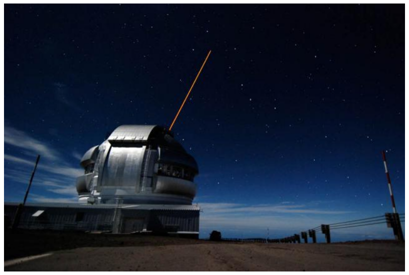
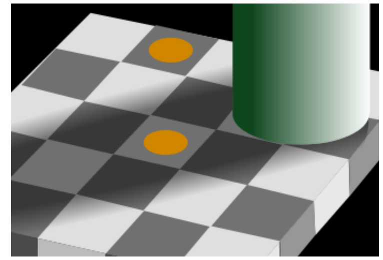
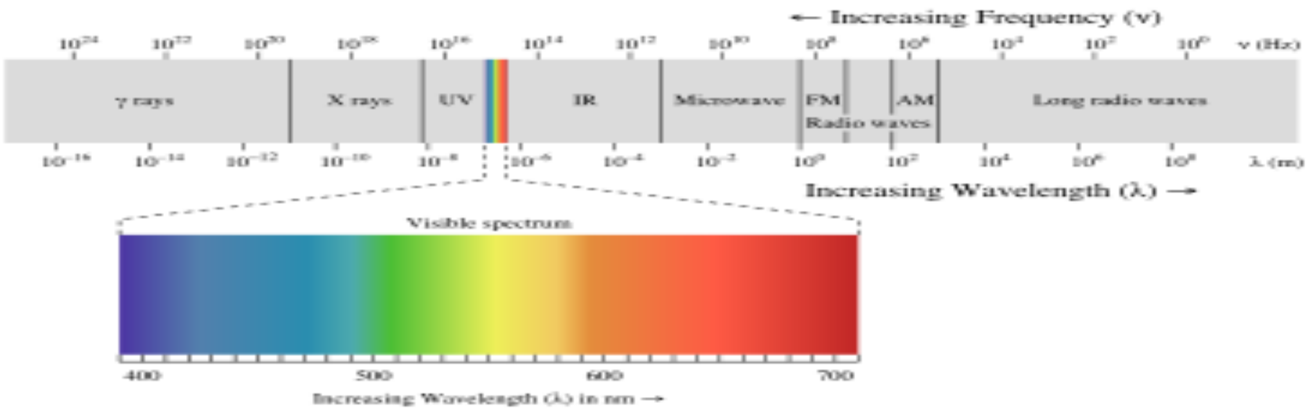
Physics 1230: Light and Color



- Prof. Leo Radzihovsky (lecturer)
- Gamow Tower F623 303-492-5436
- radzihov@colorado.edu
- office hours: T, Th 3-4pm

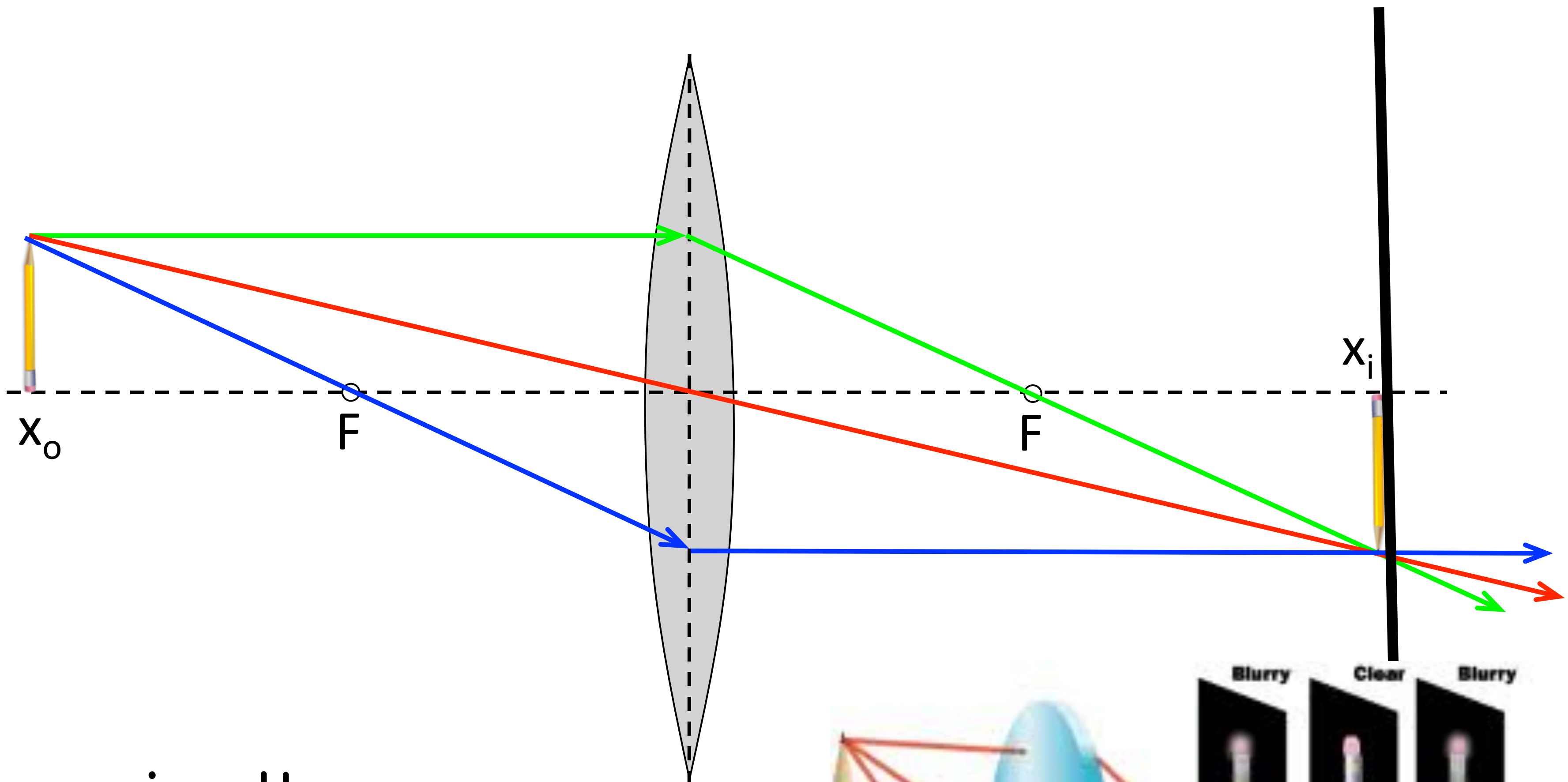
Susanna Todaro (TA/grader)
Help Room, Duane Physics
susanna.todaro@colorado.edu
M, W 3-4pm

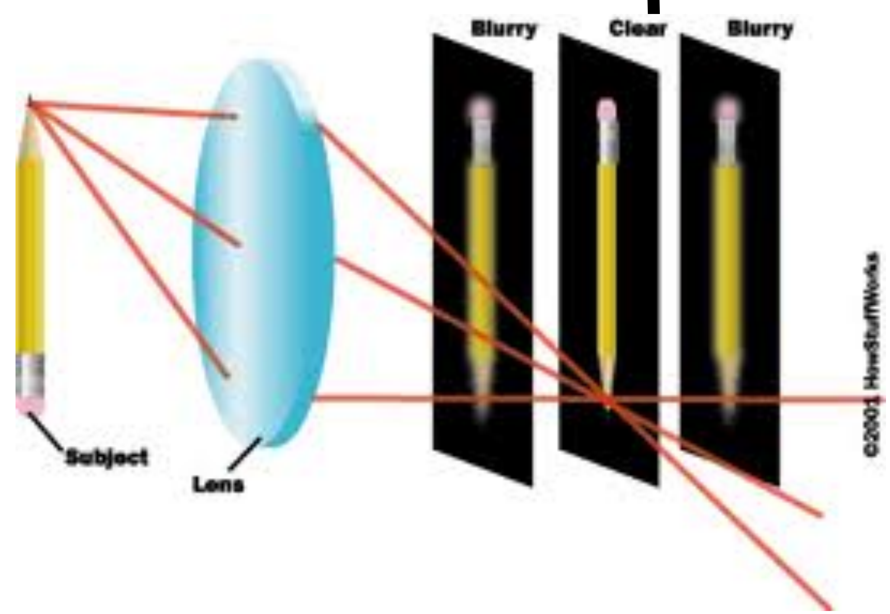
http://www.colorado.edu/physics/phys1230/

clicker question

Focusing a lens

Q: If you move the screen toward the lens, the image:





(a) remains the same
(b) gets dimmer
(c) becomes fuzzier
(d) becomes upright
(e) disappears

Lecture 8

Cameras and photography

Announcements:

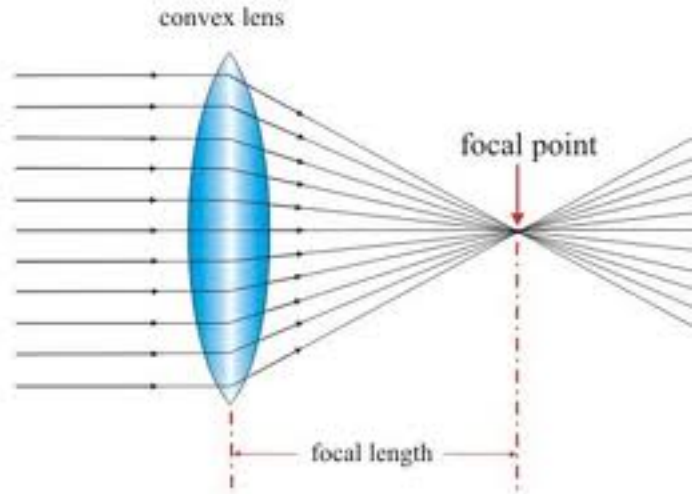
- lectures 7 is posted on the class website
- midterm 2 on Tuesday, April 15
- homework 7 is posted on D2L
  - due Tuesday, April 1 in homework box in Help Room
  - solutions will be posted on D2L
- reading for this week is:
  - Ch. 4 in SL

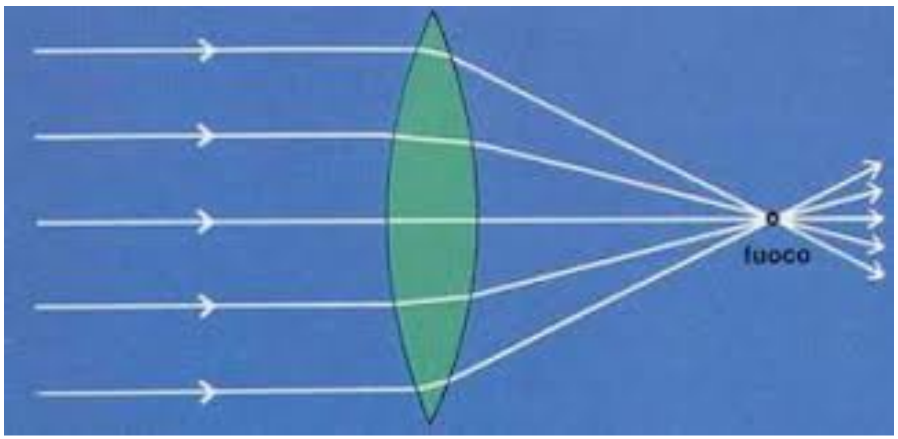
Recall

Last time

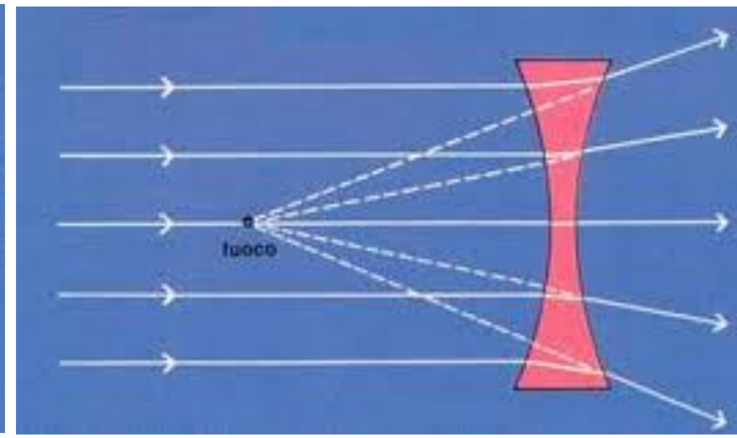
recall lecture 7: Spherical lenses

- convex and concave lenses
  - ray tracing
  - image formation
  - applications





converging lens "bi-convex" has two convex surfaces



diverging lens "bi-concave" has two concave surfaces

Today

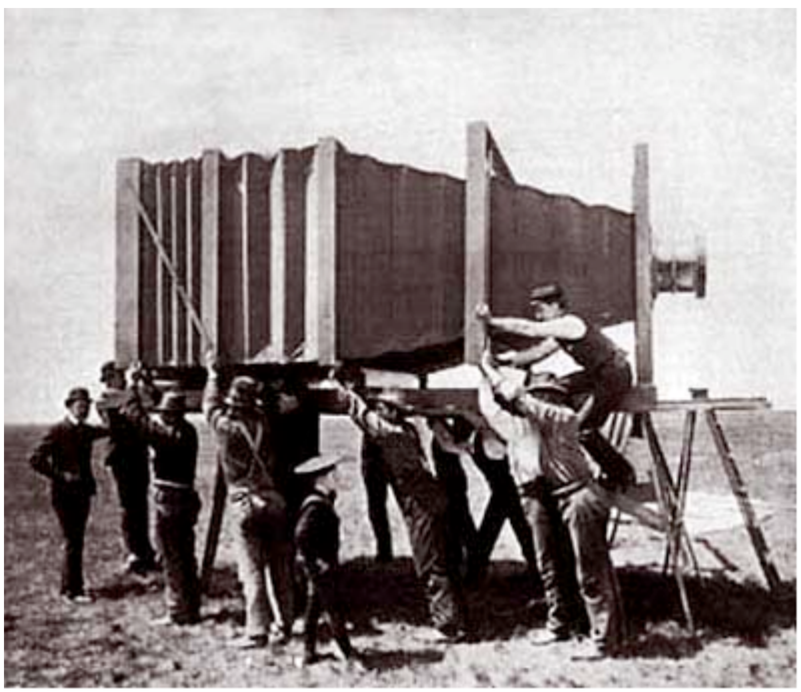
Cameras and photography

- lens-based cameras' essential parts
- different types of lenses
- f-stop and NA
- depth of field/focus
- aperture
- shutter speed

wide-angle

standard

telephoto



early 19th century

Today

Cameras and photography

Web tutorials with Java applets

Useful web links on lenses

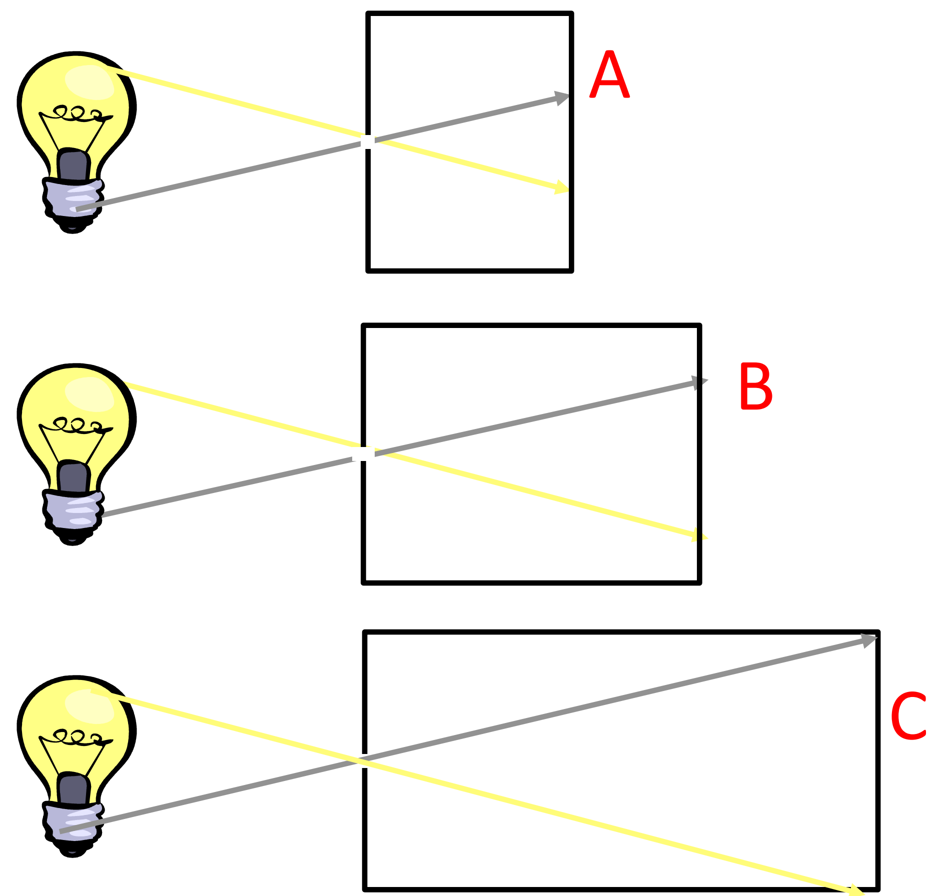
- http://micro.magnet.fsu.edu/primer/lightandcolor/lenseshome.html
- http://micro.magnet.fsu.edu/primer/java/lenses/simplethinlens/index.html
- http://micro.magnet.fsu.edu/primer/java/lenses/converginglenses/index.html
- http://micro.magnet.fsu.edu/primer/java/lenses/diverginglenses/index.html
- http://micro.magnet.fsu.edu/primer/java/components/perfectlens/index.html
- http://micro.magnet.fsu.edu/primer/java/mirrors/convex.html

clicker question

Pinhole camera image size

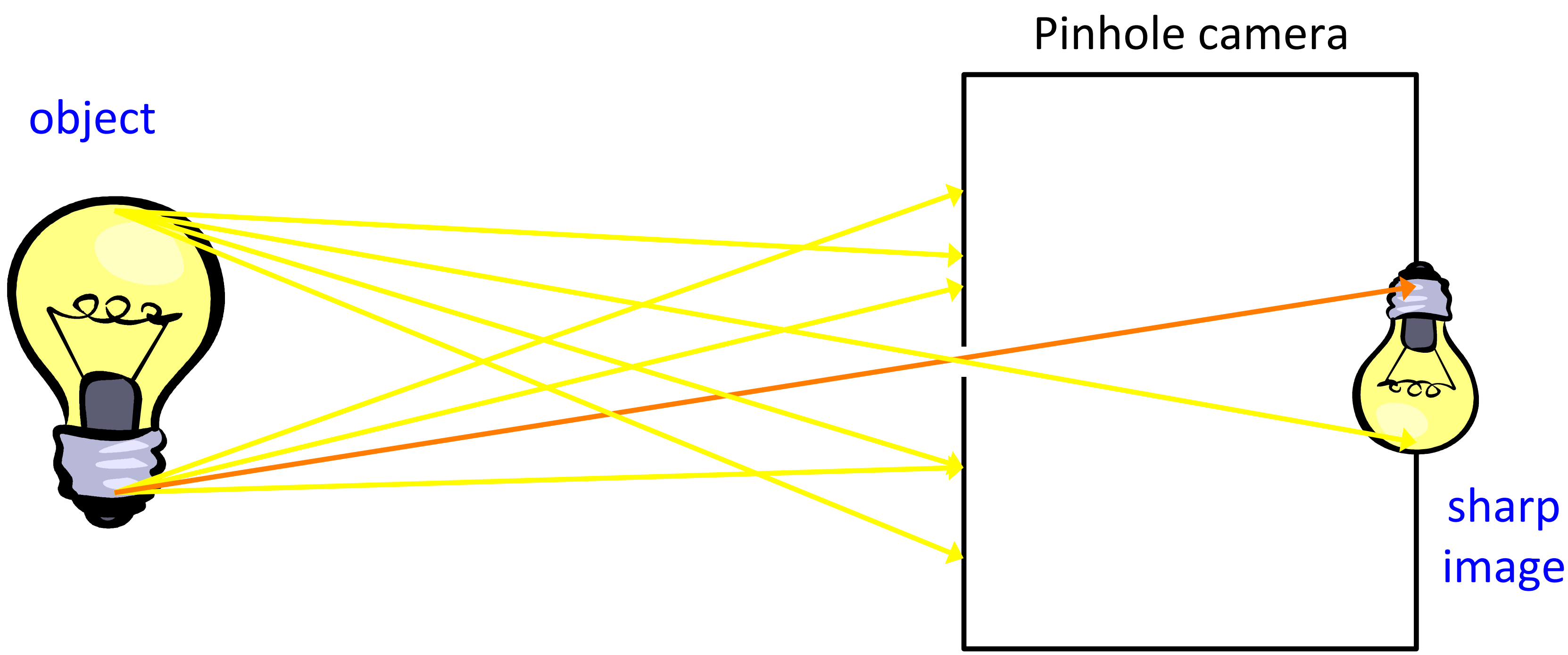
Q: Which camera will produce *smallest* image?

(a)
(b)
(c)
(d), they are same size



Pinhole camera

Recall simplest lens'less camera:

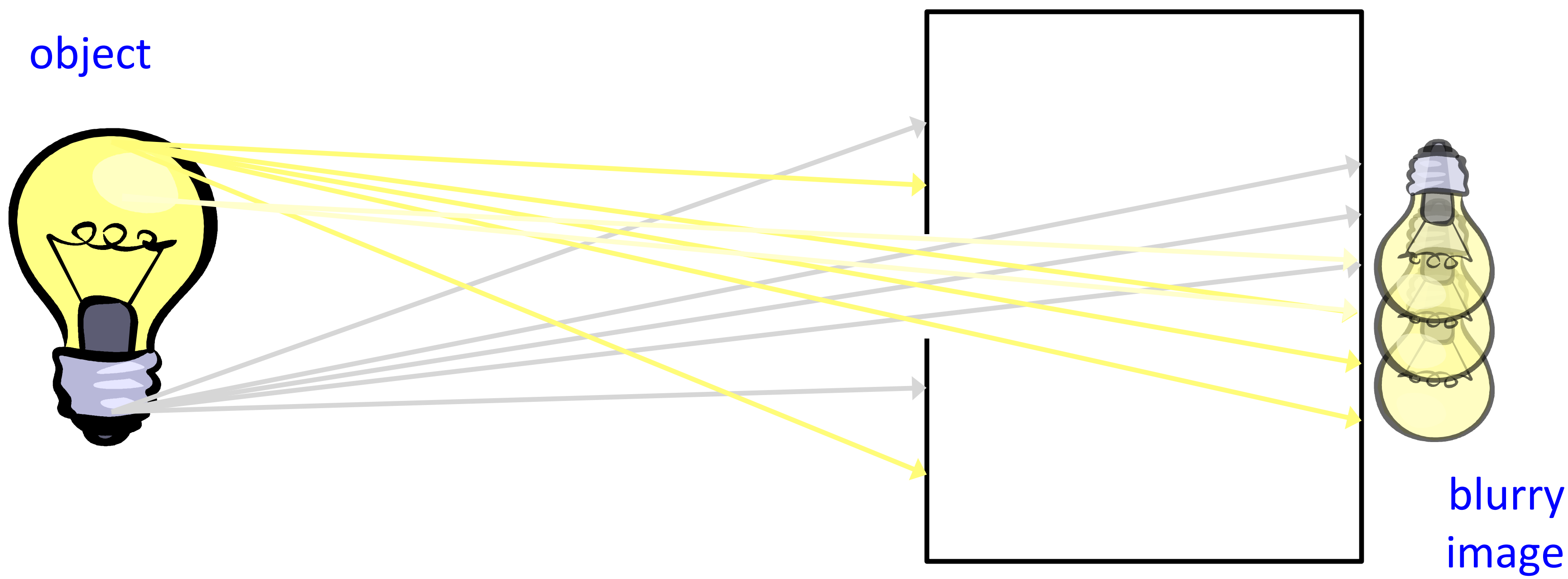


Light rays from each point on the object reach one point (and no other point) on the screen, and no rays from other points on the object reach that same point on the screen.

This produces a *focused image* at every plane, independent of the position of the object (though very faint)

Pinhole camera

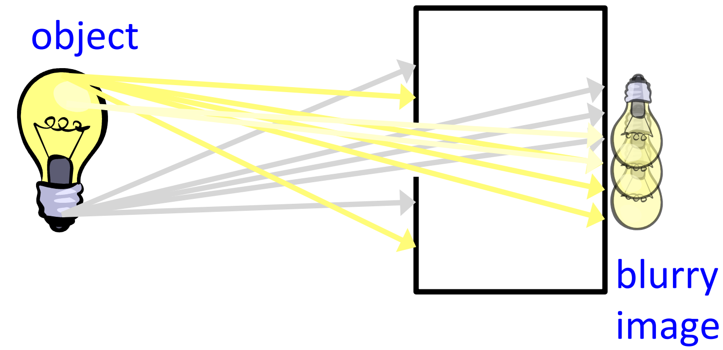
Recall simplest lens'less camera: *a poor one*

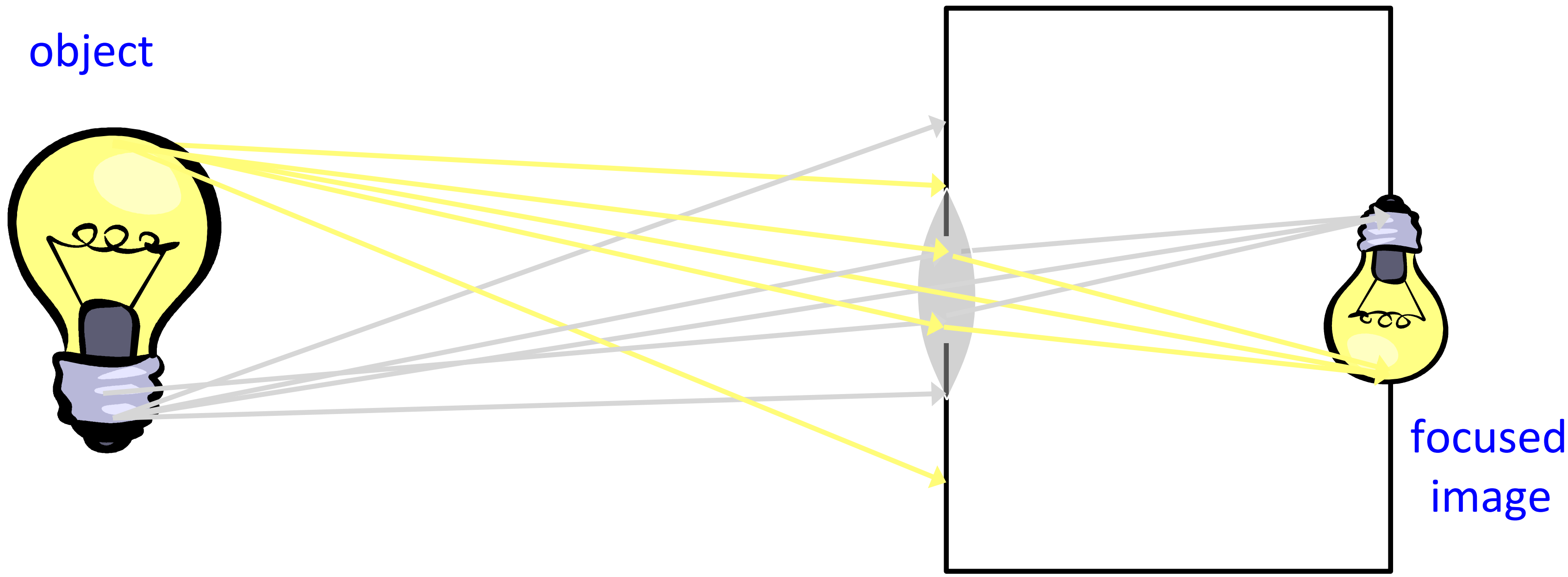


Increasing the size of the hole in a pinhole camera, allows more light to enter. But the image gets blurry, because rays from each point on the object hit more than one spot on the screen, and rays from more than one point on the object reach the same spot on the screen.

Camera with a lens

Add a lens to a poor pinhole camera:



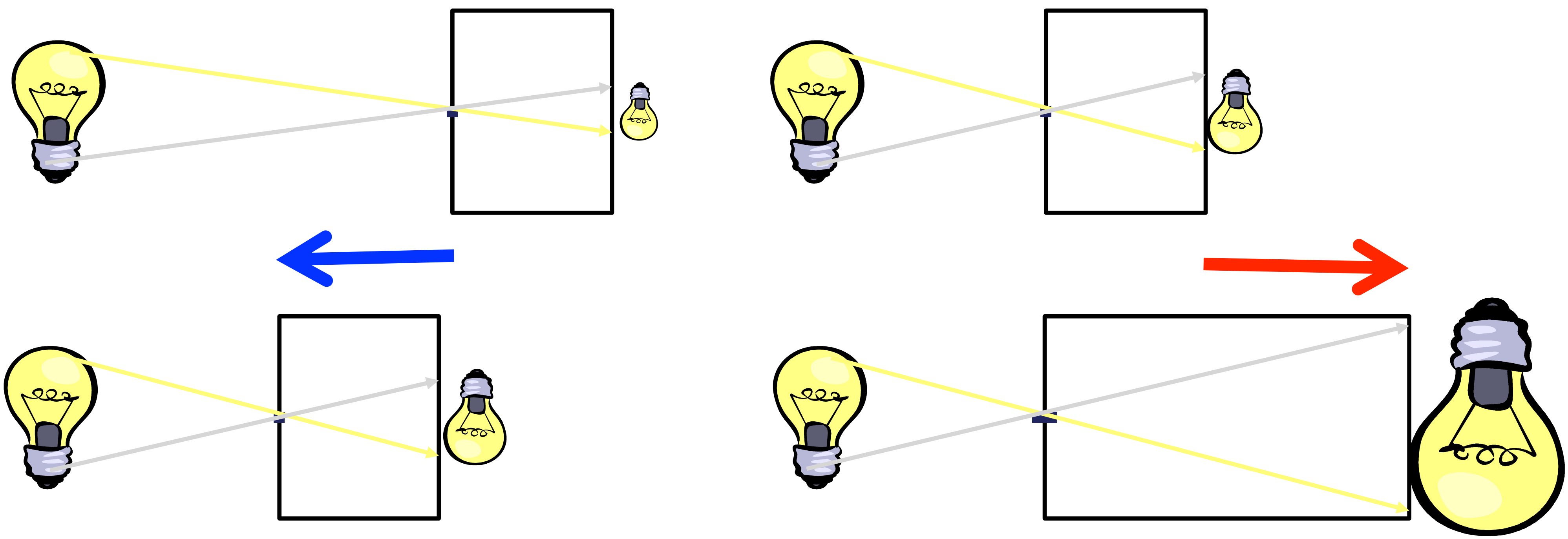


Adding a lens bends the rays so that rays from each point on the object reach only one point on the screen, and no rays from other points on the object reach that same point.

This produces a *focused image* on the screen.

Camera zoom and image size

Pinhole camera *(for simplicity):*



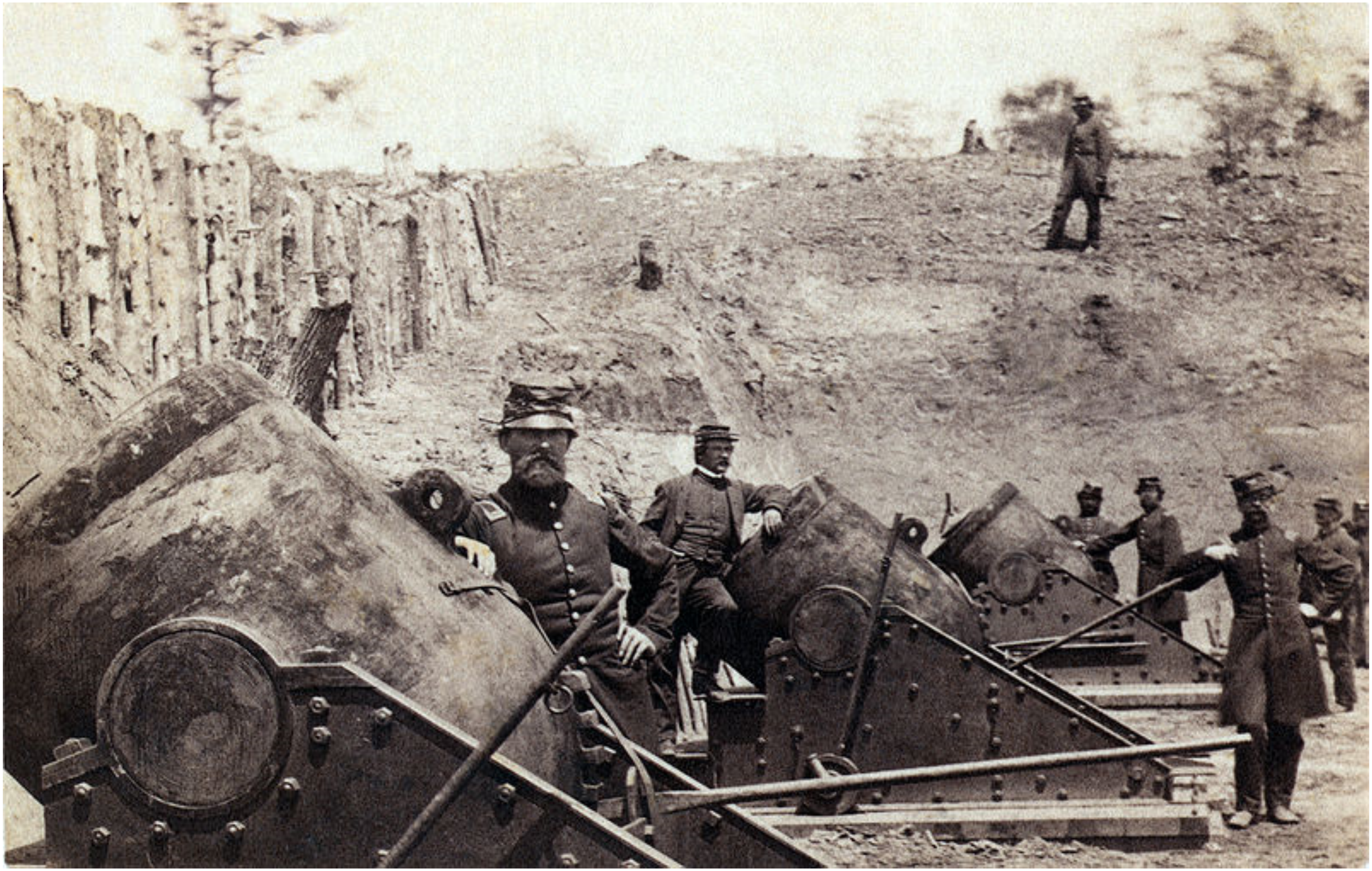
- To produce a larger image with a pinhole camera, either decrease the distance from the object to the camera, or increase the distance from the pinhole to the back screen of the camera.
- The image stays in focus because only one ray from each point on the object gets through the pinhole and reaches the screen.

Photography

Photograph = science + art

Photography

Early photography: makes scene real

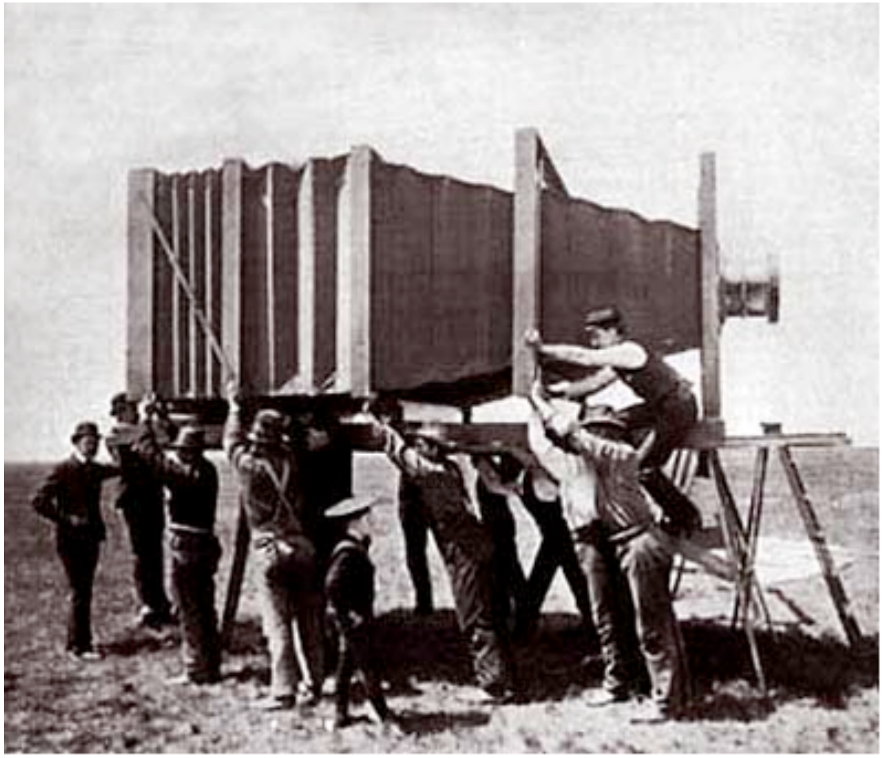


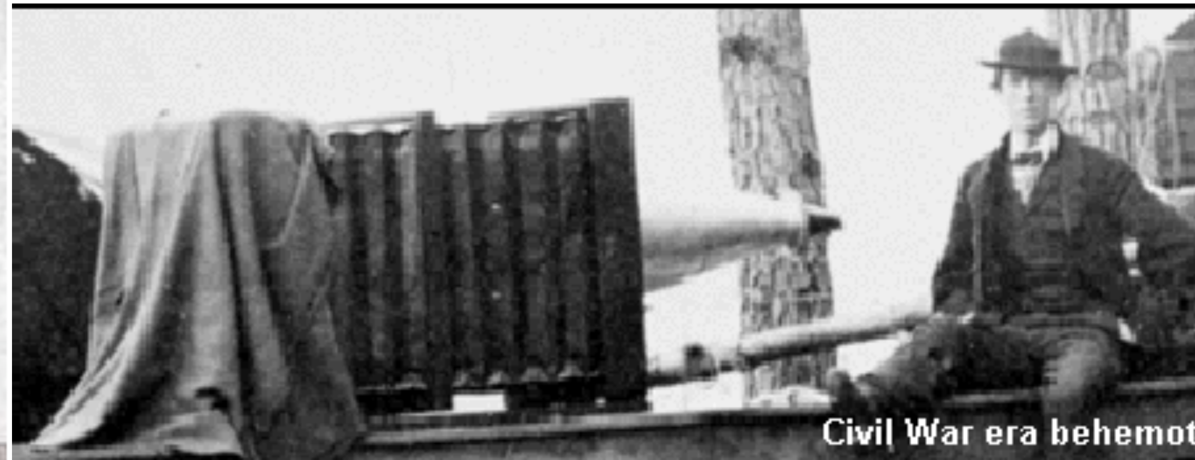
Photography = reality (?)

Siege of Yorktown, 1861
James F. Gibson

Cameras

Cameras existed for hundreds of years (pinhole and lens)





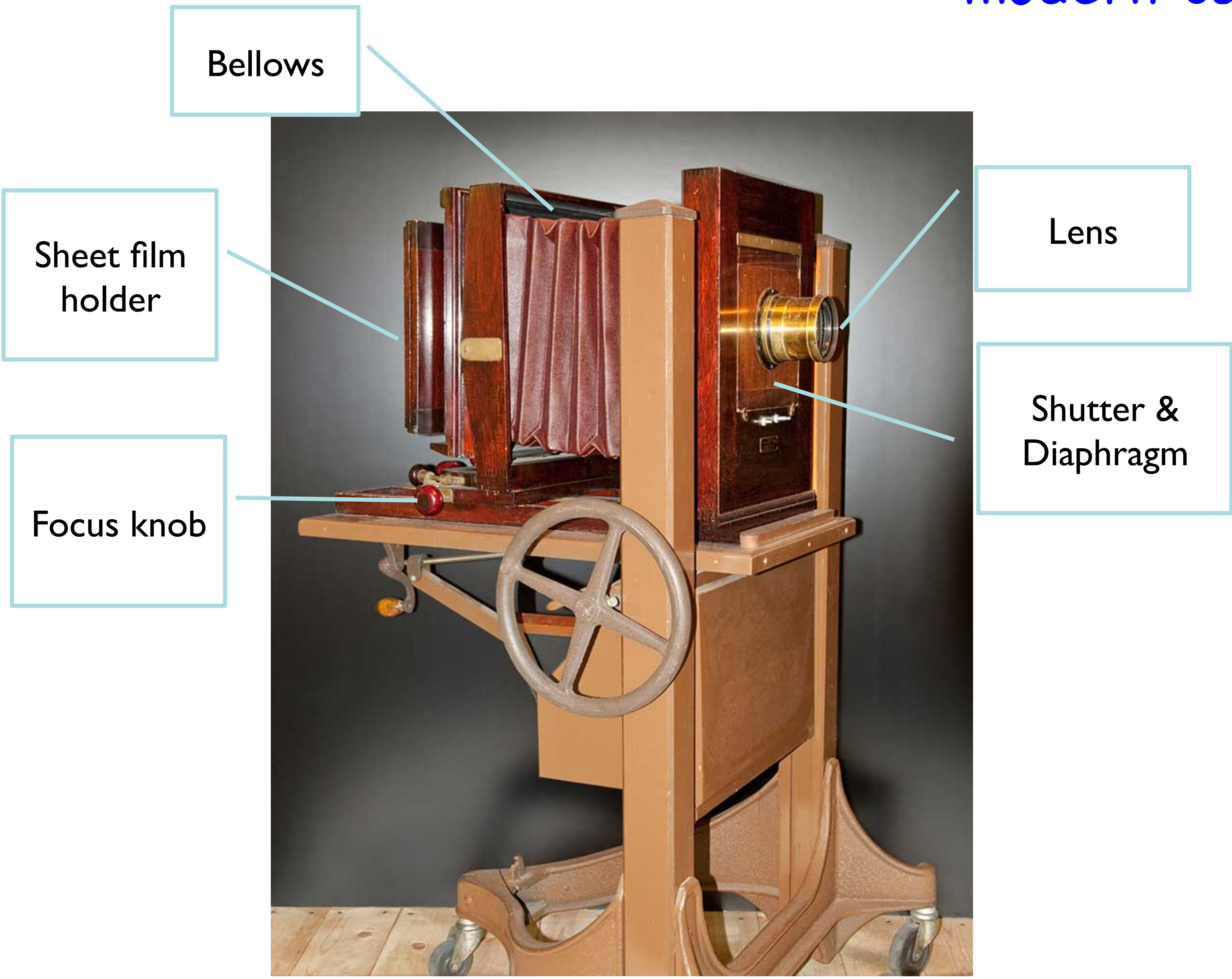
The revolution (early 19^{th} century) was *film*:

the method to store and reproduce images

...but first, let's understand the camera system

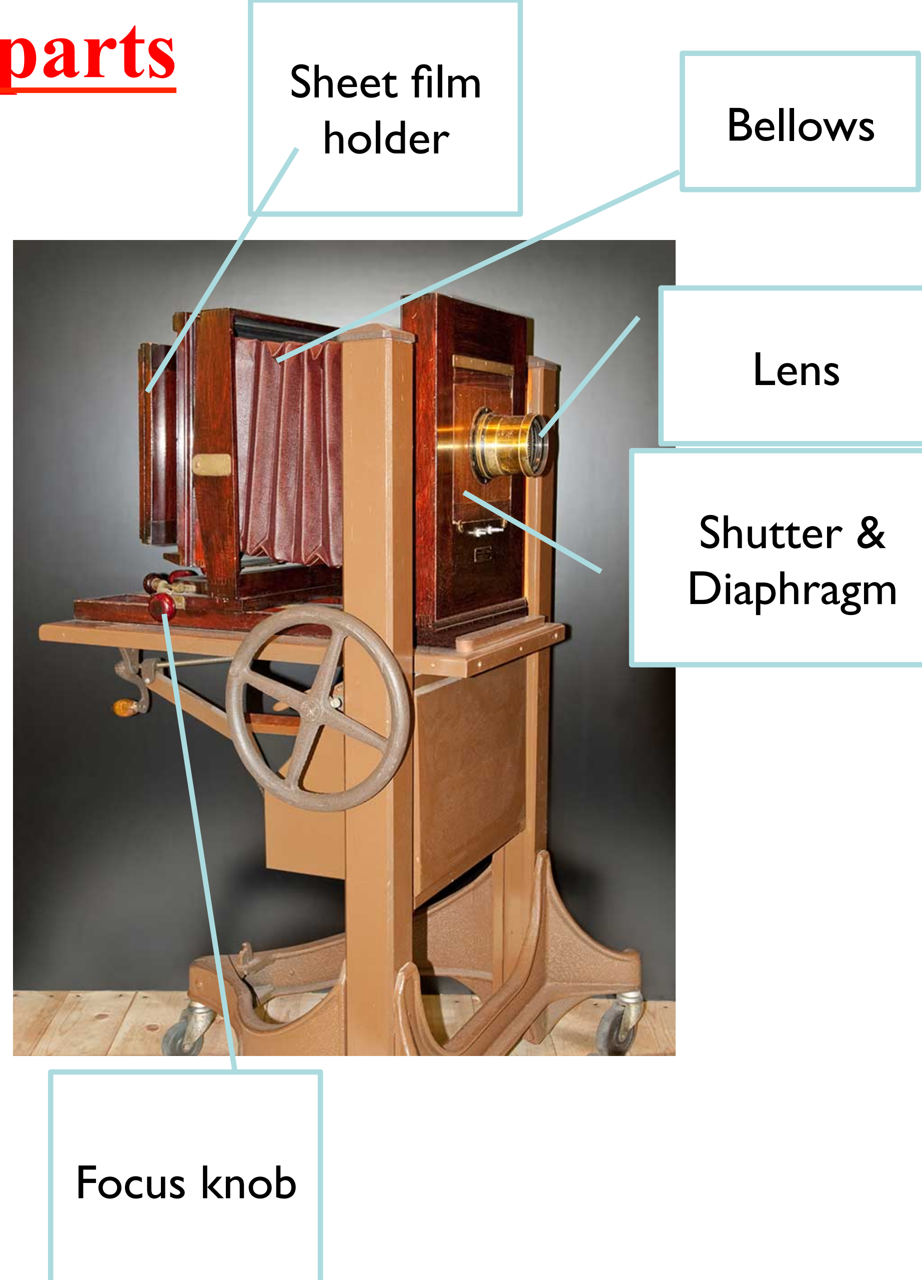
Lens camera parts

an old-fashioned view camera with same basic parts as modern camera



Lens camera parts

- lens - focuses light
- shutter – exposure time
- diaphragm – controls amount light
- focusing screen – image location
- film or digital image chip (CCD) – records the image



Lens camera parts

- lens - focuses light
- shutter – exposure time
- diaphragm – controls amount light
- focusing screen – image location
- film or digital image chip (CCD) – records the image

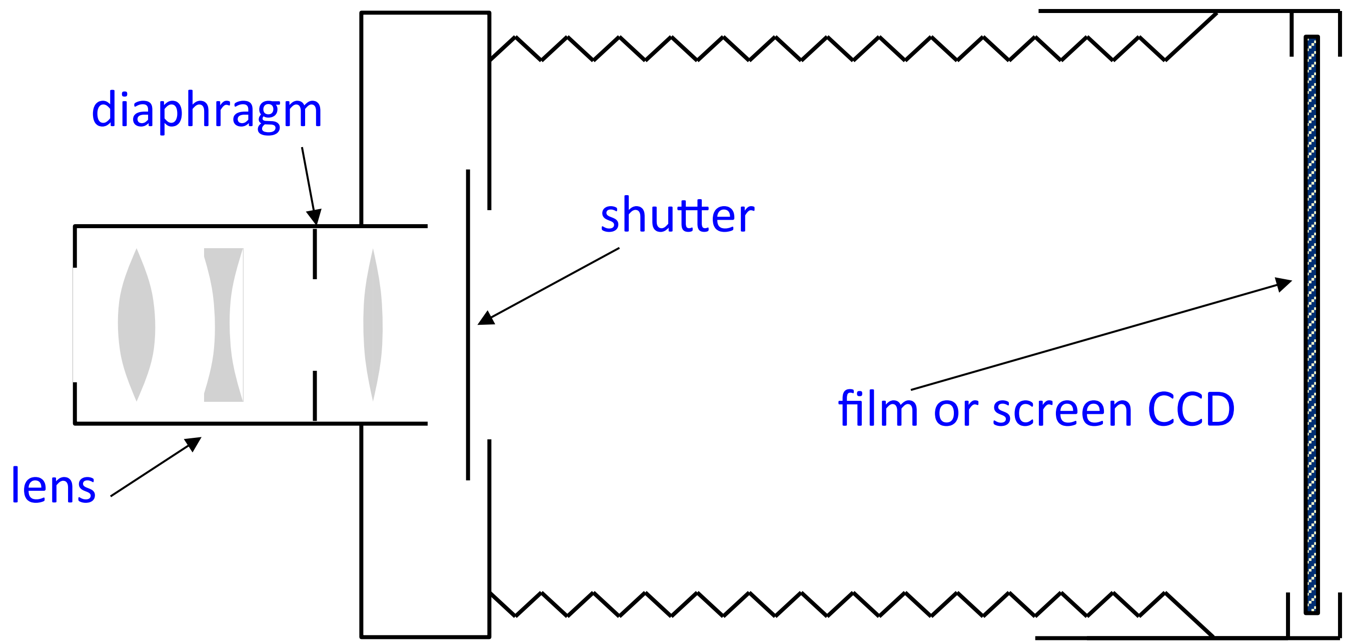
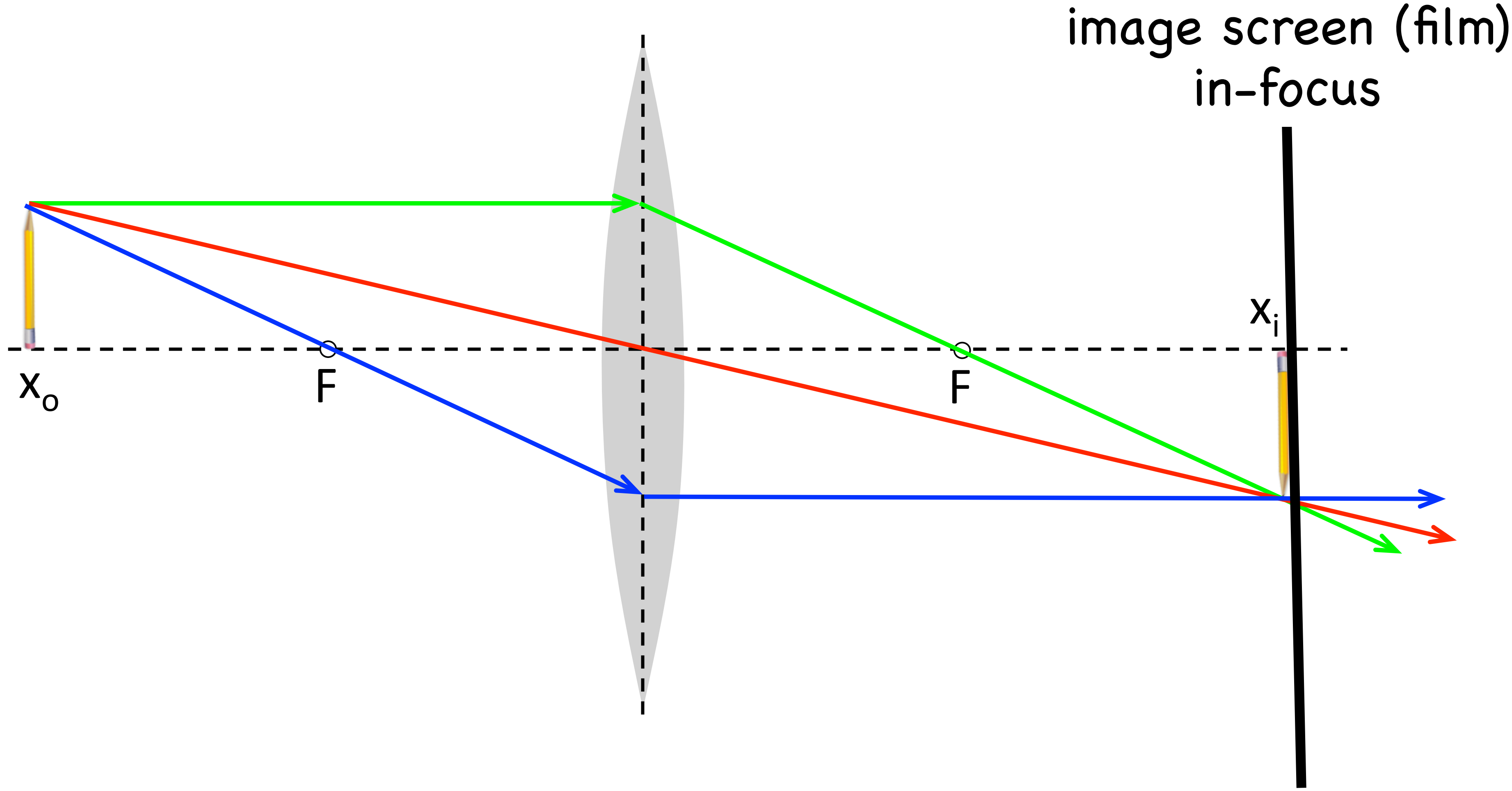


Image formation: converging lens



$x_o = 2f$ (camera image on film):

The image is *real, inverted* and of the *same size* as the object. More generally this will depend on the position of the object x_o relative to the focal point F of the lens.

If object moves (for fixed f) so will the image -> must refocus

Focus on the image plane

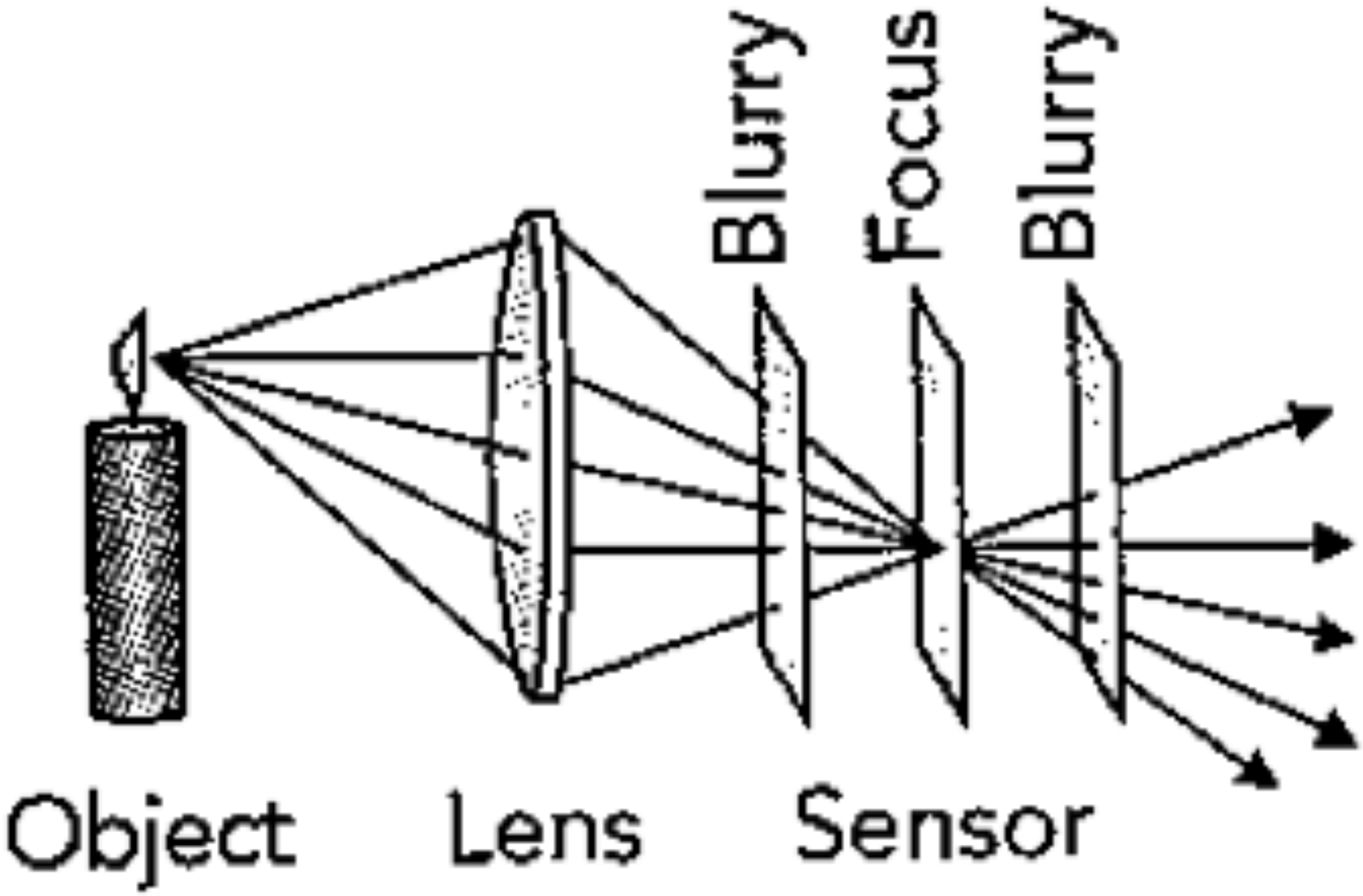
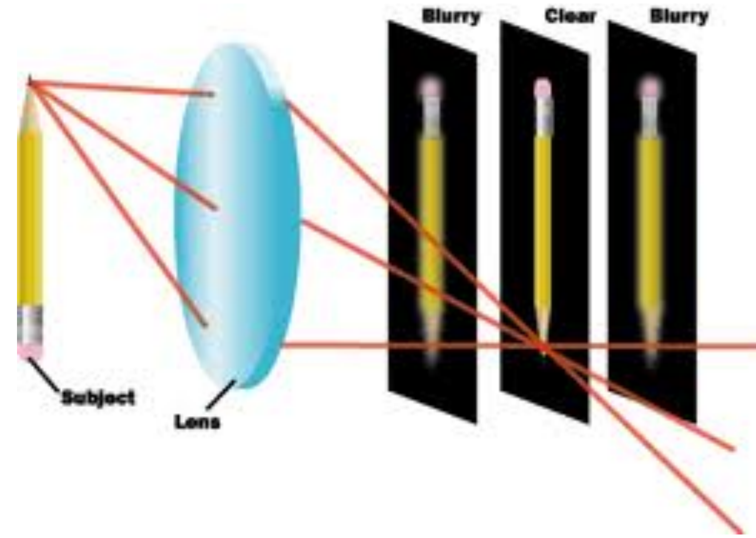
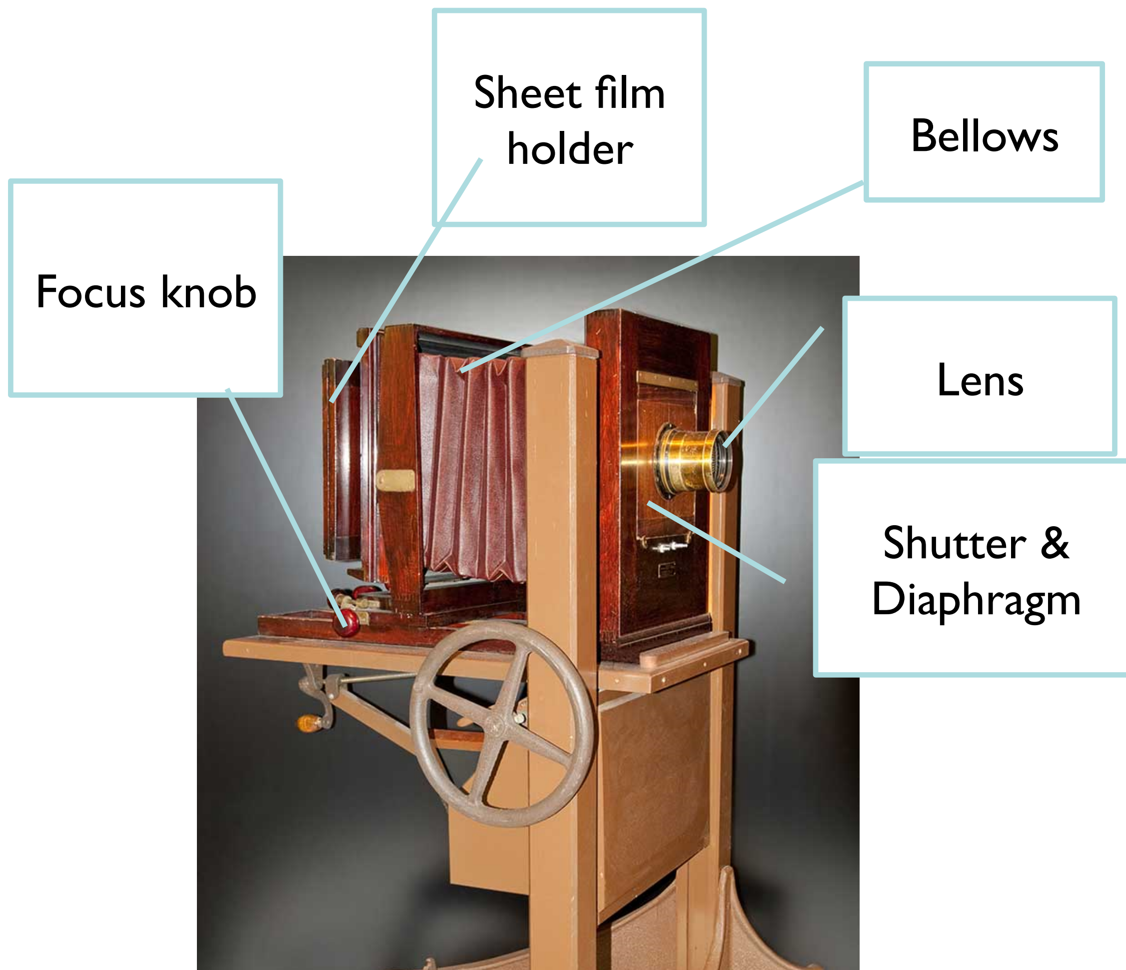


Image is only in focus at a single plane. In all other planes the image is blurry. In a camera move the lens *not* the sensor (film) to focus image

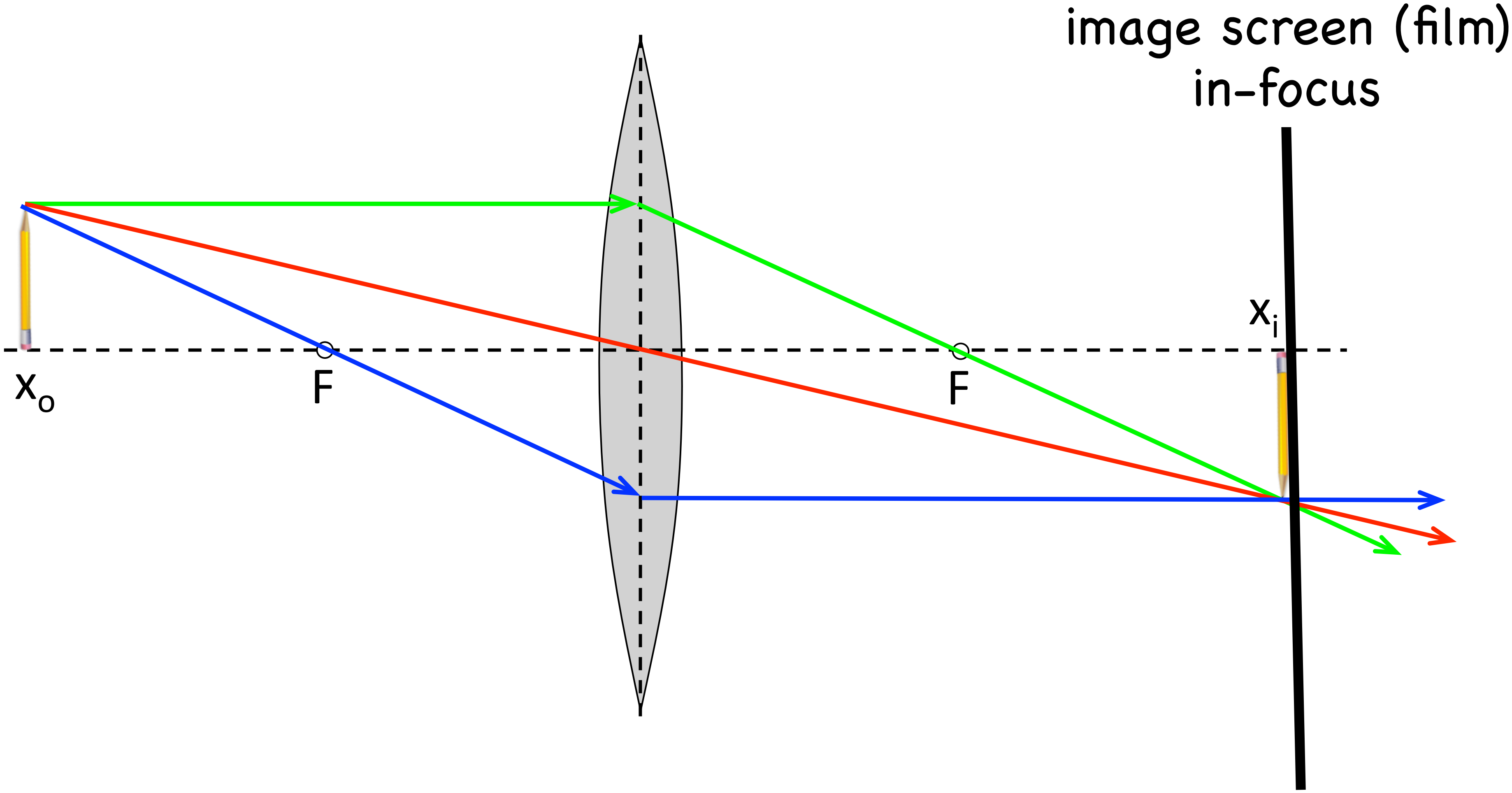
Photography principles

1. Camera focuses by moving the lens closer/further from the film





Focal length and image location

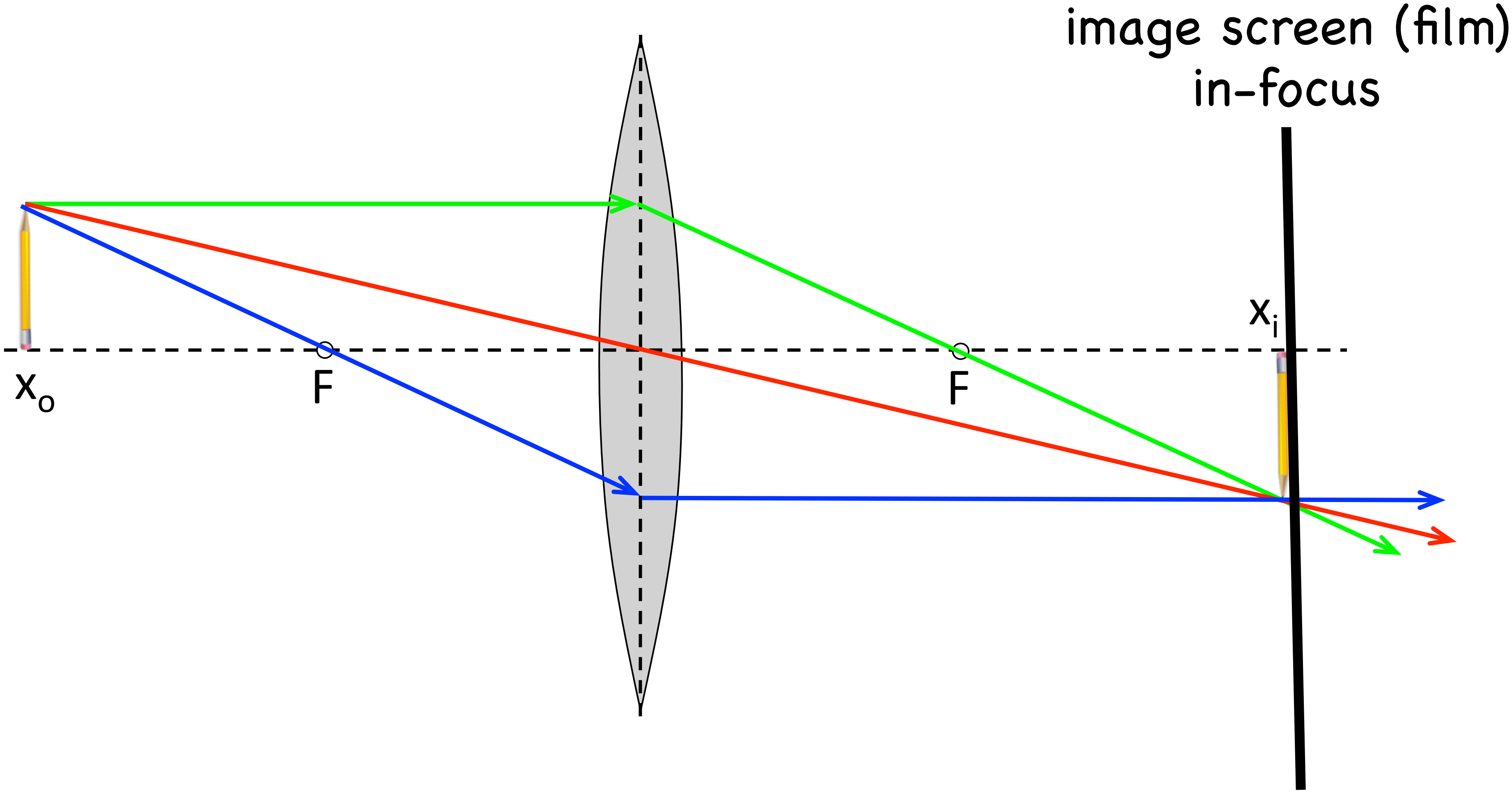


Q: What happens to the image if the focal length, f increases?

A: Image moves further away from the lens
-> so must refocus

$$\frac{1}{x_o} + \frac{1}{x_i} = \frac{1}{f}$$

Object distance and image location



Q: What happens to the image if the object distance, x_o increases?

A: Image moves closer to the lens
-> so must refocus

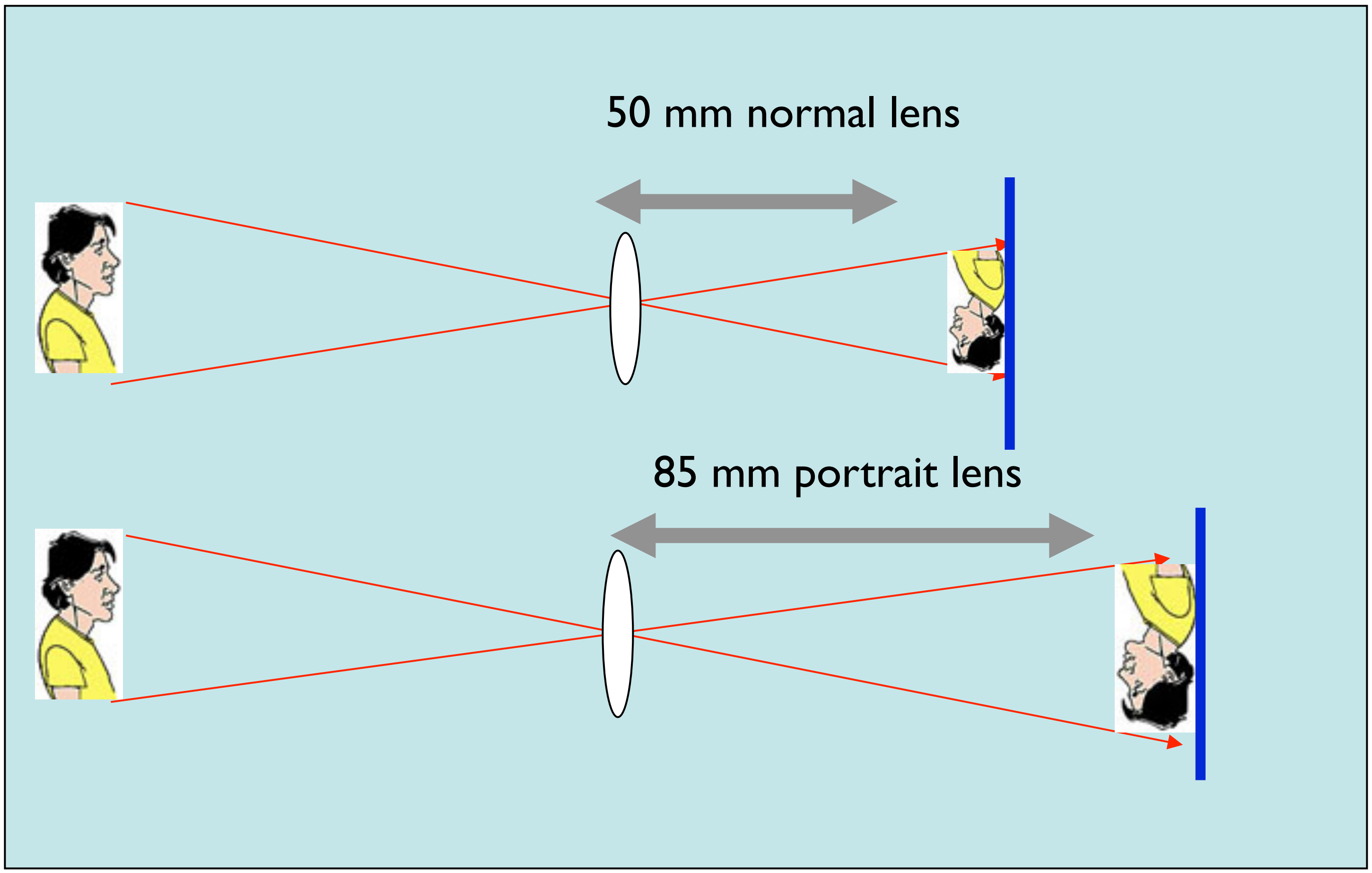
$$\frac{1}{x_o} + \frac{1}{x_i} = \frac{1}{f}$$

Lens focal length in a camera

Q: For two lenses below, which makes a bigger image?

A: The one with the longer focal length has image at larger x_i and so its magnification is larger for longer f

$$\frac{1}{x_o} + \frac{1}{x_i} = \frac{1}{f}$$



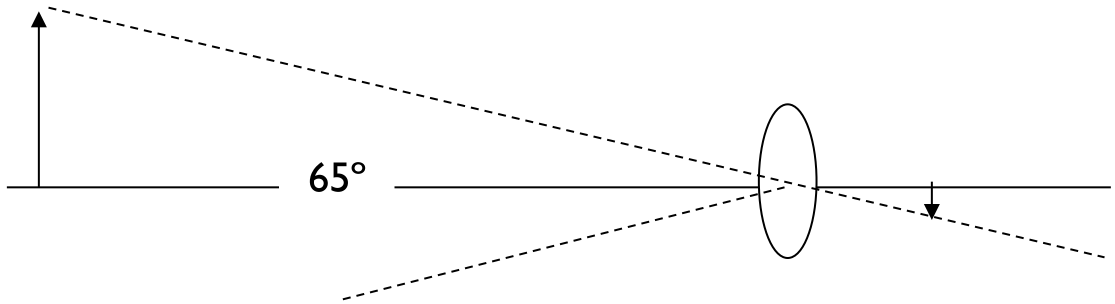
(A) 50mm

(B) 85mm

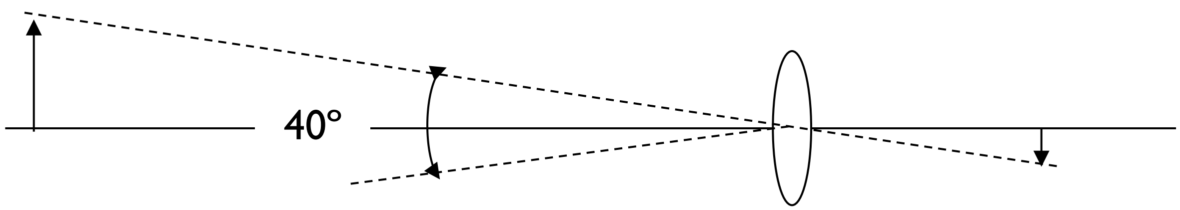
Common lens focal lengths

Lens with the longer focal length f has an image at a longer x_i and so the magnification is larger for longer f

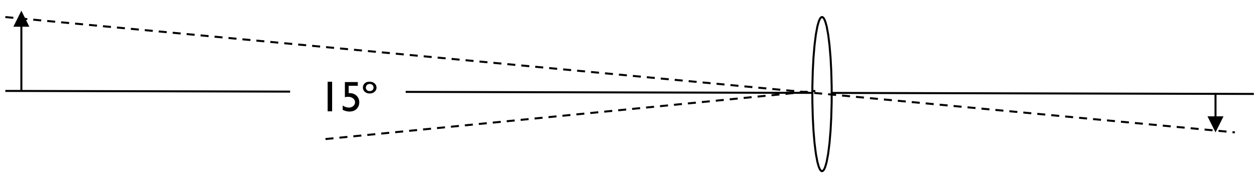
28 mm f. l.
wide angle



50 mm f. l.
normal



135 mm f. l.
telephoto



Wide-angle lens

Wide-angle ("fish-eye") lens

- short focal length
- smaller image
- larger field of view
- opposite function of zoom lens

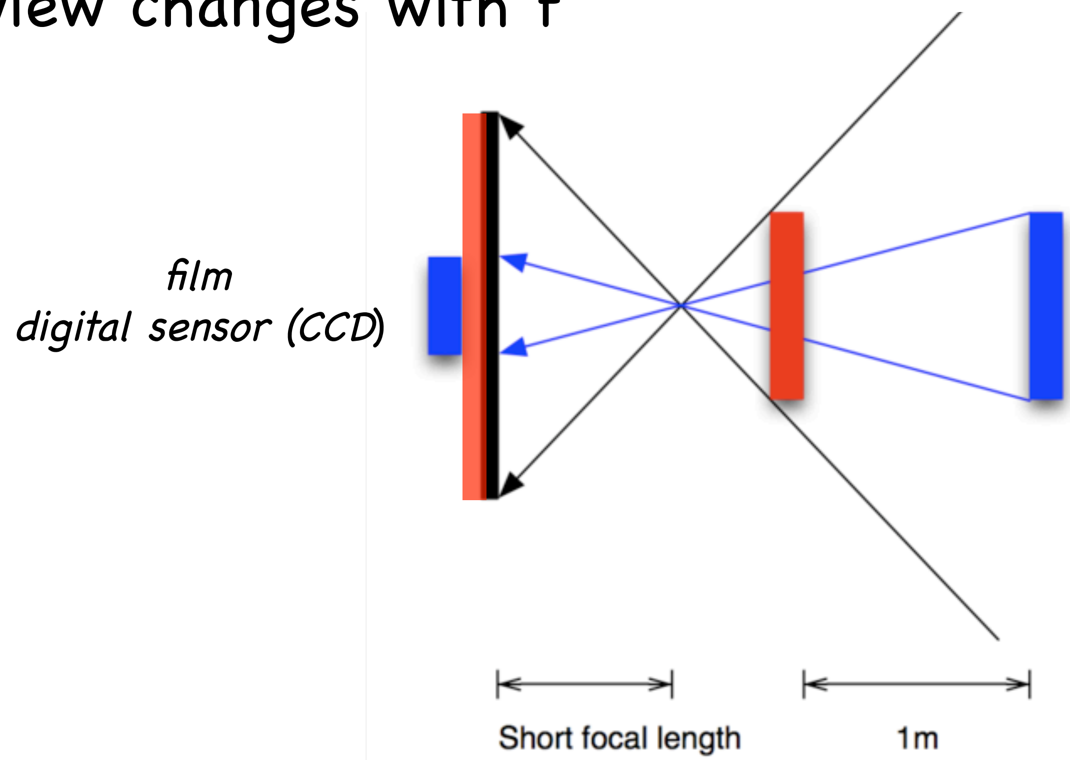
Wide-angle lens

Wide-angle ("fish-eye") lens

- short focal length
- smaller image
- larger field of view
- opposite function of zoom lens

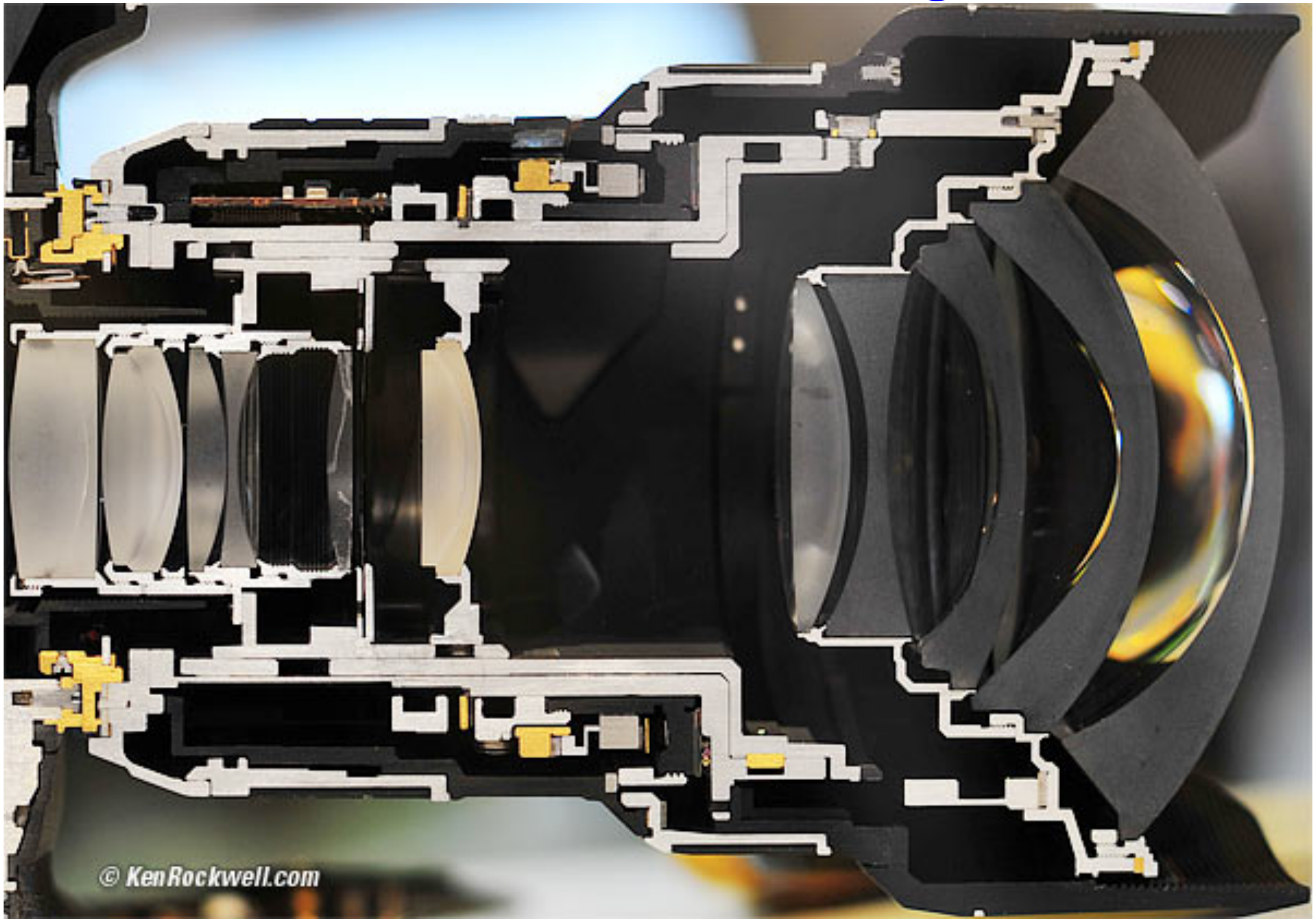
Images at three focal length:

- keeping the camera's distance (size) from the pink bottle fixed (fills the frame)
- blue bottle size changes
- field of view changes with f



Wide-angle lens

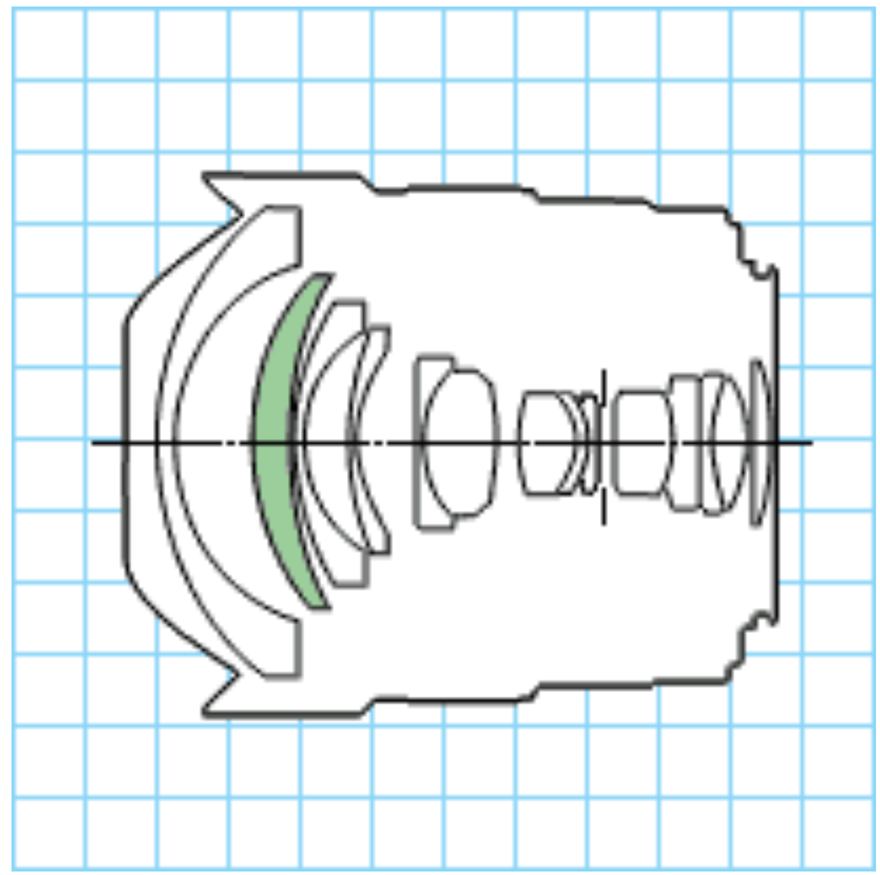
Nikon 14-24mm wide-angle lens



This lens has optics both to focus and to change the focal length

Wide-angle lens

Canon EF14mm f/2.8L



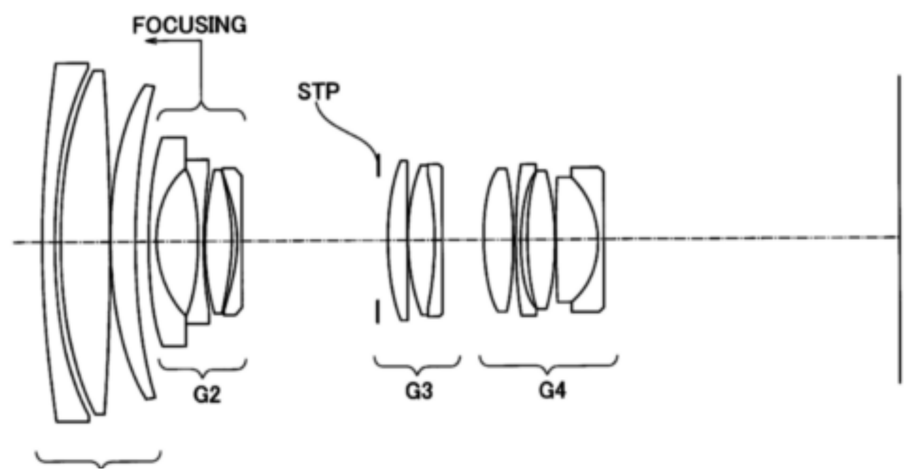
This is a fixed focal length (14mm) ultra wide-angle lens. This is more complex than the telephoto because it has to have focusing optics, because you might want to take a wide-angle photo of things at different distances rather than just at "infinity".

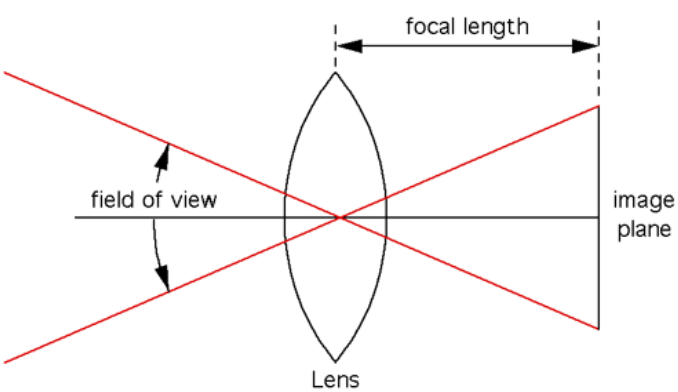
Telephoto zoom lens

Telephoto lens (opposite of wide-angle) has long focal length:
25mm f.l. -> 250mm f.l. -> 10 x zoom -> distant object, smaller scene (used by paparazzi)

Use two fixed groups and two moving groups of lenses to hold focus constant while zooming; *change f and keep image in-focus*

- longer focal length
- larger image
- very small field of view
- opposite function of wide-angle lens

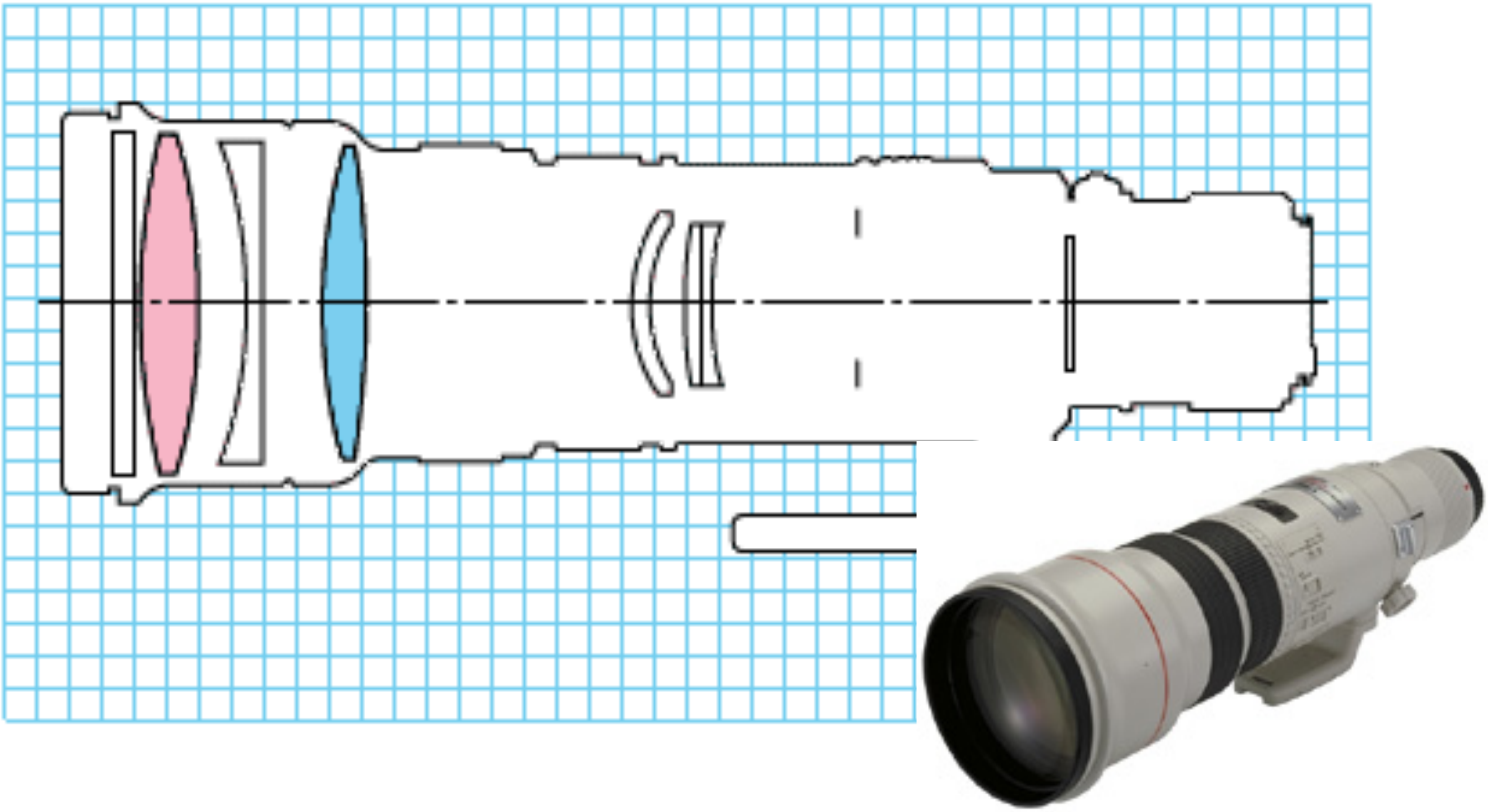




Telephoto lens

Telephoto lens (opposite of wide-angle) has long focal length:
-> distant object, smaller scene

Canon EF500mm f/4.5L



This is a fixed focal length (500mm) telephoto lens. Notice how much simpler it is without an adjustable zoom! Focusing is easier because with a telephoto you can assume that the objects are at infinity.

Lens comparison

wide angle

15 mm lens

standard

35mm lens

standard

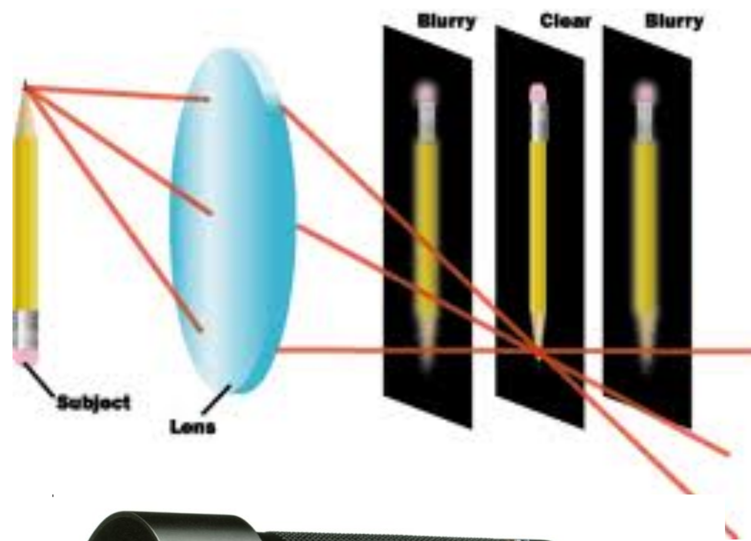
50mm lens

telephoto zoom

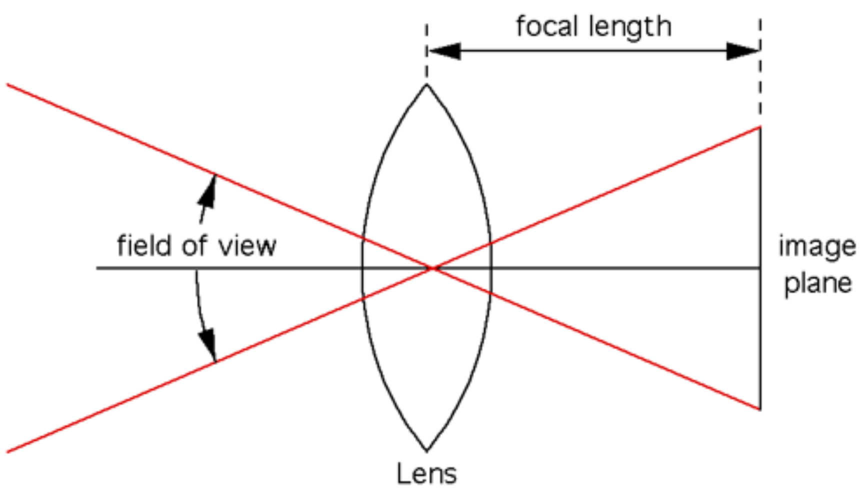
135mm lens

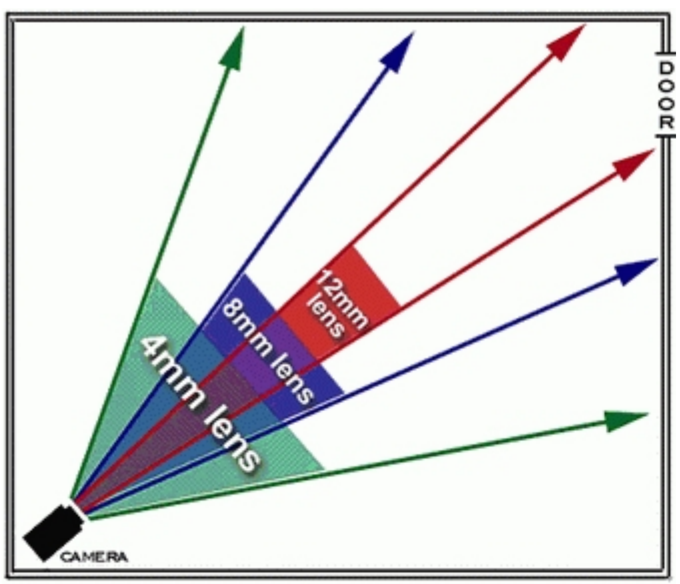
Photography principles

1. Camera focuses by moving the lens closer/further from the film



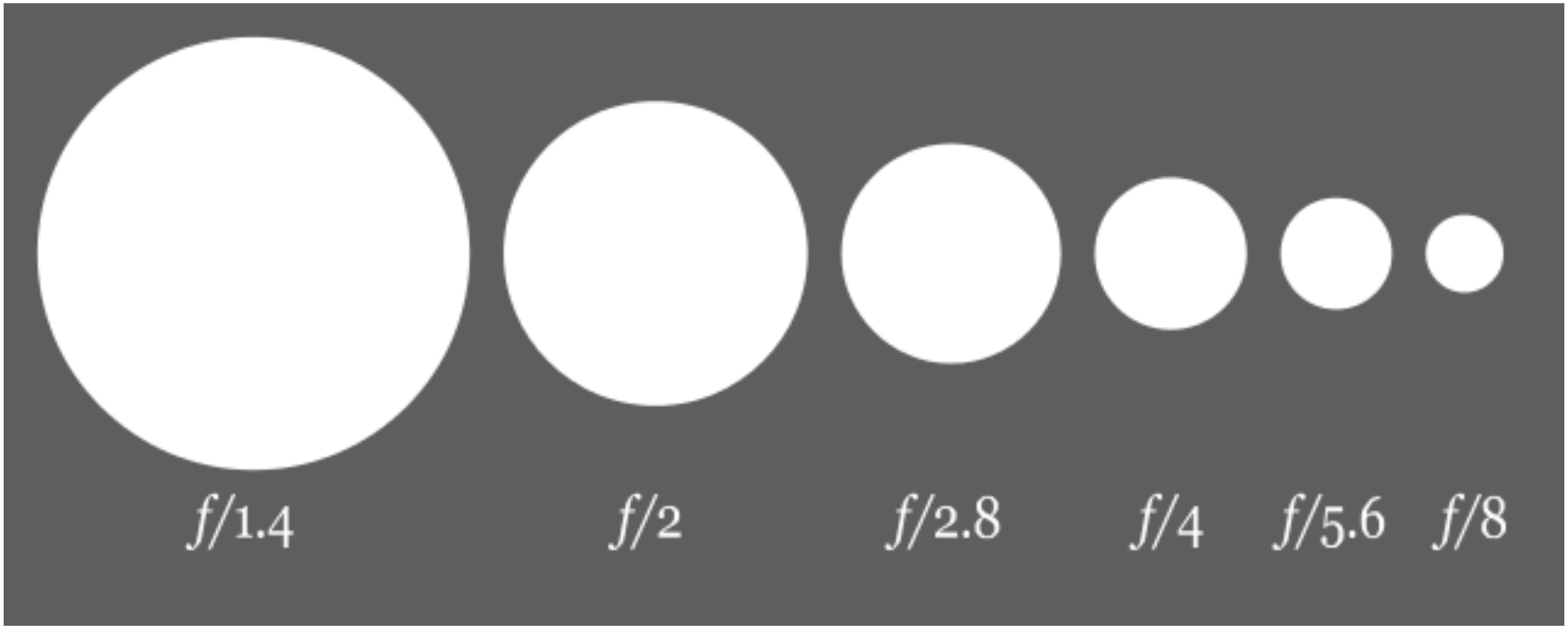
2. Longer focal length -> larger image magnification





F-number

F-number = focal length/diameter of lens = f/D
(focal ratio, f-ratio, f-stop, inverse of NA)



f-number = 1.4   2   2.8   4   5.6   8

multiply f-number by √2 -> divide D by √2 -> 1/2 reduction in light

"fast" lens   *"stopping down" the lens*   ***"slow"*** lens

f-number notation: f/# ⟷ f-# ⟷ f#

e.g., f-2 pronounced "eff two" (strictly speaking f/# gives aperture diameter)

small f-number -> bright image -> can afford fast shutter speed

ex: (f = 200mm)/(25mm diameter) = f-number 8 -> f/8

F-number

F-number = focal length/diameter of lens = f/D

(focal ratio, f-ratio, f-stop, inverse of NA)

Big diameter lens = low f-number, e.g., f-number 1.4

Heavy, cost more, works in low light and indoors

Small diameter lens = big f-number, e.g., f-number 3.5

Weigh less, less expensive, used for outdoors

small f-number -> bright image -> can afford fast shutter speed

ex: (f = 200mm)/(25mm diameter) = f-number 8 -> f/8

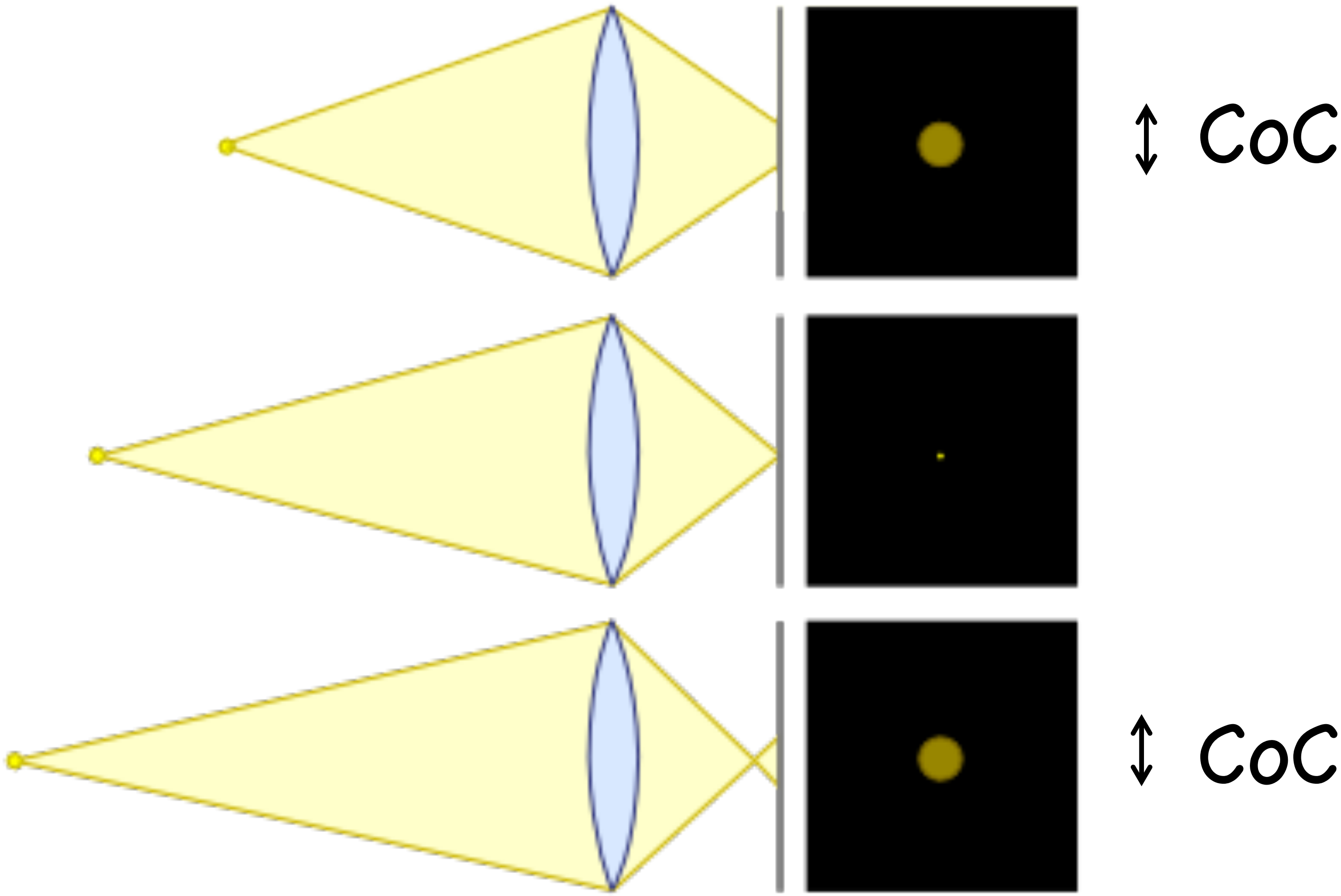
F-number

F-number = f/D (focal ratio, f-ratio, f-stop, inverse of NA)
change by changing the diaphragm size D

35 mm lens set to *f/11* (white dot on f-stop scale).
This lens has an aperture range of *f*/2.0 to *f*/22

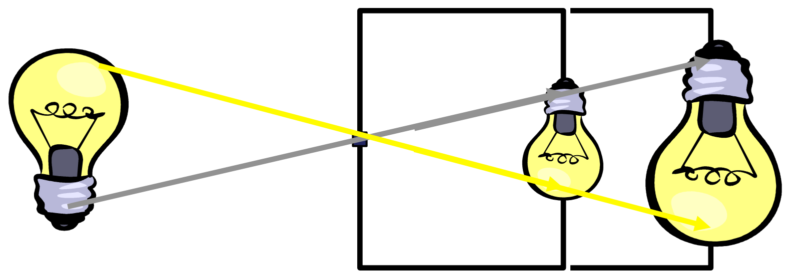
Circle of confusion

Circle of confusion (CoC) – optical spot caused by a cone of light rays not coming into perfect focus when imaging a point source

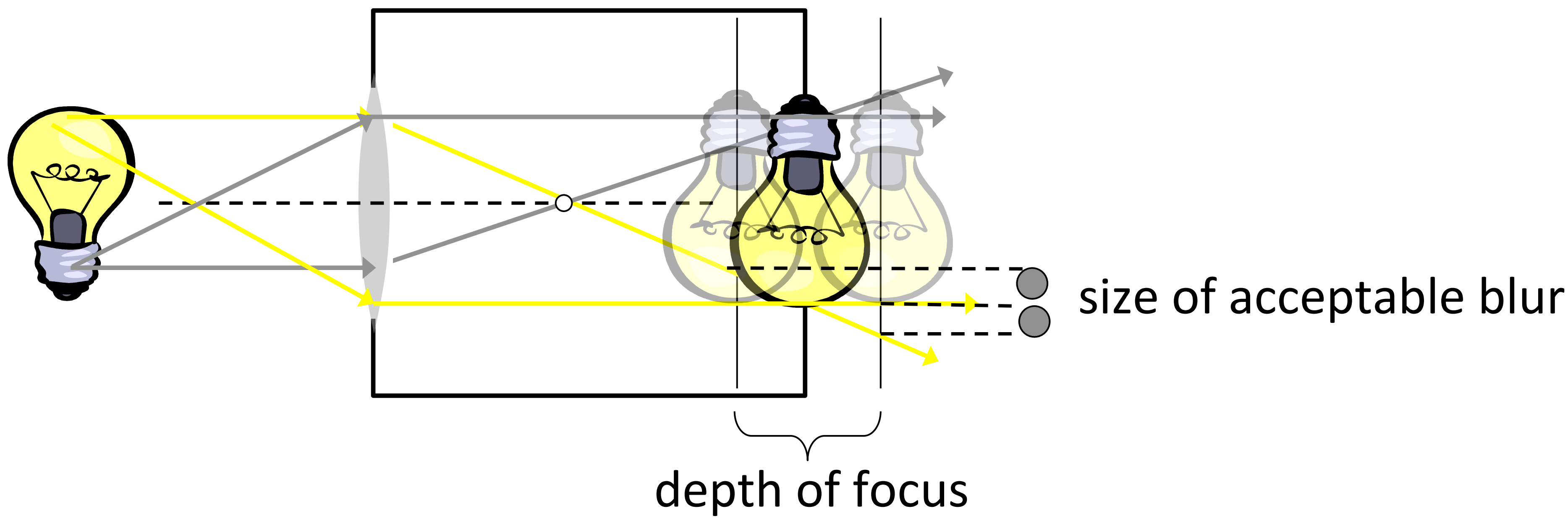


Depth of focus

Depth of focus (DOF) is how far *images* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium



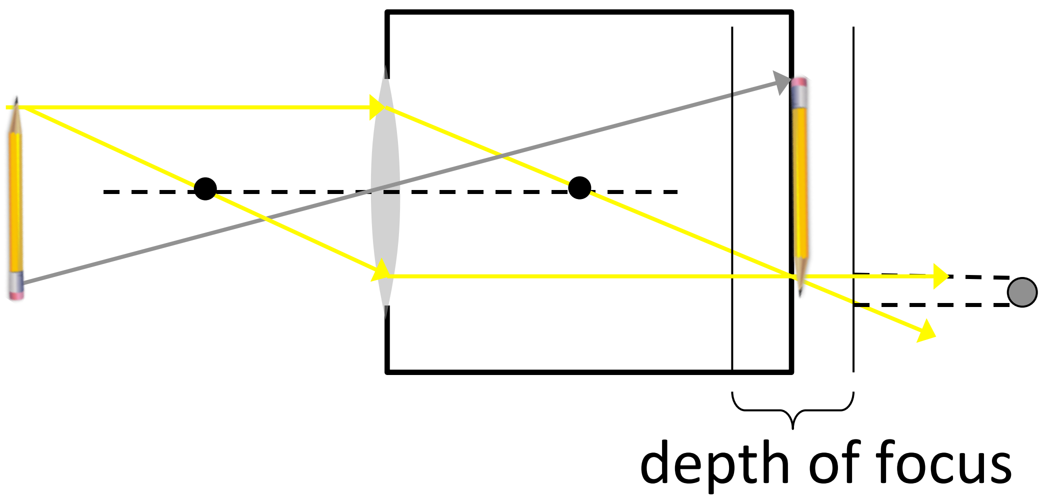
In a *pinhole camera*, the object is in focus at any plane behind the pinhole.
-> infinite depth of focus

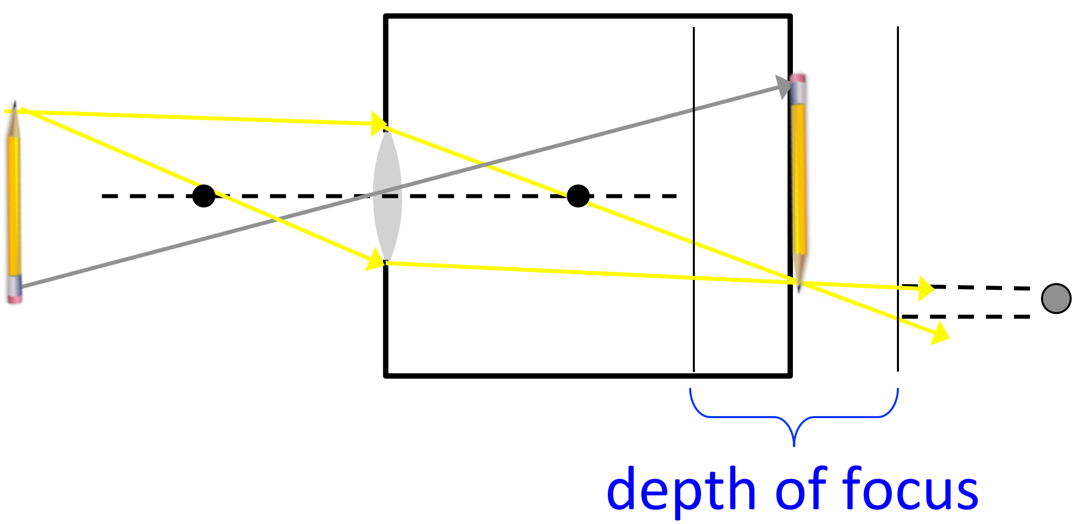


Depth of focus

Depth of focus (DOF) is how far *images* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium

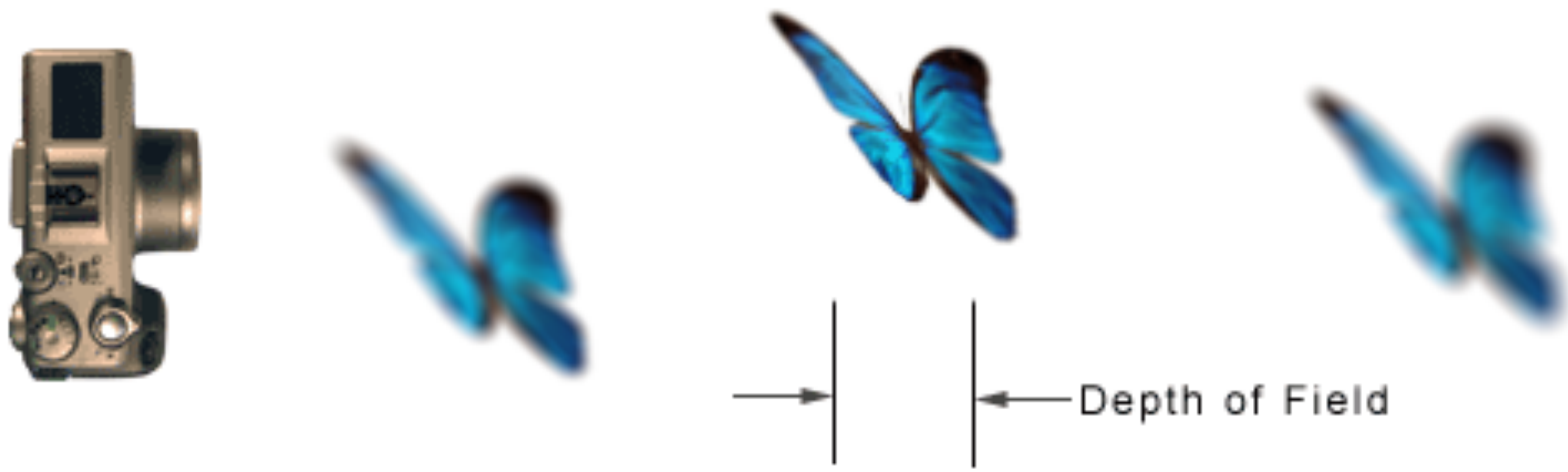
If the diameter D of the lens is reduced, without changing the focal length, f, the depth of focus that generates the same size blur (CoC) becomes larger.





Depth of field

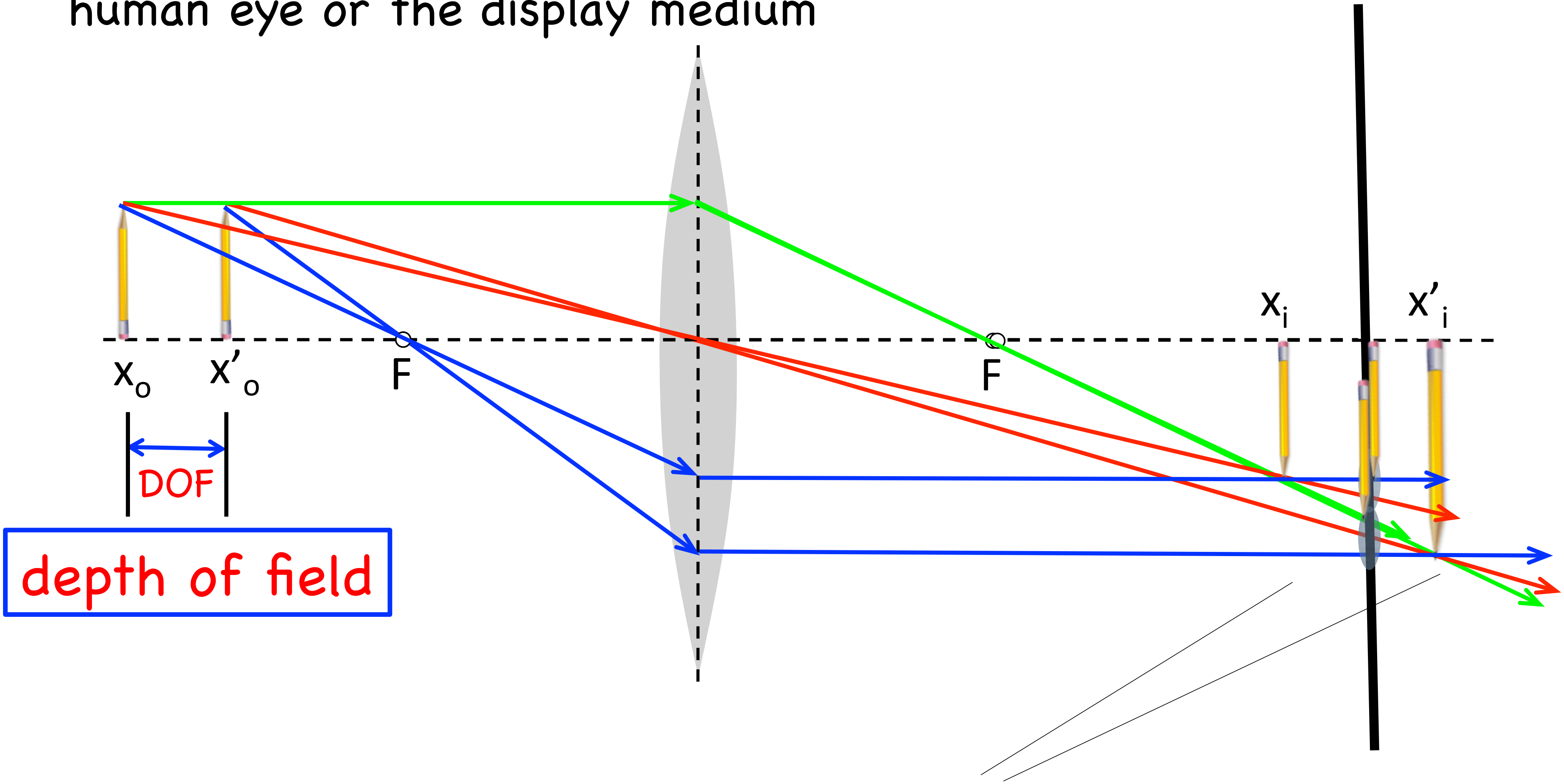
Depth of field (DOF) is how far *objects* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium



The area within the depth of field appears sharp, while the areas in front of and beyond the depth of field appears blurry

Depth of field

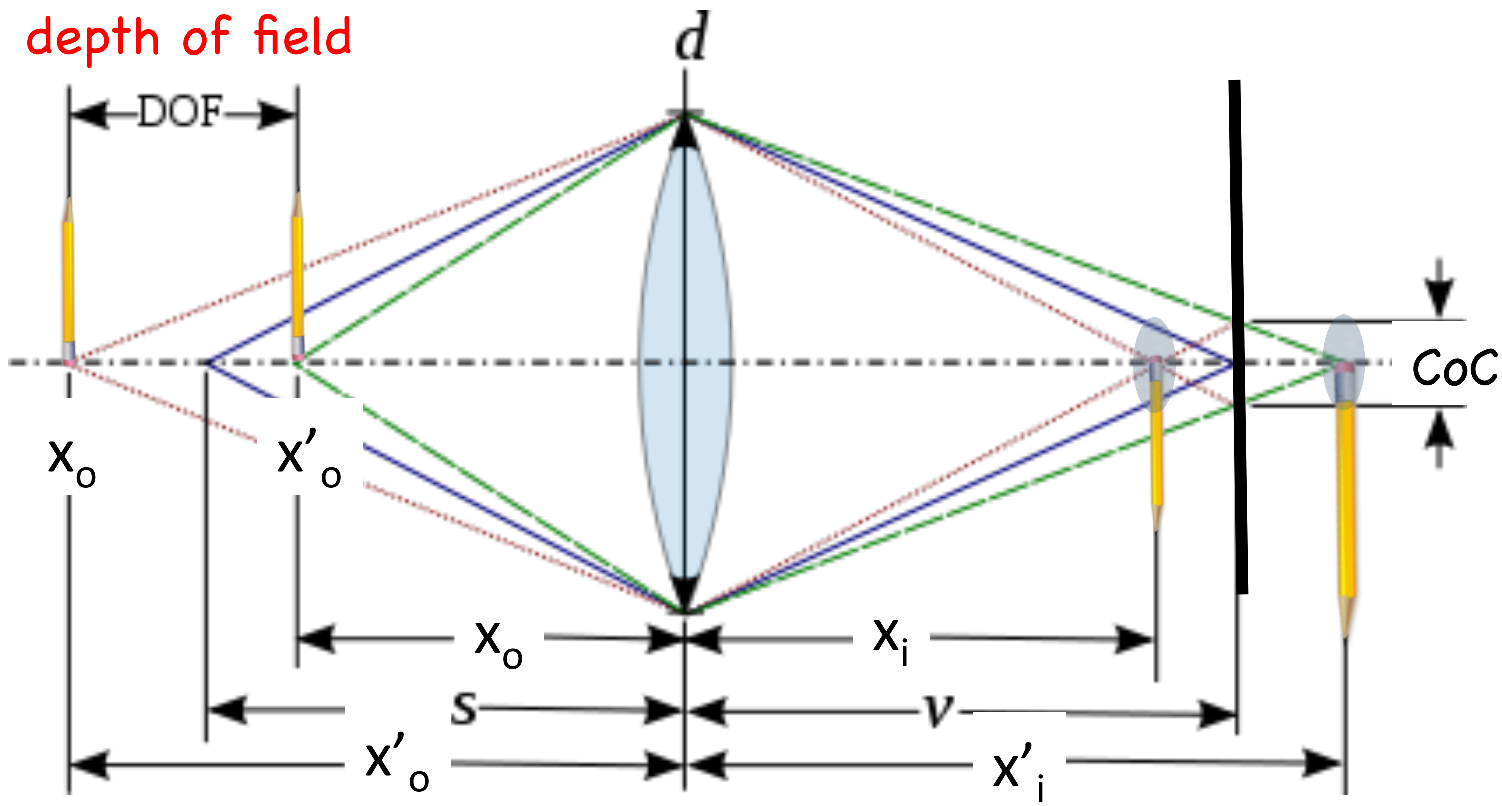
Depth of field (DOF) is how far *objects* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium



two pencils are not perfectly in focus on the screen but are acceptably in focus within eye resolution

Depth of field

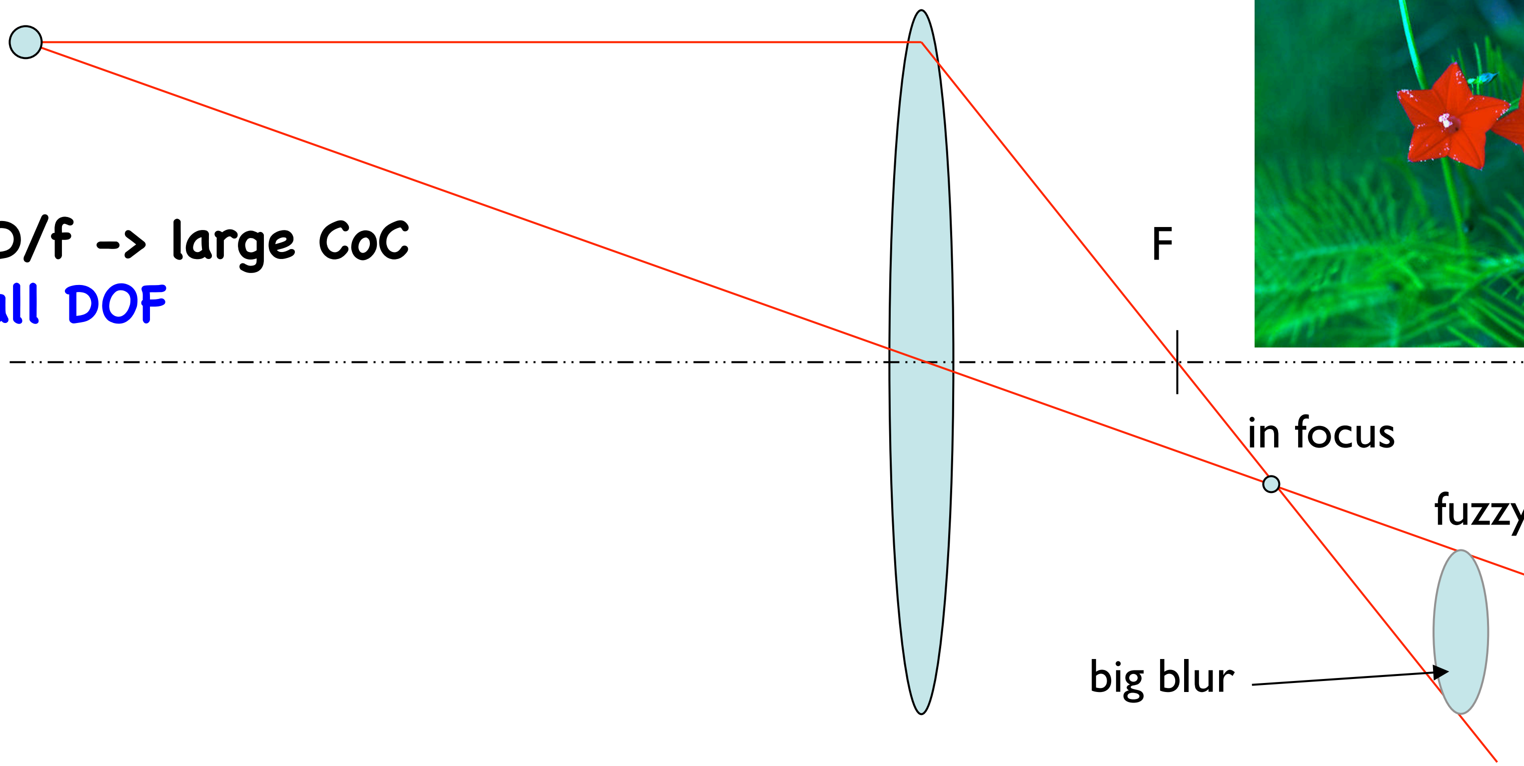
Depth of field (DOF) is how far *objects* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium



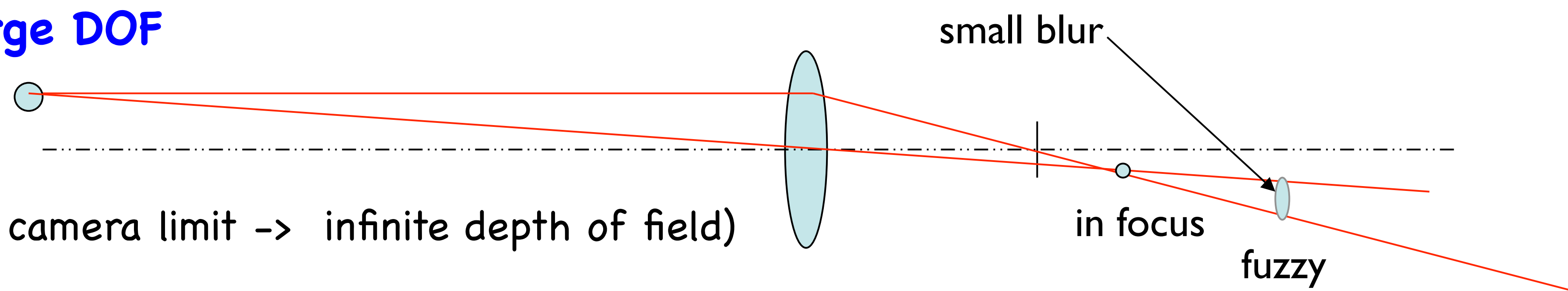
Depth of field

Depth of field (DOF) is how far *objects* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium

large D/f -> large CoC
-> small DOF



small D/f -> small CoC
-> large DOF

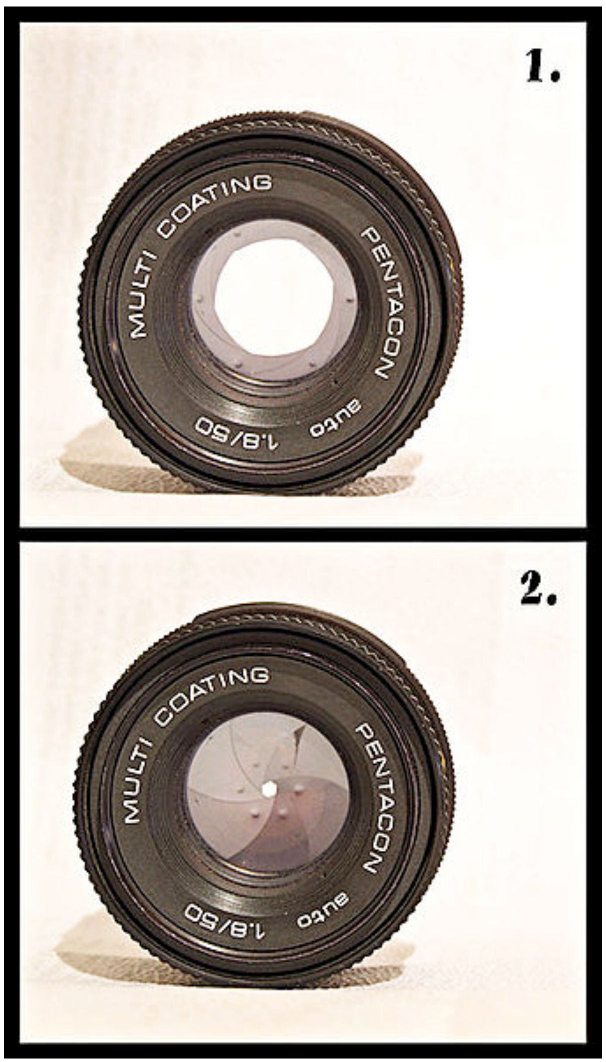


pinhole camera limit -> infinite depth of field)

Depth of field

Depth of field (DOF) is how far *objects* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium

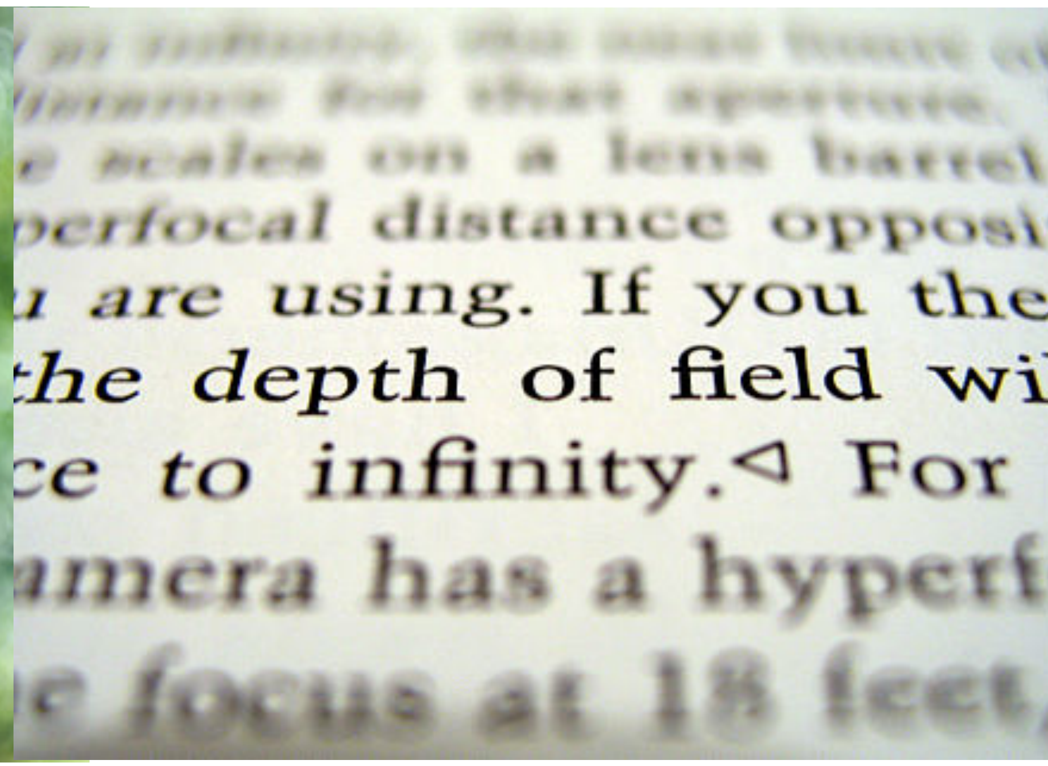
smaller aperture -> larger DOF



Depth of field

Depth of field (DOF) is how far *objects* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium

foreground (face) in focus and background (trees) out of focus



Depth of field

Depth of field (DOF) is how far *objects* can be apart and still be acceptably in near focus, i.e., with CoC less than resolution of a human eye or the display medium

foreground in focus and background out of focus

f-number = 32 (f/32)
small D, large f

f-number = 5.6 (f/5.6)
large D, small f

Adjust f-number

f-number = f/D (focal ratio, f-ratio, f-stop, inverse of NA)
change by changing the diaphragm size D

f/#:

1 big opening, D

1.4

2

2.8

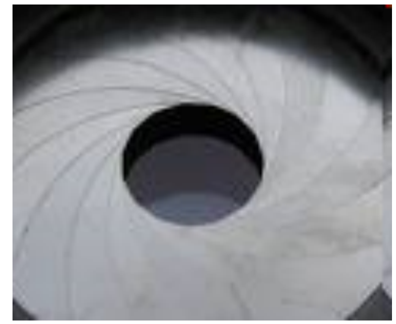
4

5.6 factors of $\sqrt{2}$ apart

8

11

16 small opening, D



Diaphragm has variable opening

Amount of light scales with area

Area scales with $(\text{diameter})^2$

Adjust f-number

f-number = f/D (focal ratio, f-ratio, f-stop, inverse of NA)
change by changing the diaphragm size D

f/#:

1 big opening, D

1.4

2

2.8

4

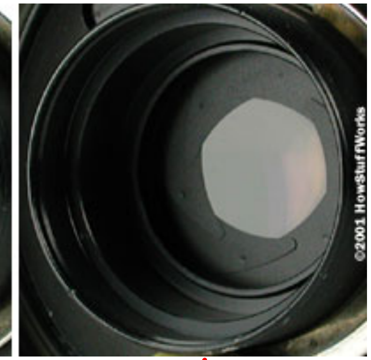
5.6 factors of $\sqrt{2}$ apart

8

11

16 small opening, D

f/22



f/2

Diaphragm has variable opening

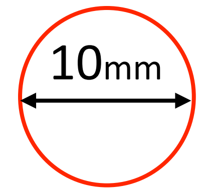
Amount of light scales with area

Area scales with (diameter)^2

Adjust f-number

f-number = f/D (focal ratio, f-ratio, f-stop, inverse of NA)
change by changing the diaphragm size D

- Calculate the f-number (f-stop) of a 40 mm focal length lens at a full aperture, diameter d=10 mm:



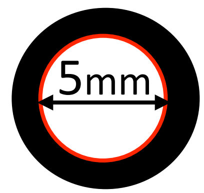
40 mm focal length lens at *full* aperture of diameter *d = 10 mm*

f-number = f/d

= 40mm/10mm

-> f-number = f/4

- What if we stop down the aperture to 5 mm, keeping the focal length, f the same?



40 mm focal length lens with aperture of diameter *d = 5 mm*

f-number = f/d

= 40mm/5mm

-> f-number = f/8

Adjust f-number

f-number = f/D (focal ratio, f-ratio, f-stop, inverse of NA)
change by changing the diaphragm size D

- Why might we want to adjust the aperture of a lens?
- There are cases when it is just too bright, and you have to reduce the light coming into the camera
- There are also artistic reasons for adjusting the f-number.

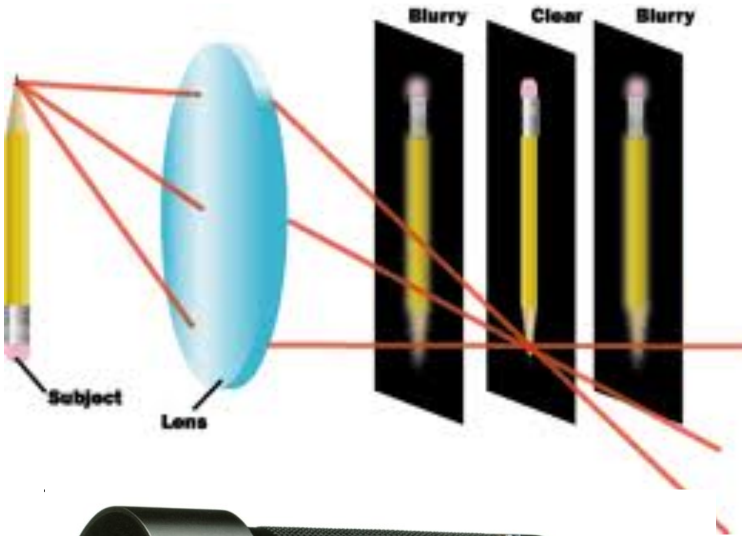
Adjust f-number

f-number = f/D (focal ratio, f-ratio, f-stop, inverse of NA)
change by changing the diaphragm size D

depth of field comparison

Photography principles

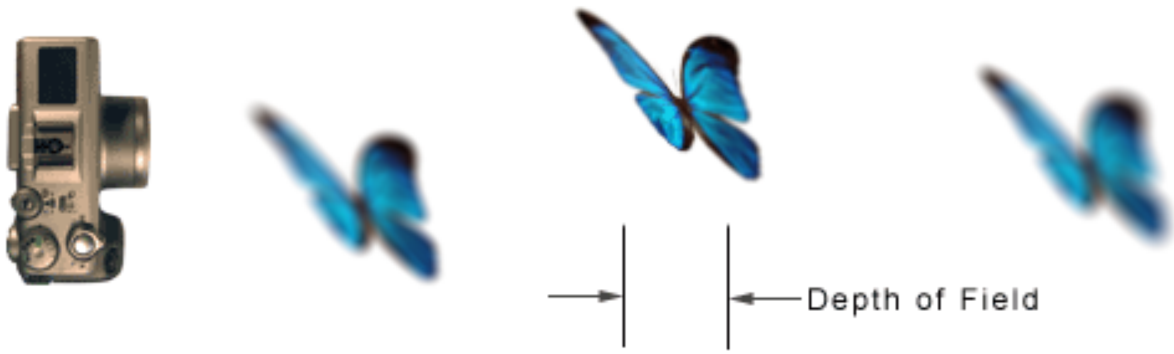
1. Camera focuses by moving the lens closer/further from the film



2. Longer focal length -> larger image magnification

3. Bigger lens, aperture (small f-number)

-> narrower depth of field, DOF

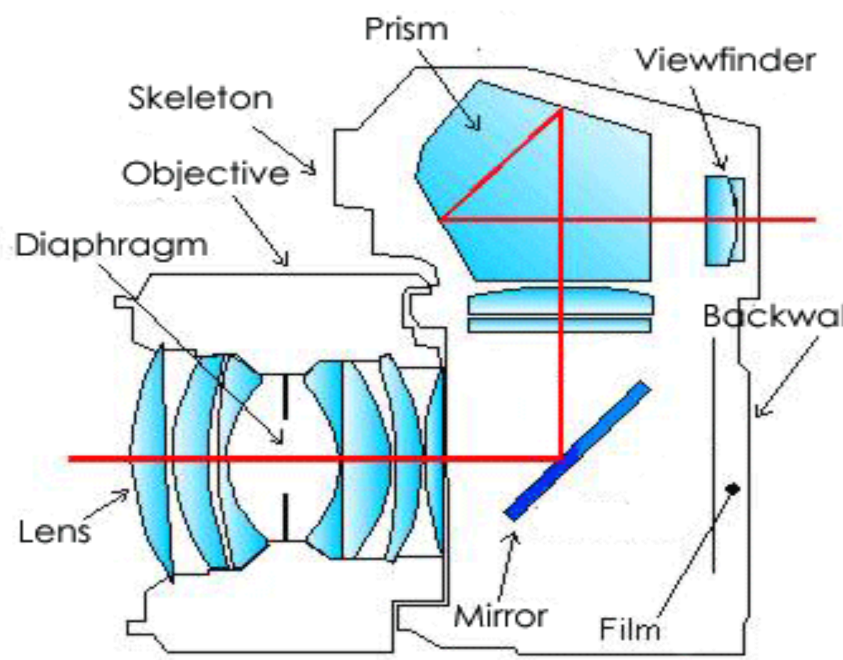


Two common camera types

Point & shoot
one lens, viewfinder,
liquid crystal display (LCD)

Single lens reflex (SLR)
interchangeable lenses

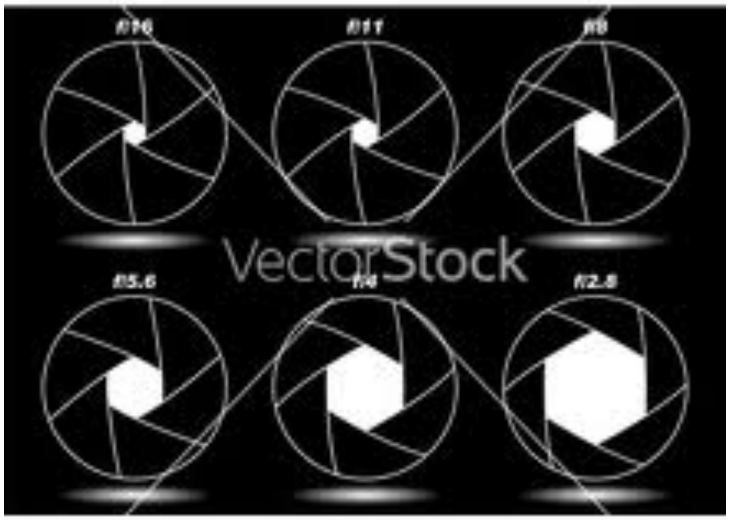
LCD is on the back

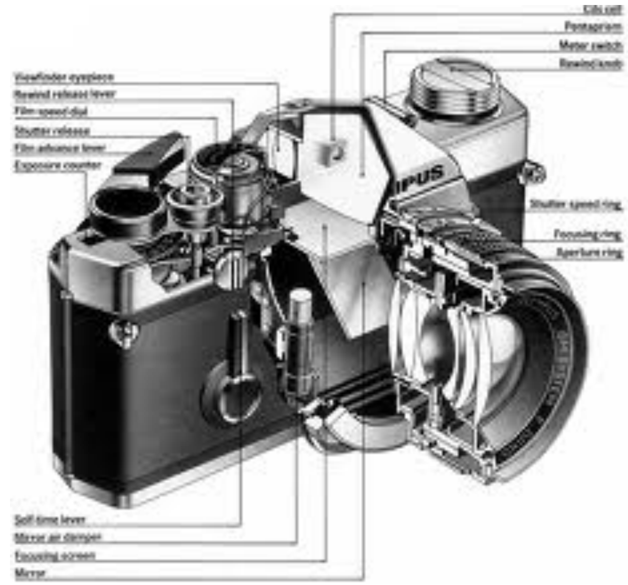


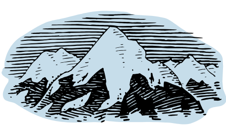
<u>Shutter speed</u>

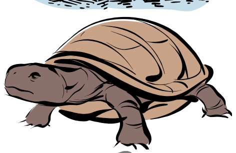
Shutter – opens the camera lens for a controlled amount of time, to let light in, exposing the film or CCD detector

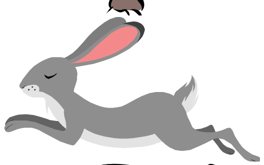
The longer the shutter open (1 second vs 1/2 second) the more light energy hits the film -> *shutter speed -> exposure time*

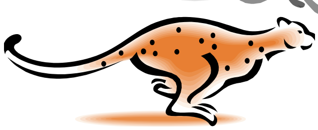












<u>Common shutter speeds</u>

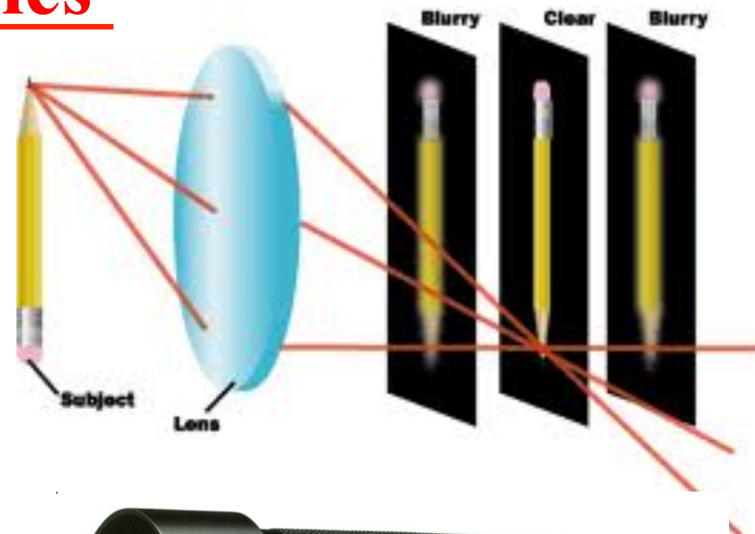
1/15 sec
1/30 sec
1/60 sec
1/125 sec
1/250 sec
1/500 sec

each change lets in half the light

<u>factor of 1/2 in light energy entering the camera</u>

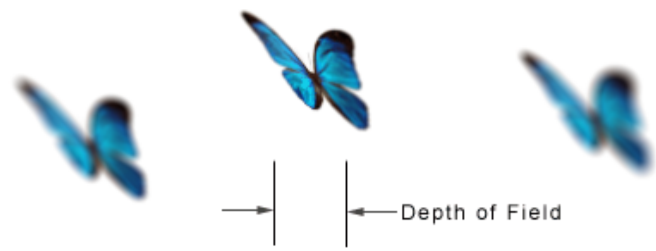
Photography principles

1. Camera focuses by moving the lens closer/further from the film



2. Longer focal length -> larger image magnification

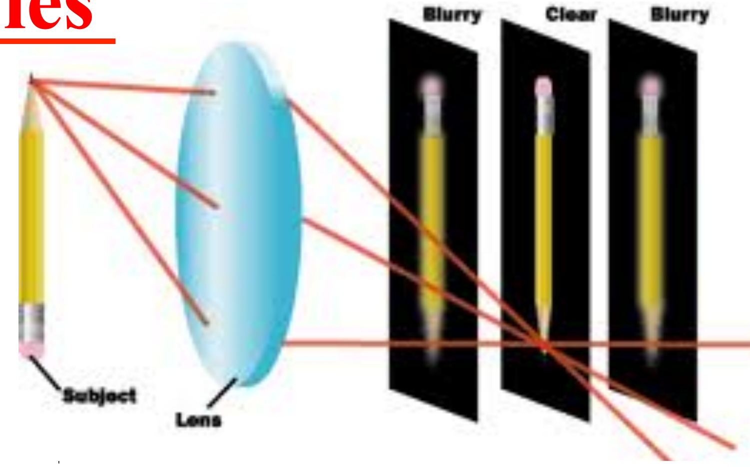
3. Bigger lens (small f-number) -> narrower depth of field, DOF



4. Faster shutter speed -> less light power

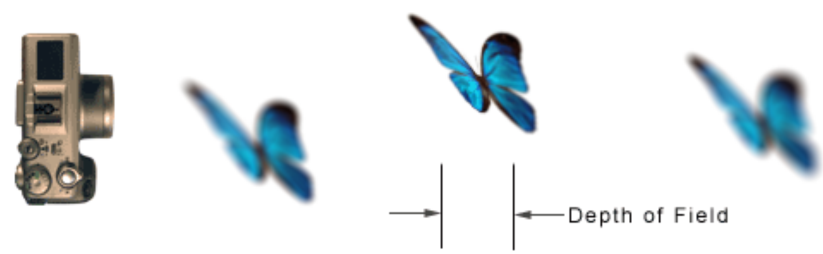
Photography principles

1. Camera focuses by moving the lens closer/further from the film



2. Longer focal length -> larger image magnification

3. Bigger lens (small f-number) -> narrower depth of field, DOF



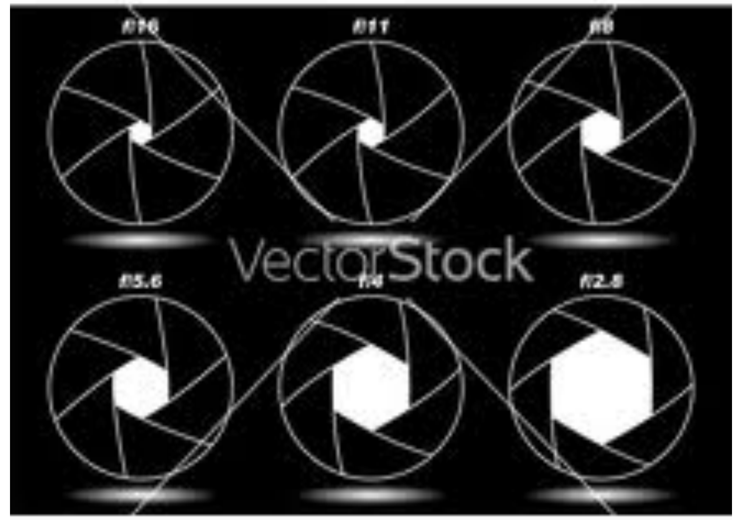
4. Faster shutter speed -> less light power
5. Small f-number -> bright image change with lens and aperture

Film exposure

Light input can be increased in two ways:

- f-number decrease <-> aperture increase

...but decreases DOF



- slow shutter speed (leave shutter open longer)

...but lets subject move during exposure

-> blurry streaks

Film exposure

different shutter speeds

sparklers motion
exposure time 4 seconds

visual sense of movement
exposure time 4 seconds

Film exposure

different shutter speeds:

a pinwheel at three exposure times

street at night
exposure time 30 seconds

Film exposure

equivalent exposure: same amount of light

1/4 sec
& long DOF

1/250 sec
& short DOF

Film exposure: speed & f-stop combinations

these f-numbers - shutter speed combinations give the same light exposure:

f-number		shutter speed	
1.4	Shallow DOP: *one plane in focus*	1/250 sec	Fast action: *stops motion for sports events*
2		1/125 sec	
2.8		1/60 sec	
4		1/30 sec	
5.6		1/15 sec	
8		1/8 sec	
11	Long DOP: *all in focus*	1/4 sec	Slow action: *streeks in motion*