Capturing images

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Introduction of the speaker

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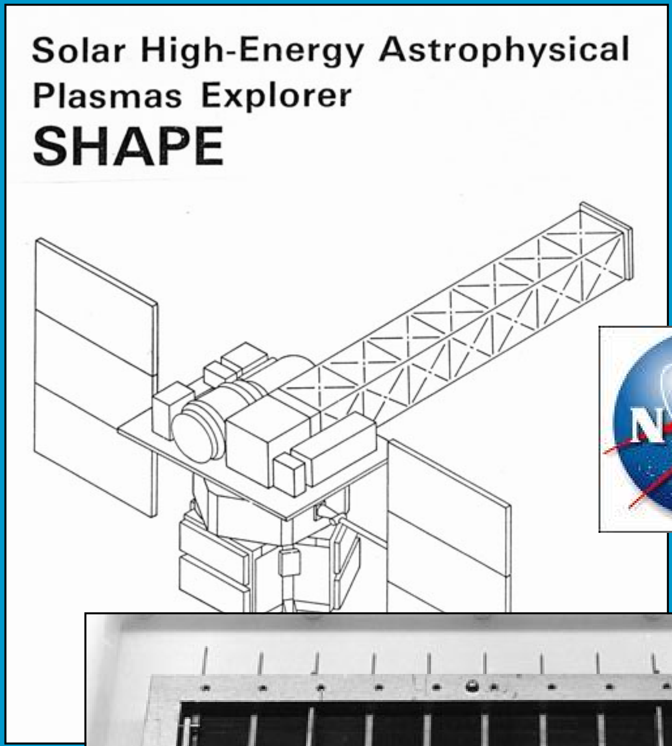
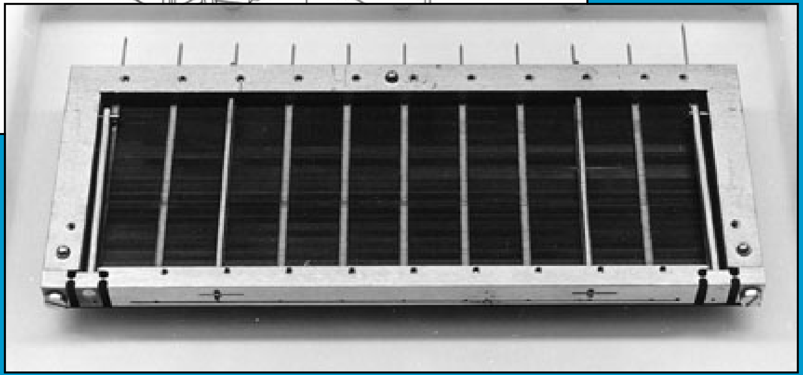
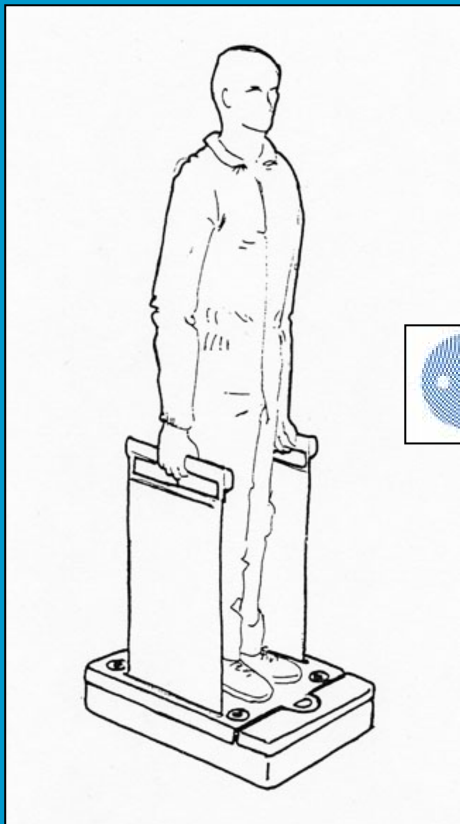




Introduction of the speaker



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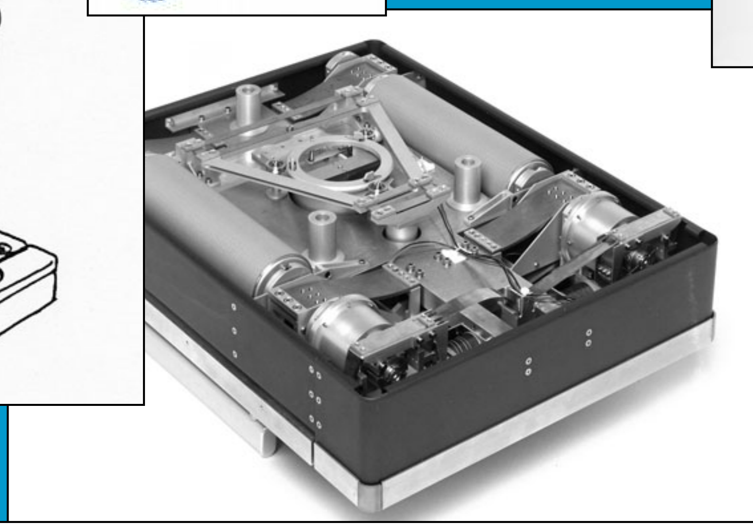

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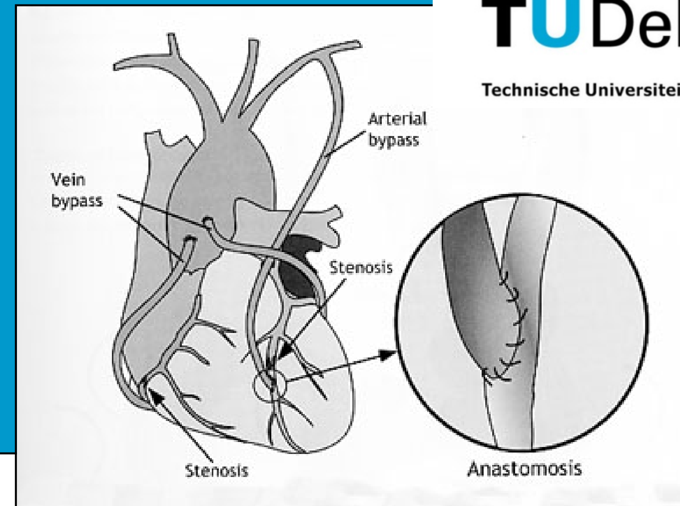

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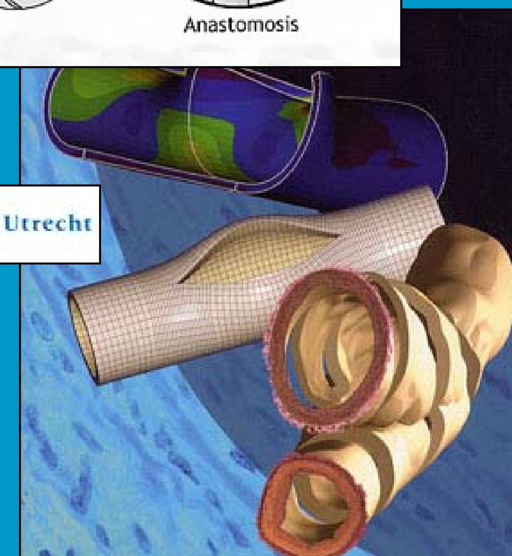
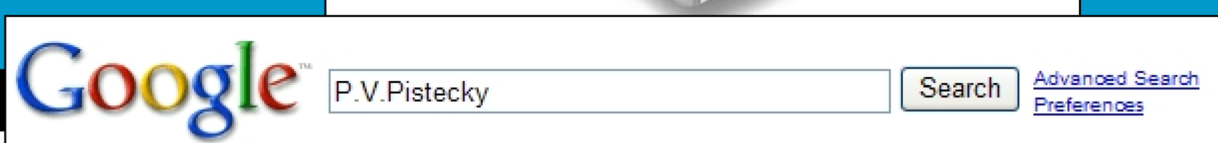




Driving forces to innovations

Human demands

- less work (effort)
- quicker (speed)
- better (quality)
- cheaper (cost)
- ......

Human curiosity

- progress in science

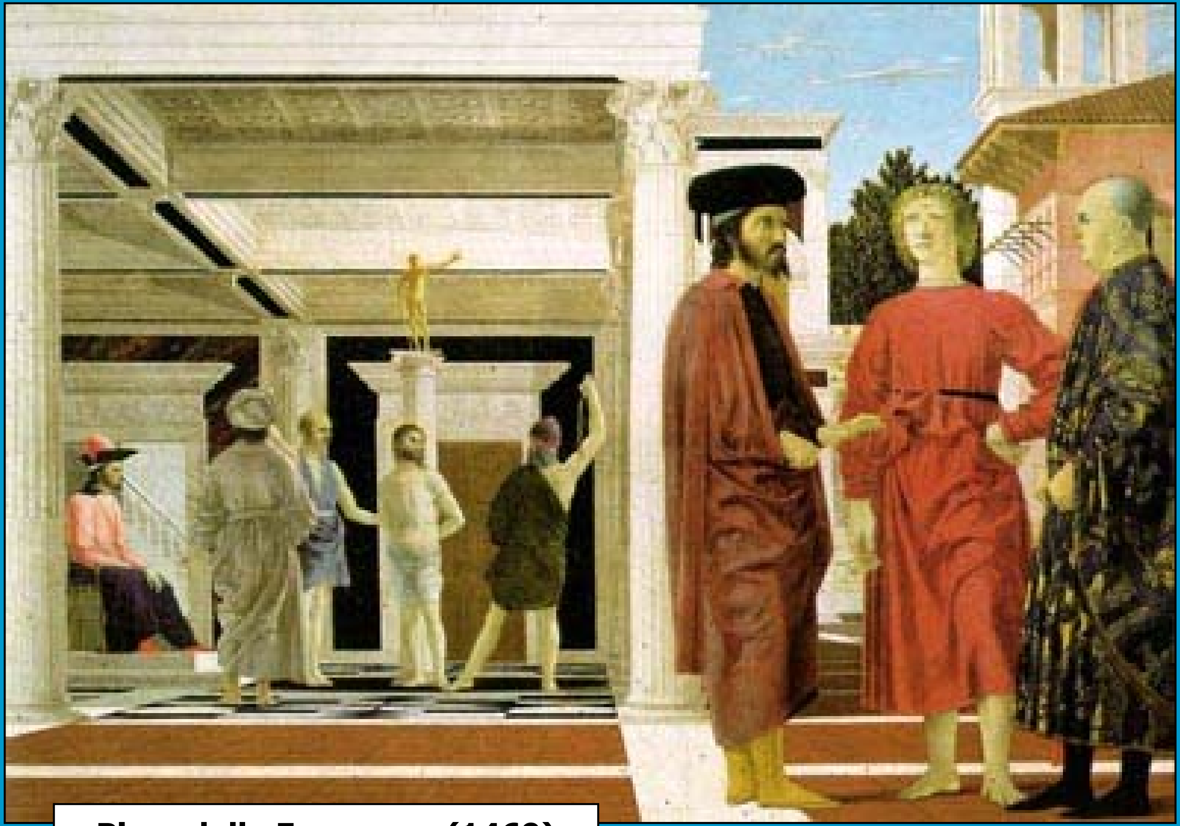
Where it all began

effort	--
speed	--
quality	+
cost	-

First storage of picture information

- Bison at Altamira cave Spain

History of image recording (paintings)

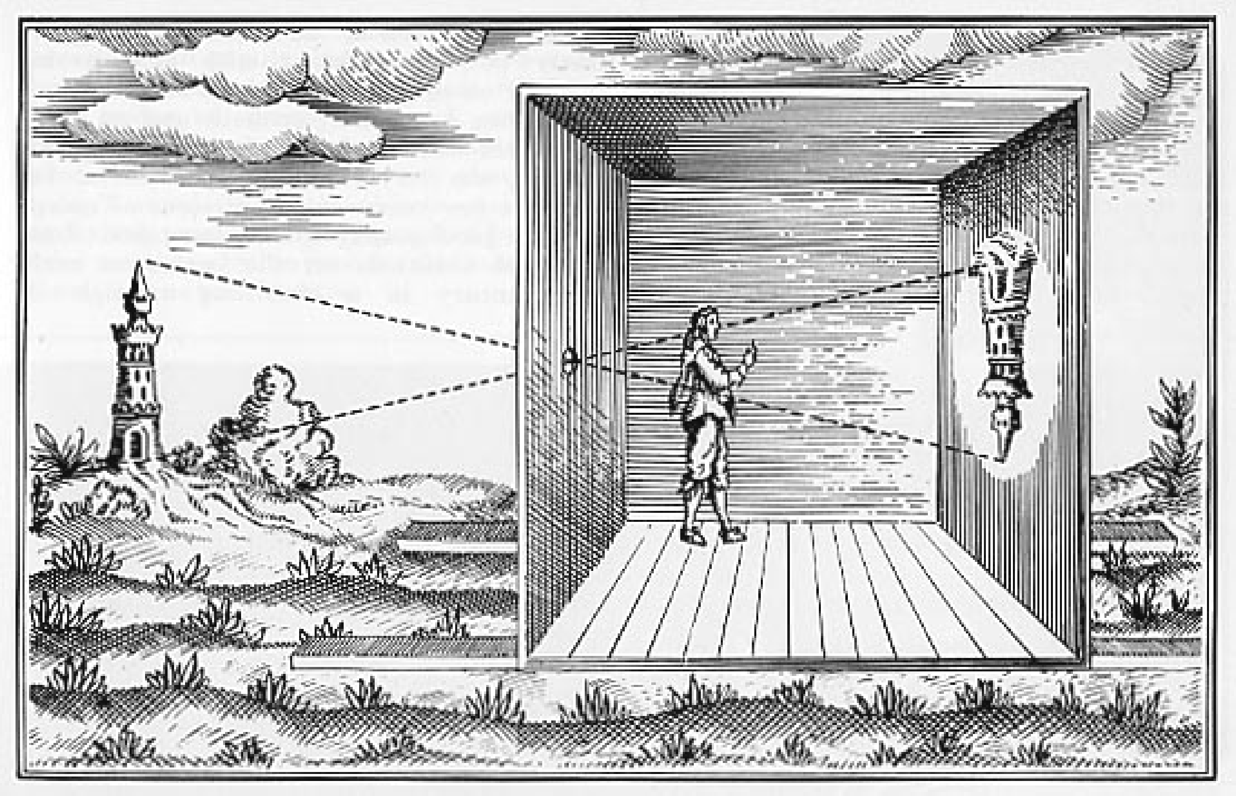


Piero della Francesca (1469)

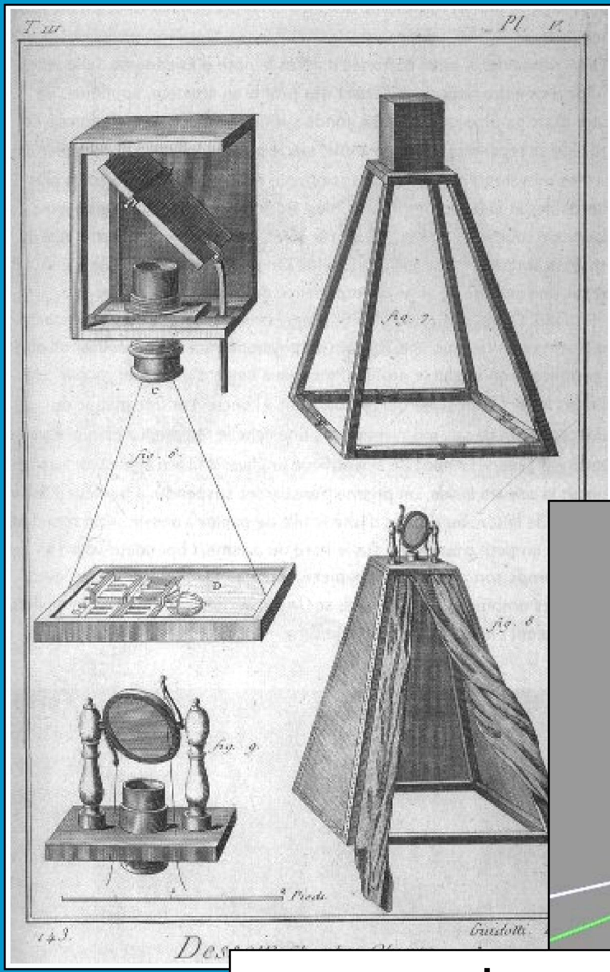
One of the first paintings using rules of perspective to add depth in the scene

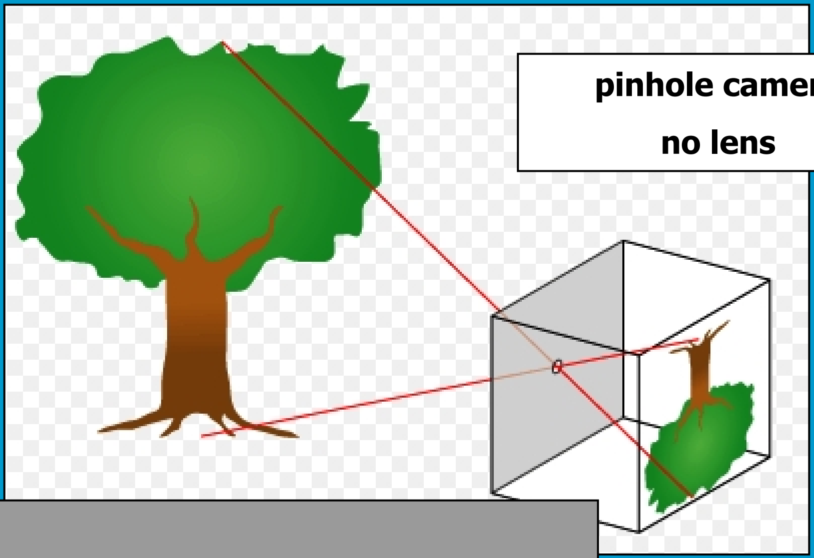
History of image recording

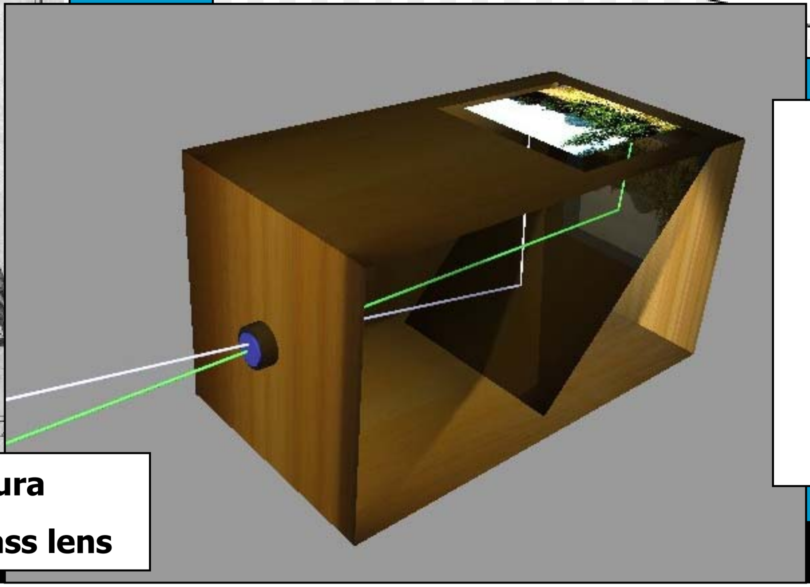
- Camera obscura (“dark room”)



History of image recording



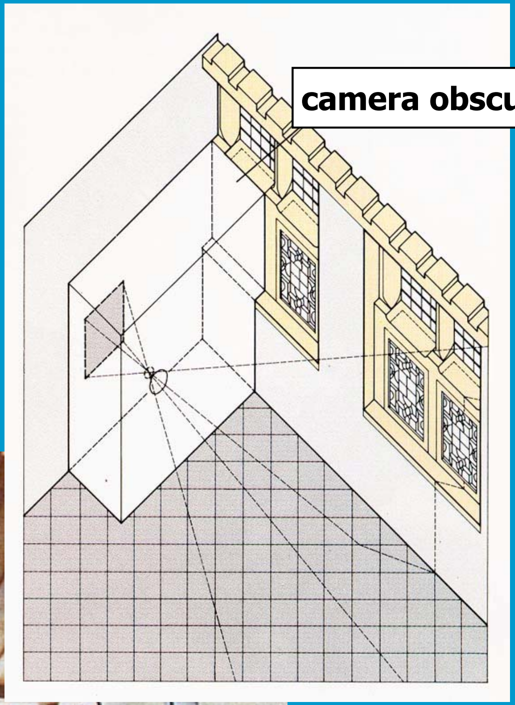




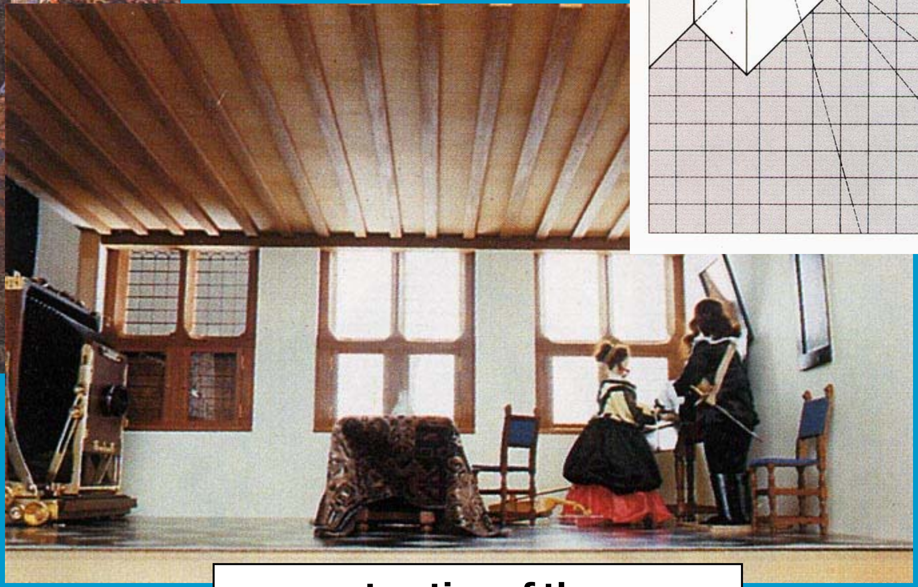
History of image recording (paintings)

Vermeer van Delft (1665)

Use of camera obscura (?) to add accuracy and speed up painting process



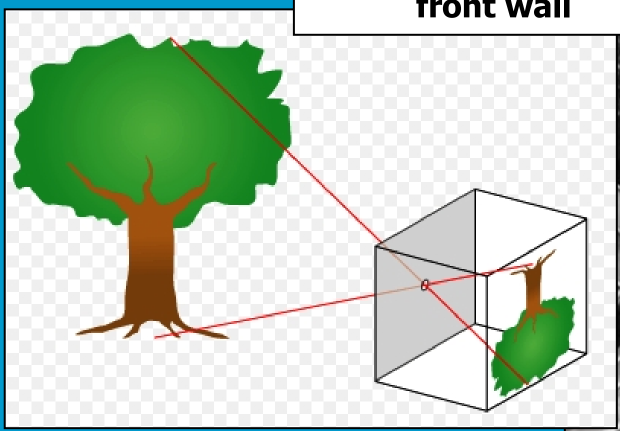
camera obscura



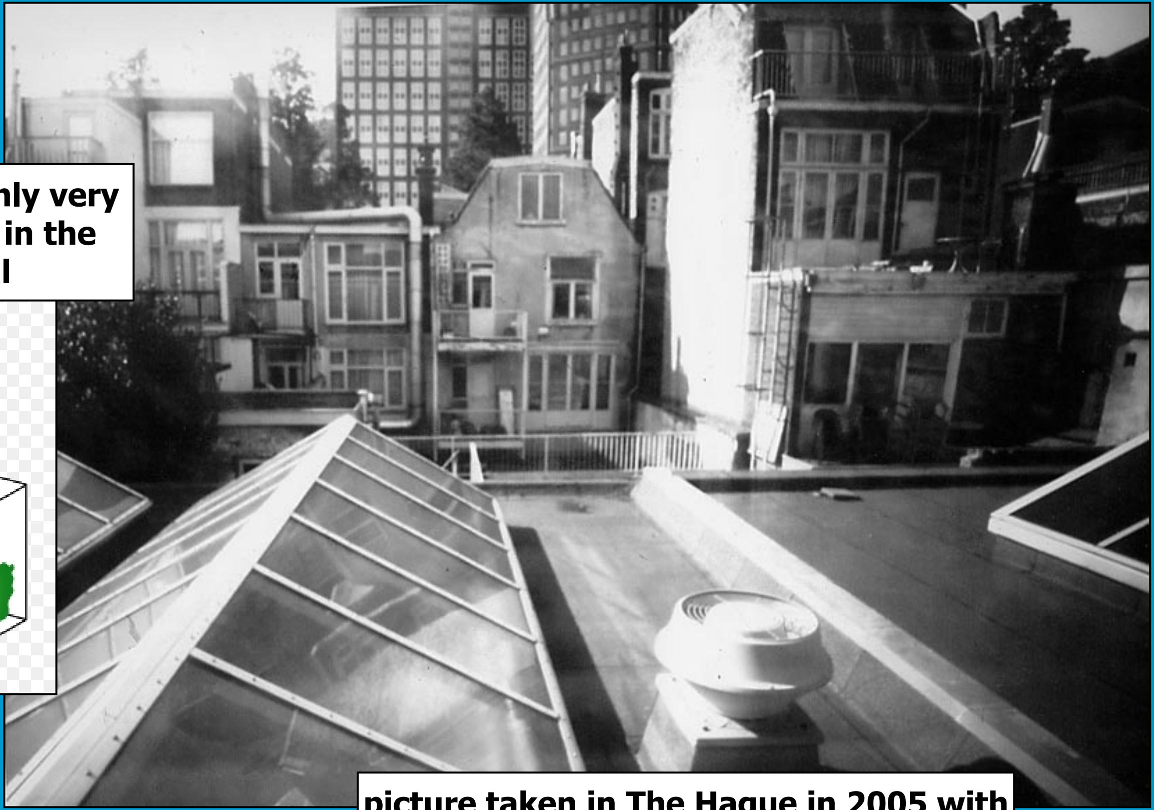
reconstruction of the scene

History of image recording

Pinhole camera

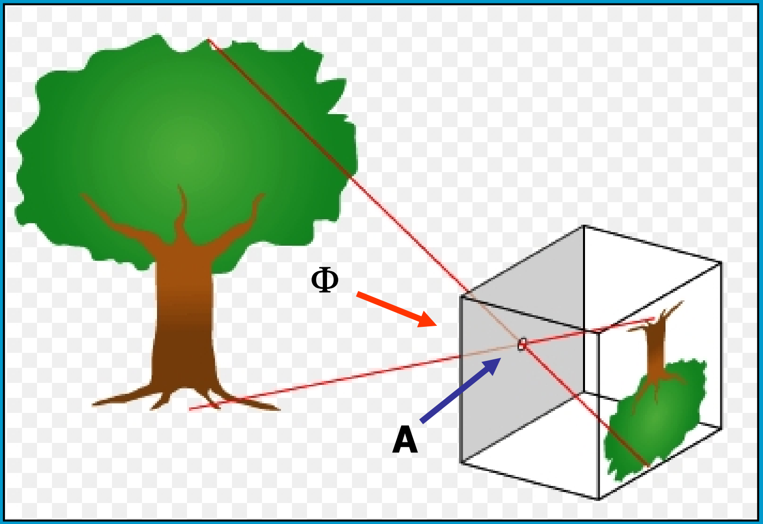


no lens at all, only very small opening in the front wall



picture taken in The Hague in 2005 with a pinhole camera

Image recording



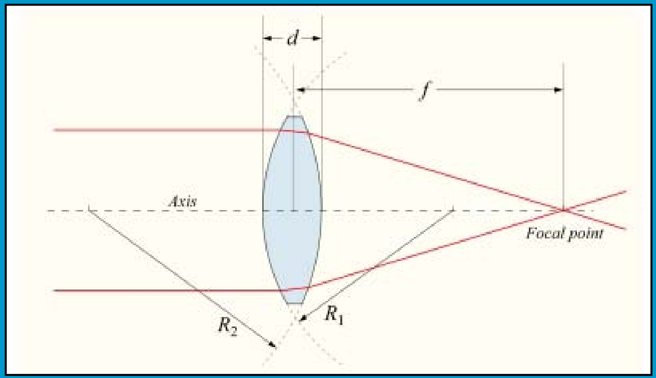
What is needed to capture an image

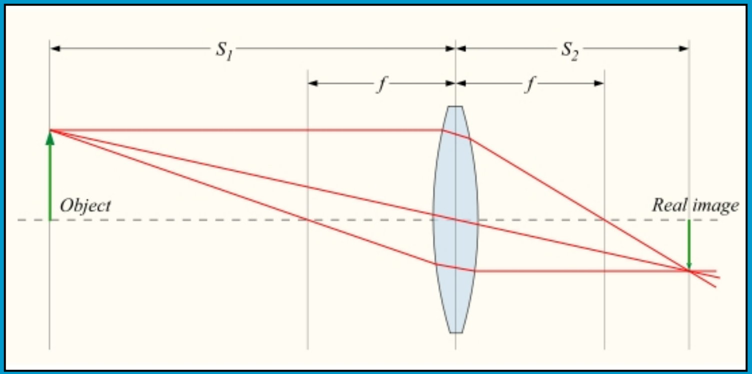
- dark box (camera)
- light sensitive material
- image producing device: pinhole/optical lens
- right dosage of light energy $E=\Phi.A.t$ $[J=W/m^2.m^2.s]$
  - shutter (exposure time t)
  - diaphragm/lens (entrance area A)

Φ = photon flow $[W/m^2]$

- processing of (latent) image:
  - chemistry/electronic circuit

History of image recording – optical lens





- known for more than 2000 years
- Aristophanes (424 BC) – burning glass (biconvex lens)
- Ibn Sahl (approx. 970) – first lens calculations
- Ibn al-Haitham (965-1038) wrote “Book of Optics”
- invention of spectacles (Italy 1280s)
- Nicolas of Cusa – discovery of concave lens (treatment of myopia)
- Ernst Abbe (1860s) - more precise lens calculations
  - establishment of Carl Zeiss company

History of image recording (photography)

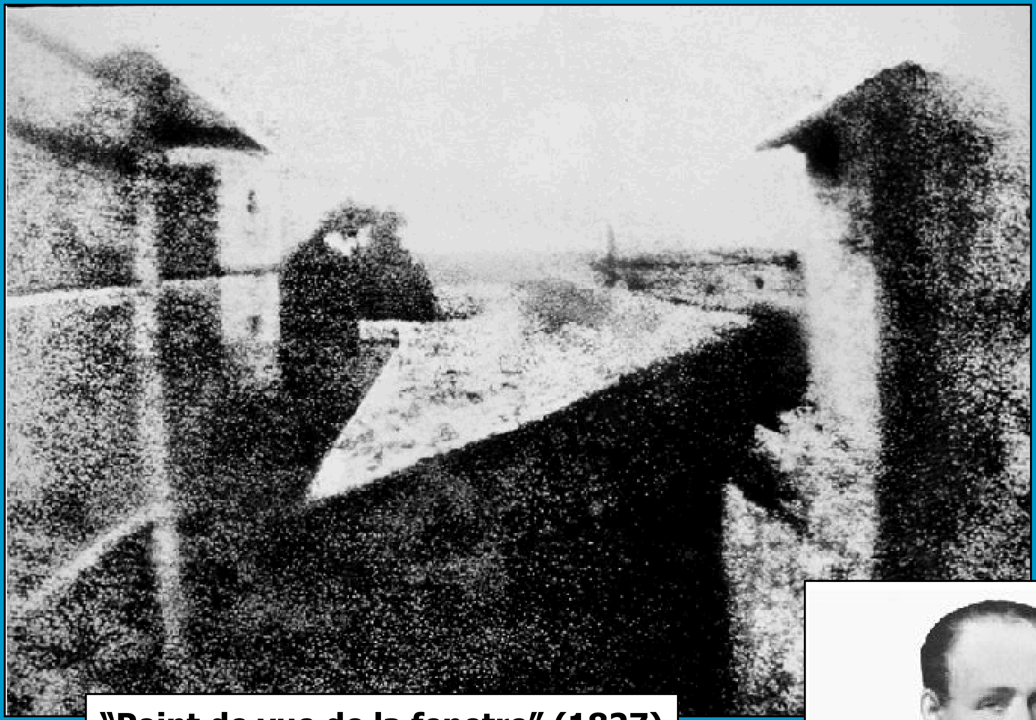
Photography

- is the result of combining several technical discoveries

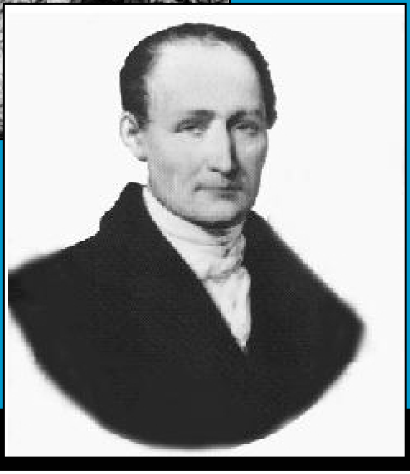
Long before the first photographs were made:

- Ibn al-Haytham (965–1038) in his “Book of Optics”
- describes the camera obscura and the pinhole camera
- Albertus Magnus (1139-1238) discovered silver nitrate
- Georges Fabricius (1516-1571) discovered silver chloride.
- Daniel Barbaro described a diaphragm in 1568.
- Wilhelm Homberg described photochemical effect in 1694.

History of image recording (photography)



"Point de vue de la fenetre" (1827)



- the first successful picture was produced in 1827 by Nicephore Niépce, using material that hardened on exposure to light
- exposure of eight hours on an unetched tin plate

History of image recording (photography)

"Boulevard du Temple" (1839)

Louis Daguerre

- images on silver-plated copper, coated with silver iodide and "developed" with warmed mercury
- reduced the exposure time from eight hours down to 10 minutes

History of image recording (photography)

“L’Atelier de l'artiste”

Daguerrotype

- direct photographic process
- however without the capacity for duplication

At that time some artists saw in photography a threat to their livelihood and some even prophesied that painting would cease to exist.

History of image recording (photography)

Daguerreotype

- the first commercially viable photographic process and the first to permanently record an image with reasonable exposure times – minutes)
- for the first time in history, people could obtain an exact likeness of themselves for modest cost

History of image recording (photography)

- 1834 - Henry Fox Talbot creates permanent negative images using paper soaked in silver chloride and fixed with a salt solution. Talbot created positive images by contact printing onto another sheet of paper.
- 1851 - Frederick Scott Archer improves photographic resolution by spreading a mixture of collodion (nitrated cotton dissolved in ether and alcohol) and chemicals on sheets of glass.
  - Wet plate collodion photography was much cheaper than daguerreotypes, the negative/positive process permitted unlimited reproductions
- 1861 - James Clerk-Maxwell demonstrates a color photography system involving three black and white photographs, each taken through a red, green, or blue filter.

Image recording – from big to small

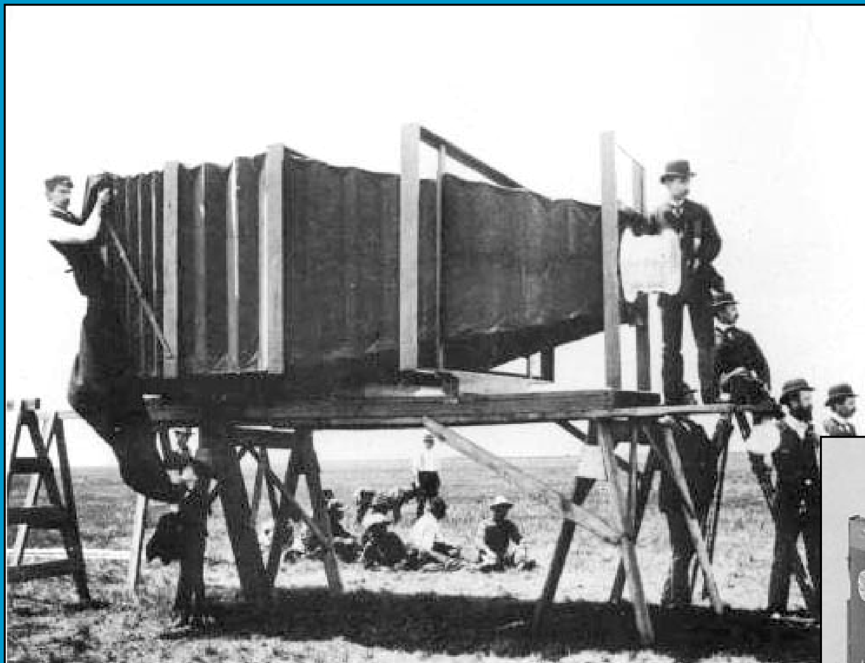
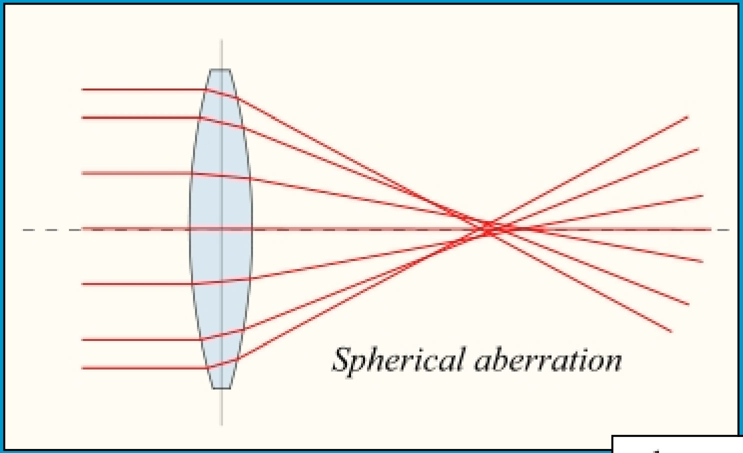
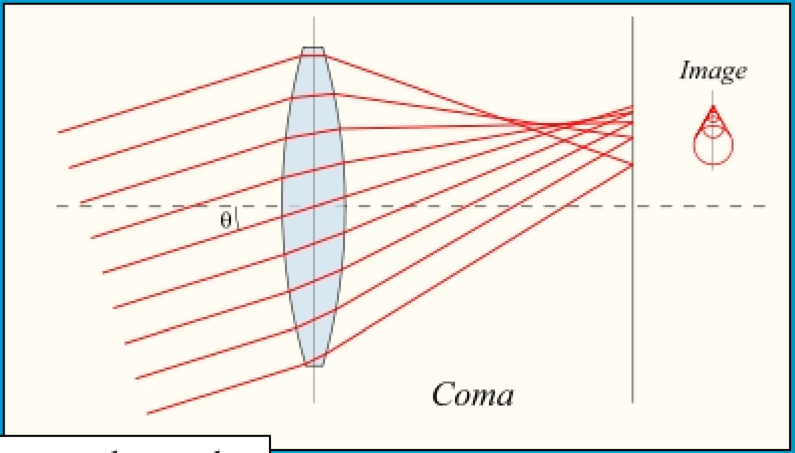


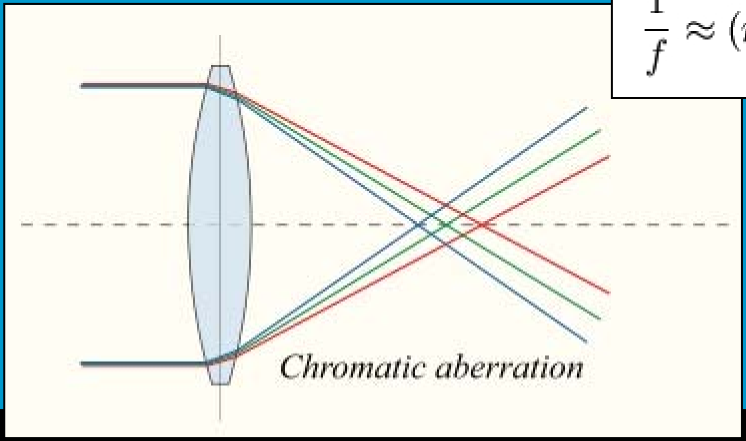
Image recording – optical lens

- Properties of single optical lens





$$\frac{1}{f} \approx (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

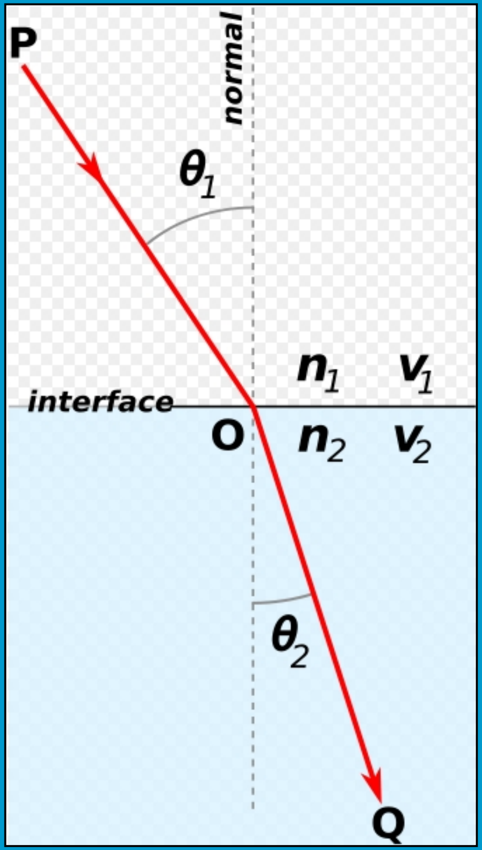


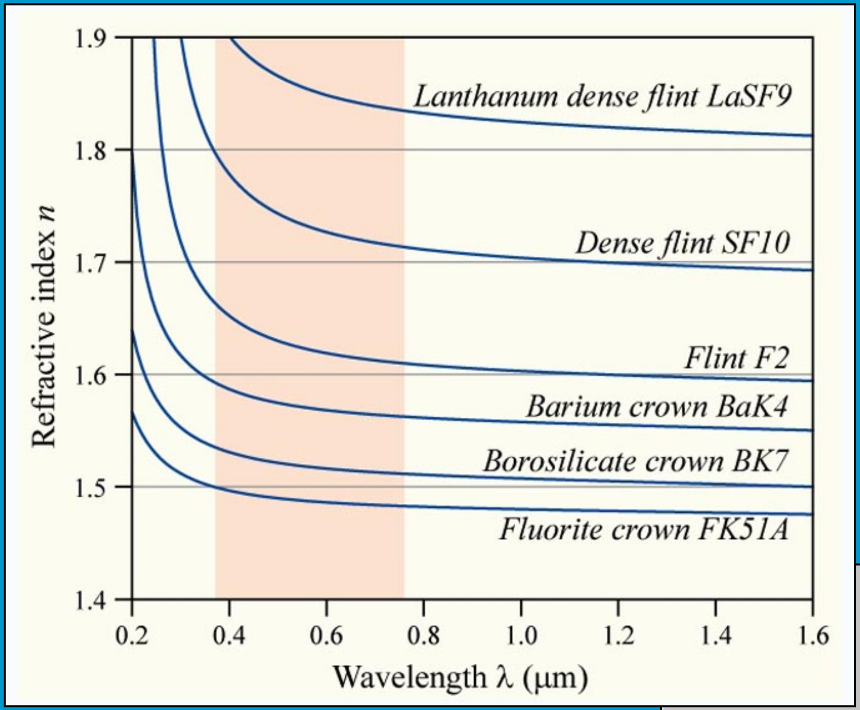
optical lens – formed by two spherical surfaces cannot produce sharp image by itself

Image recording – optical lens

- Dispersion (described by Snell's law)

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





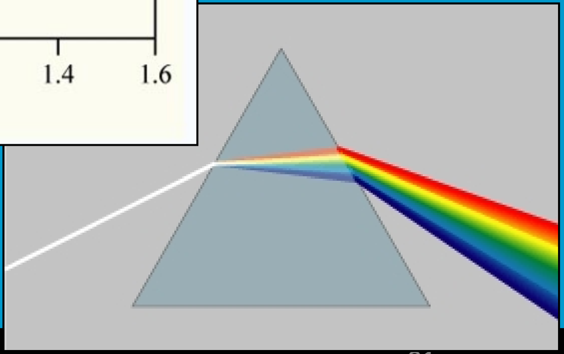
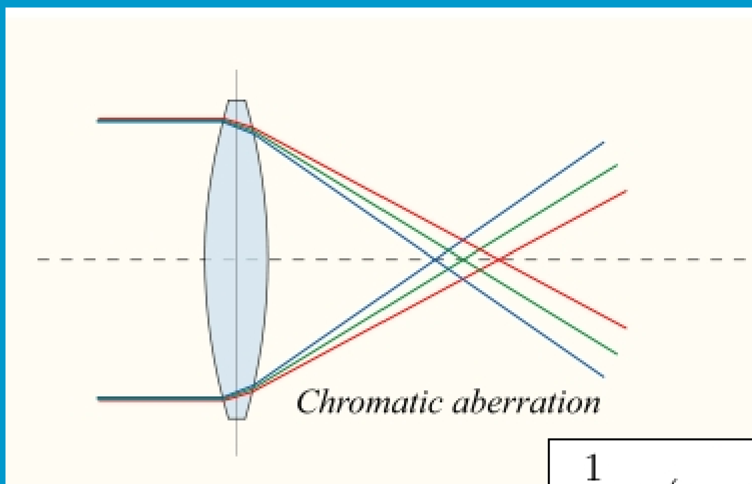
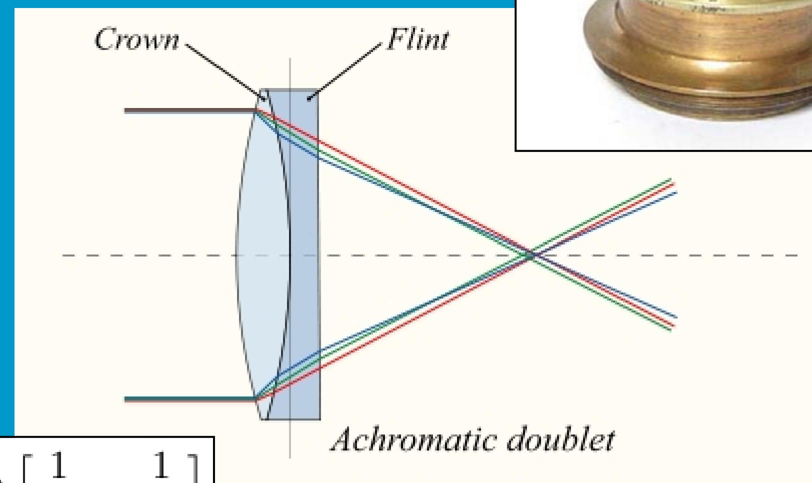


Image recording – optical lens

- Ernst Abbe (1860s) - more precise lens calculations
  - allow for higher quality of images





$$\frac{1}{f} \approx (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

chromatic aberration caused by dispersion of the lens material – variation of its refractive index n with the wavelength of light

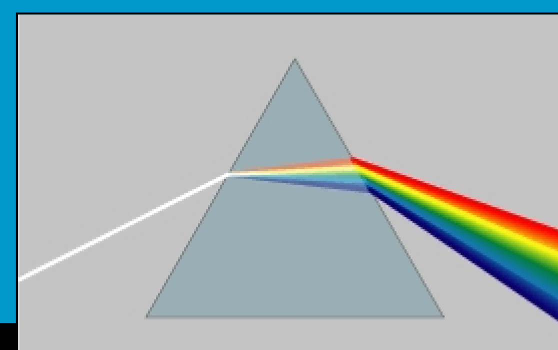
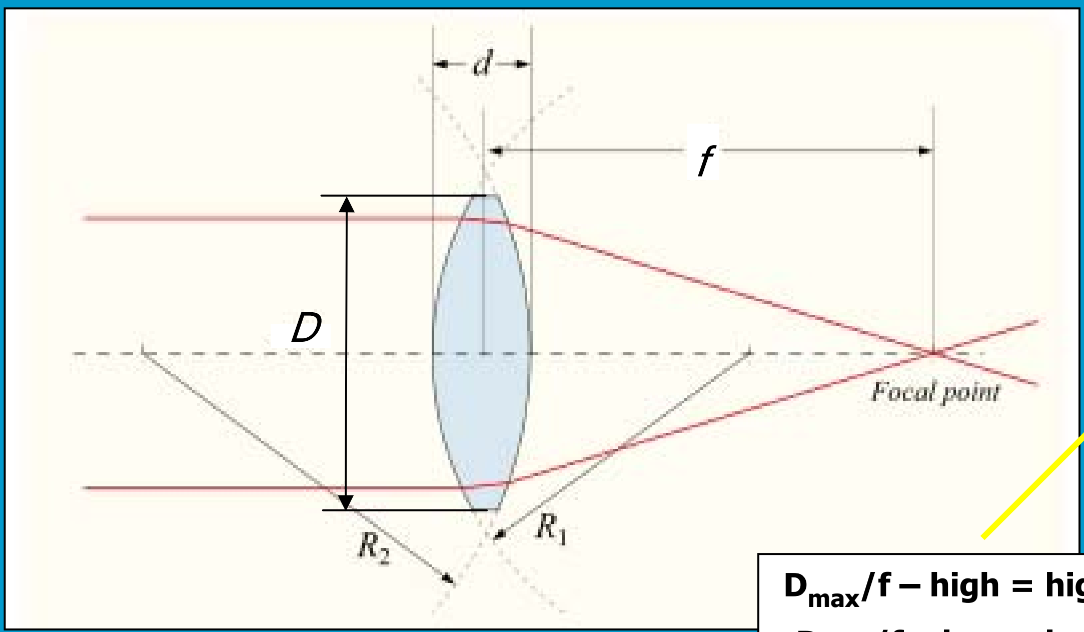


Image recording – optical lens

Lens "speed"

- ratio of the maximum lens diameter and its focal length D_{max}/f



D_{max}/f – high = high speed lens
D_{max}/f – low = low speed lens

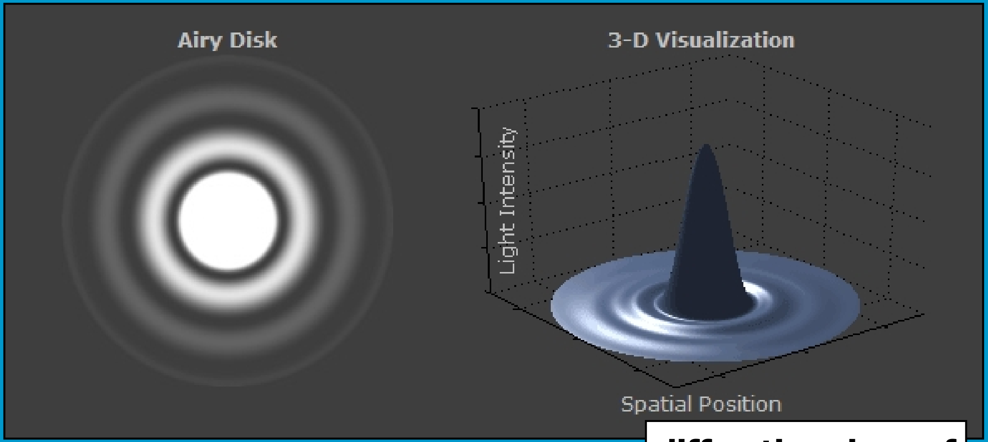
Image recording – optical lens

Spatial resolution of the lens

- limitation by diffraction

size of smallest object that the lens can resolve

Reynolds criterium



diffraction rings of single point

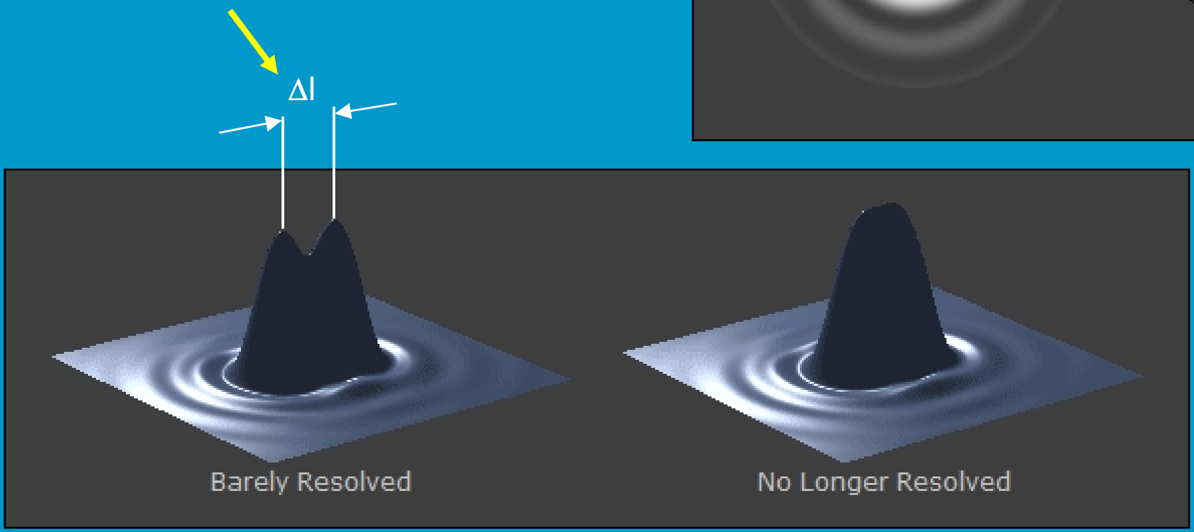


Image recording – optical lens

Spatial resolution of the lens

- Resolving power of a lens is ultimately limited by diffraction. This is the size of smallest object that the lens can resolve, and also the radius of the smallest spot that a beam of light can be focused to

$$\Delta\ell = 1.2\frac{f \times \lambda}{D} \quad (\text{Reynolds criterium})$$

λ - wavelength of light (approx. 0.5 μm)
D - diameter of the lens opening (aperture)
f – focal length

Example:
for f/D = 1/2 is Δl =0.3 μm (lens full open)
small depth of field

for f/D = 1/32 = 4.8 μm (smallest lens opening)

large depth of field

Image recording - diaphragm

- depth of field (DOF)

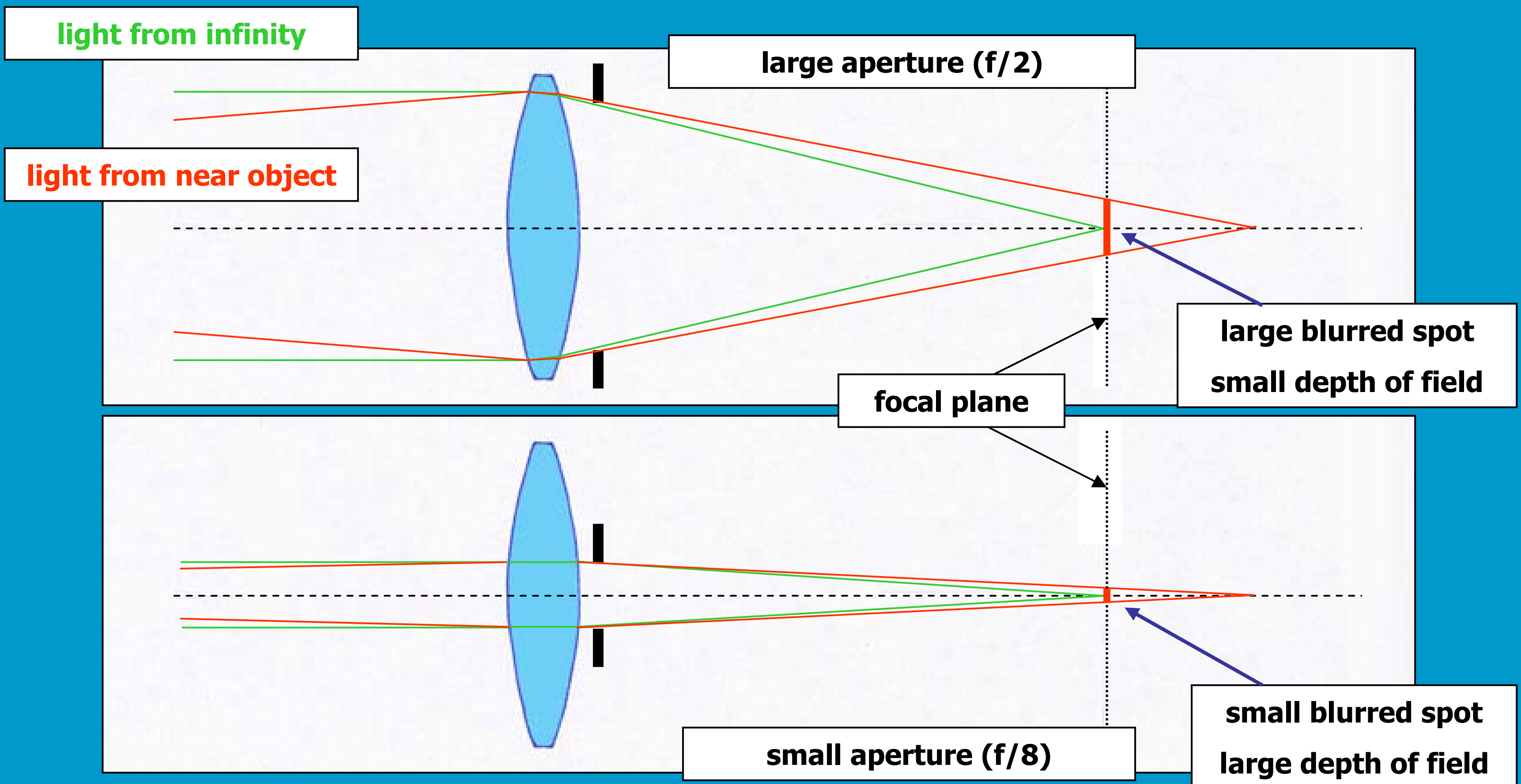
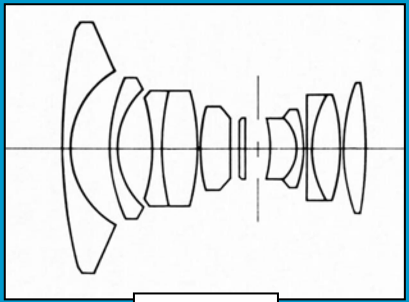


Image recording – optical lens

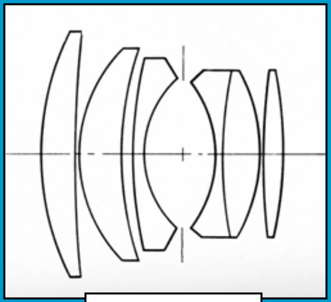
Development of optical lenses systems

- several goals:
  - improvement of lens performance
  - broader range of focal lengths (from wide angle to telephoto)
  - built in continuous change of focal length (zoom lenses)

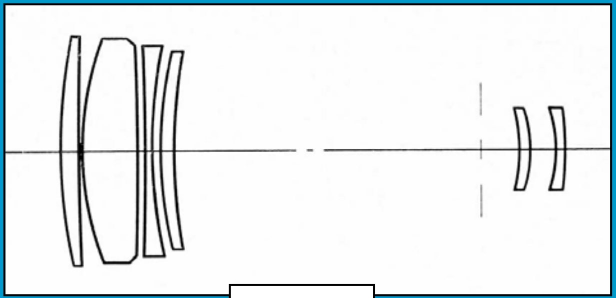
Image recording – optical lens



wide



normal



tele

Film format	Image dimensions	Image diagonal	Normal lens focal length
9.5 mm Minox	8 × 11 mm	13.6 mm	15 mm
APS C	16.7 × 25.1 mm	30.15 mm	28 mm, 35 mm
135	24 × 36 mm	43.27 mm	50 mm, 45 mm
120/220, 6 × 4.5 (645)	56 × 45 mm	71.84 mm	75 mm
120/220, 6 × 6	56 × 56 mm	79.20 mm	80 mm
120/220, 6 × 7	56 × 68 mm	88.09 mm	90 mm
120/220, 6 × 9	56 × 84 mm	100.96 mm	105 mm
large format 4 × 5 sheet film	96 × 120 mm (image area)	153.67 mm	150 mm
large format 8 × 10 sheet film	194 × 245 mm (image area)	312.51 mm	300 mm

Image recording – optical lens

Demand for high picture quality leads:

- to short exposure times
  - -> high lens “speed” = high D_{max}/f ratio
- to large light sensitive area (film or sensor)
  - -> relative long focal lengths

- result – large, heavy lenses for professional use

14 mm f/2.8

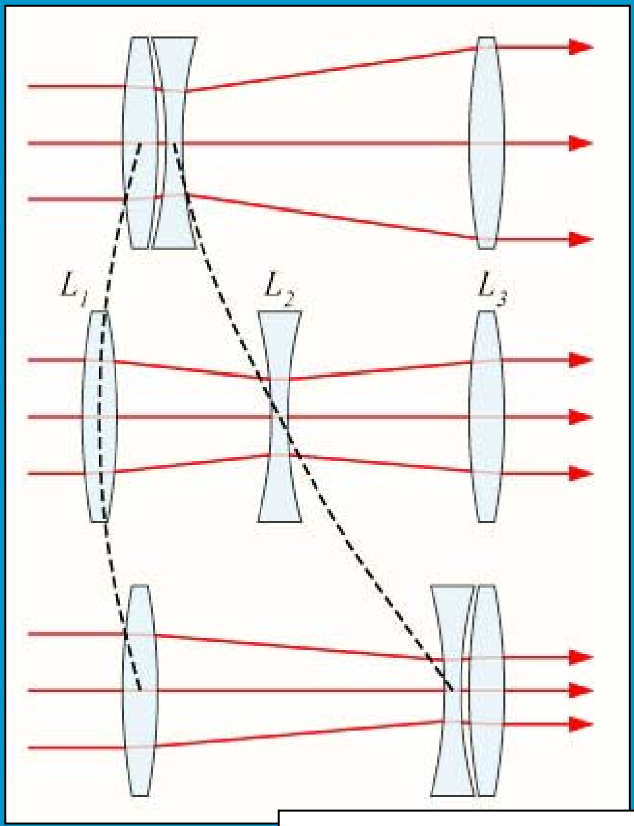
670 g

200 mm f/2

2900 g

Image recording – optical lens

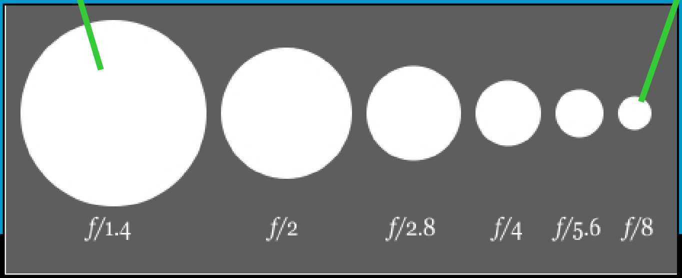
- Variable focal length – zoom lenses



these designs are only possible due to the fast calculating power of modern computers

Image recording - diaphragm

- controls (together with the shutter) the amount of exposure (total light energy) of the photosensitive material
- controls the depth of field



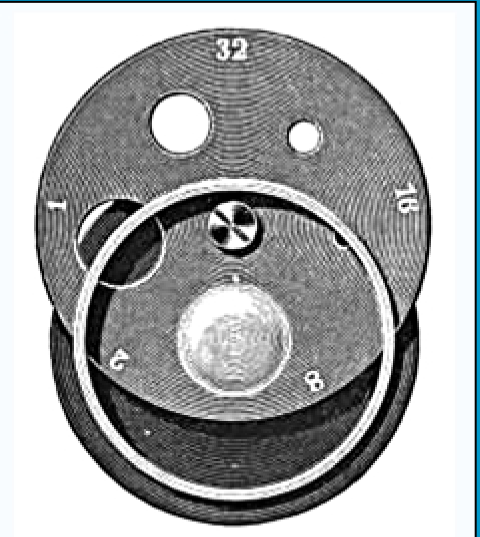


Fig. 50. Rotating Diaphragm. Carl Zeiss.

Image recording - diaphragm

- depth of field (DOF)

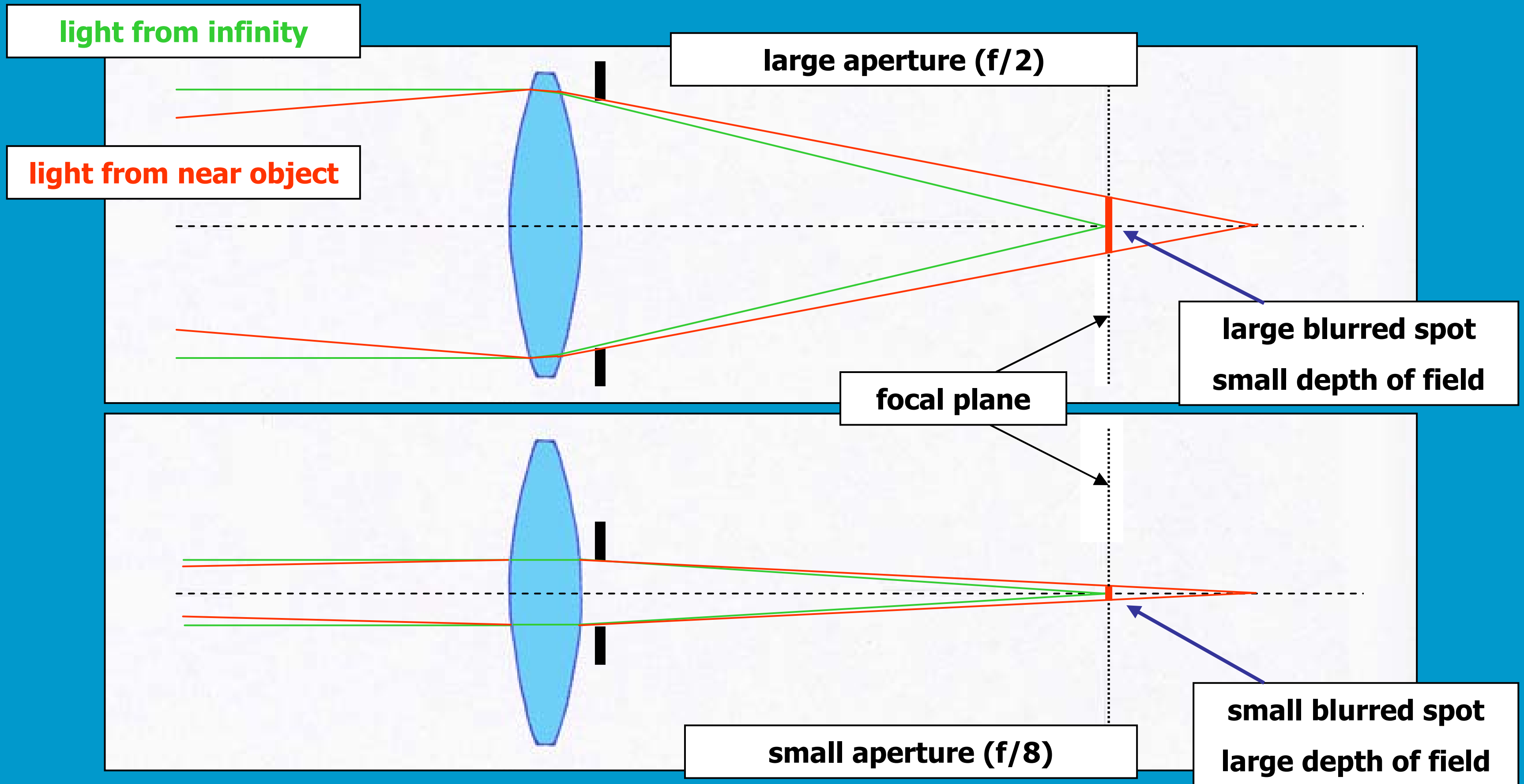
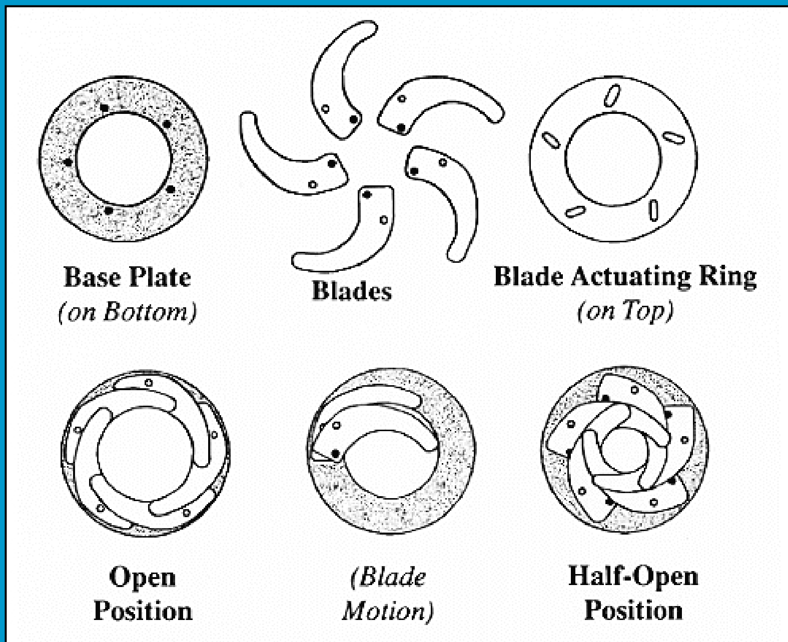


Image recording - diaphragm



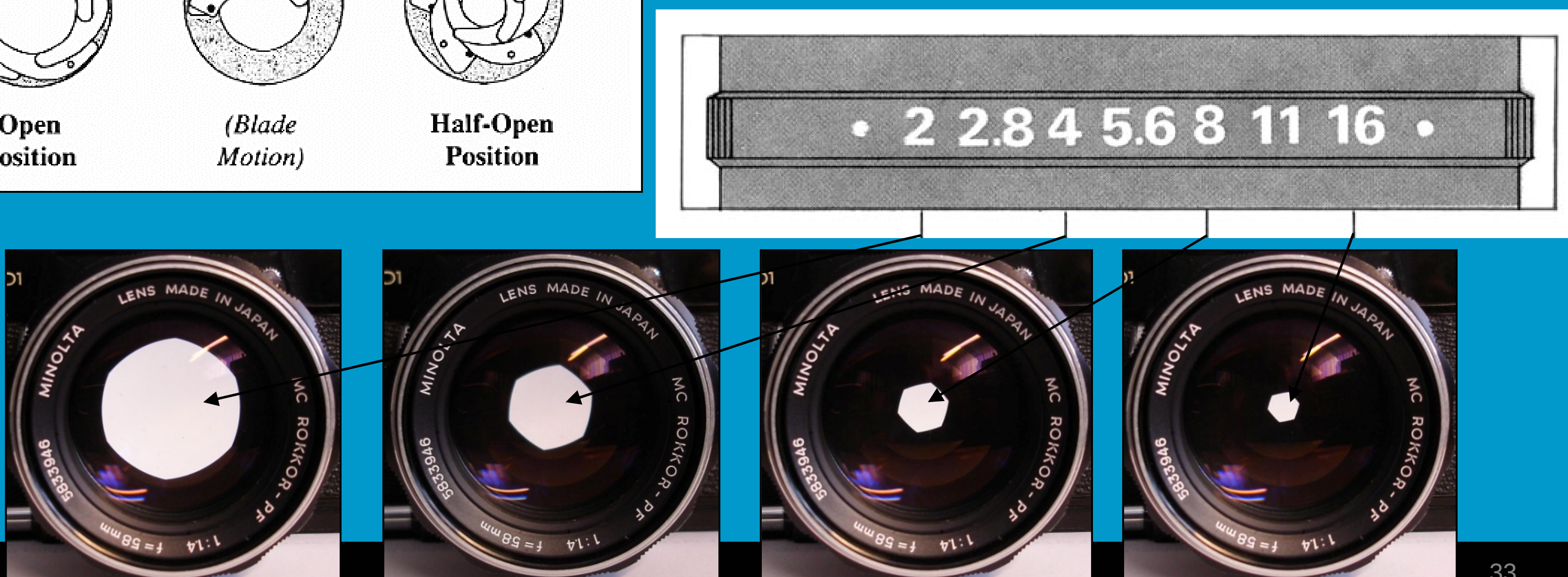
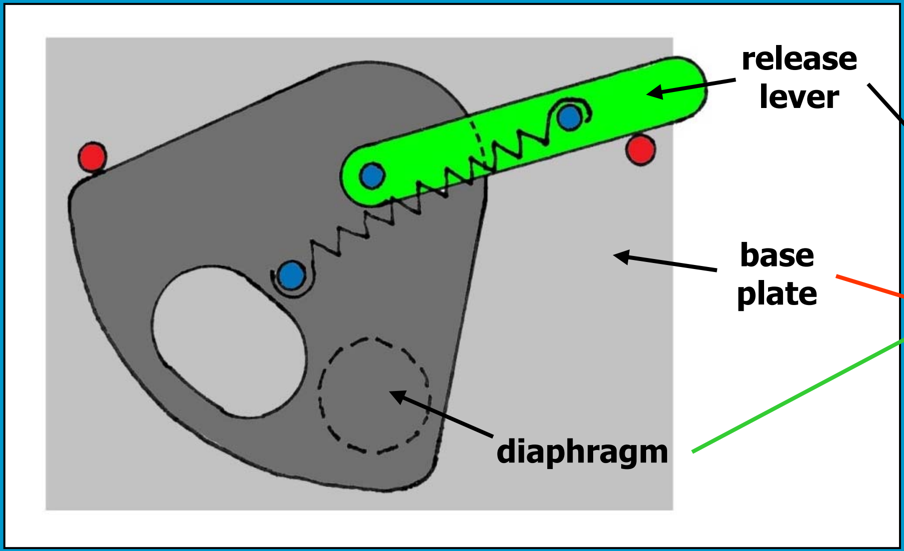
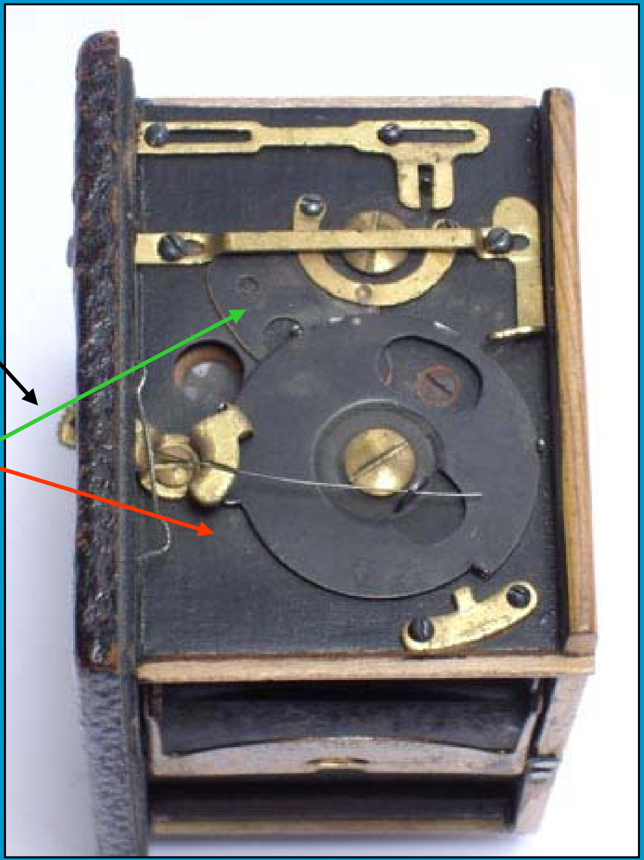


Image recording - shutter

- allows light to pass to the photosensitive layer for a precise time interval (usually between 30 s and 1/8000 s)
- Basic types
  - single leaf shutter

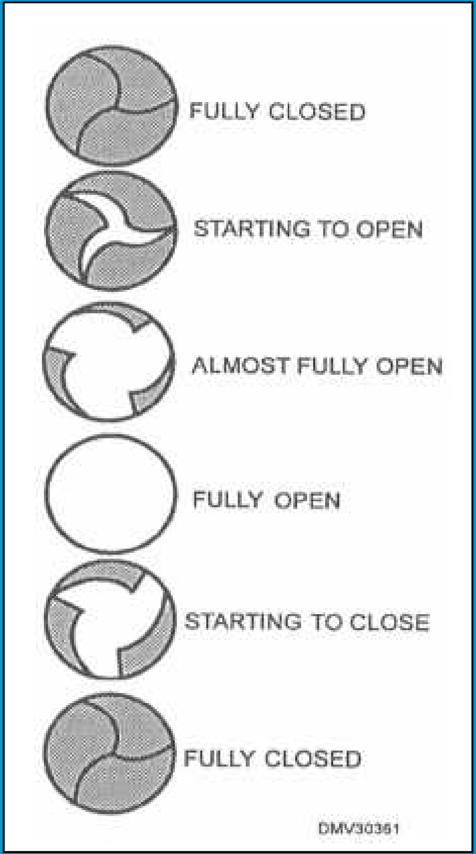


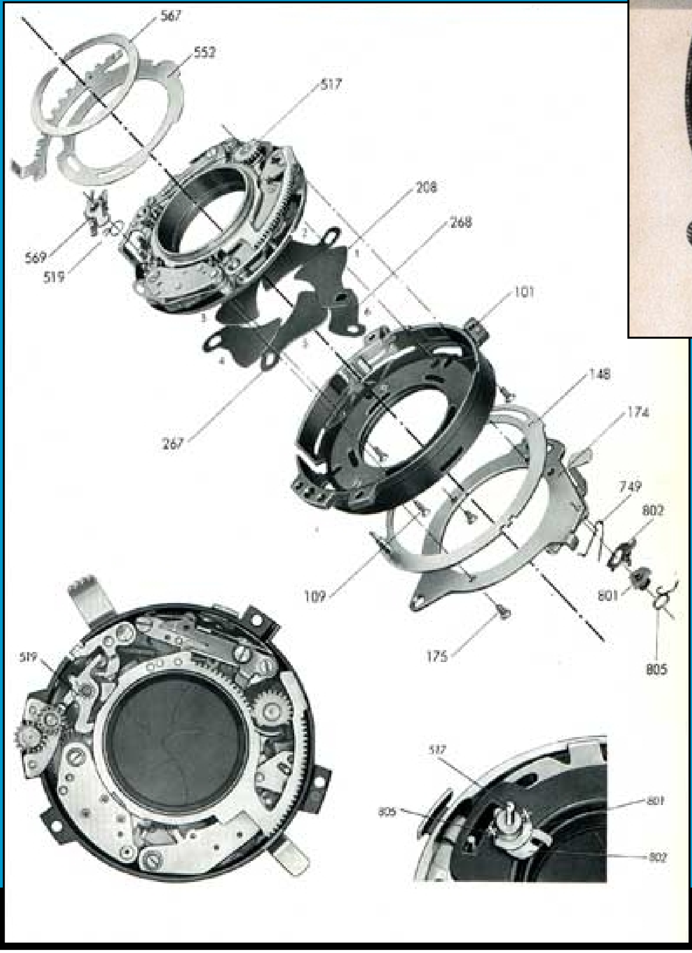


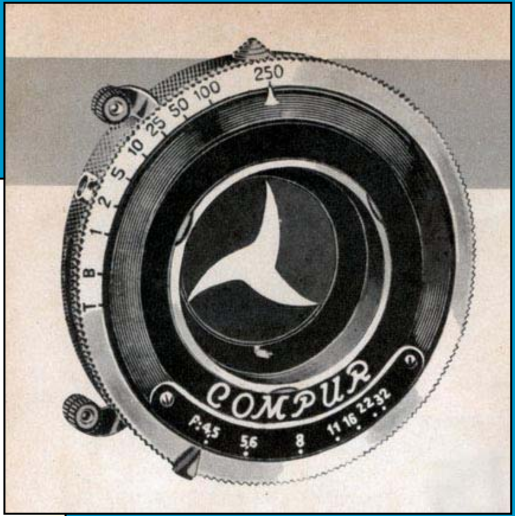
  - circular leaf shutter
  - focal plane shutter

Image recording - shutter

Circular leaf shutter



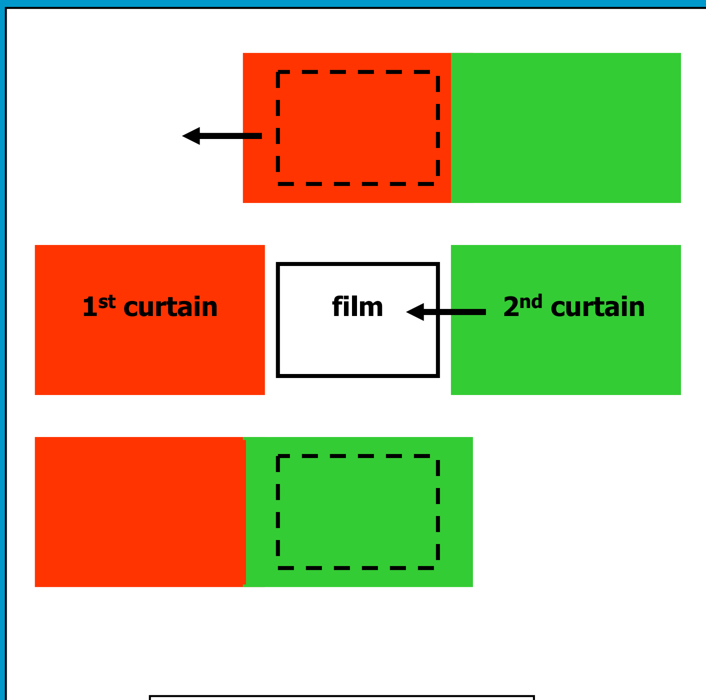




this very successful design lasted from 1930 to 1980

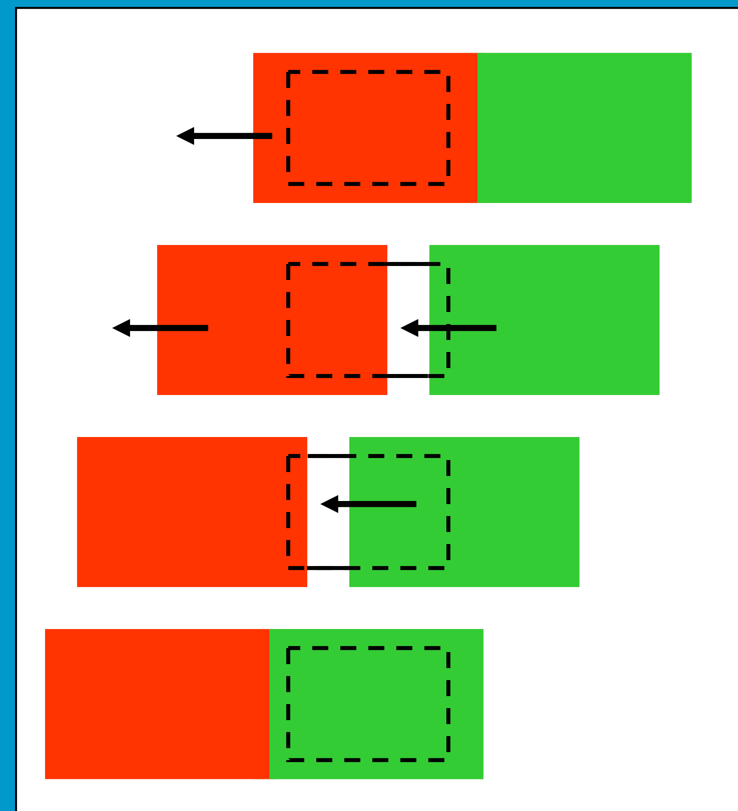
Image recording - shutter

- Focal plane shutter – principle of operation



long exposure

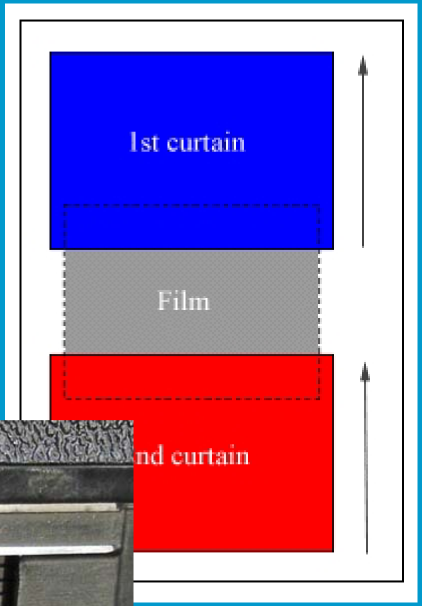
movement of the curtains can be both, horizontal and vertical

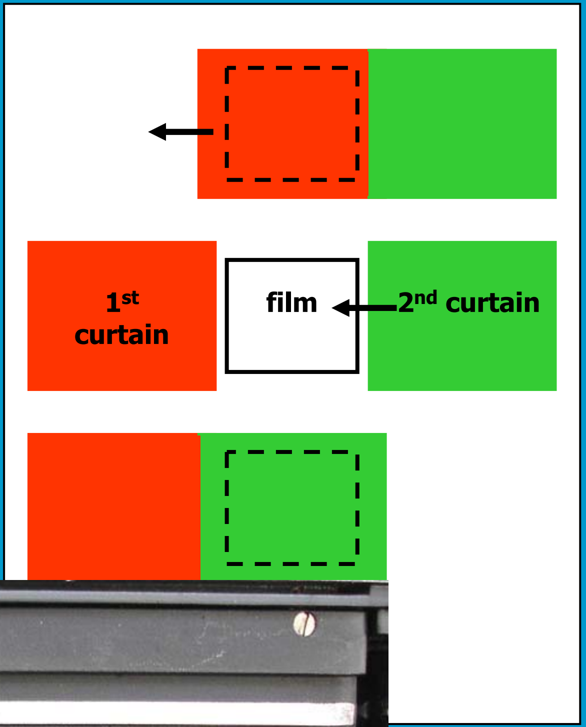


short exposure

Image recording - shutter

Focal plane shutter



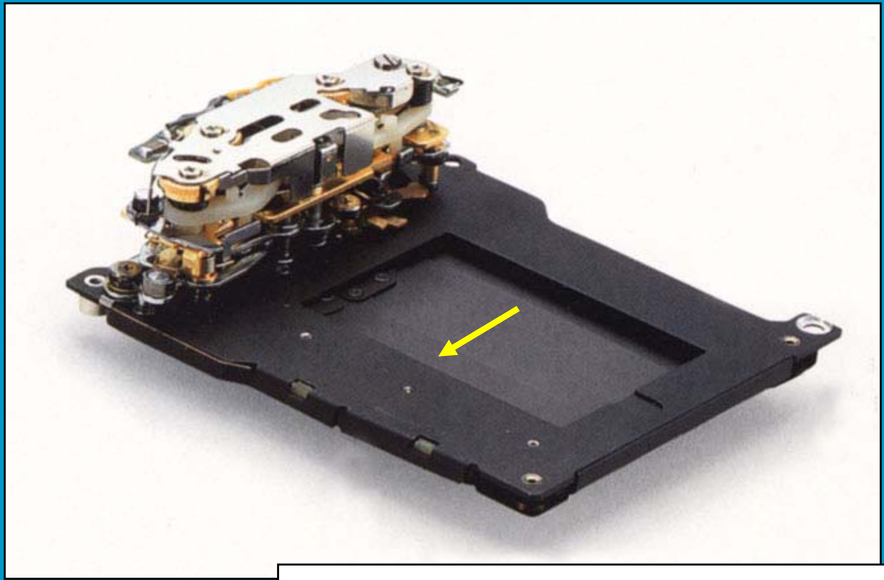


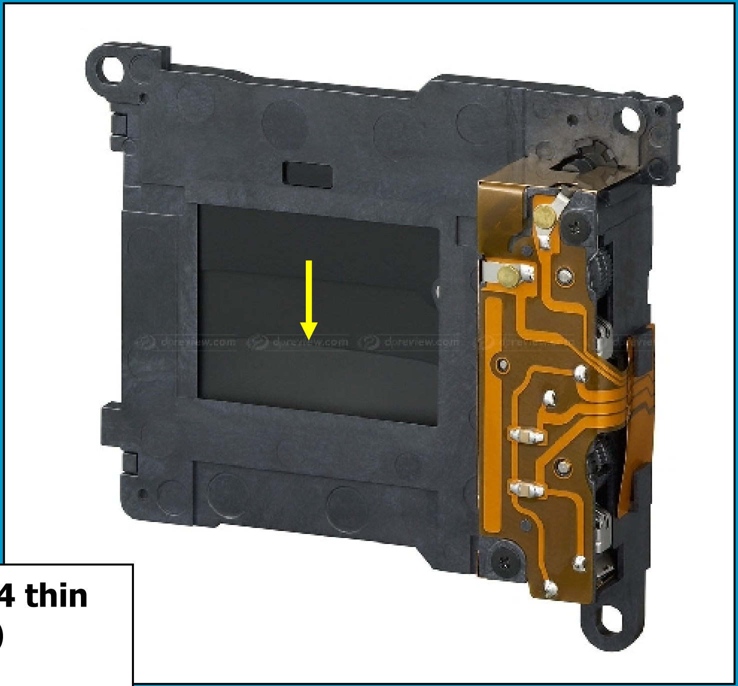
vertical metal curtains

horizontal cloth curtains

Image recording - shutter

Focal plane shutter – state of the art





both shutter curtains consists of 3 to 4 thin blades (titanium or carbon fiber)

passing speed approx. 20 m/s

power needed to accelerate the blades comes from energy stored in metal springs

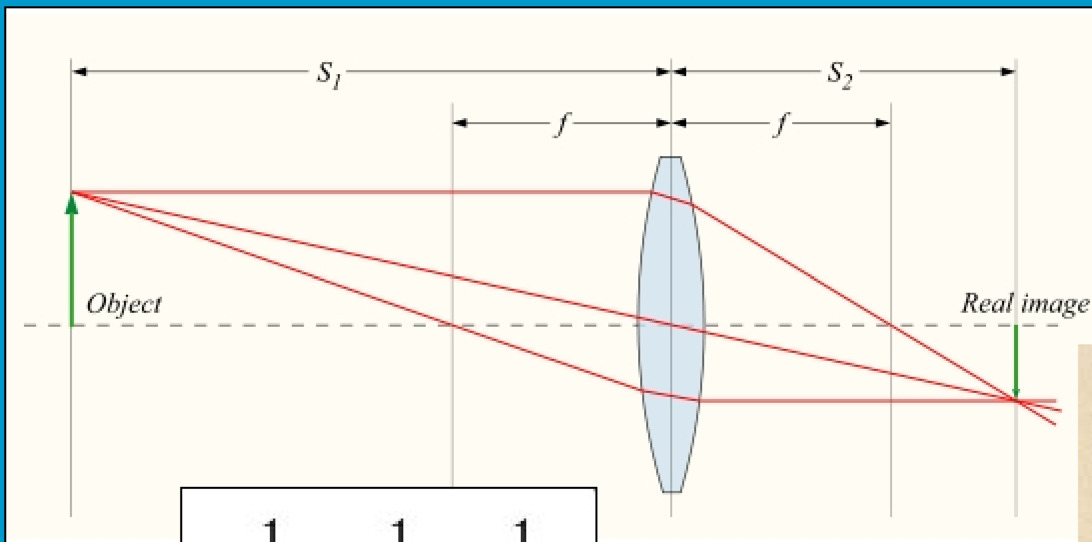
storing energy by electric actuators

typical exposure times:

30 s to 1/8000 s

Image recording - focusing

in order to obtain a sharp image



$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

lens displacement necessary to change the distance S_2 to the photosensitive medium

for $S_1 \rightarrow \infty$ S_2 = focal distance (for example 150 mm)

for S_1 = 0,5 m , S_2 = 214 mm

total lens displacement 214 – 150 = 64 mm

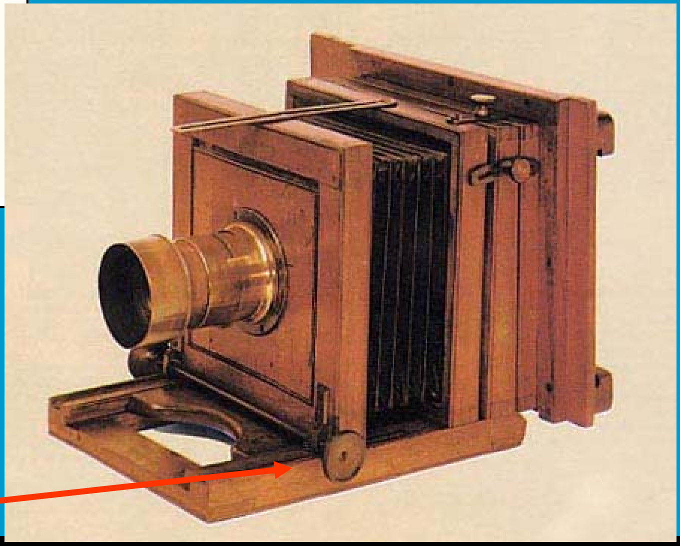
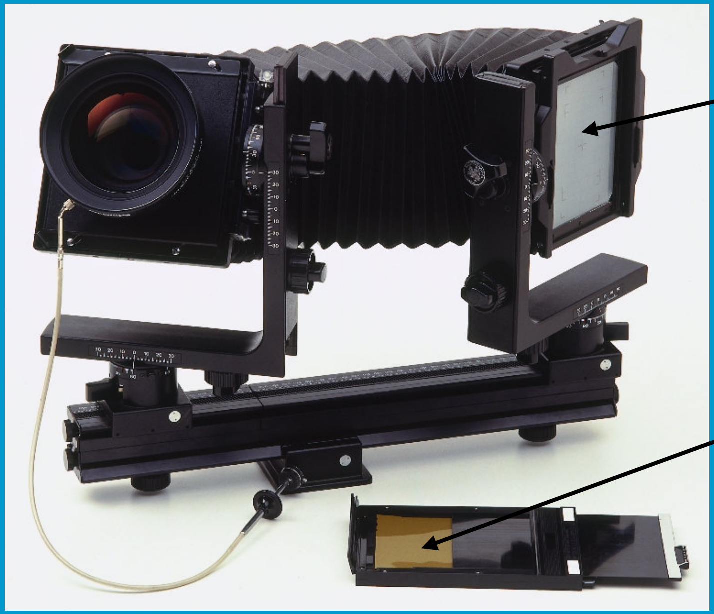


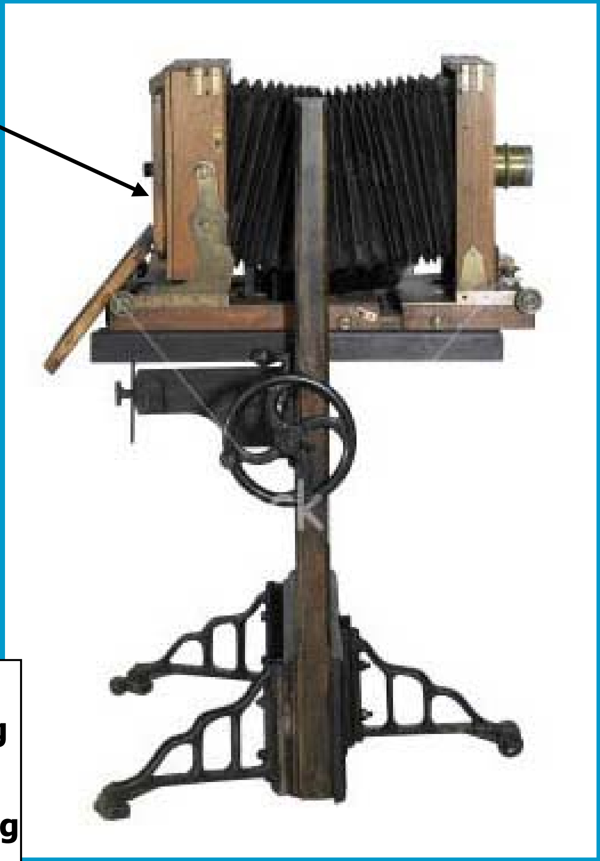
Image recording - focusing

- Focusing aid - glass focusing plate



focusing glass

photosensitive material



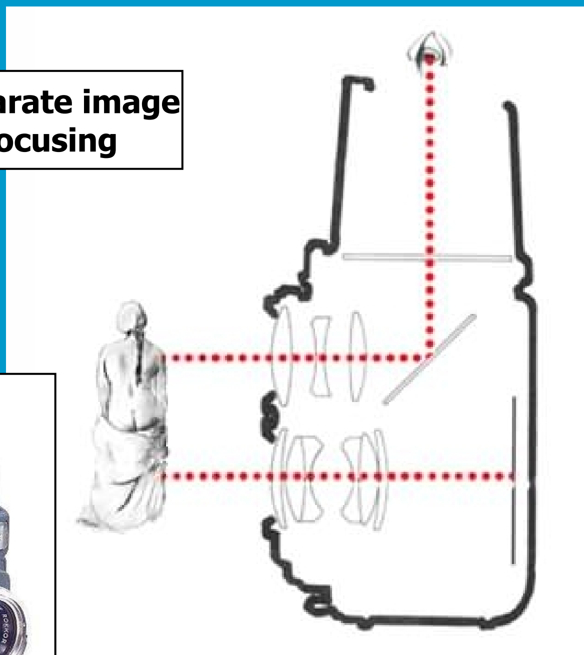
manual focusing by judging image projected on the focusing glass

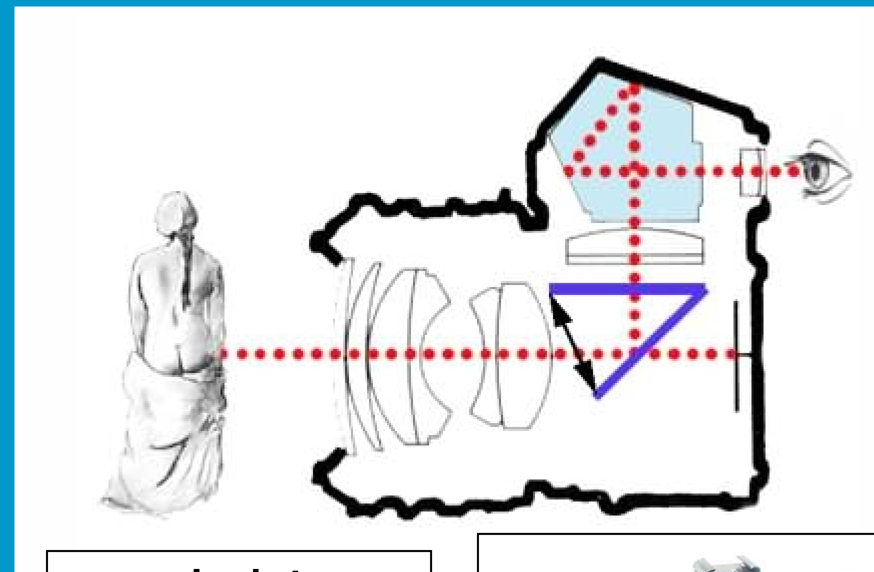
when in focus, swapping focusing glass for photosensitive glass plate or sheet film

Image recording - focusing

Focusing aid - glass focusing plate

one separate image for focusing





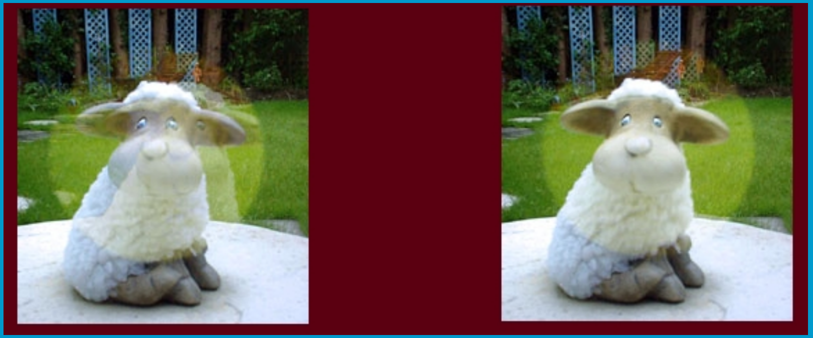
swapping between images using movable mirror

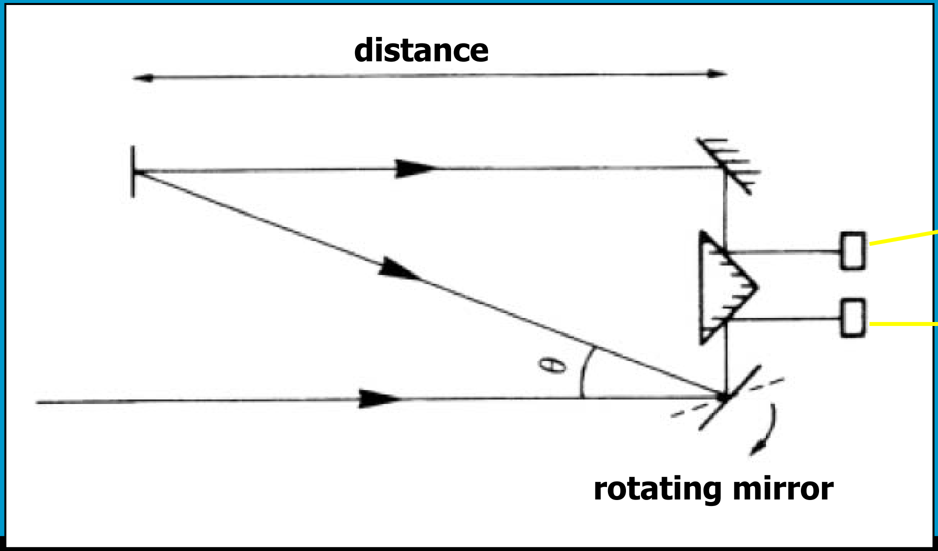
using rolls of film, no more possible to swap between focusing glass and photosensitive material

Image recording - focusing

Focusing aid - rangefinder

Rotating mirror sweeps the scene until the image is aligned with fixed image from mirror (triangulation)





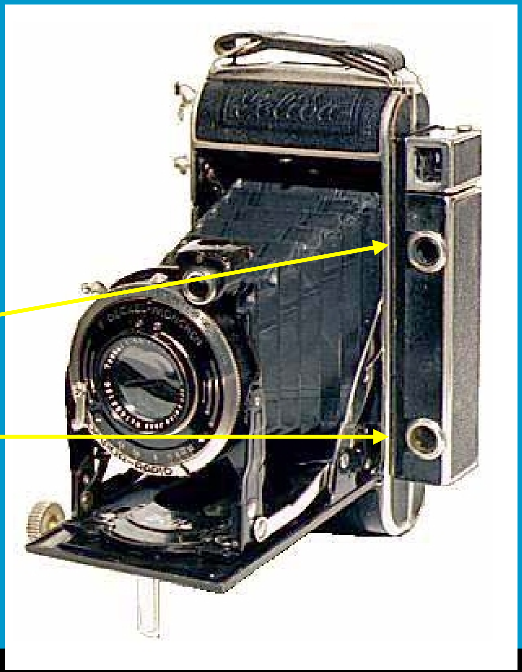


Image recording - focusing

No focusing aid - distance adjustment based on user estimation

- moving the lens according to distance scale

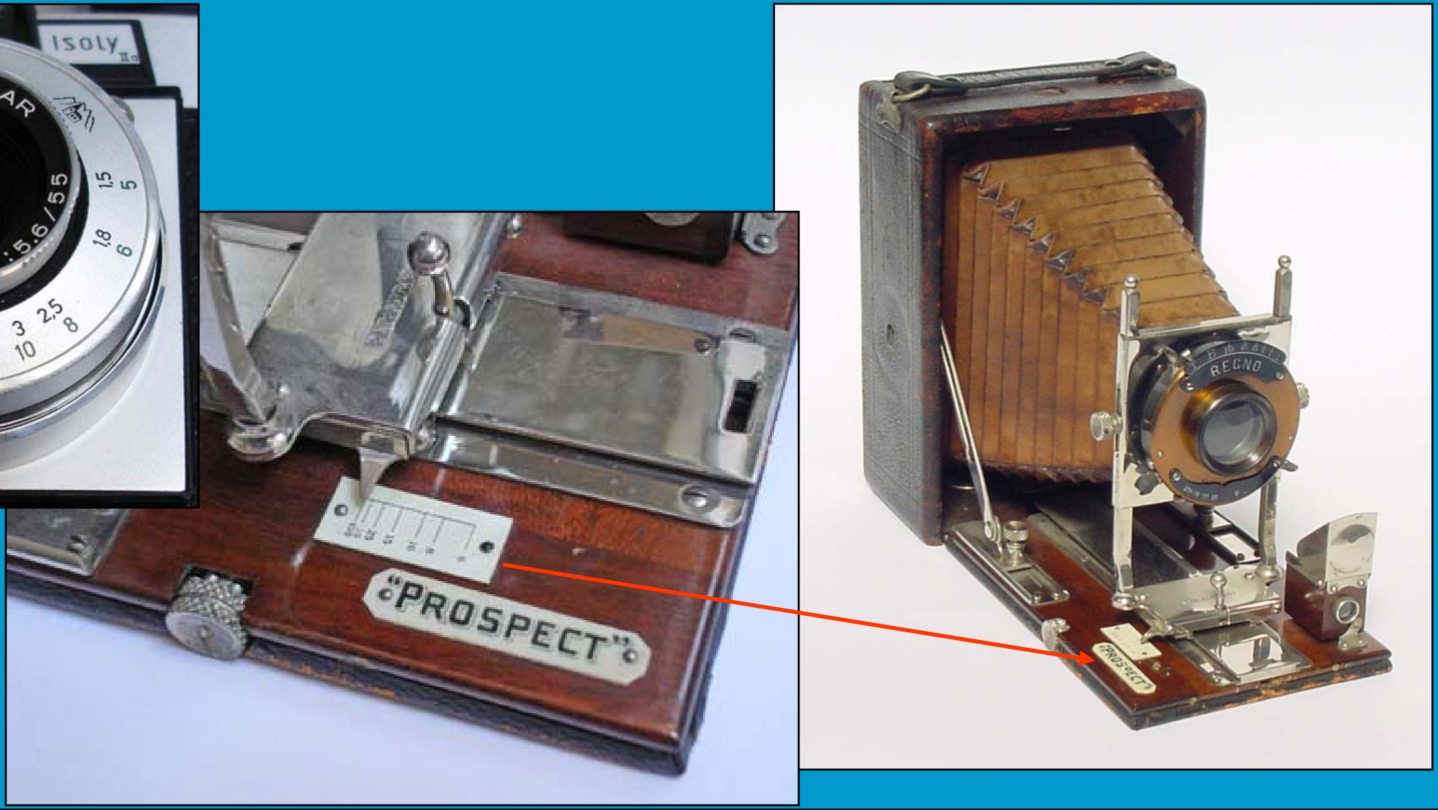


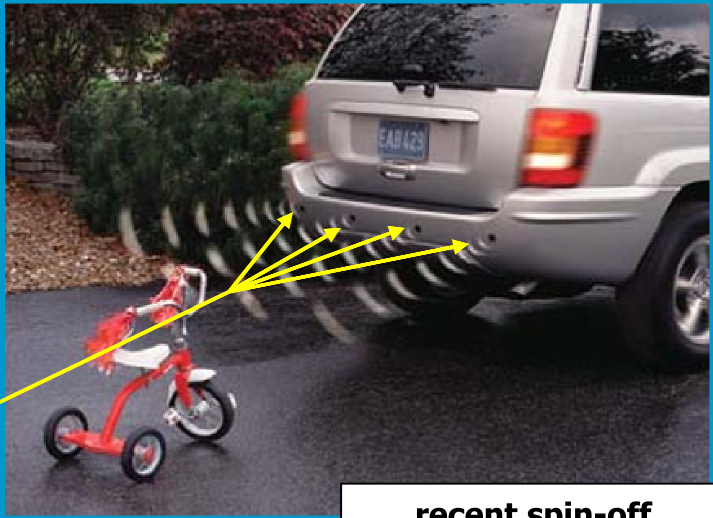
Image recording - focusing

Focusing aid – active autofocus

1980

ultrasound sensors

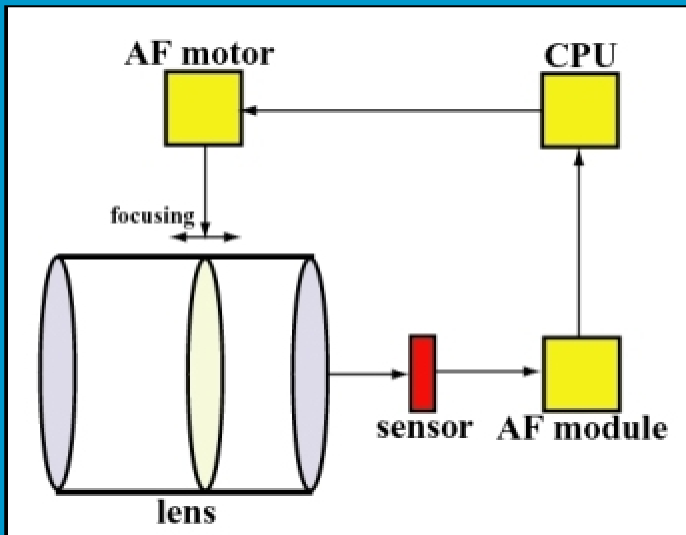
Polaroid Ultrasound
- **sending pulses of sound**
- **time of flight (sonar principle)**
- **limited range**
- **stopped by glass**

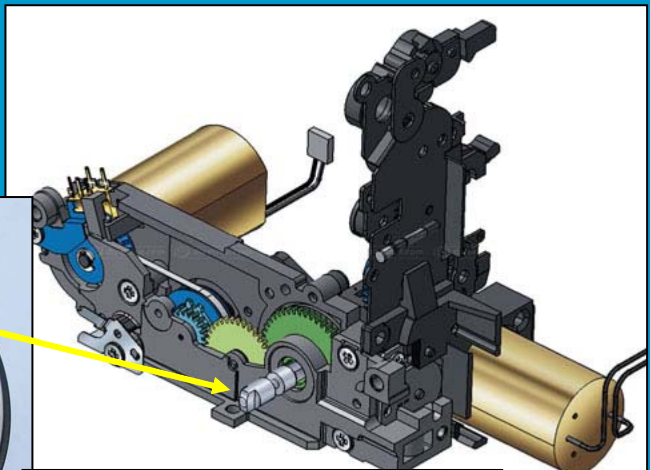


recent spin-off

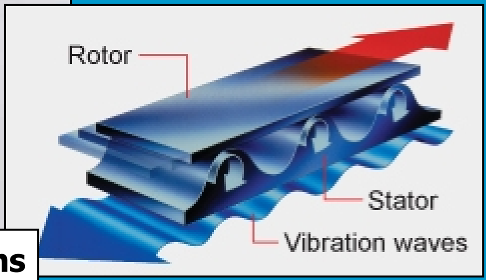
Image recording - focusing

Focusing aid – passive autofocus





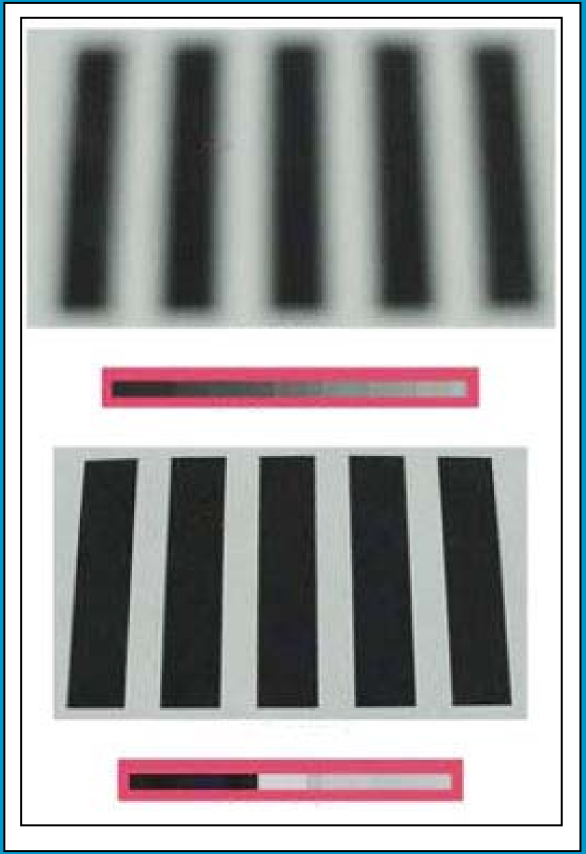
AF motor inside the camera

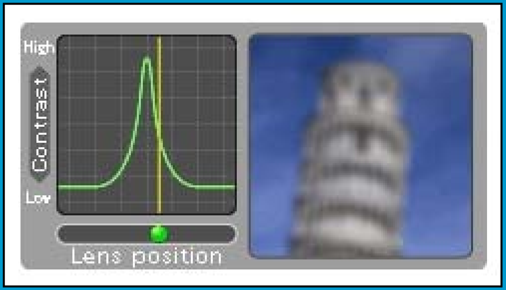


AF motor around the lens

Image recording - focusing

Passive autofocus - contrast measurement

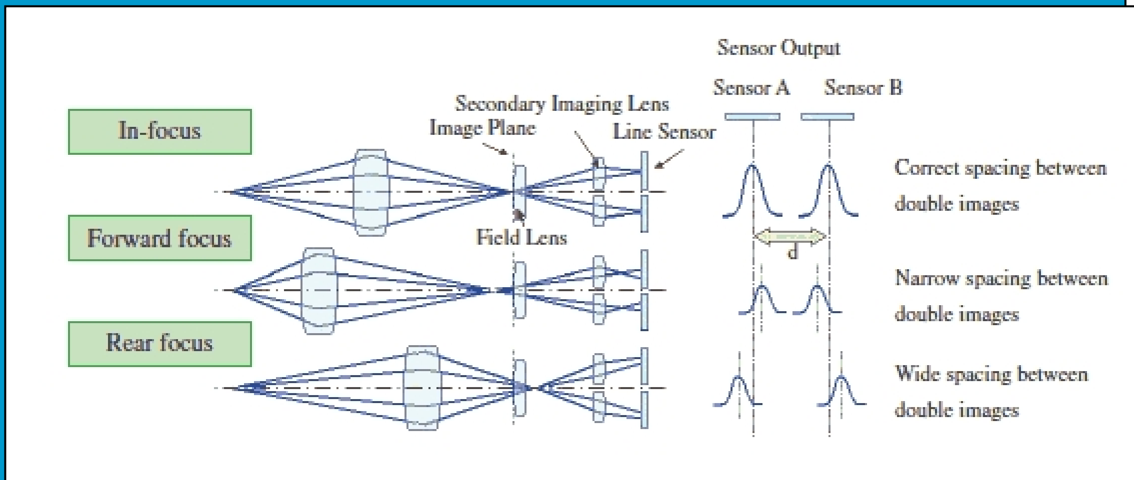


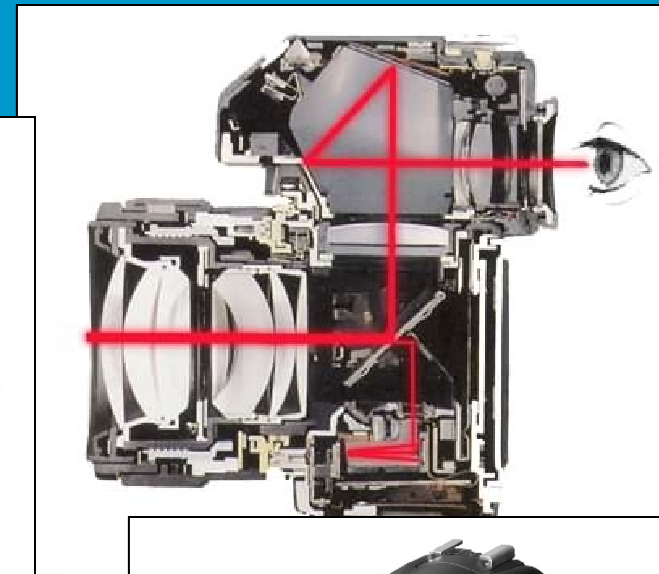


Measuring contrast within a sensor field, through the lens. The intensity difference between adjacent pixels of the sensor naturally increases with correct image focus.

Image recording - focusing

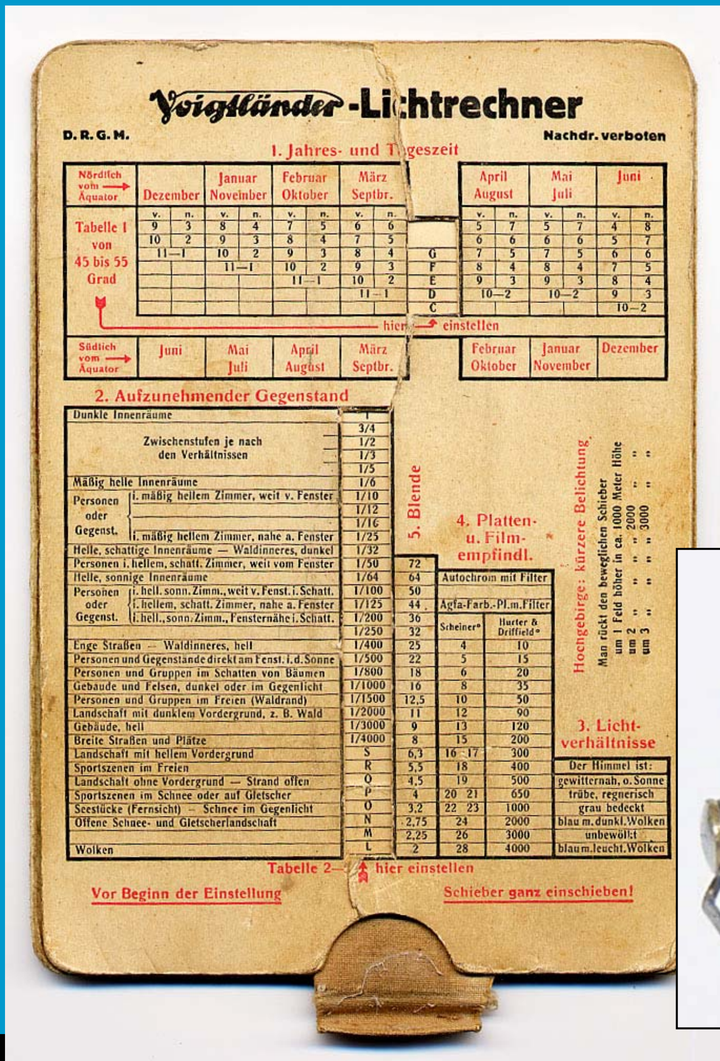
Passive autofocus - phase detection





Light rays coming from the opposite sides of the lens are diverted to the AF sensor, creating a simple rangefinder with a base identical to the lens' diameter. The two images are then analyzed for similar light intensity patterns (peaks and valleys) and the phase difference is calculated. The AF motor brings the lens in focus

Image recording – defining exposure time



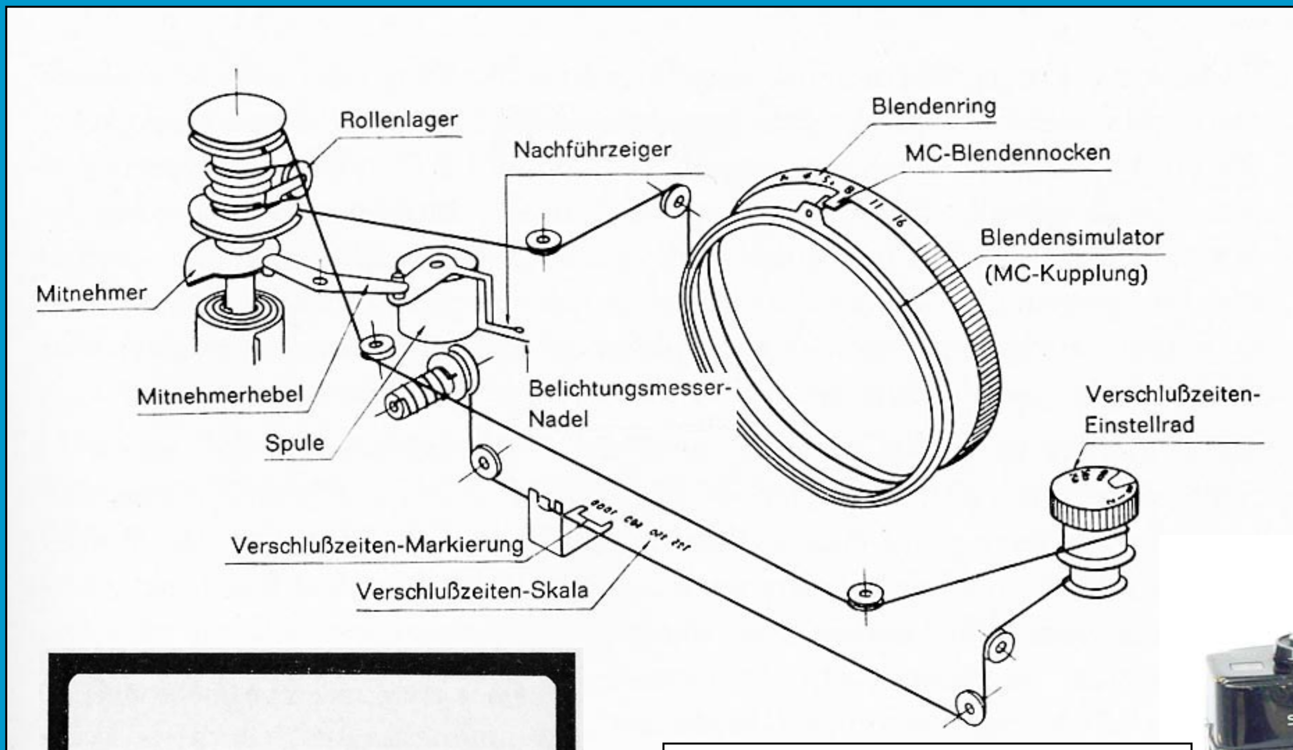
hand held

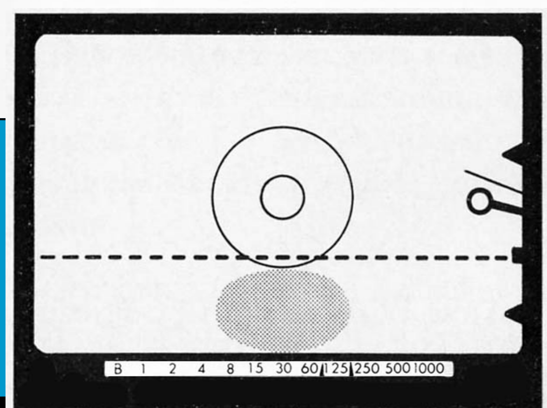
Selenium exposure meters

Selenium produces a small current in response to light like a solar cell.

biult-in

Image recording – defining exposure time





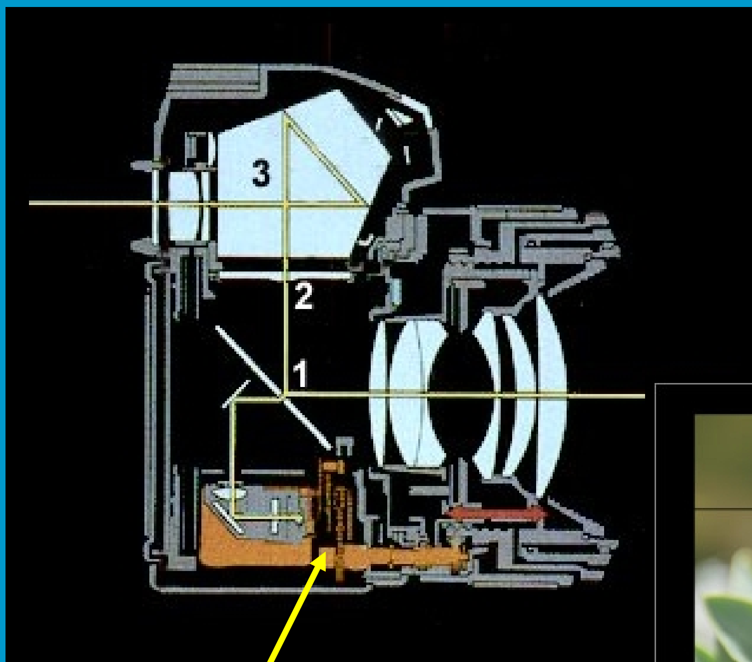
exposure metering through the lens with CdS cell

manual adjustment of exposure time/diaphragm combination

limited to mechanical means

Image recording – defining exposure time

Fully automated exposure using multiple sensors



exposure metering sensor

flexible multi spot metering

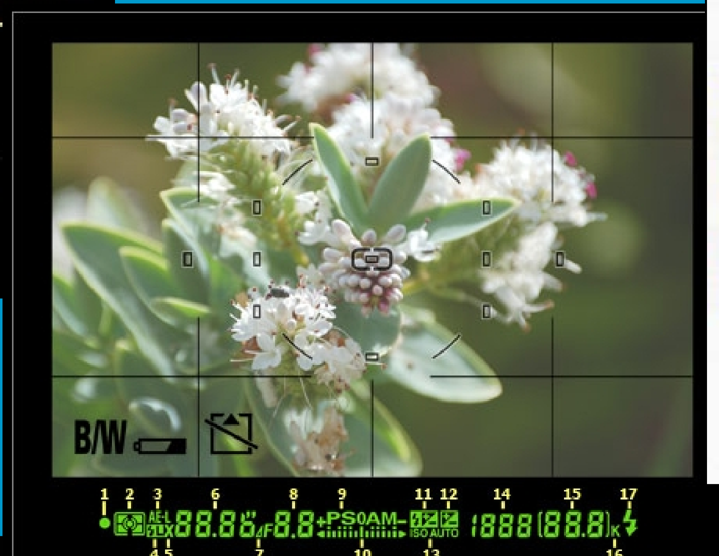
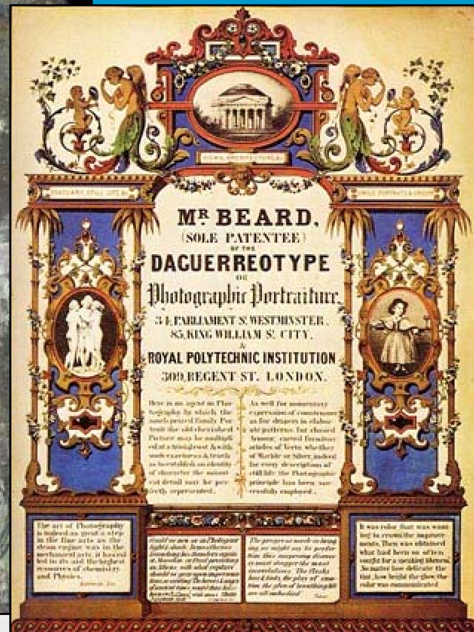
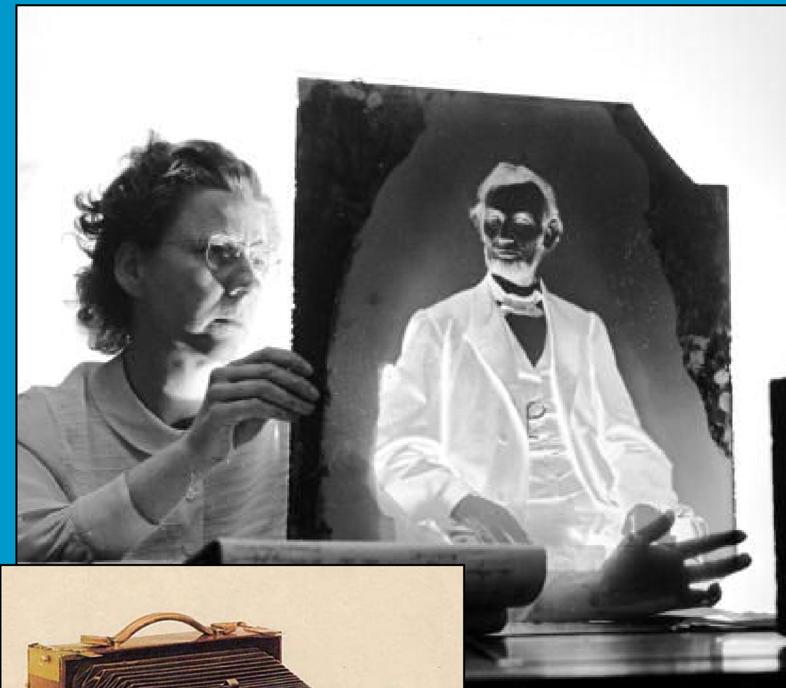


Image recording – photosensitive materials

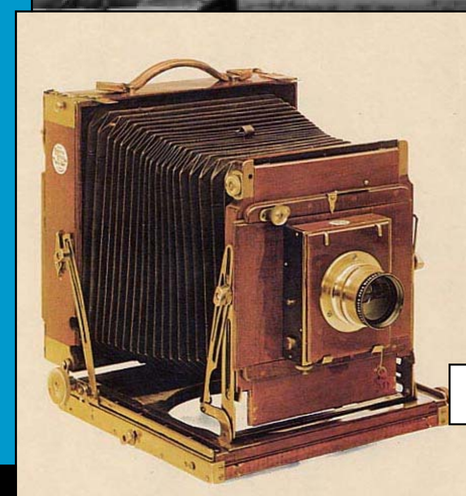
silver plate
(from 1839)





glass plate
(from 1850)

1845



1903

Image recording – photosensitive materials

sheet film

Image recording – photosensitive material

First roll film

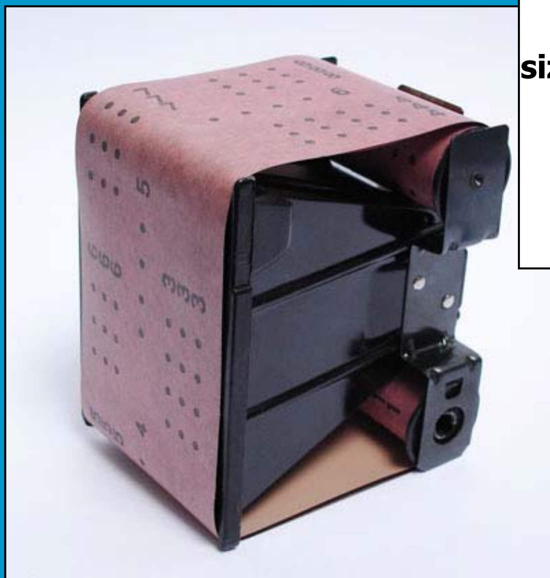
1889 !

Factory loaded with roll film for 100 exposures 50x37 mm

Full film has to be sent , with the camera, back for development

Image recording – photosensitive material

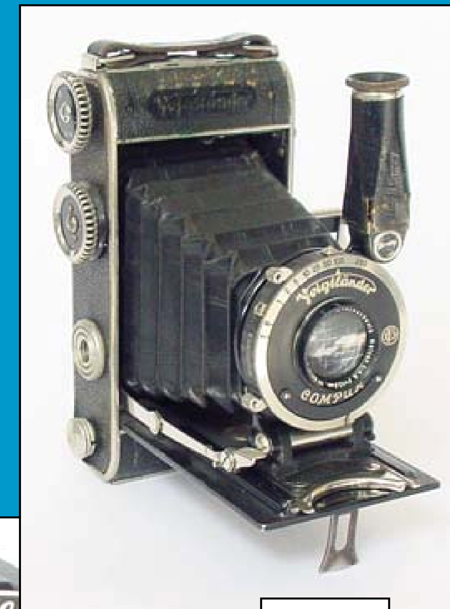
Roll film



"120" format for image sizes 9x6, 6x6, 4,5x6 cm

First introduced 1901

1953



1932

1980

1949

Image recording – photosensitive material

roll film "135" film (image size 36x24 mm)

1923

1998

1955

1932

Image recording – photosensitive material

Roll film

"126" cartridge (image size 30x30 mm)

1972 -

"110" cartridge (image size 19x13 mm)

1974 -

Image recording – photosensitive material

Roll film

16 mm film (image size 14.5x11.5 mm)

1949 -

miniature cameras

cartridge with 16 mm film (image size 10x8 mm)

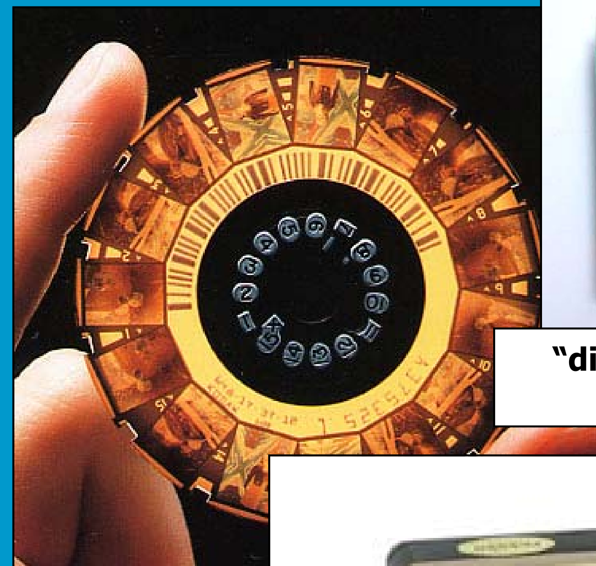
1960 -

Image recording – photosensitive material

Formats with a short market life

APS format (image size 25x17 mm)

Film with transparent magnetic coating, used for *information exchange* (IX) system for recording information about each exposure



"disc" (15 images 11x8.5 mm)

Image recording – improvements

- efforts to speed up workflow (from picture taking to press)
  - processed film converted to digital data (only possible with high resolution scanners)
- efforts to make picture enhancement more sophisticated
  - using computer programs for digital data processing (only possible with powerful computers)
- looking for replacement of wet processed film
  - using photovoltaic effect (only feasible with modern integrated circuit lithography technology)

Image recording – digital sensors

Photovoltaic effect

- direct conversion of light into electricity at atomic level
- first noted by a French physicist, Edmund Bequerel, in 1839
- in 1905, Albert Einstein described the nature of photoelectric effect (Nobel prize)
- first photovoltaic module was built by Bell Laboratories in 1954
- through the space programs, the technology advanced, its reliability was established, and the cost began to decline.

Image recording – going digital

Main advantages of digital photography

- almost immediate control of results
- huge storage capacity of memory cards
- already better performance than best films
- fast workflow due to photo editing software
- fast results due to ink jet printers
- no need for dark room (think of working mothers)

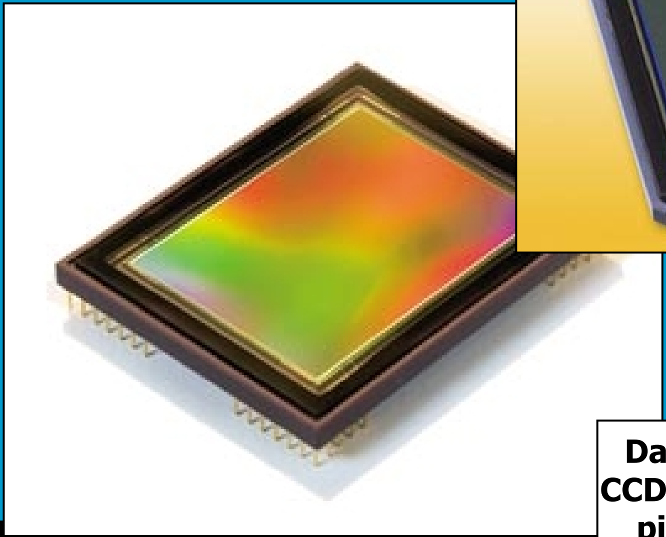
Image recording – going digital

- SONY introduced first digital camera in 1981
- CCD size was 570 x 490 pixels on a 10mm x 12mm chip

0.28 megapixels

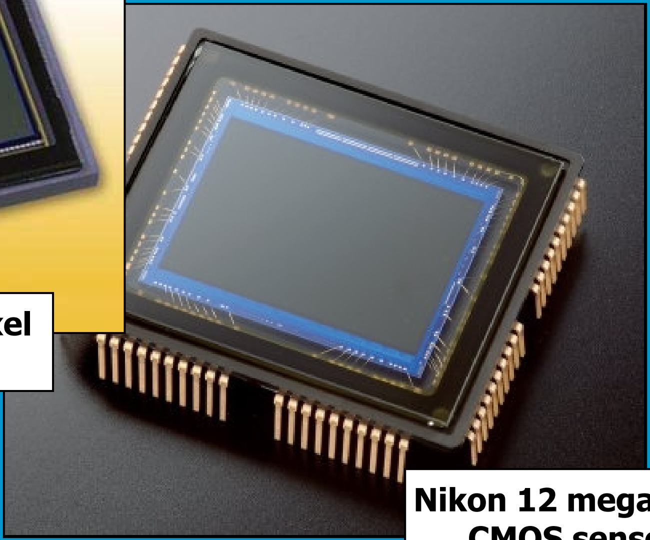
Image recording – digital sensors (2008)

- CCD – charged coupled device
- CMOS – complimentary metal-oxide semiconductor



Dalsa 33 megapixel
CCD sensor 36x48 mm
pixel size 7x7 μm^2

Kodak 50 megapixel
CCD sensor



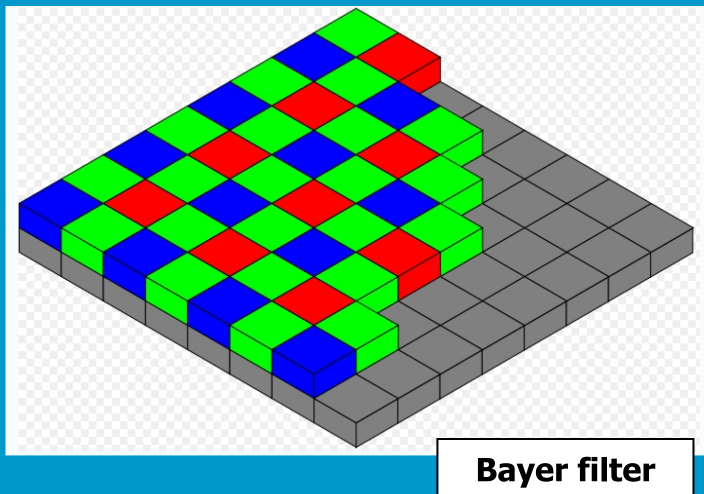
Nikon 12 megapixel
CMOS sensor

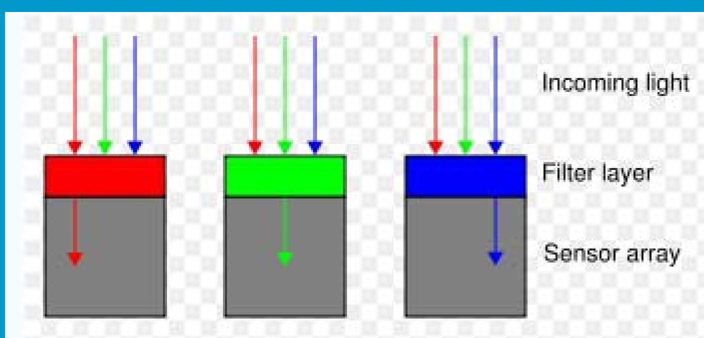
Image recording – digital sensors

- Both CCD (charge-coupled device) and CMOS (complimentary metal-oxide semiconductor) image sensors start at the same point -- they have to convert light into electrons (photovoltaic effect)
- In a CCD device, the charge is actually transported across the chip and read at one corner of the array
- In CMOS devices, there are several transistors at each pixel that amplify and move the charge using more traditional wires.
- Analog-to-digital converters turn each pixel's value into a digital value

Image recording – digital sensors

Principles





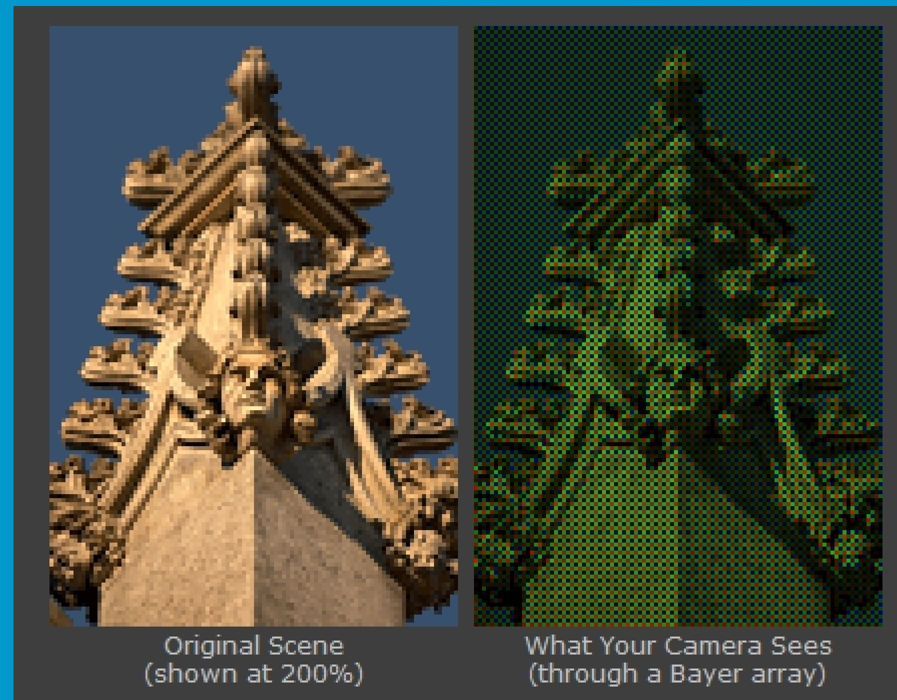
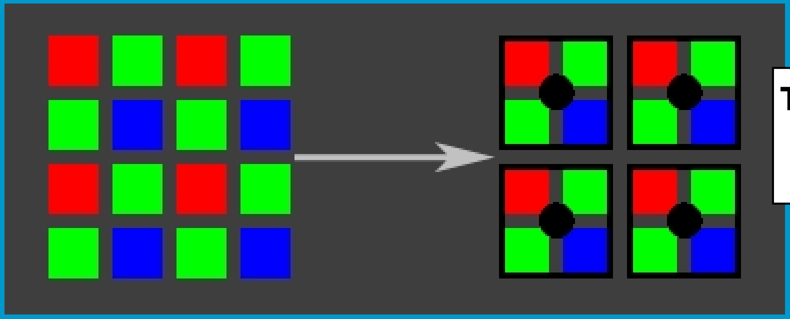
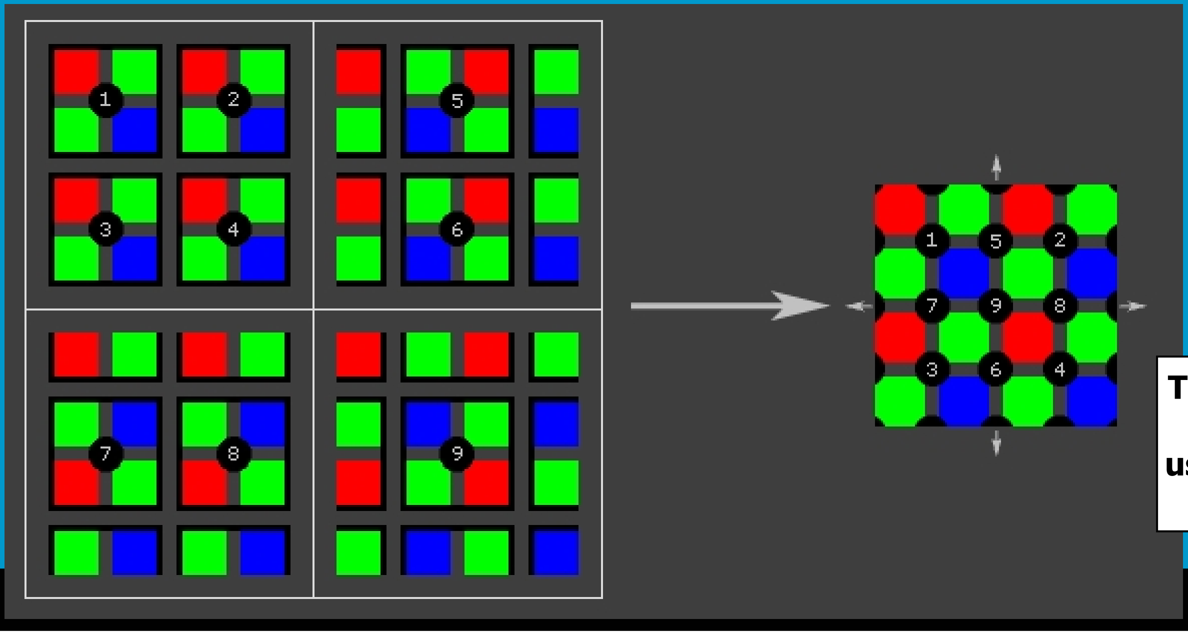


Image recording – digital sensors

Principles



Translating of Bayer array of primary colors into a final image which contains full color information at each pixel is called "de-mosaic"

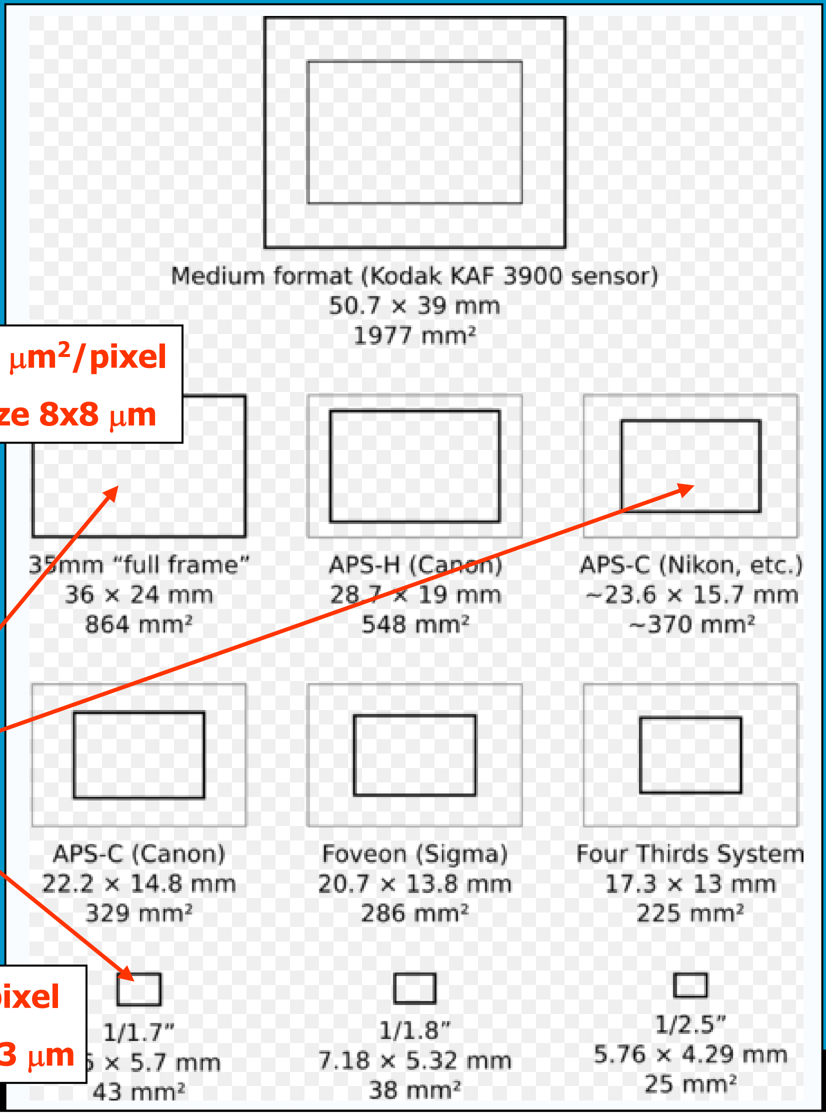


To achieve a higher resolution camera computes the color using several overlapping 2x2 arrays

Image recording – digital sensors

- Sensor formats

camera type	sensor [Mp]	pixel area [µm²]
Canon 1D Mark IV	CMOS 17	30.5
Canon 5D Mark II	CMOS 22	39.2
Canon 600D	CMOS 18	18.4
Nikon D3S	CMOS 12.1	66.8
Nikon D300S	CMOS 12.3	28.4
Nikon D7000	CCD 16.2	23.0
Sony HX9V	CCD 16.2	1.76
Sony A580	CCD 16.2	22.6
Sony A850	CMOS 24.6	35.1



68 µm²/pixel
size 8x8 µm

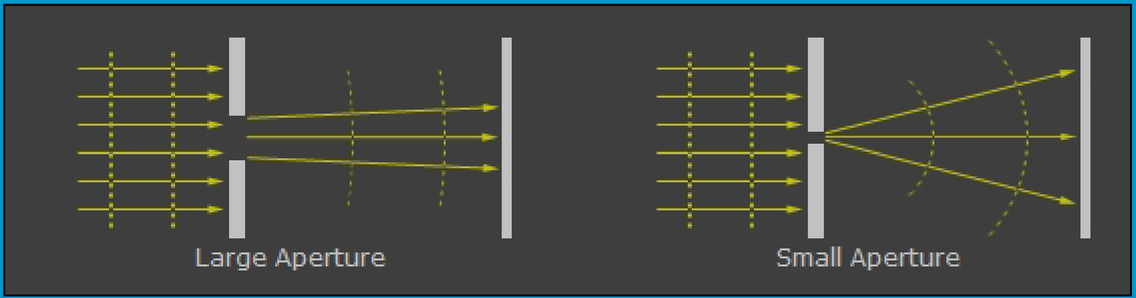
Different formats can contain the same number of sensors (here 16 Mp - 2011)

1.8 µm²/pixel
size 1.3x1.3 µm

Image recording – digital sensors

Factors limiting resolution

- influence of diaphragm (aperture) value



large aperture
for f/D = 1/2 is Δl =0.3 µm (lens full open)
shallow depth of field (DOF)
low diffraction

small aperture
for f/D = 1/32 = 4.8 µm (smallest lens aperture)
deep depth of field (DOF)
large diffraction

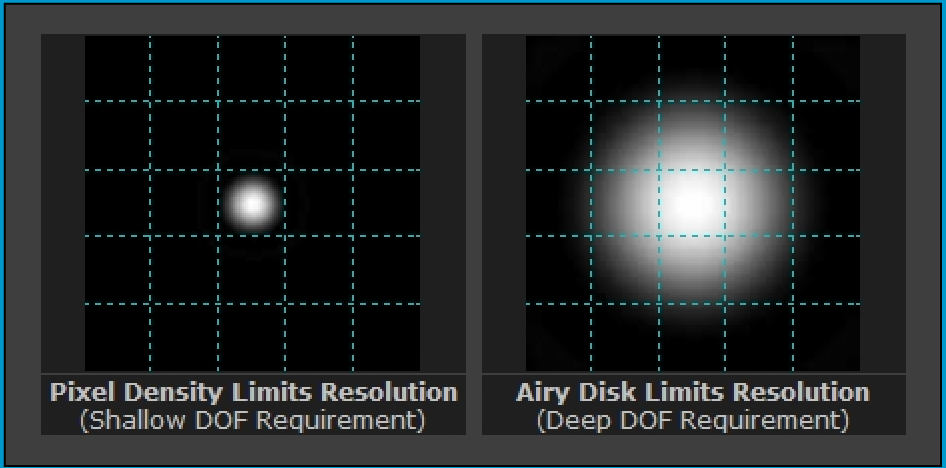
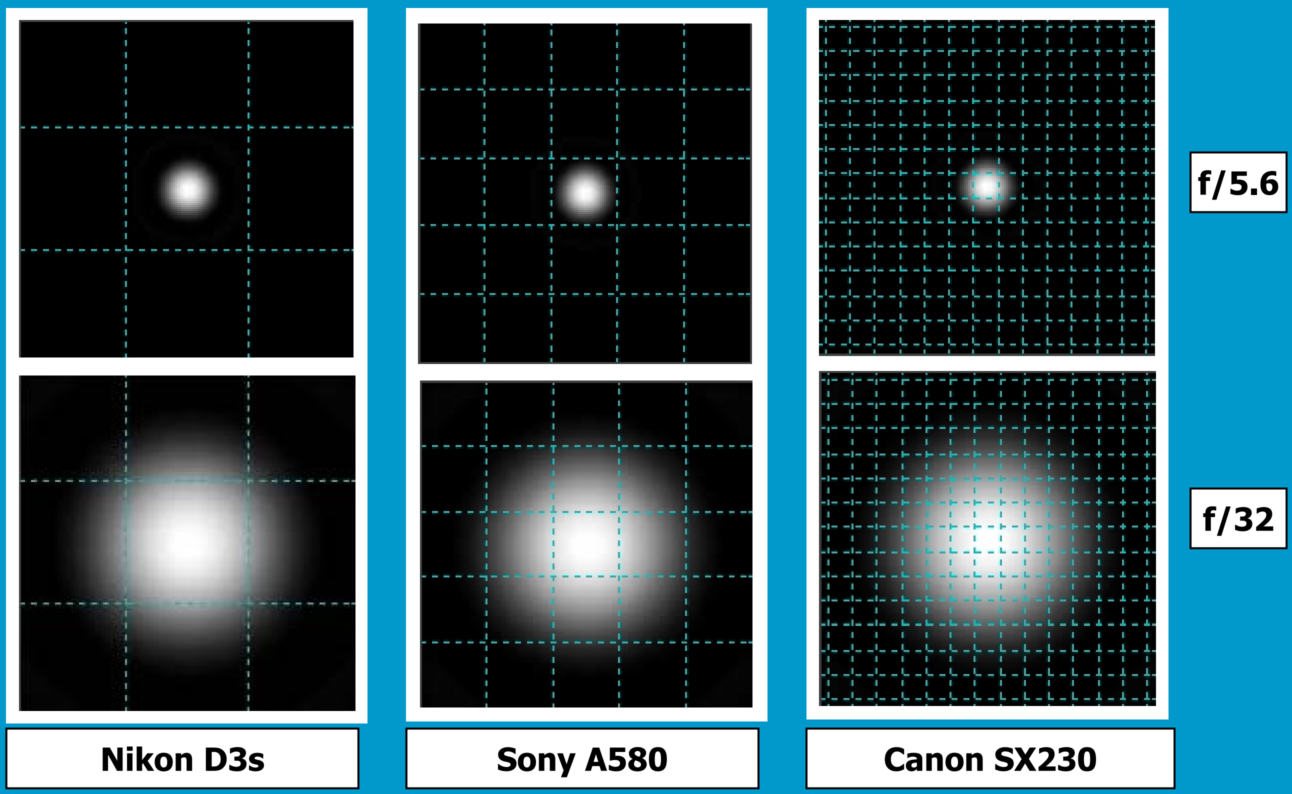


Image recording – digital sensors

Factors limiting resolution

- pixel density vs. aperture



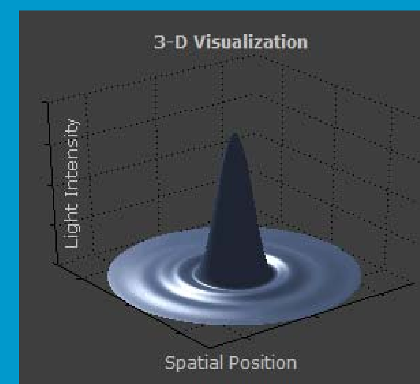
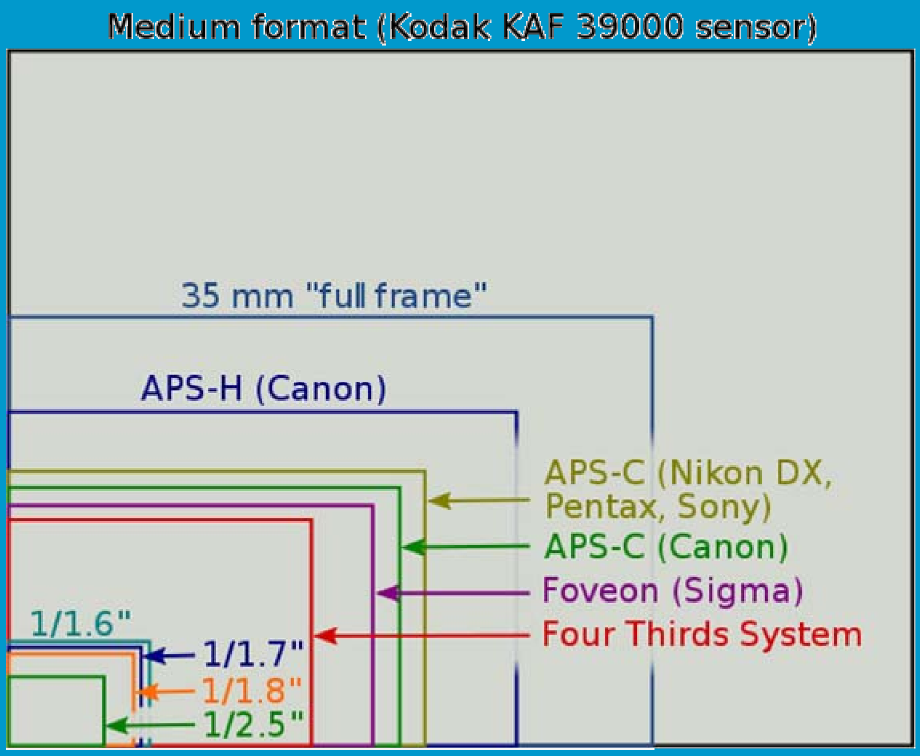
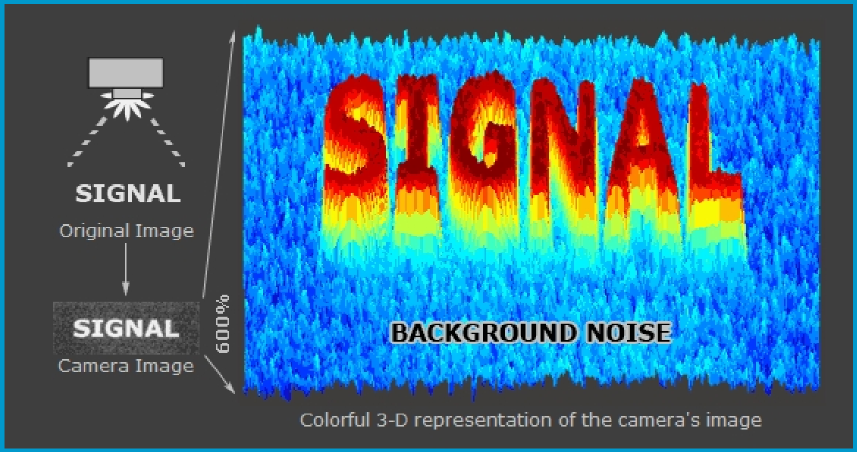


Image recording – digital sensors





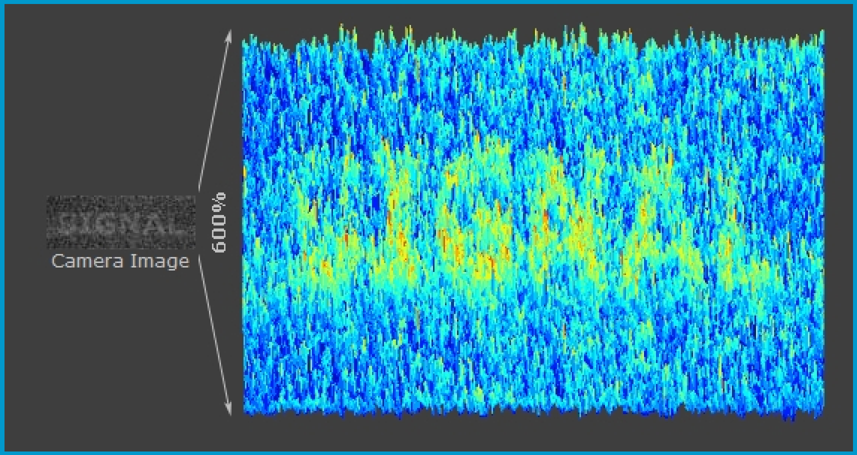


Image recording – camera features

- Optical image stabilization
  - controlled movement of image sensor compensates for camera shake (Sony – Minolta system)
  - works with any lens !!

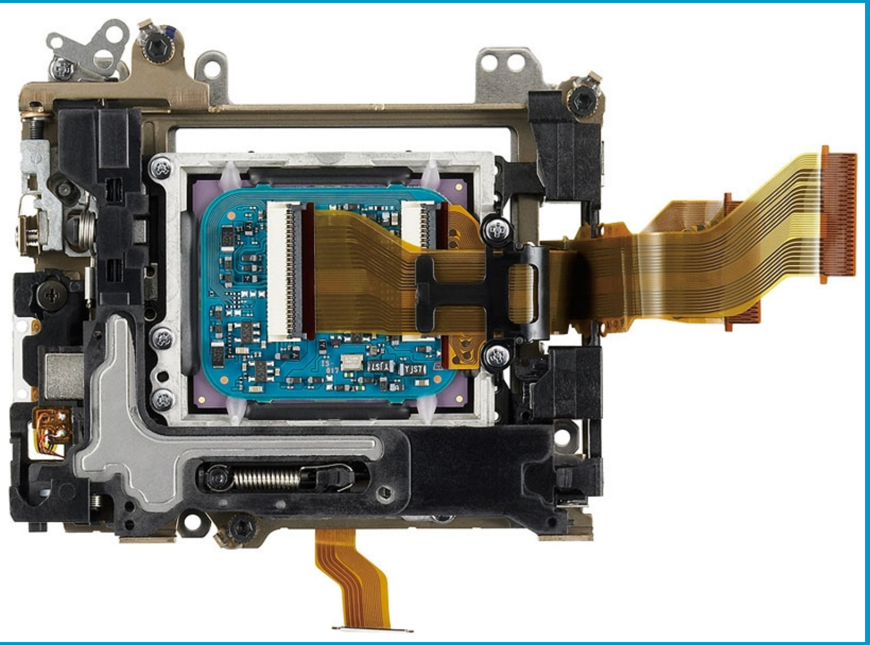


Image recording – camera features

- Optical image stabilization
  - controlled movement of some of the lens elements inside the lens compensates for camera shake (Nikon system)

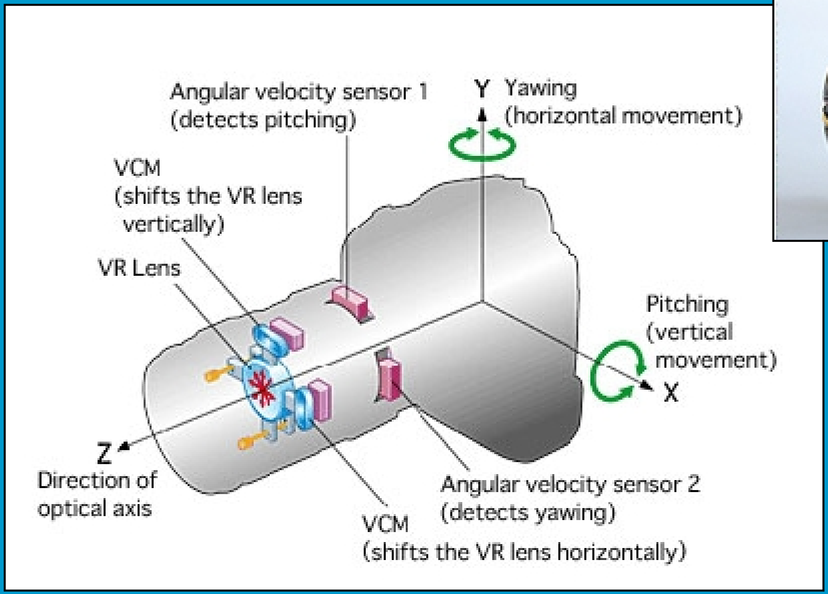
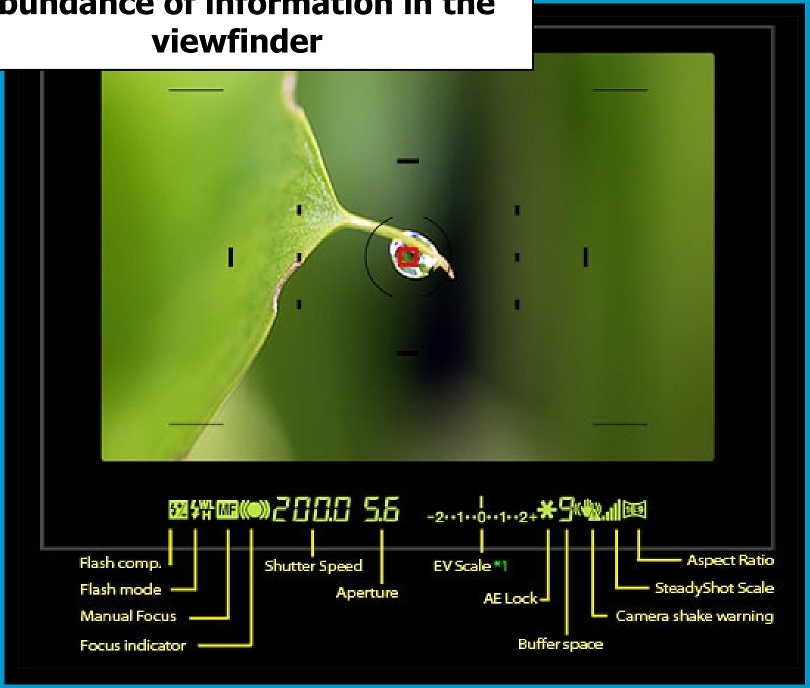


Image recording – more camera features

Contribution to easy work and higher quality

abundance of information in the viewfinder



D-SLR Live View

Image recording – camera features

- Due to the mass production and possibilities of microprocessors there is a fast number of additional features, like
  - different picture formats (JPEG, TIFF, RAW)
  - scene (face) recognition
  - white balance
  - continuous shooting
  - predicting (3D) auto focus
  - high frequency dust removal
  - HDMI output
  - HD movie capture
- but:
  - 90 % of all users will take advantage of 10% of all camera features

Image recording - trends

- less moving parts

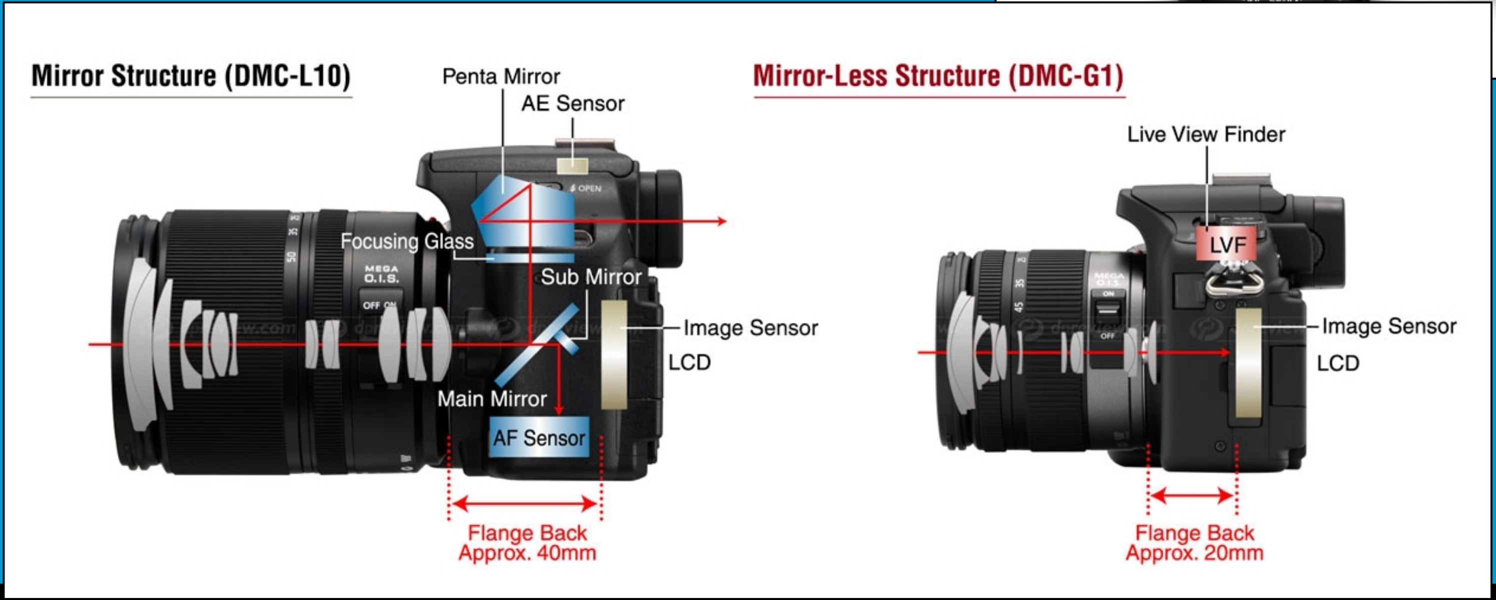


Image recording - trends

- less moving parts

Sony translucent mirror

Image recording - trends

60 Mp

37.5 Mp

24 Mp

Image recording - trends

- users getting younger and younger

Image recording – what is new?

OLD

- focusing screen (1839)
- lens system (1860)
- zoom lens (1902)
- diaphragm (1930)
- metal shutter (1932)
- interchangeable lens (1933)
- pentaprism viewfinder (1949)

NEW?

- autofocus (1977)
- digital sensor (1981)
- storage on memory cards (1990)
- image stabilization (1995)
- polycarbonate body (1995)

new is the combination of all parts

Image recording – future development

big (semi)prof cameras

(very) small cameras – taking real advantage of the technology

large sensors >24 Mp

very small sensors

>8 Mp

>16 Mp