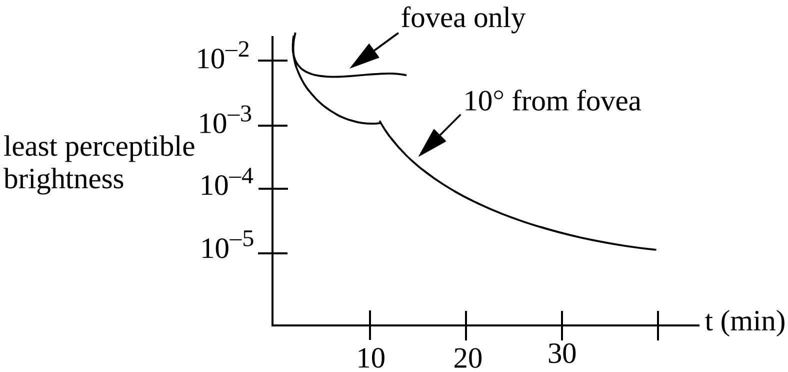
Lecture 9

<u>Sensitivity of the Eye</u>

The eye is capable of “dark adaptation.” This comes about by opening of the iris, as well as a change in rod cell photochemistry



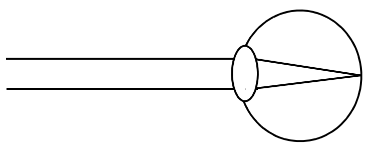
in the dark, the fovea becomes a blind spot

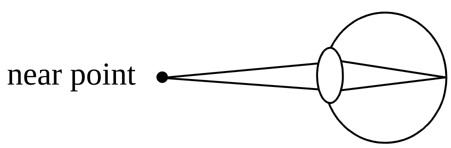
Min detectable flash:outside fovea 50-150 photons

inside fovea ~150,000 photons

<u>Accommodation</u> – Ability of eye to focus (automatically)

The relaxed lens focuses far (infinity). The lens “accommodates” to focus near.



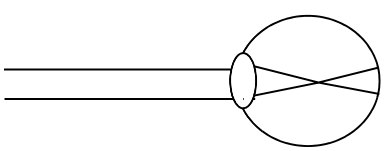


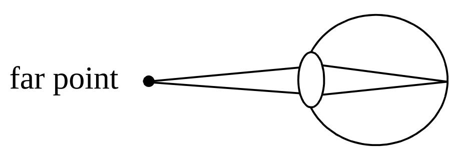
at maximum power of the eye, the closest image plane occurs at the “near point”

Amount of accommodation:10 diopters at age 20

~2 diopters at age 60

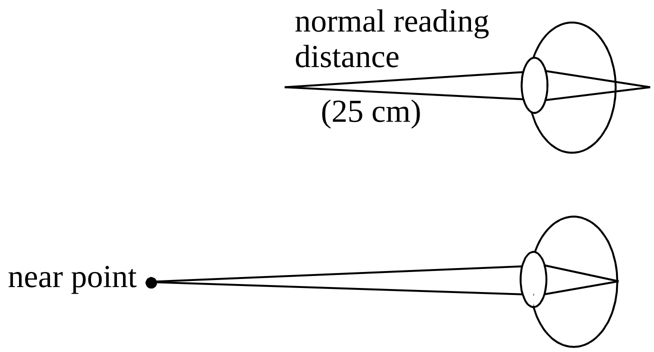
Myopia (nearsightedness) – lens power too large, or eyeball too long





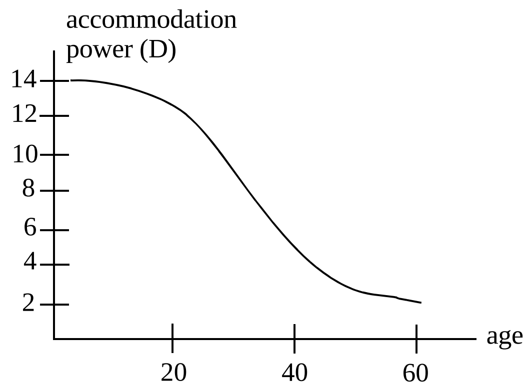
The myopic eye can only accommodate between a far point and the near point. This can be corrected by a negative lens, chosen so that an object at infinity has a virtual image at the far point.

Hyperopia (farsightedness) – too little power in lens, or the eyeball is too short



In this case, the near point is too far for comfort. It is corrected with a positive lens.

Presbyopia



As we age, the eye loses the ability to accommodate. This is why "reading glasses" are used.

Astigmatism

– Shape of cornea is not radially symmetric.

– Focal power is different along 2 orthogonal axes.

– Must be corrected using a cylindrical lens, oriented along the proper axis.

Radial keratotomy (RK)

– Correction of shape of cornea by radial cuts (part way through cornea).

– This causes the cornea to bulge in the region of the cuts, changing the shape of the cornea.

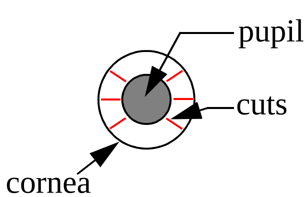
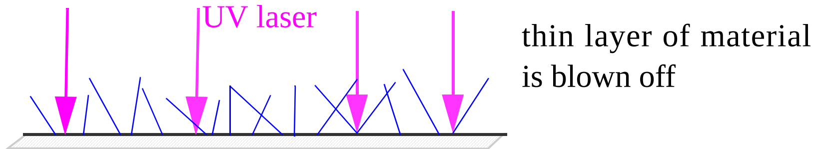


Photo-refractive keratotomy (PRK)

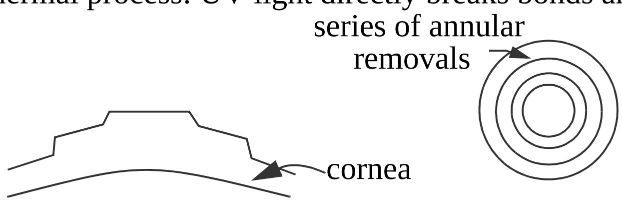
– In this case, we use laser ablation in the clear aperture of cornea.

– The idea is to reshape the cornea surface itself.

Laser ablation

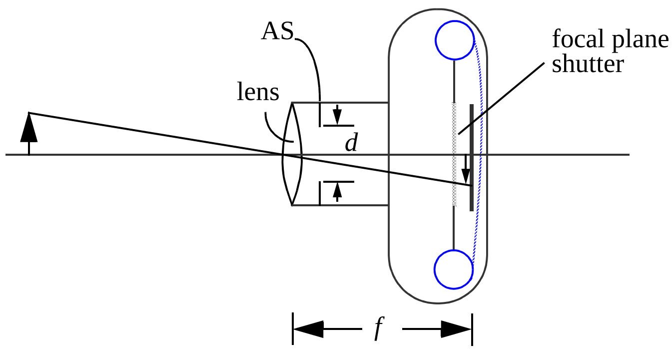


– Laser ablation is not a thermal process: UV light directly breaks bonds and decomposes the material.



Still Camera

[Reading assignment: Hecht 5.7.6]



The aperture stop (AS) is variable to control the amount of light reaching the film. By convention, the AS is normalized to the lens focal length to give a dimensionless parameter called *F number* or *F-stop*

$$F = f/d \qquad \text{note: NA} \cong \frac{1}{2F}$$

usually written as $f/8$, which means F# = 8.

The amount of light reaching the film is also controlled by the shutter. Shutter speed is expressed as the inverse fraction of 1 sec.

$$s = 125 \quad \text{means} \quad 1/125 \text{ sec}$$

The energy density reaching the film (i.e., film exposure) is given by

$$E \propto \frac{BA}{sf^2} = \frac{B\pi d^2}{4sf^2} = \frac{B\pi}{4sF^2}$$

where B is object brightness.

Film exposure variation by 2× is called 1-stop. Shutter speeds are usually varied by 1 stop, i.e., 1, 2, 4, 8, 16, 32, 64, 125, 250, 500, 1000.

Lens aperture also varies by stops. In F-number, one stop is a factor of $\sqrt{2}$. (Why?) Typical lens F# settings: 2, 2.8, 4, 5.6, 8, 11, 16. So an exposure setting with $S = 125, f/4$ is equivalent in terms of film exposure to $S = 64, f/5.6$.

How to choose? Trade-offs:

Shutter speed: Faster → less blur, slower → more light

F-stop: Wider (lower F#) → more light

Depth of focus (DOF): Range of object distances in ‘good’ focus

$$\boxed{\text{DOF} \propto F^2}$$

So lower F → less DOF.

In principle, lower F → higher resolution, but most consumer camera lenses are aberration limited, not diffraction limited. So, sharper pictures are usually obtained with larger F, since aberrations reduce at larger F.

Modern cameras have auto-exposure. The exposure program steps S and F together in a compromise, middle range. Better cameras allow over-ride of one or the other. They also allow deliberate over- or under-exposure by ± 1 - ± 2 stops. A photodetector inside the camera is used to control the exposure.

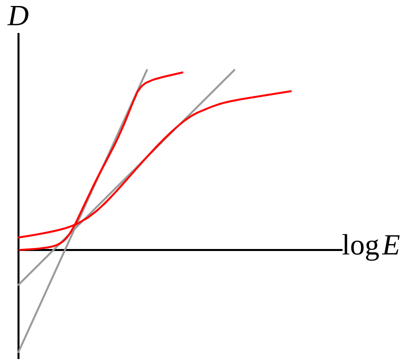
<u>Film</u>

Photographic film is made by coating a special silver halide “emulsion” on an acetate film backing. The emulsion consists of silver halide particles suspended in some matrix. Light absorbed in a particle causes a photochemical change. Chemical *development* causes exposed grains to convert to silver. Unexposed grains are washed away. The result is a film density given by

$$\boxed{D \equiv -\log T_i}$$

where T_i is the intensity transmittance of film.

D relates to film exposure E as:



From the straight line part of the curve

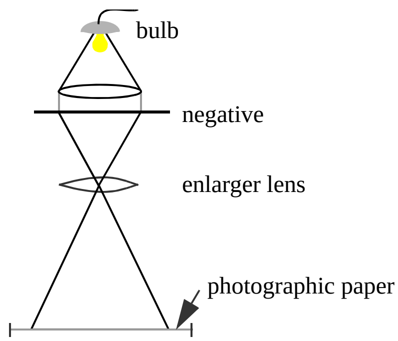
$$D = \gamma_n \log E - D_0$$

Note the *negative* character: Film gets *darker* for more light *exposure*.

γ_n: contrast.

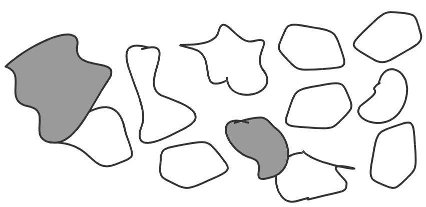
Prints or slides are made in a second step:

Paper also has a negative response, like the film. The combined response can be made linear.



Sensitivity $\rightarrow$ ***resolution*** trade-off

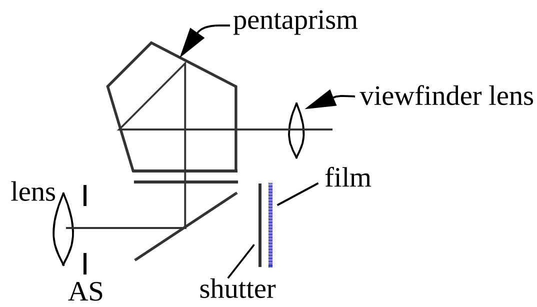
The photochemical reaction is catalytic,



that is, when part of a grain is exposed, the *whole grain* is converted in development. So, film with large grains is more sensitive.

But, the spatial resolution of the film is set by the grain size.

Single-lens Reflex Camera



- Facilitates interchangeable lenses. The finder shows exactly what goes on film.
- A focal plane shutter is required. To obtain high shutter speeds, the shutter is operated as a thin scanning slit.
- Automatic aperture: AS stays open until exposure, so the finder remains bright. During exposure, the AS automatically closes down to the appropriate F stop.

Electronic Camera

Film is replaced by an electronic detector. Most commonly, this is a CCD image array. The analog to grain size is the CCD resolution.

Consumer 35mm film is equivalent to 10-20 Mpixel. However, very acceptable pictures are obtained with 1-2 Mpixel, and consumer cameras today are available with 12 or more Mpixel CCDs.

Film format: Bigger negative → more resolution. Professionals use $2\frac{1}{4}'' \times 2\frac{1}{4}''$ or bigger film format.

CCD sensors have become available for professional use with this larger format. These sensors may have in excess of 40 Mpixels.