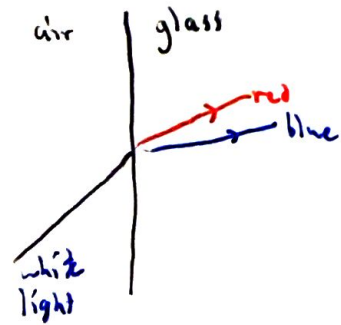
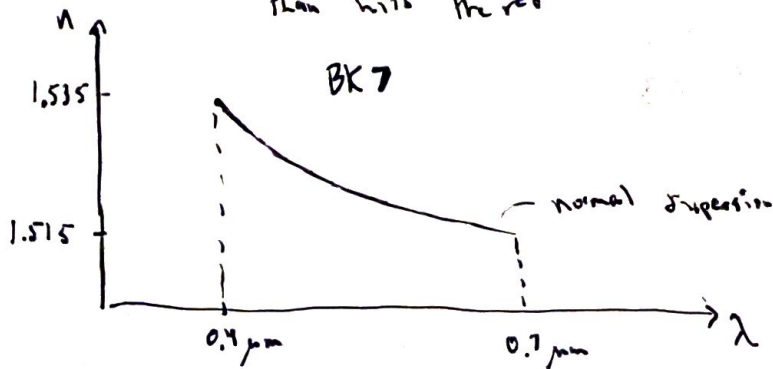


# Chapter 3: optical instrumentation

Dispersion,  $n(\lambda)$

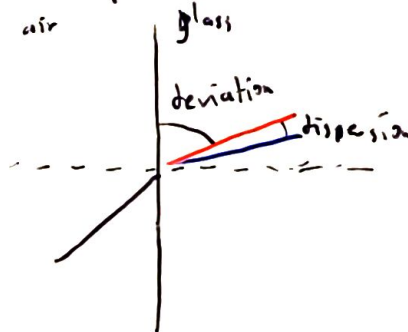
in general  $n$  will be larger with the blue than with the red



Cauchy relationship:  $n(\lambda) = A + \frac{B}{\lambda^2}$  for BK7,  $A \approx 1.505$   $B \approx 0.0042 \mu\text{m}^2$   
then dispersion

$$\frac{dn}{d\lambda} = -\frac{2B}{\lambda^3}$$

distinguish dispersion and deviation



We specify the glass dispersion by the Abbé number

Hydrogen: 486 nm - F line

Sodium: 589 nm - D line

Hydrogen: 656 nm - C line

Define the dispersive power  $\Delta = \frac{n_F - n_C}{n_D - 1}$

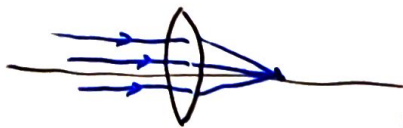
$$\Delta_{\text{crown glass}} \approx \frac{1}{65} \Rightarrow 65 \text{ Abbé num.}$$

$$\Delta_{\text{flint glass}} = \frac{1}{30} \Rightarrow 30 \text{ Abbé num.}$$

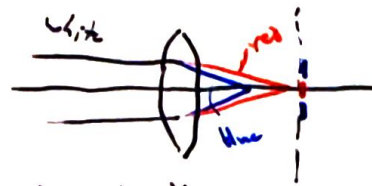
the Abbé number is  $\frac{1}{\Delta}$

the smaller the Abbé number, the more dispersive the glass

# Some comments on lenses



but when there are multiple colors



chromatic aberration

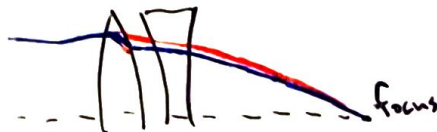
This is not a problem with mirrors  $\rightarrow$  use reflecting system for imaging  
Can make a partial correction using an acromat

not so strong  
dispersion  
(crown glass)

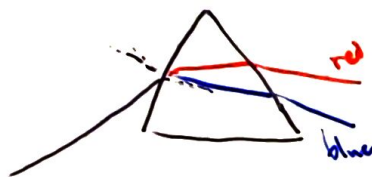


weaker  
from dispersion (flint glass)

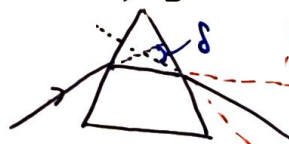
(stronger - shorter focal length)



prism and prism spectrometer



minimum deviation



position of minimum deviation

upon rotating there is

you'll see

As we rotate the prism we see that there is one position of minimum deviation

This occurs when input and output angle are the same



$$n = \frac{\sin\left(\frac{A+\delta}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

prism chromatic resolution

$$\frac{AB}{V_{light}} + \frac{BC}{V_{light}} = \frac{b}{V_{light}/n}$$

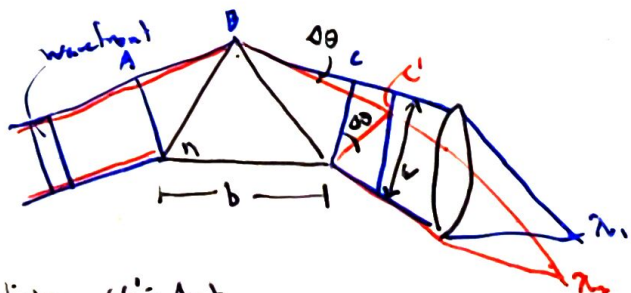
$$AB + BC = nb$$

$$AB + BC' = (n \pm \Delta n) b$$

$$\text{distance } CC' = \Delta n b$$

the smallest angle that can be resolved by the lens is

$$\Delta\theta = \frac{\lambda}{w}$$



this  $\Theta = \frac{\lambda}{W}$  comes from the wave picture of light  
(from diffraction)

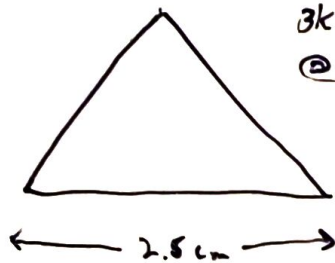
$$\therefore CC' = W \Delta \theta = \Delta n b$$

$$W \frac{\lambda}{W} = \Delta n b \Rightarrow \lambda = \Delta n b$$

$$\text{Resolution: } \frac{\lambda}{\Delta \lambda} = b \frac{\Delta n}{\Delta \lambda}$$

$$R = b \frac{\Delta n}{\Delta \lambda}$$

Example



3K7 glass  
@ 589 nm

$$R = 1025 \text{ (from eq.)}$$

$$\therefore \Delta \lambda = \frac{\lambda}{R} \approx 0.6 \text{ nm}$$

$$n(\lambda) = A + \frac{B}{\lambda^2}$$

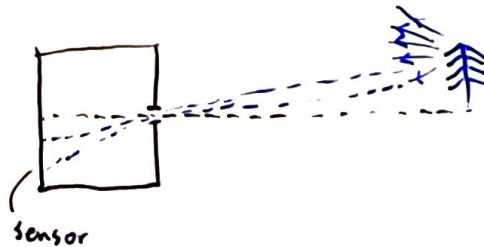
$$\frac{dn}{d\lambda} = -\frac{2B}{\lambda^3} = \frac{2 \cdot 0.0042}{(589 \text{ nm})^2} = 0.041 \mu\text{m}^{-1}$$

typically, prism is about  $\sim R=1000$

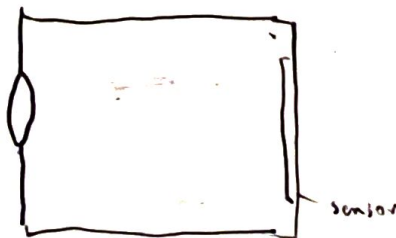
Camera

pinhole camera

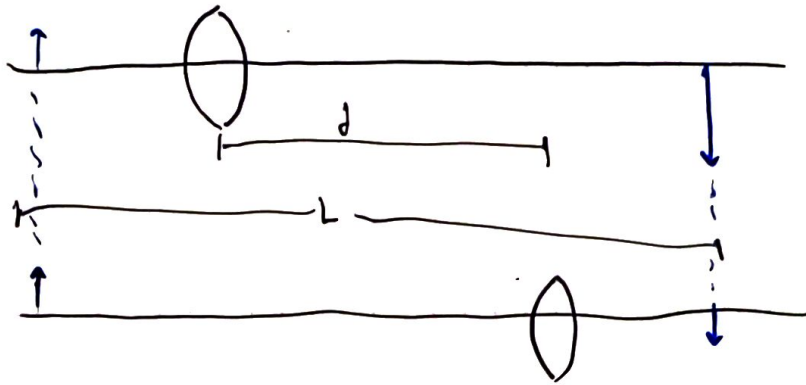
infinite depth of field  
not very efficient with light



how to improve the camera? use a lens



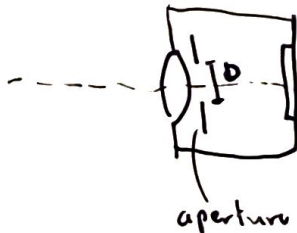
big aperture  
limited depth of field



the  $f = \frac{L^2 - d^2}{4L}$

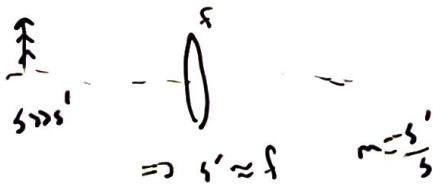
prove it.

Back to the camera:



can control exposure by shuttering  
or by changing aperture

Image brightness  $\propto D^2$



so the brightness  $\propto \frac{1}{f^2}$

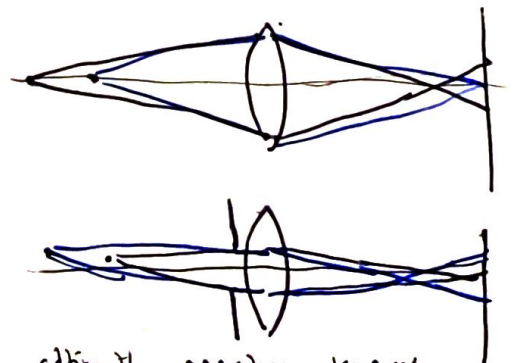
define relative aperture

$A = \frac{f}{D}$ , sometimes called f stop  
or f/#

brightness  $\propto \frac{1}{(f/\#)^2}$

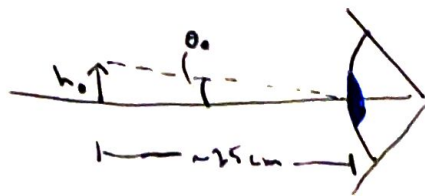
changing the aperture changes  
depth of field

f/#	f/D	brightness
1	1	1
1.4	1.4	2
2	2	4
2.8	2.8	8
5.6	5.6	
...		

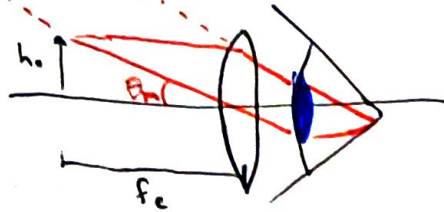


adding the aperture decreases  
blurriness for a bigger length

## Simple magnifier



$$\tan(\theta_o) = \frac{h_o}{25}$$



$$\tan(\theta_m) = \frac{h_o}{f_c}$$

define the magnification

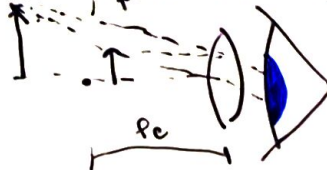
$$m = \frac{\tan \theta_m}{\tan \theta_o} = \frac{\theta_m}{\theta_o} \quad (\text{angular magnification})$$

$$m_p = \frac{h_o}{f_c} \cdot \frac{25}{h_o} = \left[ \frac{25}{f_c} \right]$$

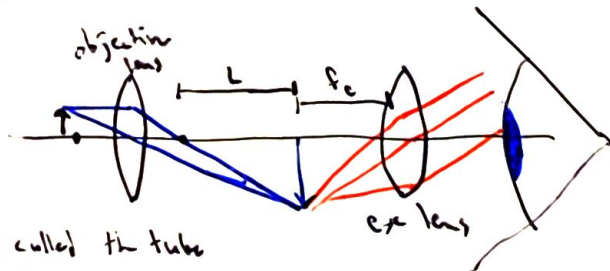
First microscope was like this, Leeuwenhoek  
↳ look up foldscope

fun thing:

if the image is at 25 cm, prove that the angular mag is  $\frac{25}{f_c} + 1$



## compound microscope



$L$  is called the tube length

$L = 160 \text{ mm}$  traditionally