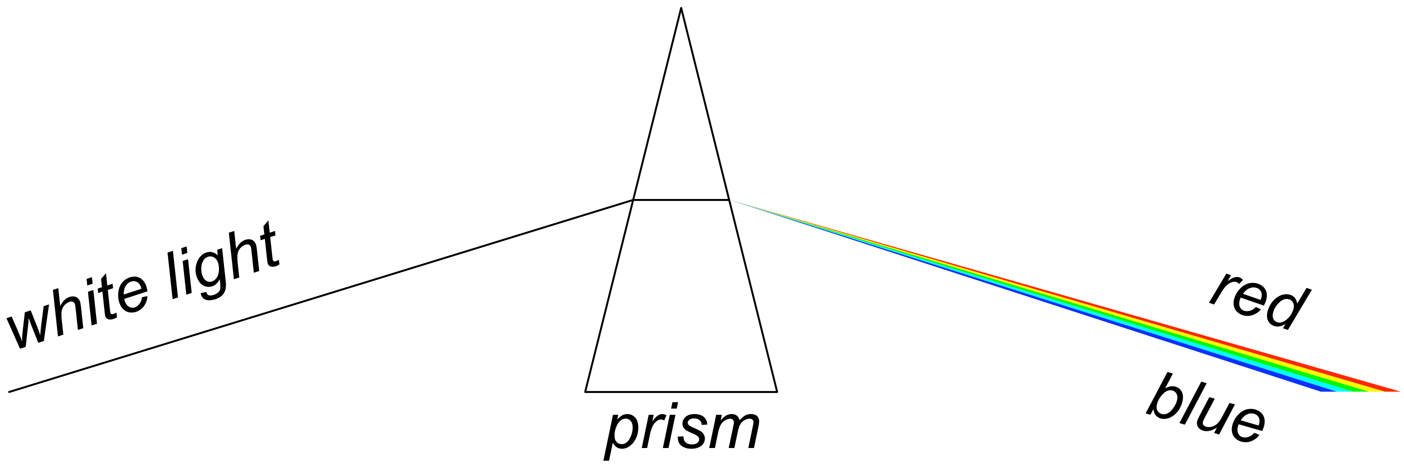
TOPICS

- Recap of PHYS110 *- 1 lecture*
- Physical Optics *- 4 lectures*
  - EM spectrum and colour
  - Light sources
  - Interference and diffraction
  - Polarization
- **Lens Aberrations** *- 3 lectures*
  - Spherical aberrations
  - Coma, astigmatism, field curvature, distortion
  - **Chromatic aberrations**
- Instrumental Optics *- 4 lectures*
  - Telescope, microscope
  - Stops, eyepieces
  - Instruments for the anterior eye
  - Instruments for the posterior eye

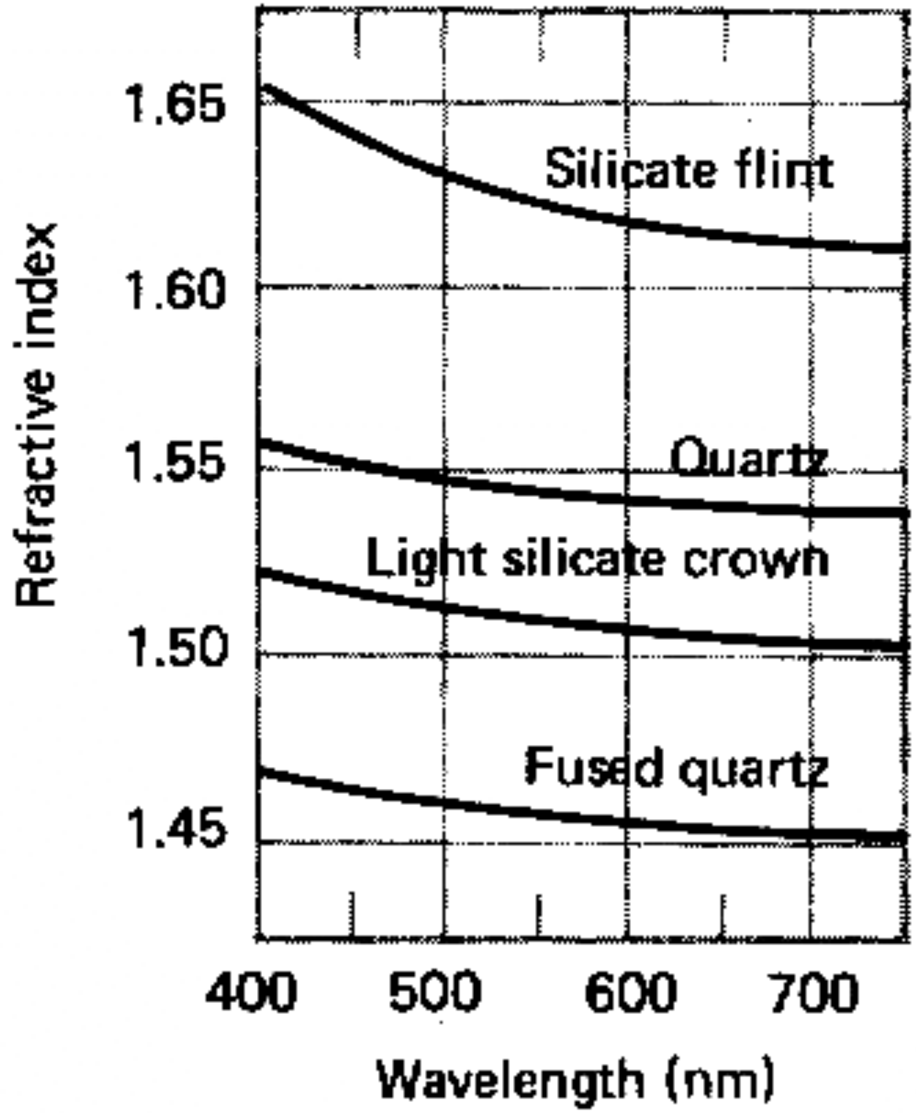
Dispersion

- For most materials, the refractive index depends on the wavelength of the incident light
- This effect is called ***dispersion***
- Refracted light that is not monochromatic is split up into its components



Dispersion

- Most materials have a higher refractive index for blue light (short wavelength) than for red light (long wavelength)
- Materials with a high refractive index usually have a stronger dispersion



The dispersive index V

- The variation of refractive index with wavelength is characterised by the ***dispersive index*** V, defined as:

$$V = \frac{n_Y - 1}{n_B - n_R}$$

n_Y : refractive index for yellow light $(\lambda = 589\text{nm})$

n_B : refractive index for blue light $(\lambda = 486\text{nm})$

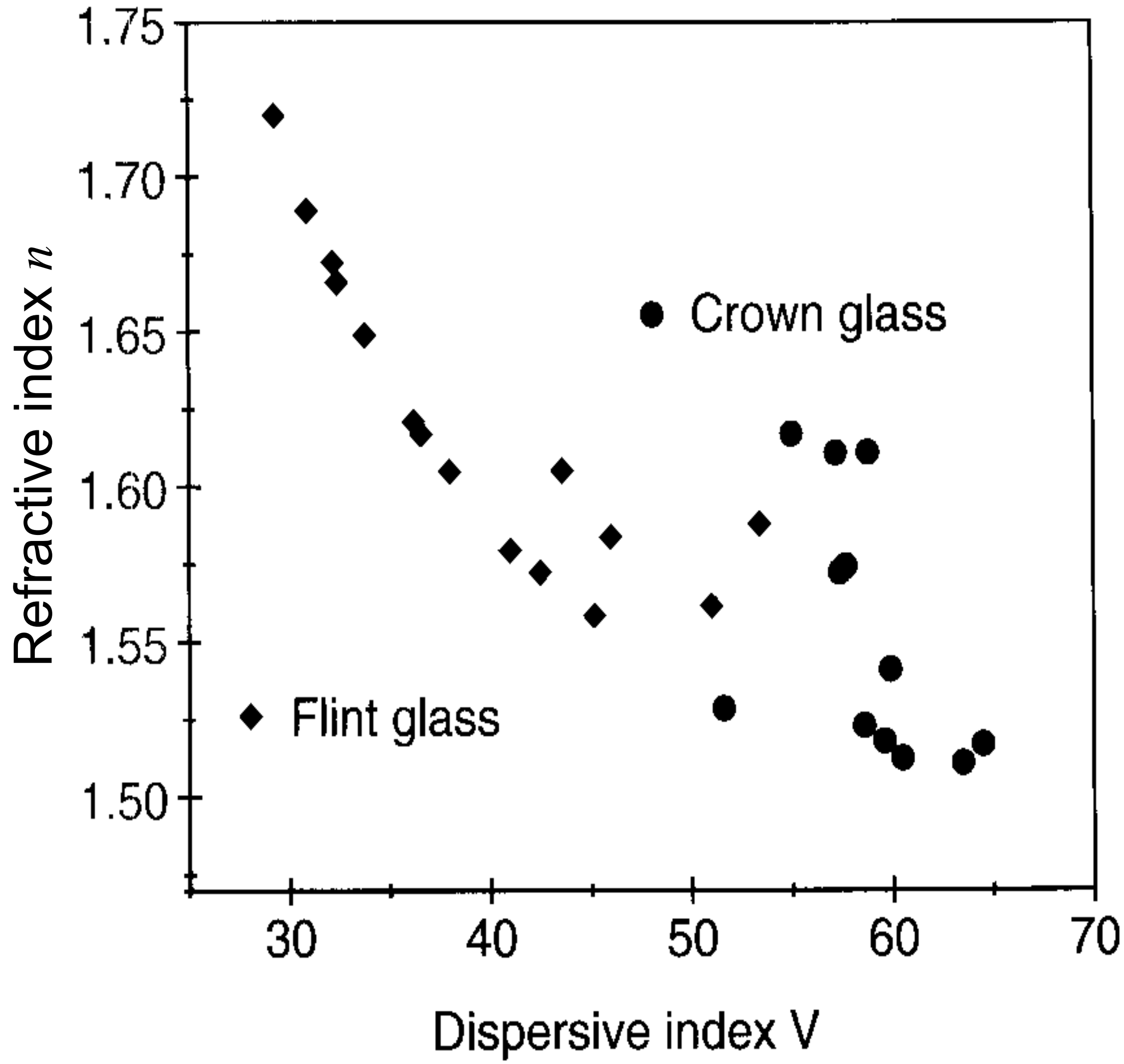
n_R : refractive index for red light $(\lambda = 656\text{nm})$

$\Rightarrow$ *High values of V correspond to little dispersion!*

$\Rightarrow$ *Low values of V correspond to strong dispersion!*

The dispersive index V

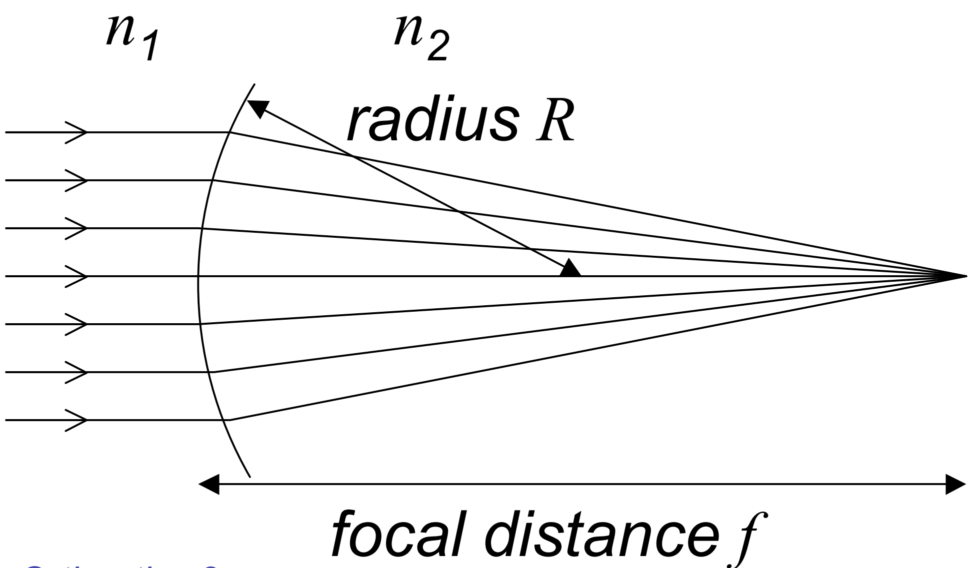
- Crown glass:
  - low refractive index n
  - high value of V
  - little dispersion
- Flint glass: (*lead glass*)
  - high refractive index n
  - low value of V
  - strong dispersion



Effect of dispersion on lenses

- The vergence power F (in Dioptres) of a curved surface with radius R (in metres) going from a medium with refractive index n_1 to n_2 is

$$F = \frac{1}{f} = \frac{n_2 - n_1}{R}$$



Effect of dispersion on lenses

- Example: a bi-convex lens with two surfaces with a radius of 30 cm and refractive index 1.60 for red light, has a vergence power of:

  F = 2×(1.60-1.00)/0.30 = 4.00 Dioptres

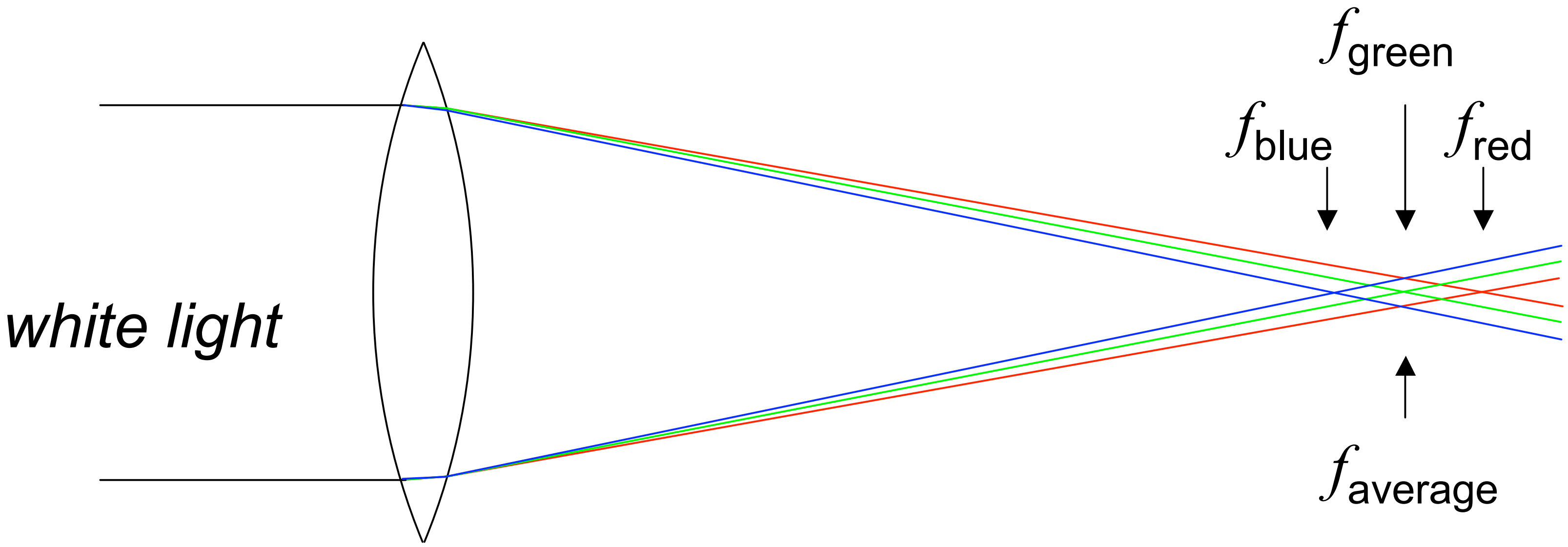
  Focal distance $f = 1/F = 1/4.00\ m = 0.250\ m = 25.0\ cm$

- For blue light, the refractive index is 1.62.

  F = 2×(1.62-1.00)/0.30 =4.13 Dioptres

  Focal distance $f = 1/F = 1/4.13\ m = 0.25\ m = 24.2\ cm$

Longitudinal chromatic aberration

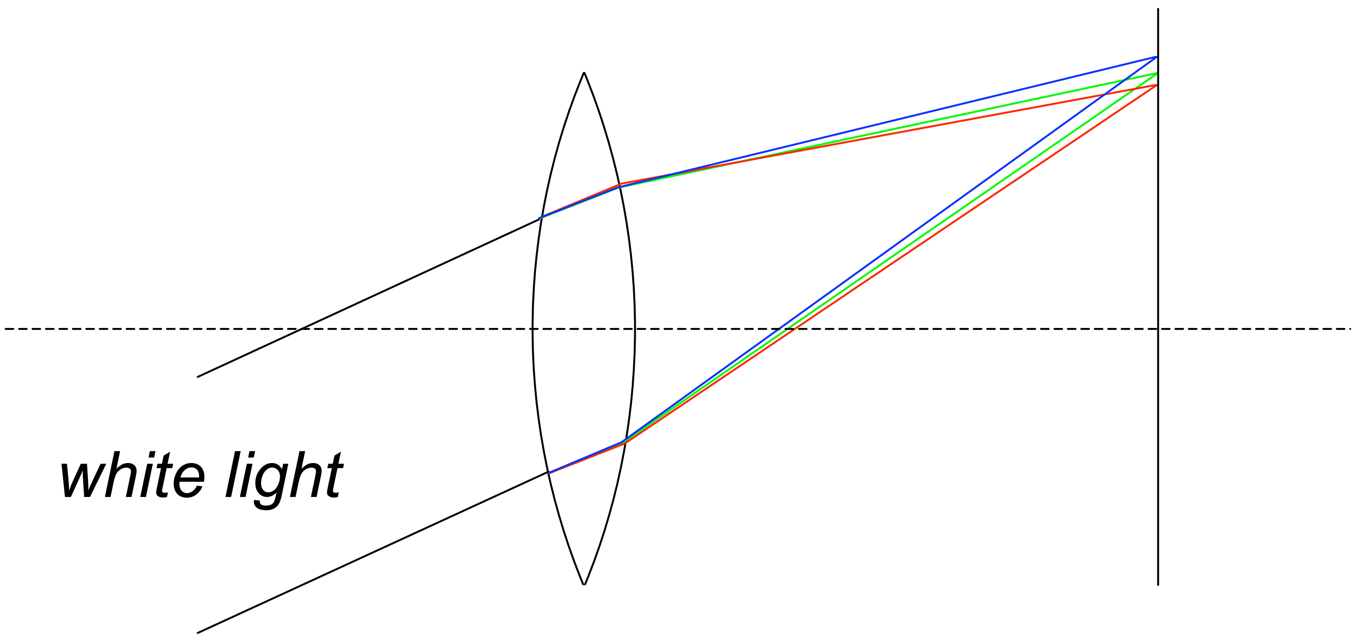


Consequence:

- blurred image
- sharpest image when using the average focal distance
- green will be sharp, but red and blue blurred

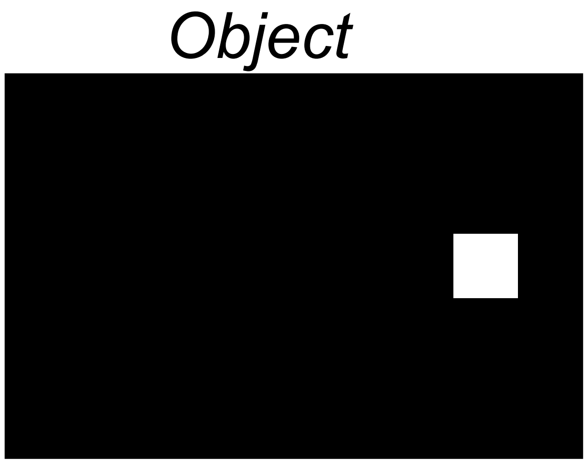
Transverse chromatic aberrations

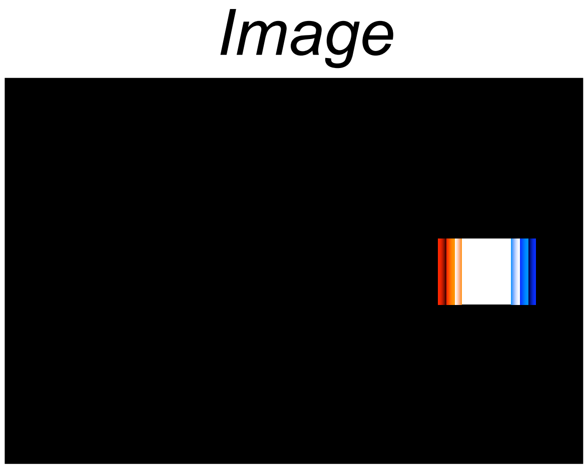
- In addition, off-axis objects suffer from transverse chromatic aberration as the magnification of an image varies with the wavelength.



Transverse chromatic aberrations

- The image of an off-axis white object will have a blue rim on one side and a red rim on the other side:



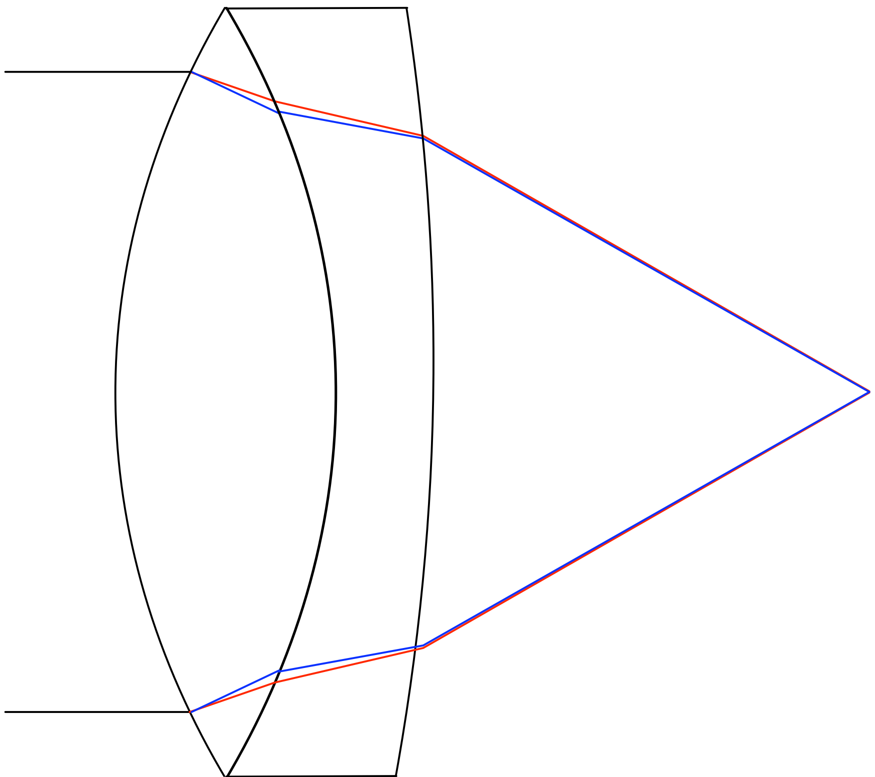


Reducing chromatic aberrations

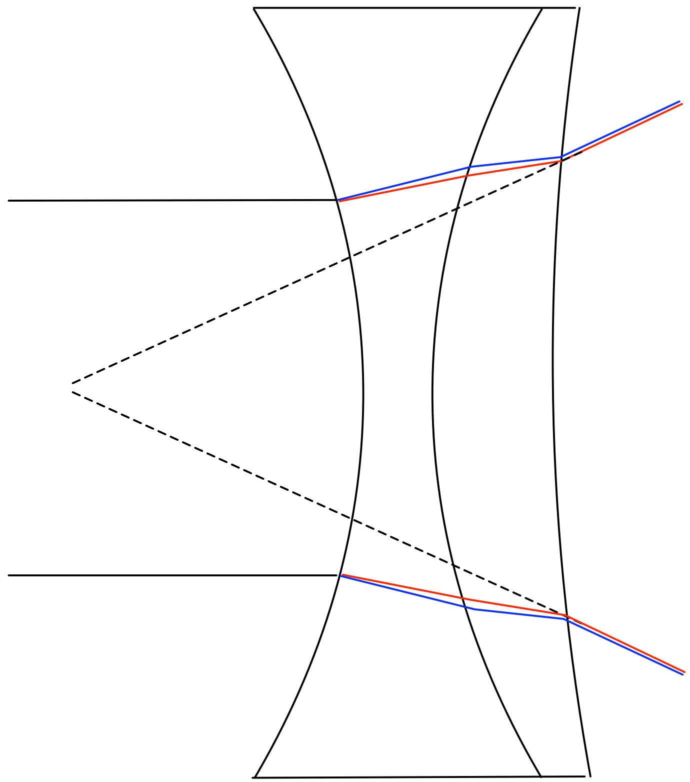
1. Using lens materials with little dispersion (high dispersion index V)
   - Relevant for single-lens systems such as spectacle glasses, magnifying glass
2. Using an achromatic doublet
   - Combine a strong lens with little dispersion and a weaker lens with strong dispersion, *of the opposite vergence power*
   - The second lens will neutralize the dispersion of the first lens while preserving most of the refractive power

The achromatic doublet

- Converging doublet:
  - Strong converging lens with little dispersion
  - Weak diverging lens with strong dispersion



- Diverging doublet:
  - Strong diverging lens with little dispersion
  - Weak converging lens with strong dispersion



More about achromatic doublets

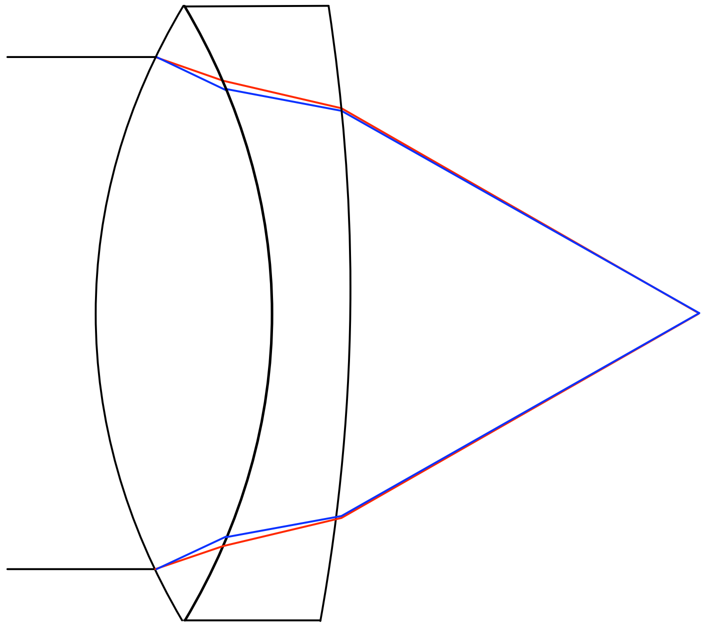
- The two lenses are usually glued (cemented) together to reduce reflections
  - The faces in common need to have the same radius of curvature
- Doublets can be designed to reduce both chromatic and spherical aberrations
- With a doublet the lens power can be made equal for two wavelengths, but small residual chromatic aberration remain for all other wavelengths
- Real optical systems often contain more than two elements to reduce all aberrations

Achromatic prisms

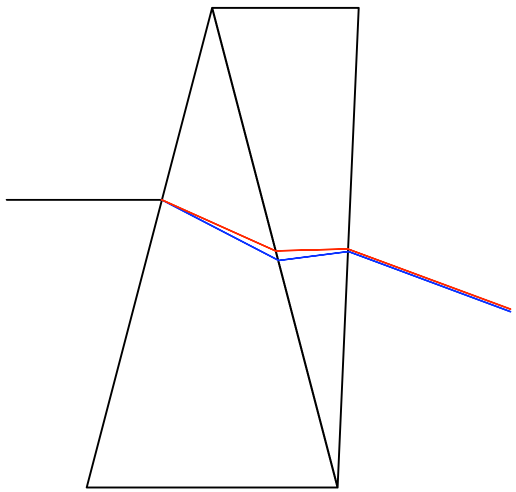
- Dispersion causes chromatic effect in prisms
  - The prism power P is stronger for blue light than for red light
- For many applications of prisms, the chromatic effects are undesirable
- The methods used for achromatic lenses also apply to achromatic prisms:
- An achromatic doublet can be made by combining a strong prism with little dispersion and a weaker prism with high dispersion, *with the opposite orientation*

The achromatic doublet

- Lens:
  - Strong converging lens with little dispersion
  - Weak diverging lens with strong dispersion



- Prism:
  - Strong prism with little dispersion
  - Weak prism with strong dispersion *with the opposite orientation*

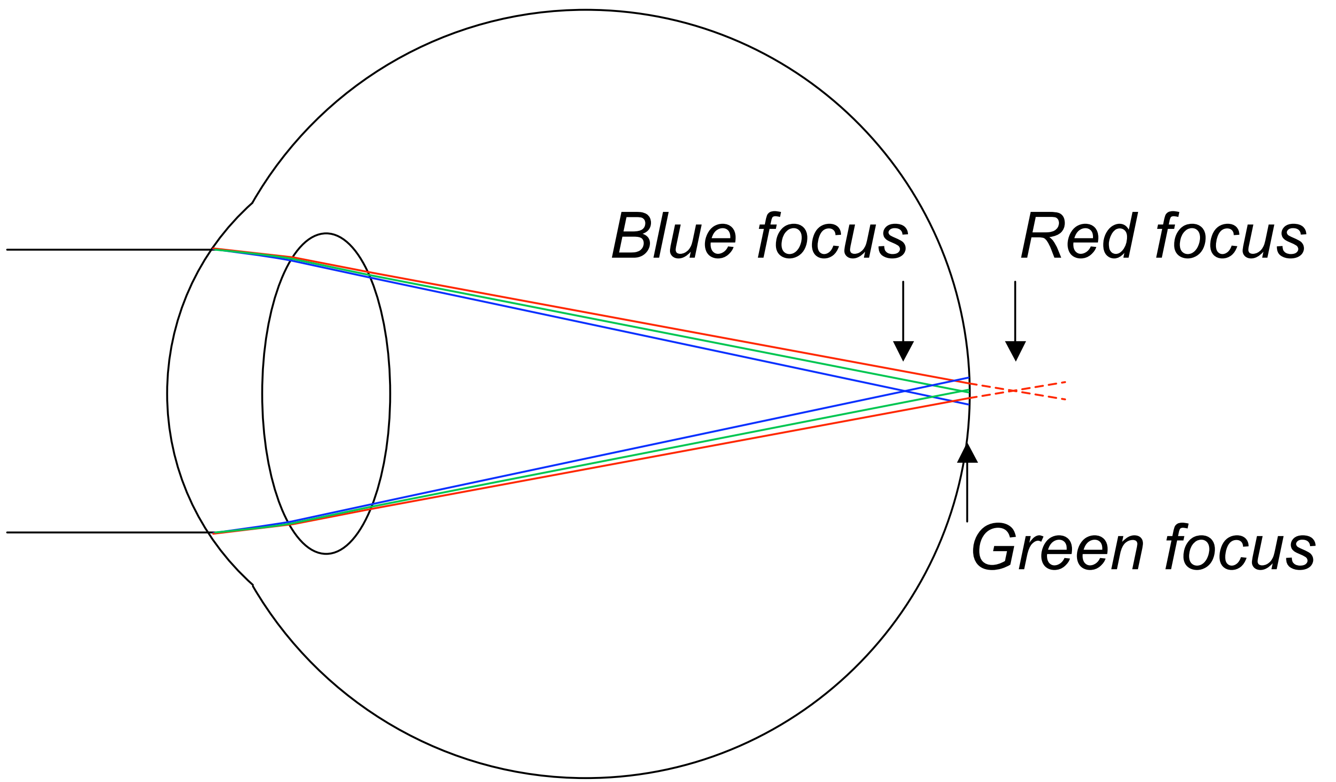


Chromatic aberration in the Eye.

- In the eye, the focal length is shorter for blue than for red light.
- Spread in power from blue to red is approximately 2 Dioptres.
- For an emmetropic eye, the centre of spectrum (yellow-green) is focused on the retina.
- Blue light is focused in front of the retina, red light behind the retina.

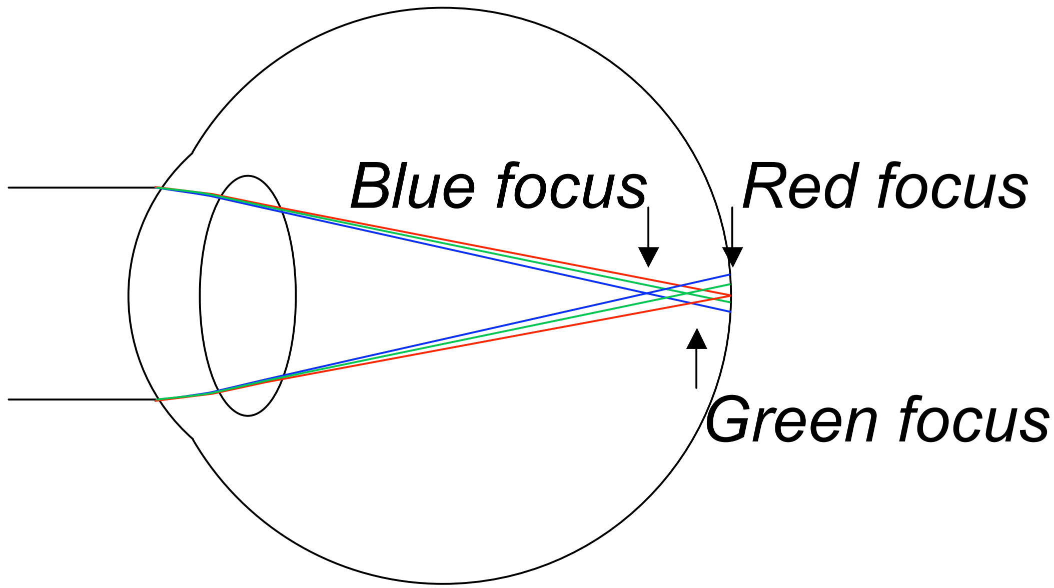
Chromatic aberration in the Eye.

Emmetropic eye:

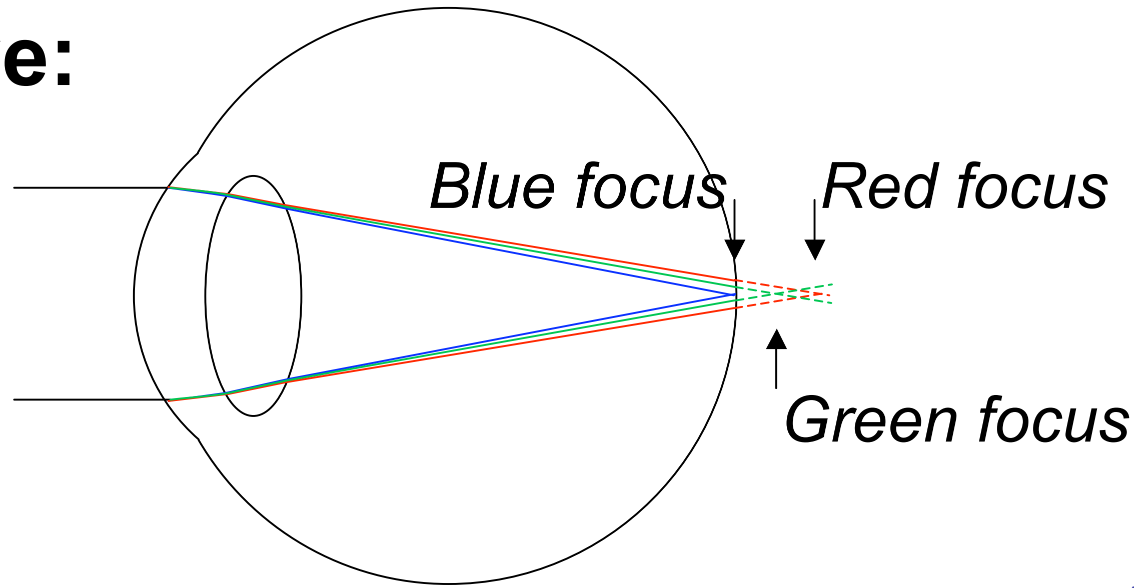


Chromatic aberrations & ametropia

Myopic eye:
(near-sighted)
sees red sharper
than blue

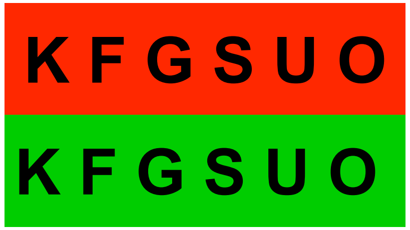


Hypermetropic eye:
(far-sighted)
sees blue sharper
than red



The Duochrome test:

- Uses chromatic aberrations to detect myopia
- Two sets of black letters:
  - one set with red background
  - one set with green background



- A myopic patient will see letters on the red background more clearly
- A hypermetropic patient will see letters on the green background more clearly
- A corrected eye should see both sets of letters with equally clarity
- *NB1: Green is used instead of blue, which is a poorly perceived colour*
- *NB2: Duochrome test is valid even for colour-blind patients*