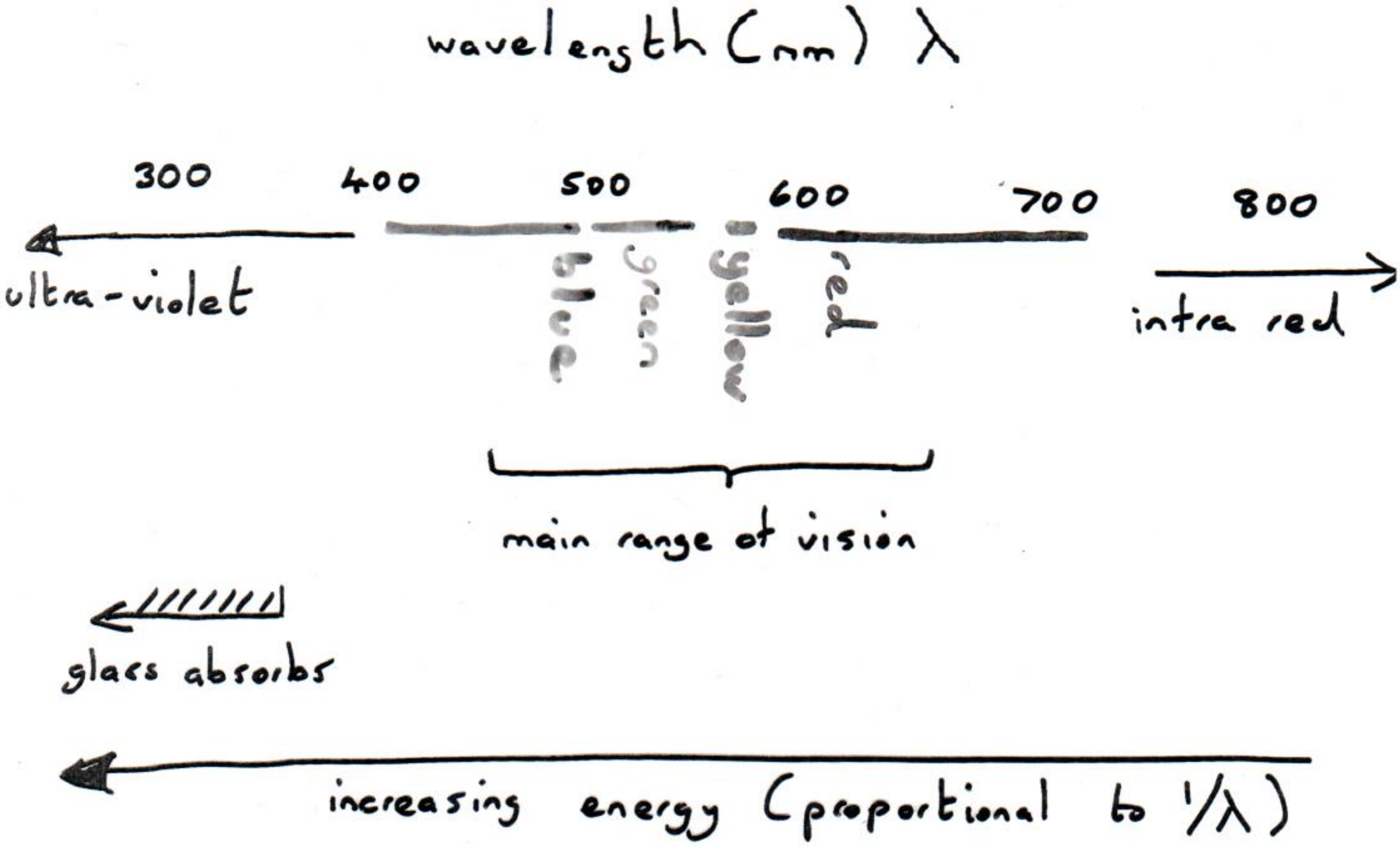
PHOTONICS – 'The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon'.

Nature of light

WAVE PHOTON	} generally behaves in way that will give you most trouble!

Light as a wave



Wave nature limits resolution

resolution improves at shorter wavelengths

Light as photons

velocity 300,000 km s^{-1}

(or about 30μm in 100fs)

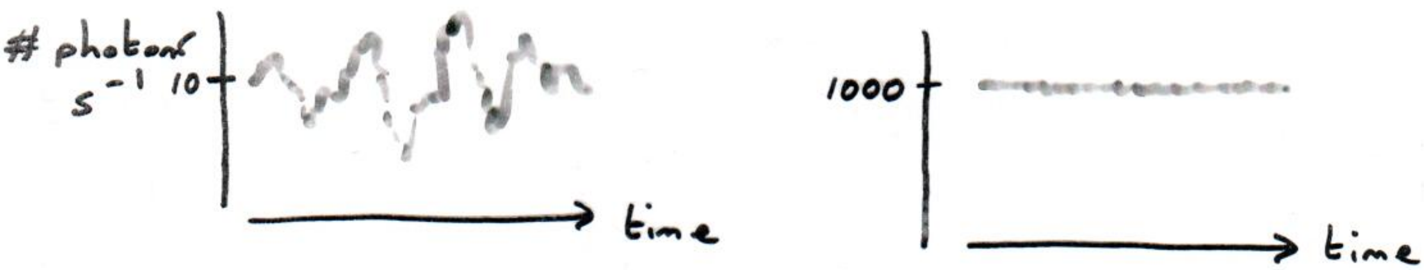
Very sensitive detectors can respond to individua
photons.

Energy of photon increases with decreasing λ

Quantal nature of light sets ultimate limit
to detection of faint signals

'Shot noise'

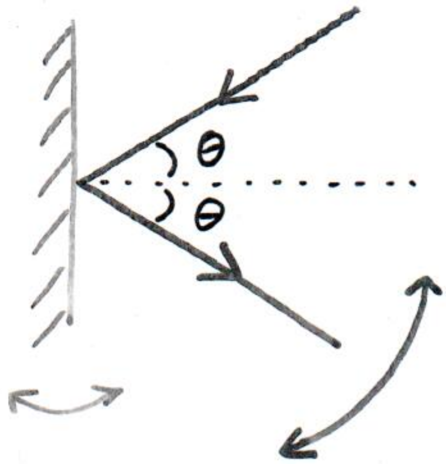
10 photons s^{-1}



Signal-to-noise ratio improves as $\sqrt{\# photons}$
$\equiv \sqrt{\text{light intensity}}$. <u>The more potons you detect, the bett</u>

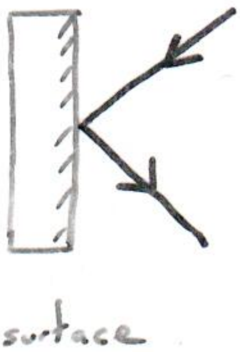
Classical Optics

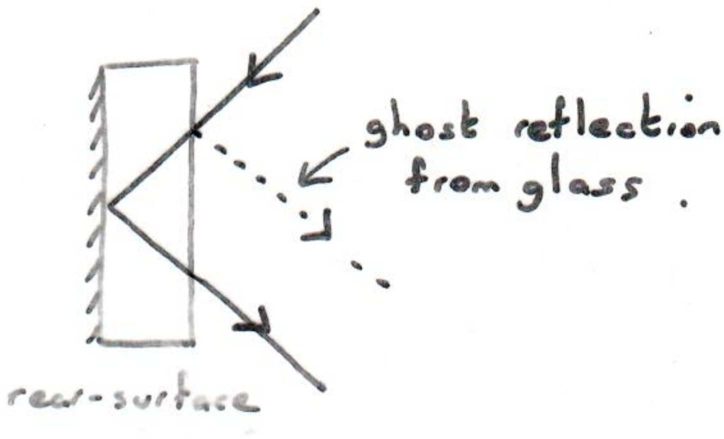
Reflection



reflected beam rotates twice the angle the mirror is rotated

Front-surface mirrors

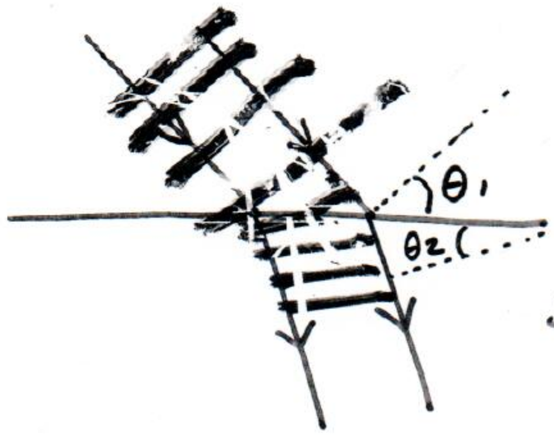




Ordinary glass/air interface reflects ~ 5%. Can minimize by coating to get reflection < 0.5%. Important for lenses (light loss) as well as mirrors.

Mirror surface usually Al or Ag – protected by coating to stop oxidation and enhance reflection.

Retraction



air – refractive index ~ 1

glass " " ~1.5

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

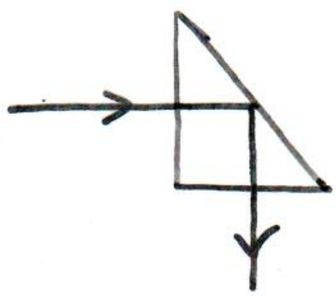
retractive index. (→ n_1)

Velocity of light is slower in materials with higher refractive index. Some values of n

vacuum	1.0	cells	1.36
air	1.0003	glass	1.52
water	1.333		

Total internal reflection

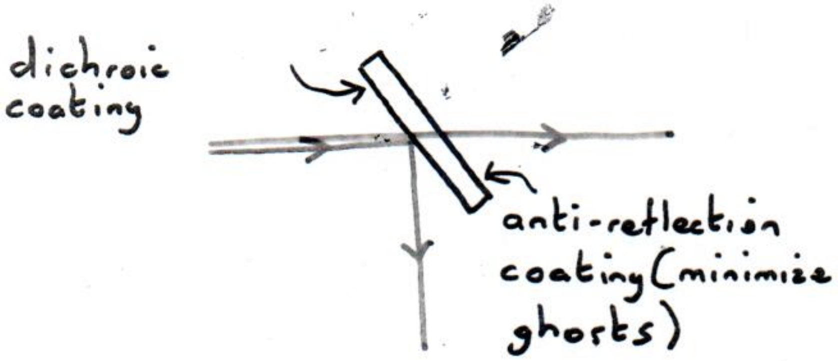
'fish-eye view of the world'

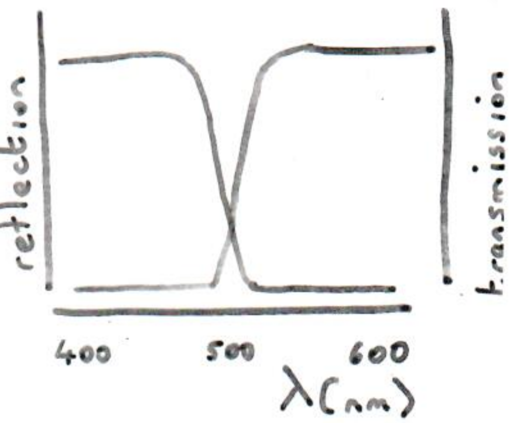


prism as a reflector

Dichroic mirrors

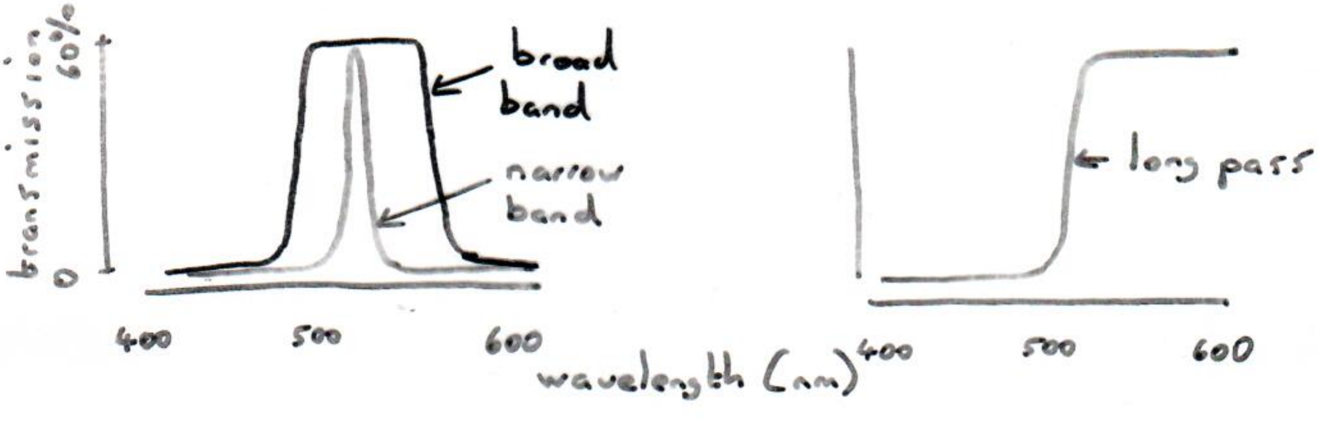
Reflect certain wavelengths (usually short λ) and transmit others (usually long λ). Work by interference; very delicate coating! expensive!



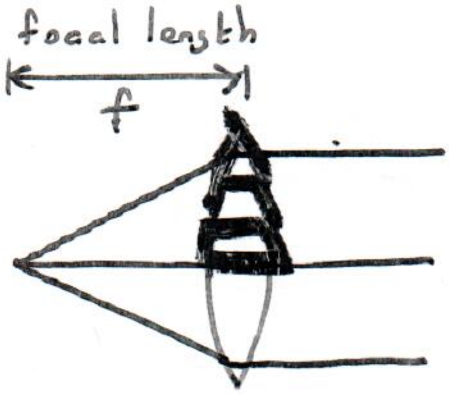


Interference filters

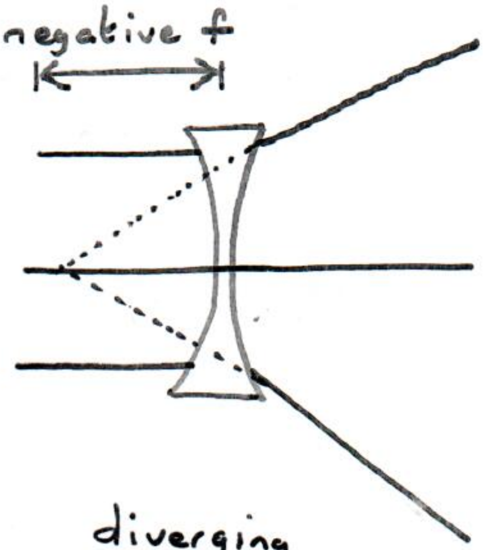
Transmit only very specific wavelengths. Work by interference (angle-sensitive: light must be near-normal incidence). Can be narrow- or broad-pass; long or short pass.



Lenses

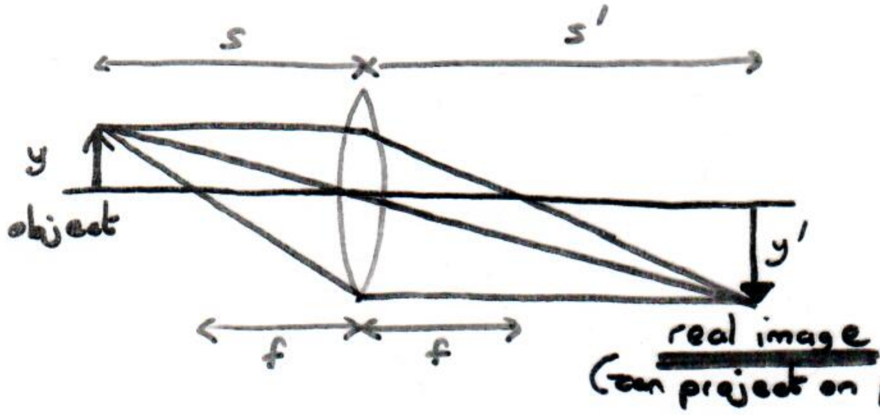


converging
(positive)



diverging
(negative)

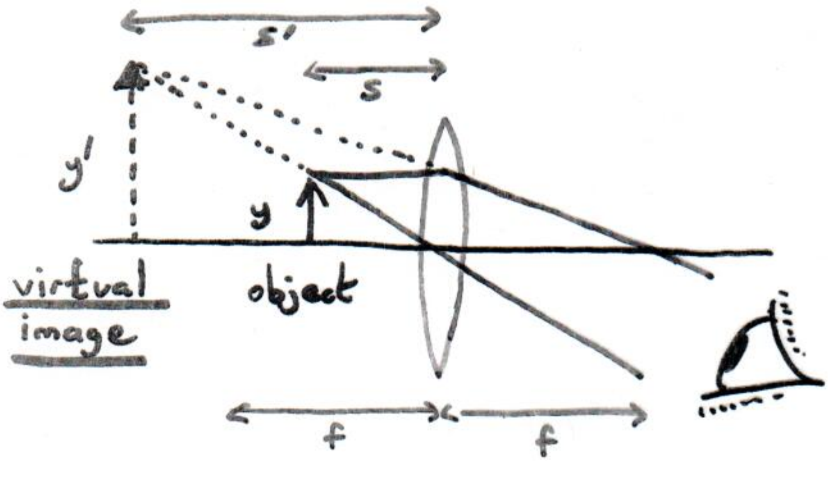
Magnification



magnification

$$m = \frac{y'}{y} = \frac{s'}{s}$$

[NB. $s > f$]

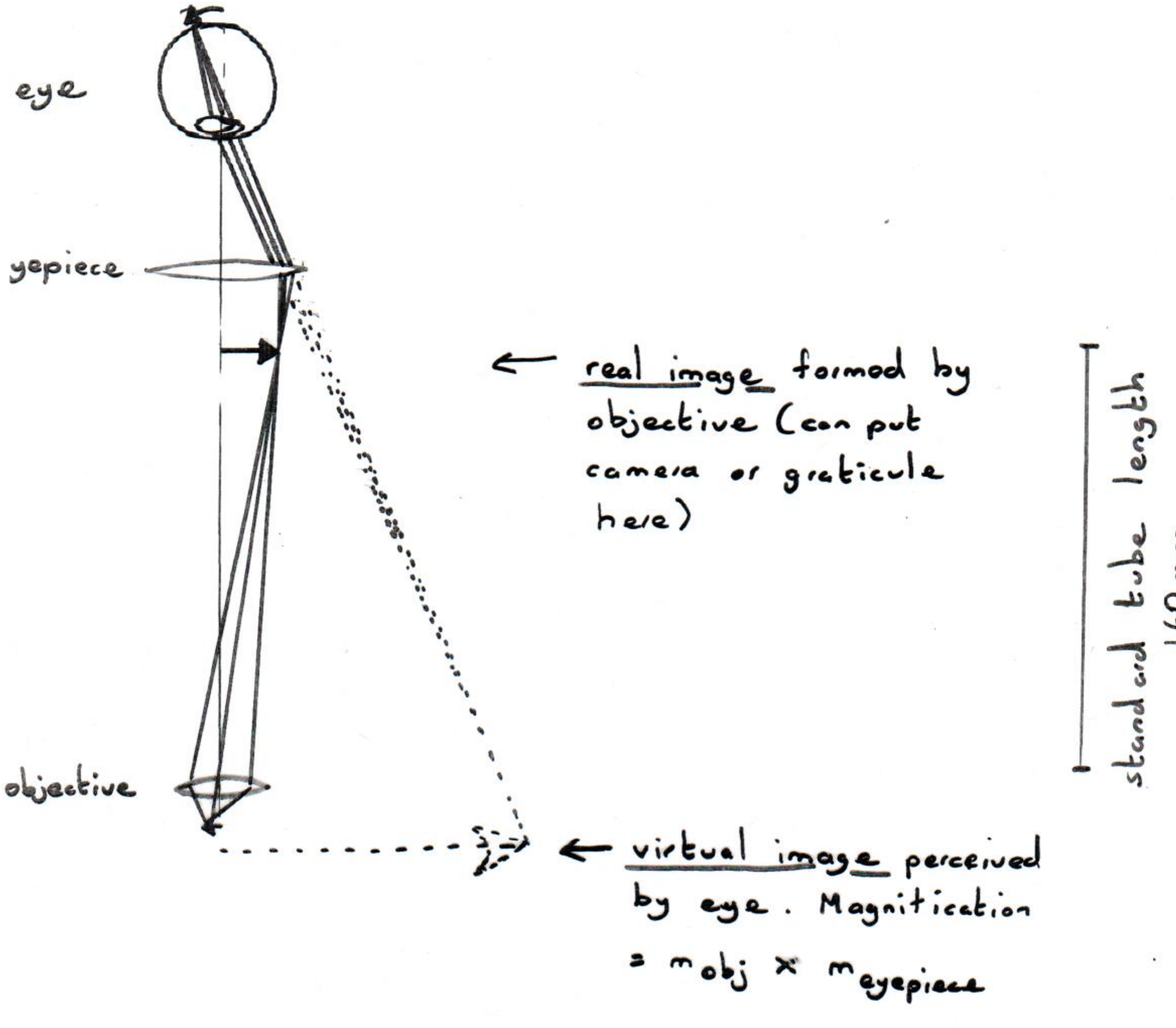


virtual image appears (right way up) behind the lens. Magnifying glass.

$$m = \frac{s'}{s}$$

[NB $s < f$]

The compound microscope



Objective magnification stated with respect to standard tube length. Corrected only for this length.

The objective lens

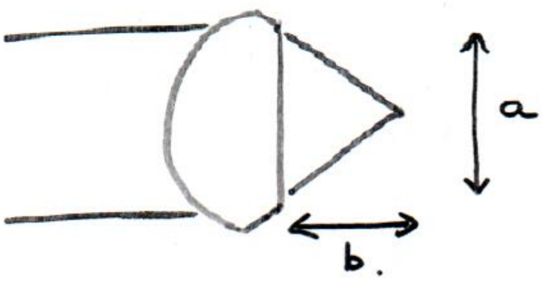
The most important part of a microscope – all the rest is just ergonomics.

Corrections and features

- Ach – achromatic : corrected for 2 colors
- Apo – apochromatic : " " 3 colors
- Fluar – improved UV transmission : for fluorescence
- Plan – flat field of view
- LWD – long working distance
- NA – numerical aperture (the bigger the better

$\uparrow$ corrections and $\uparrow$ NA = $\uparrow$ $$

The importance of numerical aperture



$$NA = \frac{a}{b}$$

① The higher the NA, the more light you collect – particularly important for fluorescence

collection improves as square of NA

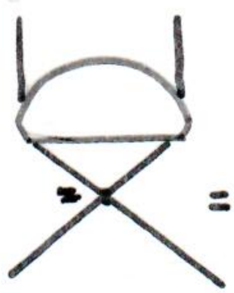
collect only those falling within cone set by NA.

light (photons) emitted in all directions

② High NA ≡ shallow depth of field (improved optical section)

objects will look in sharp focus over wide range

Low NA



= sharp focus over narrow range

High NA

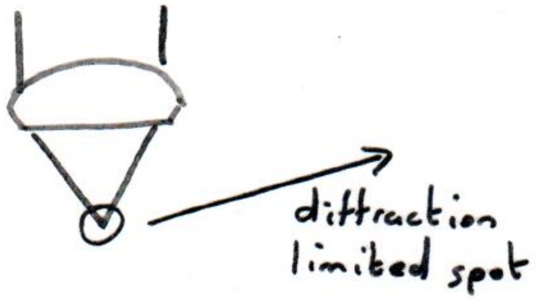
③ Resolution improves with increasing NA.

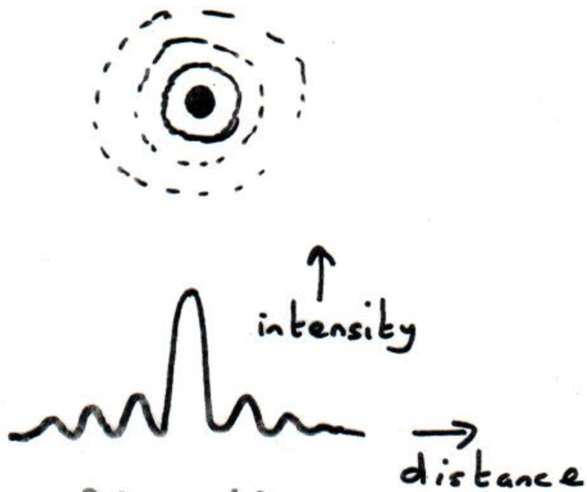
Rayleigh formula for transverse resolution

$$S_{min} = 0.6\lambda / NA$$

S_{min} ↗ minimum spacing at which 2 points can be seperately resolved

λ ↑ wavelength





Airy disc

Width of central peak ↓ as NA ↑ and λ ↓

Can only resolve if central peaks seperable