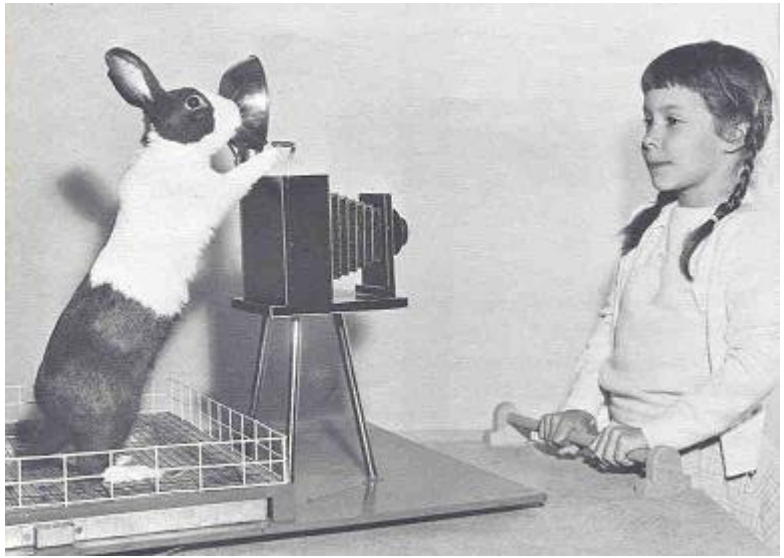
Discussion 09

Cameras

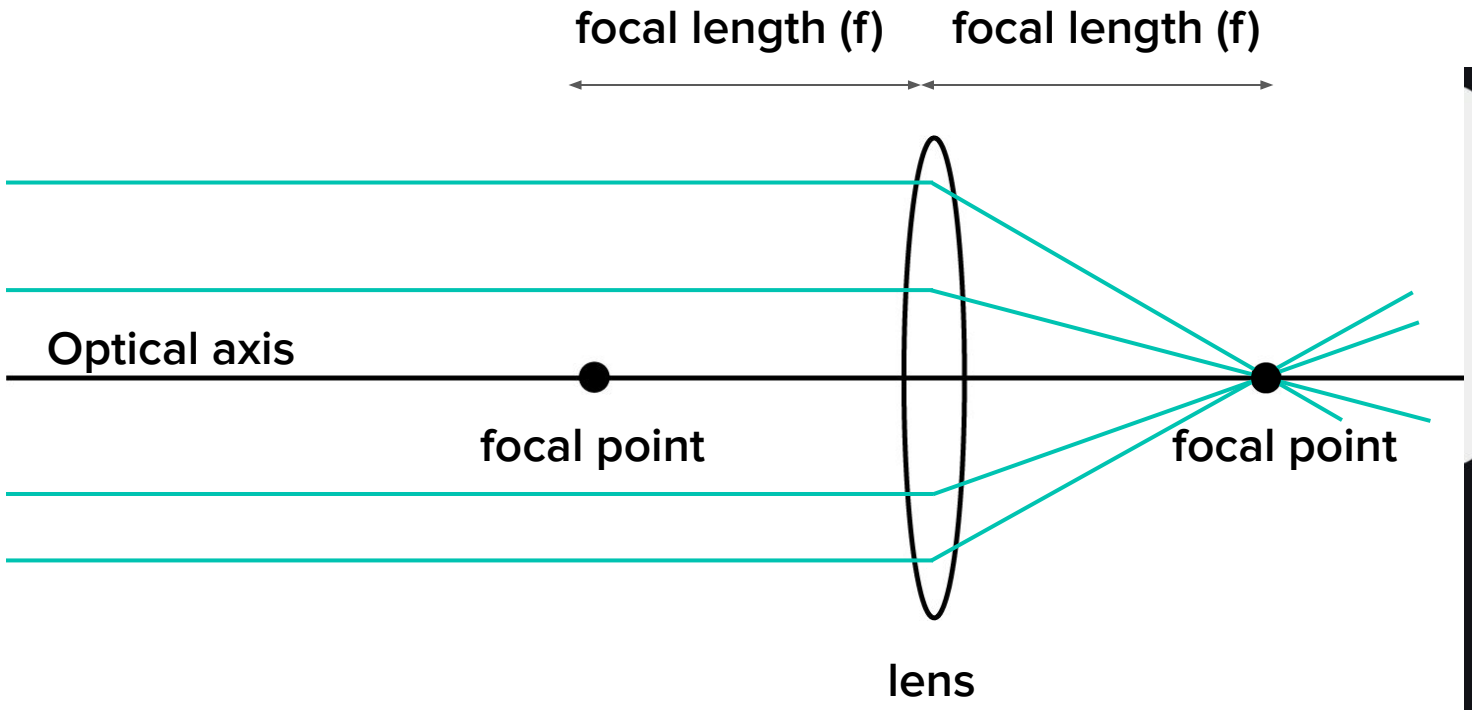


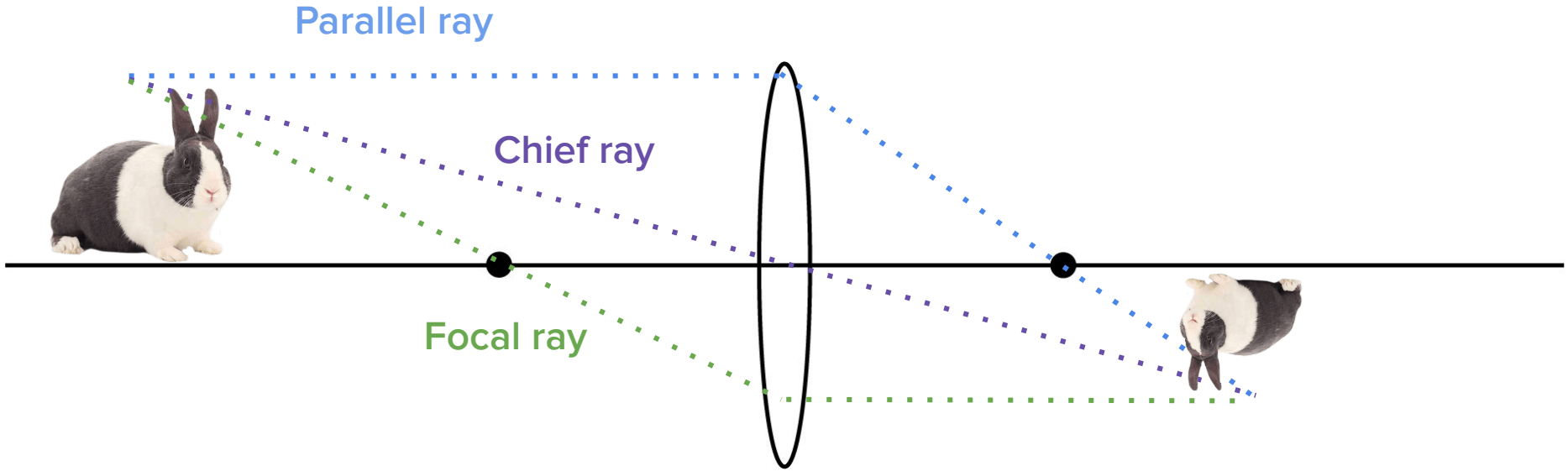
Computer Graphics and Imaging
UC Berkeley CS 184/284A

Week 9 Announcements

- Final project proposal was due 07/27!
- Homework 3 due 08/01
- Final project milestone due 08/04
- Exam 2 is on 08/07

Thin Lens


focal length (f)
focal length (f)
Optical axis
focal point
focal point
lens


Parallel ray
Chief ray
Focal ray

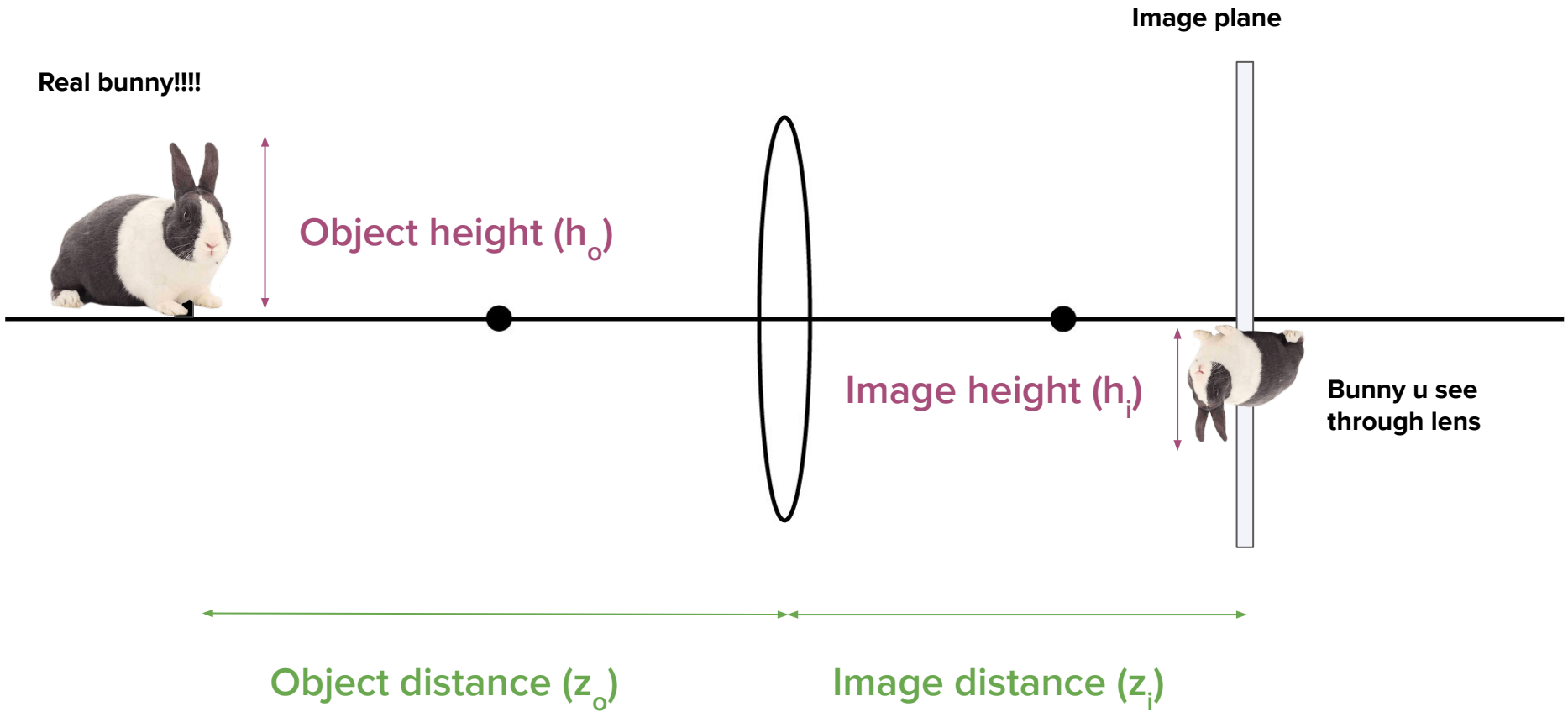


Image plane
Real bunny!!!!
Object height (h_o)
Image height (h_i)
Bunny u see through lens
Object distance (z_o)
Image distance (z_i)

If the image plane is not at z_i,
bunny on image plane appears blurry!
(Circle of confusion)

Image plane

Real bunny!!!!

Object height (h_o)

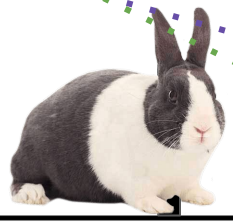
Object distance (z_o)

Image distance (z_i)

If the image plane is not at z_i,
bunny on image plane appears blurry!
(Circle of confusion)

Image plane

Real bunny!!!!



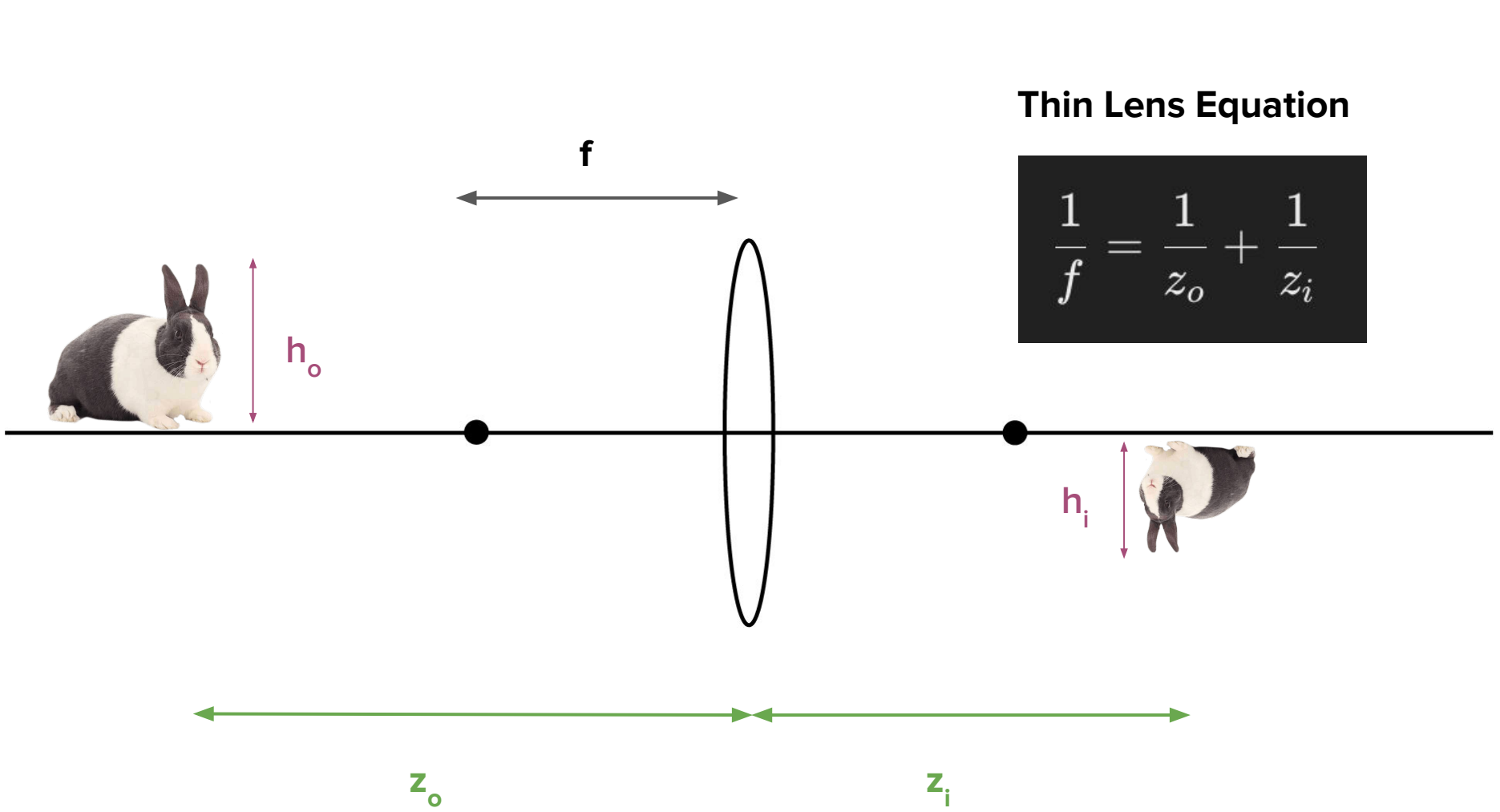
Object height (h_o)

Object distance (z_o)

Image distance (z_i)

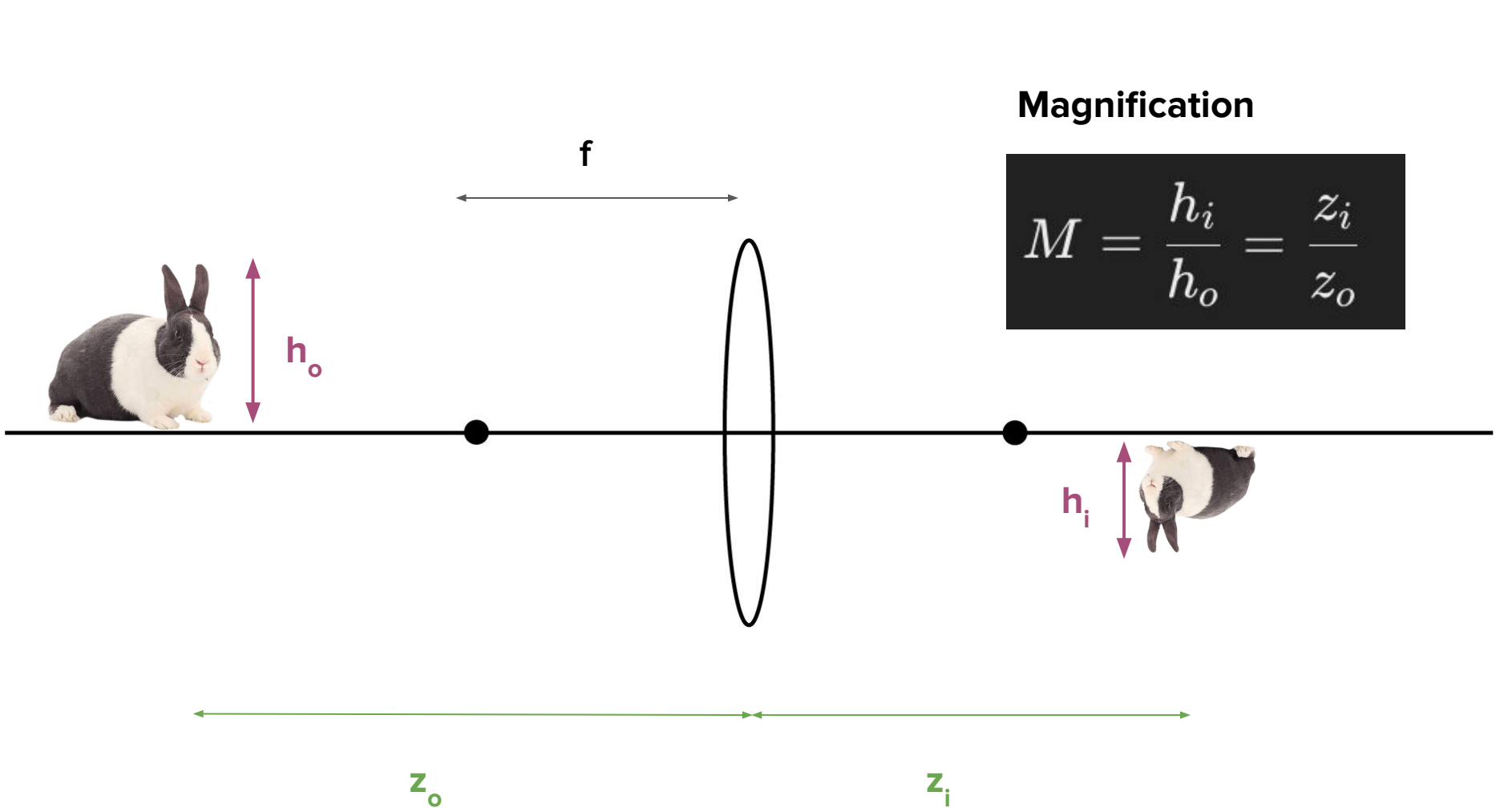
Thin Lens Equation

$$\frac{1}{f} = \frac{1}{z_o} + \frac{1}{z_i}$$



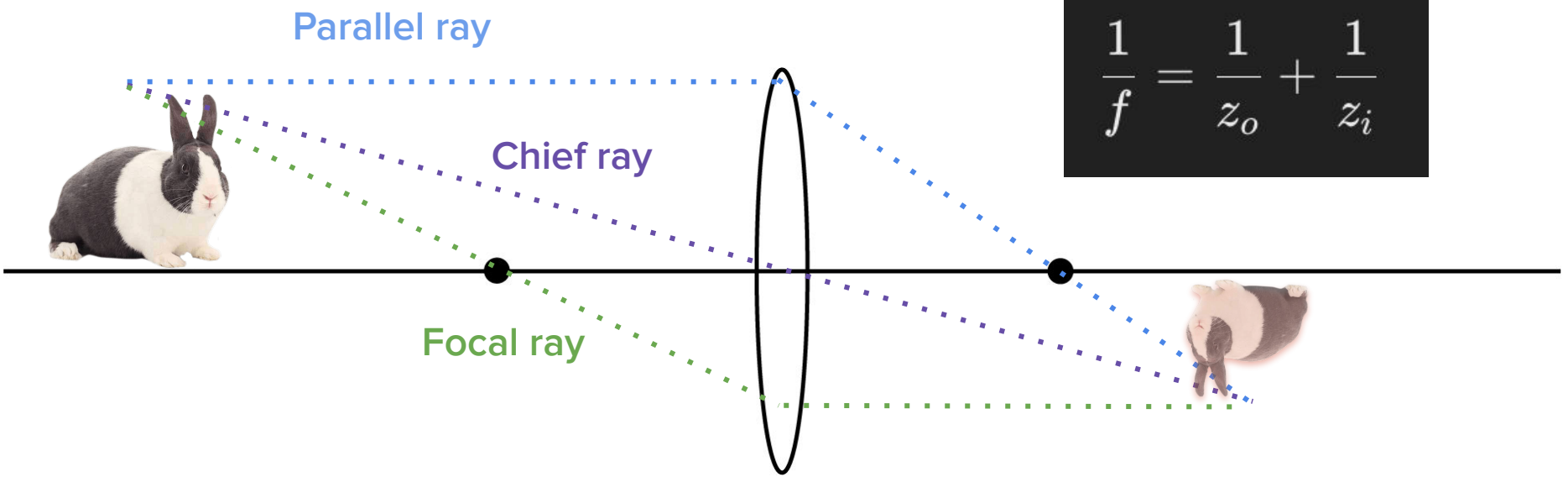
Magnification

$$M = \frac{h_i}{h_o} = \frac{z_i}{z_o}$$



Thin Lens Equation

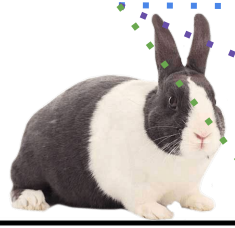
$$\frac{1}{f} = \frac{1}{z_o} + \frac{1}{z_i}$$



$$M = \frac{h_i}{h_o} = \frac{z_i}{z_o} \leq 1$$

Thin Lens Equation

$$\frac{1}{f} = \frac{1}{z_o} + \frac{1}{z_i}$$

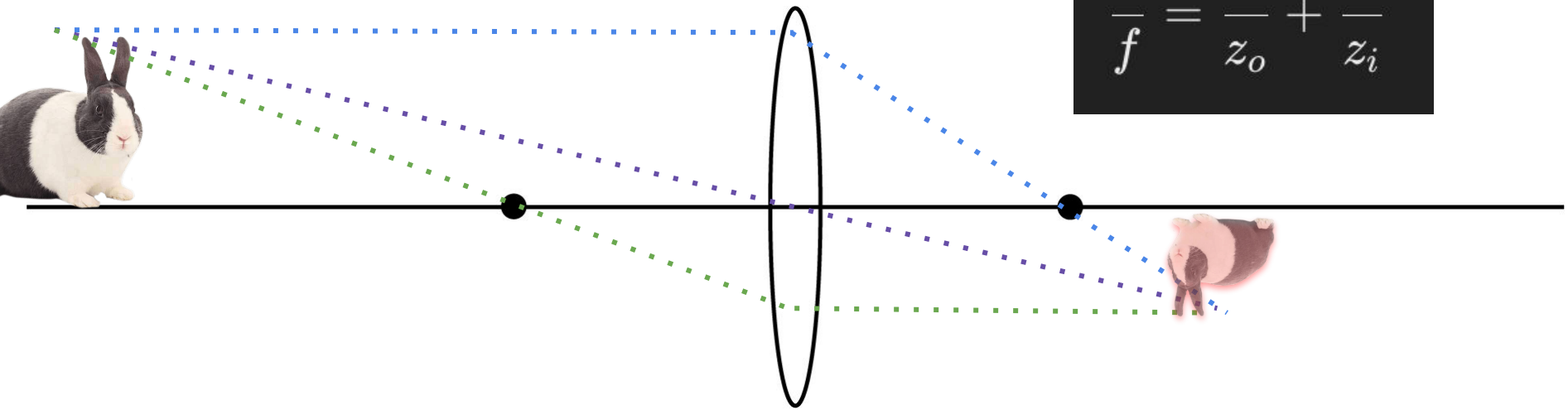


$$M = \frac{h_i}{h_o} = \frac{z_i}{z_o}$$

≥ 1

Thin Lens Equation

$$\frac{1}{f} = \frac{1}{z_o} + \frac{1}{z_i}$$



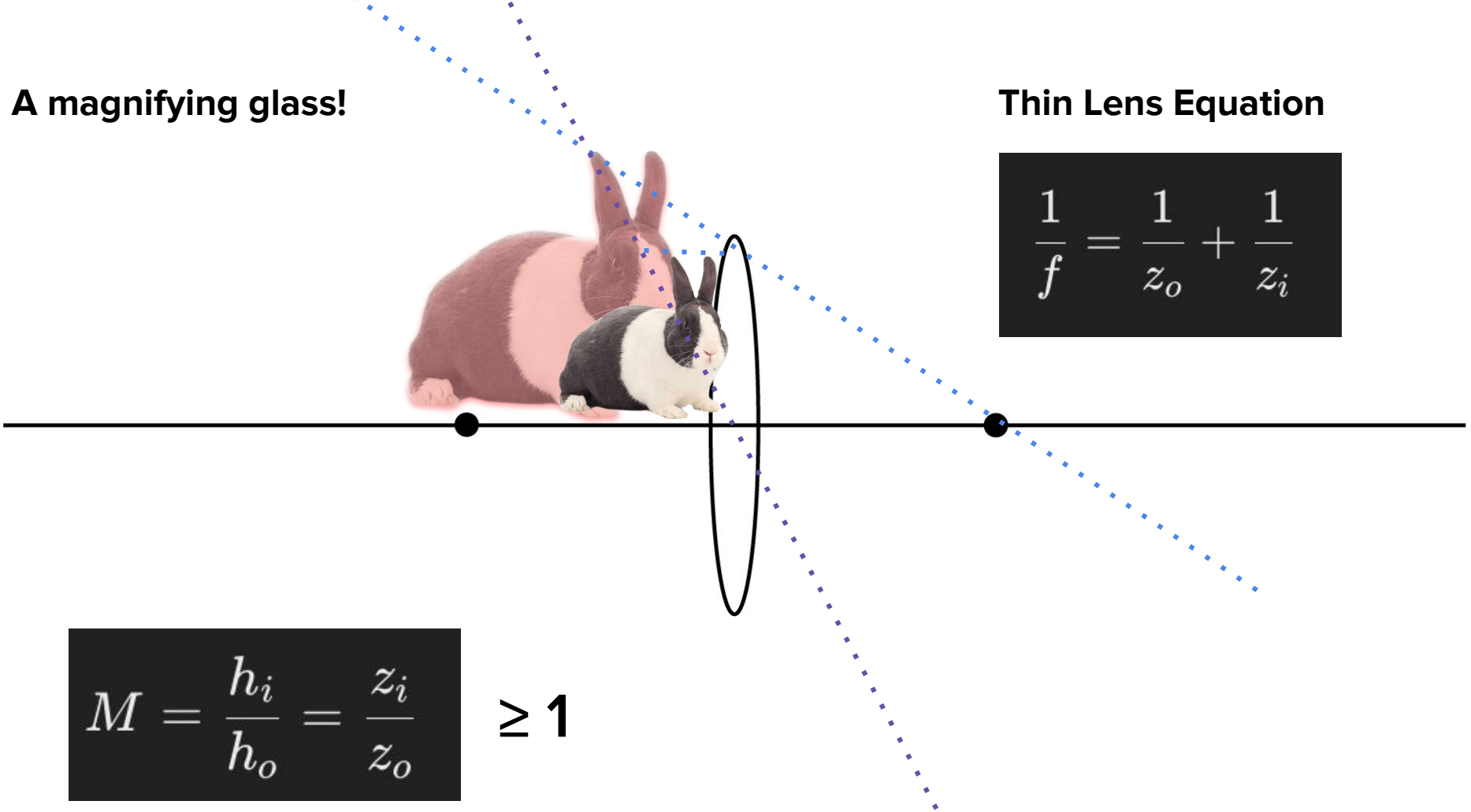
$$M = \frac{h_i}{h_o} = \frac{z_i}{z_o}$$

≤ 1

A magnifying glass!

Thin Lens Equation

$$\frac{1}{f} = \frac{1}{z_o} + \frac{1}{z_i}$$

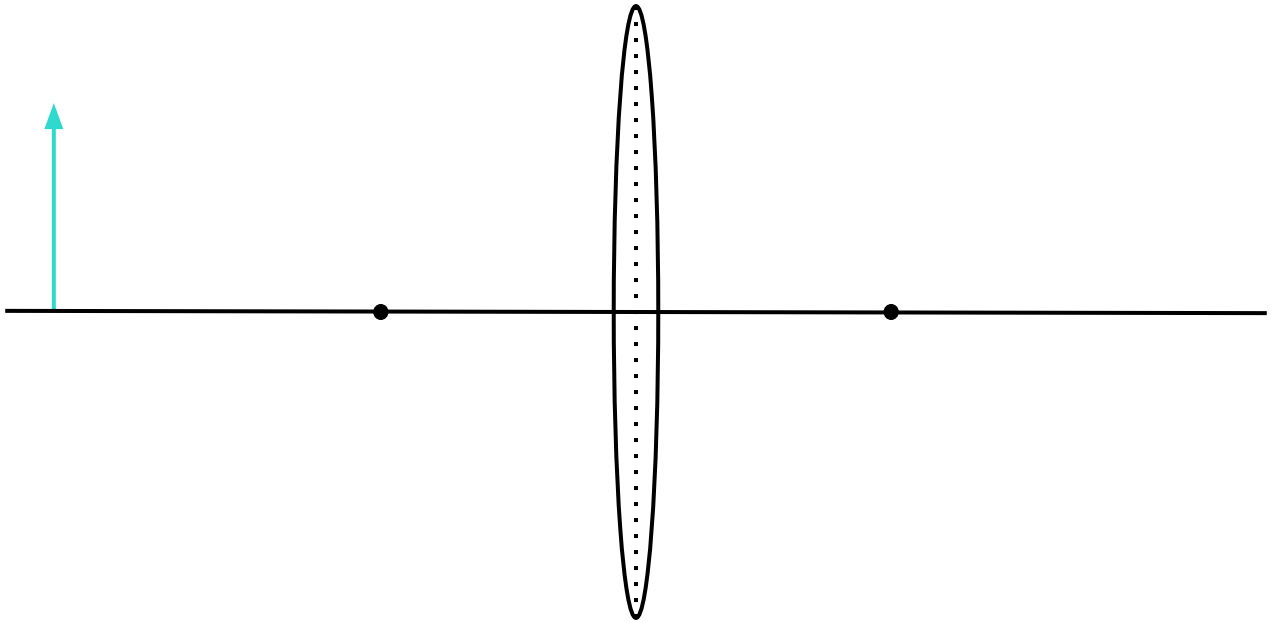


$$M = \frac{h_i}{h_o} = \frac{z_i}{z_o}$$

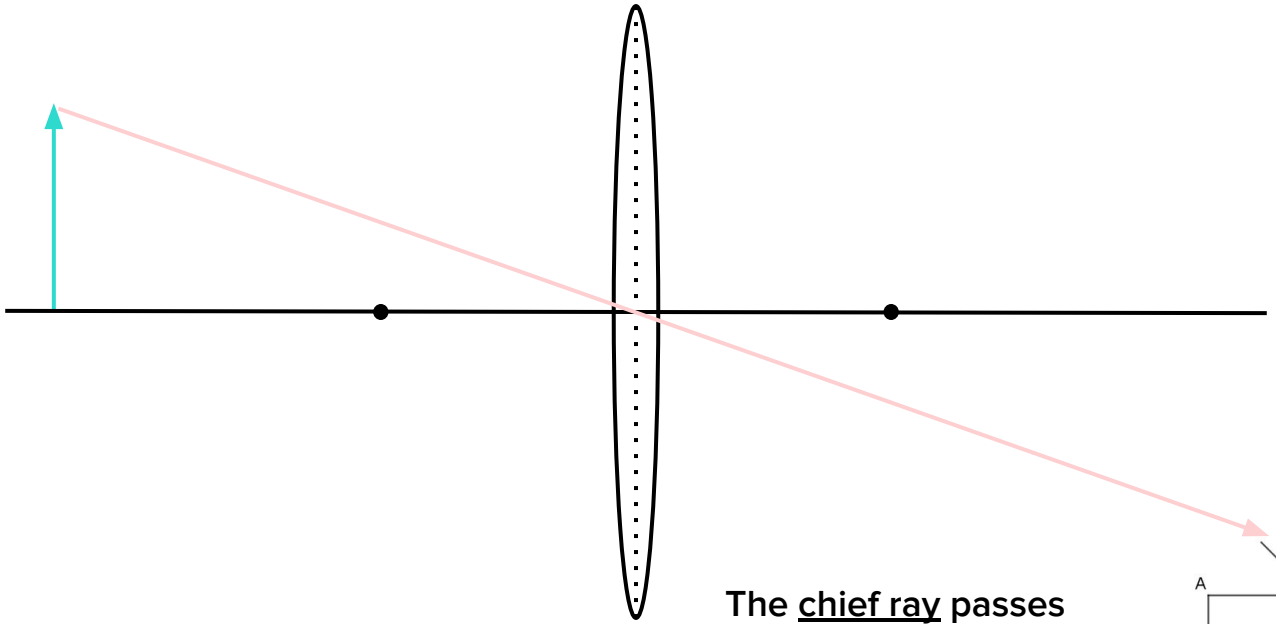
≥ 1

Thin Lens Equation

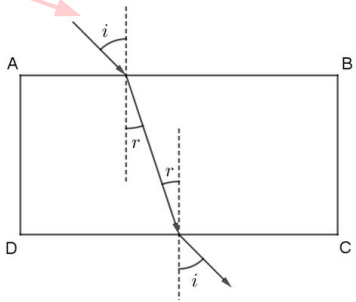
This is an object.



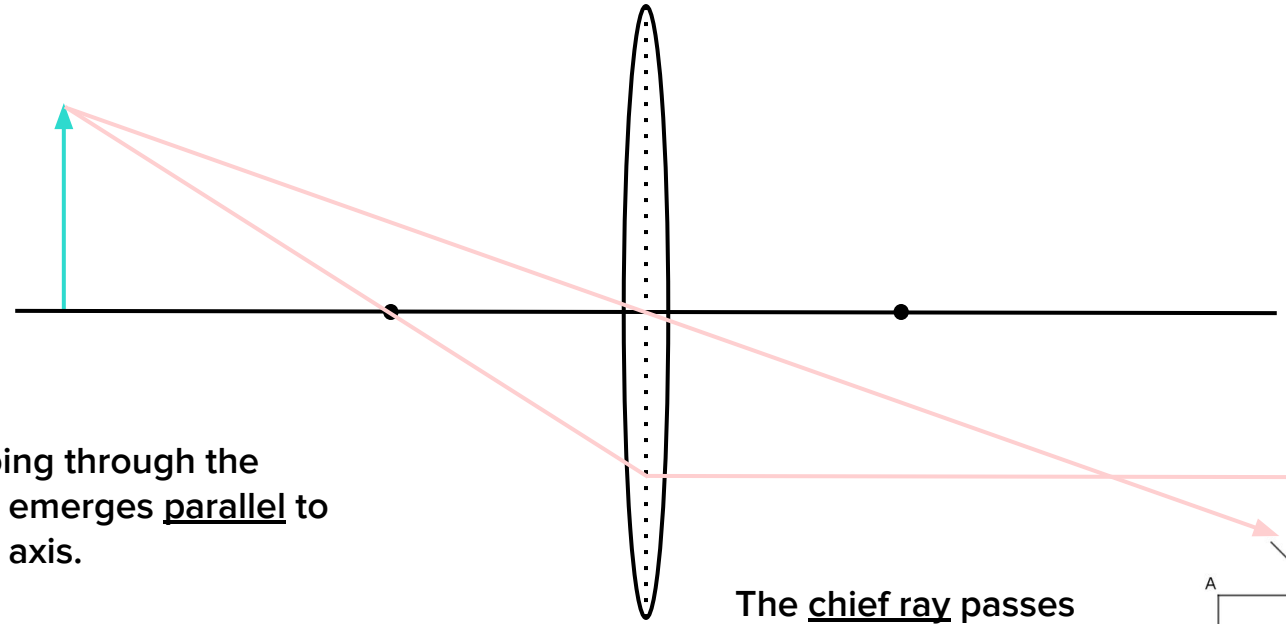
Thin Lens Equation



The chief ray passes through the center of the lens, where the surfaces are approximately parallel.

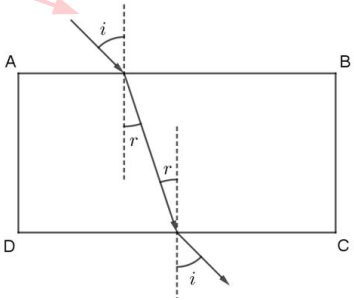


Thin Lens Equation

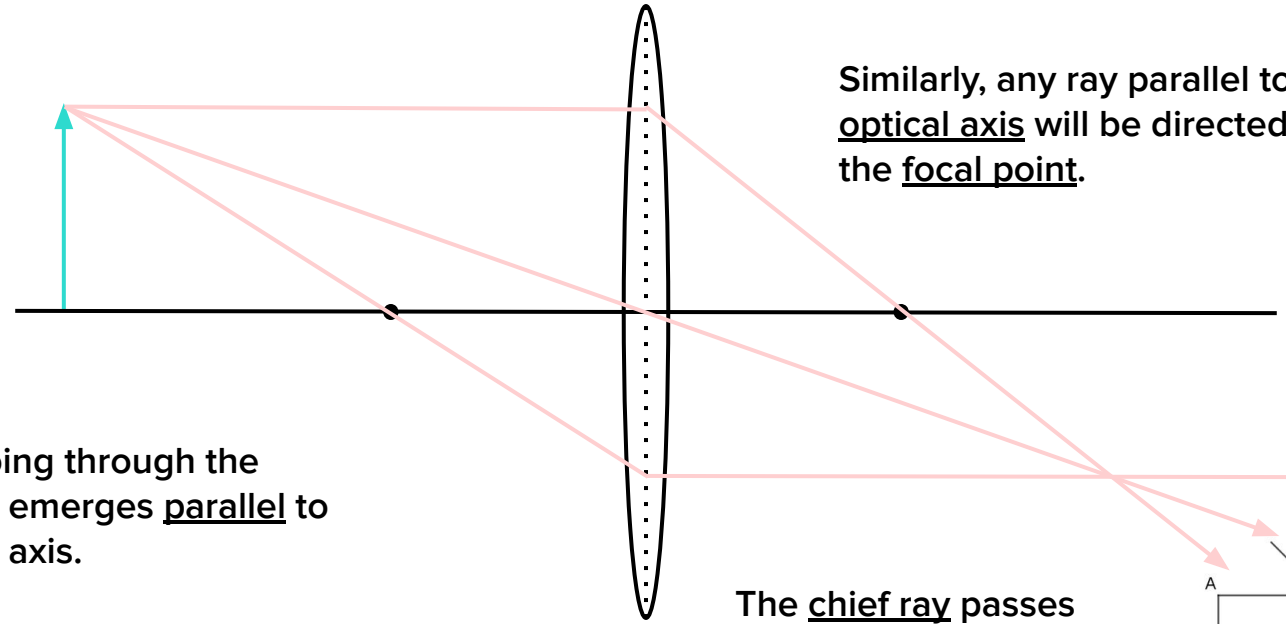


Any ray going through the focal point emerges parallel to the optical axis.

The chief ray passes through the center of the lens, where the surfaces are approximately parallel.



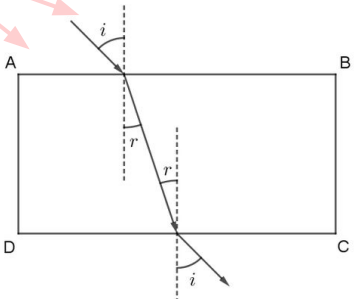
Thin Lens Equation



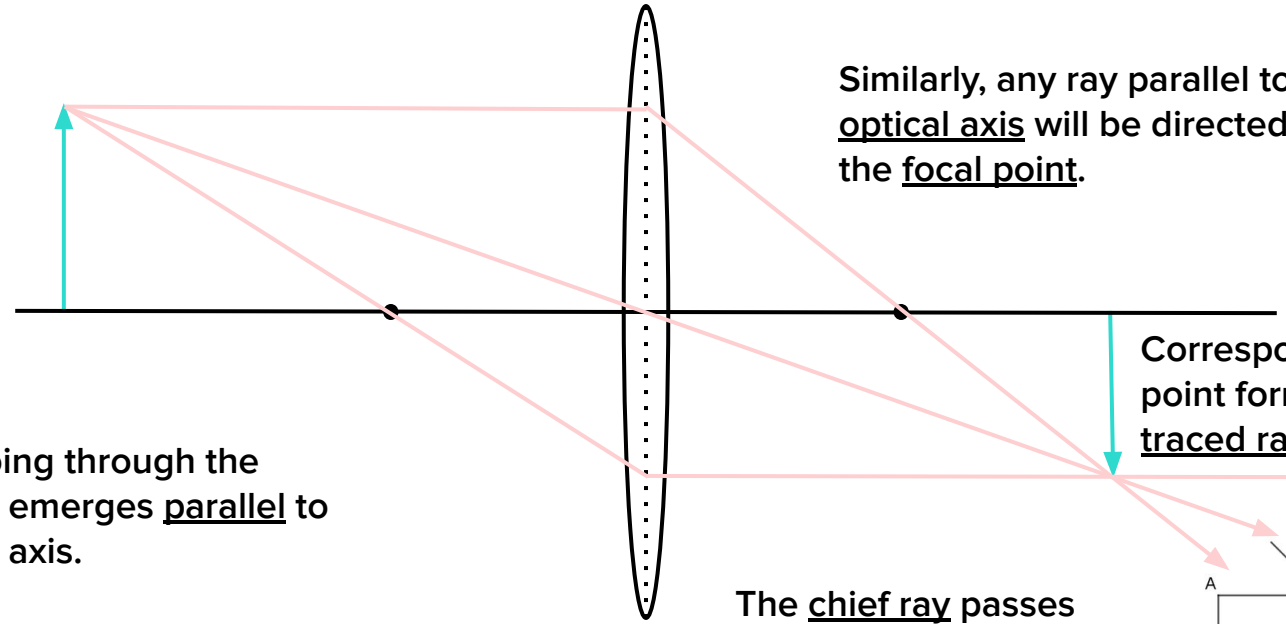
Similarly, any ray parallel to the optical axis will be directed through the focal point.

Any ray going through the focal point emerges parallel to the optical axis.

The chief ray passes through the center of the lens, where the surfaces are approximately parallel.



Thin Lens Equation



Similarly, any ray parallel to the optical axis will be directed through the focal point.

Corresponding image point forms where the traced rays intersect.

Any ray going through the focal point emerges parallel to the optical axis.

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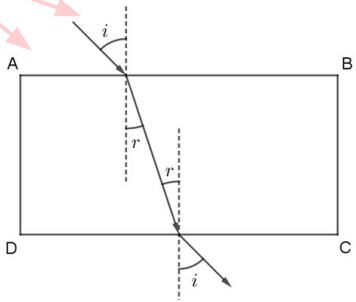
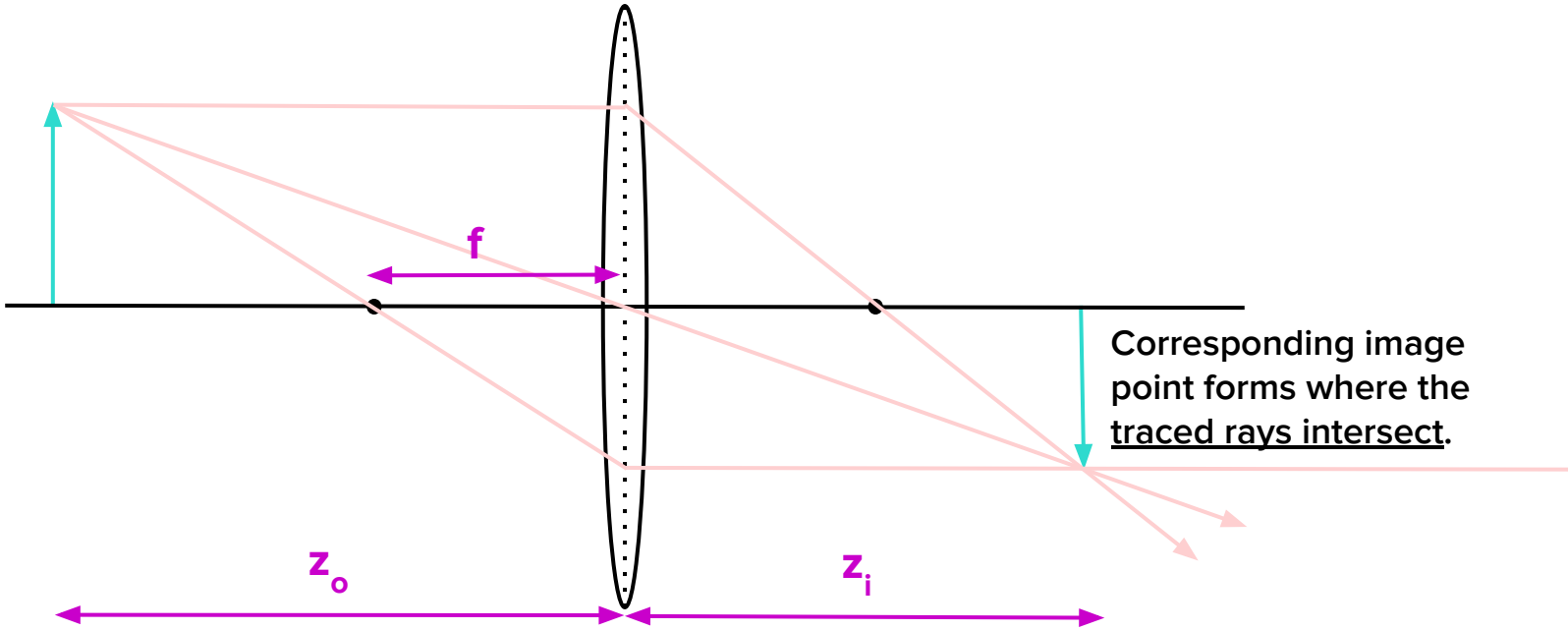


Thin Lens Equation



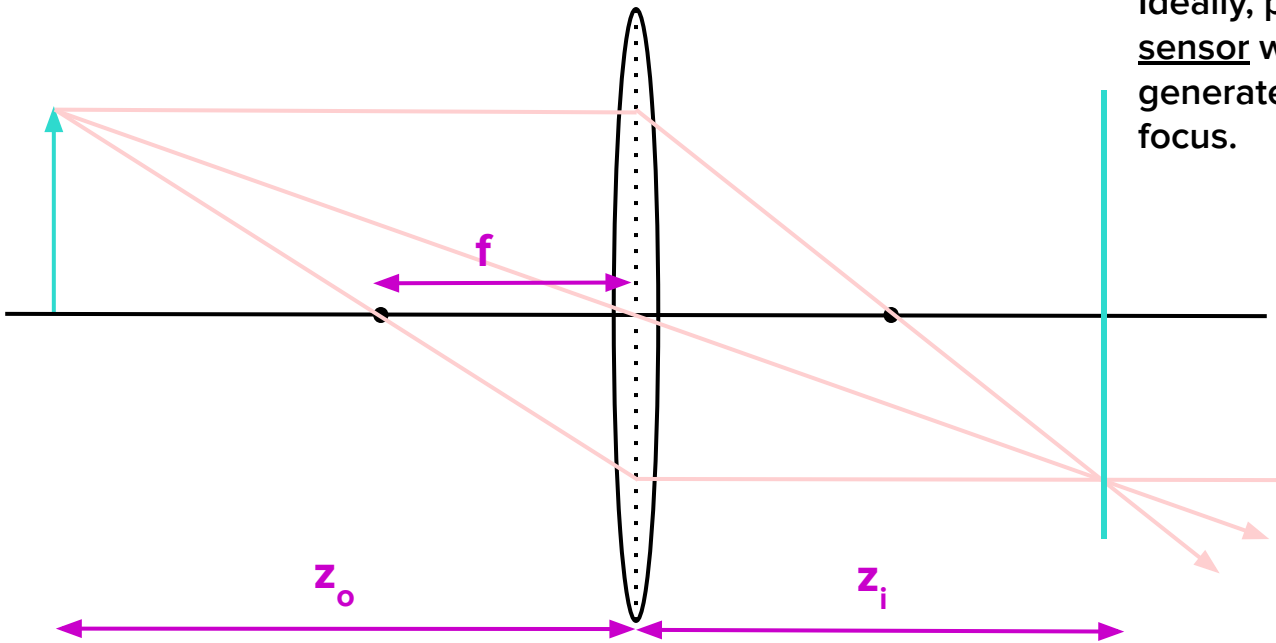
Corresponding image point forms where the traced rays intersect.

To find this point analytically, use the Thin Lens Equation.

$$\frac{1}{f} = \frac{1}{z_i} + \frac{1}{z_o}$$

Thin Lens Equation

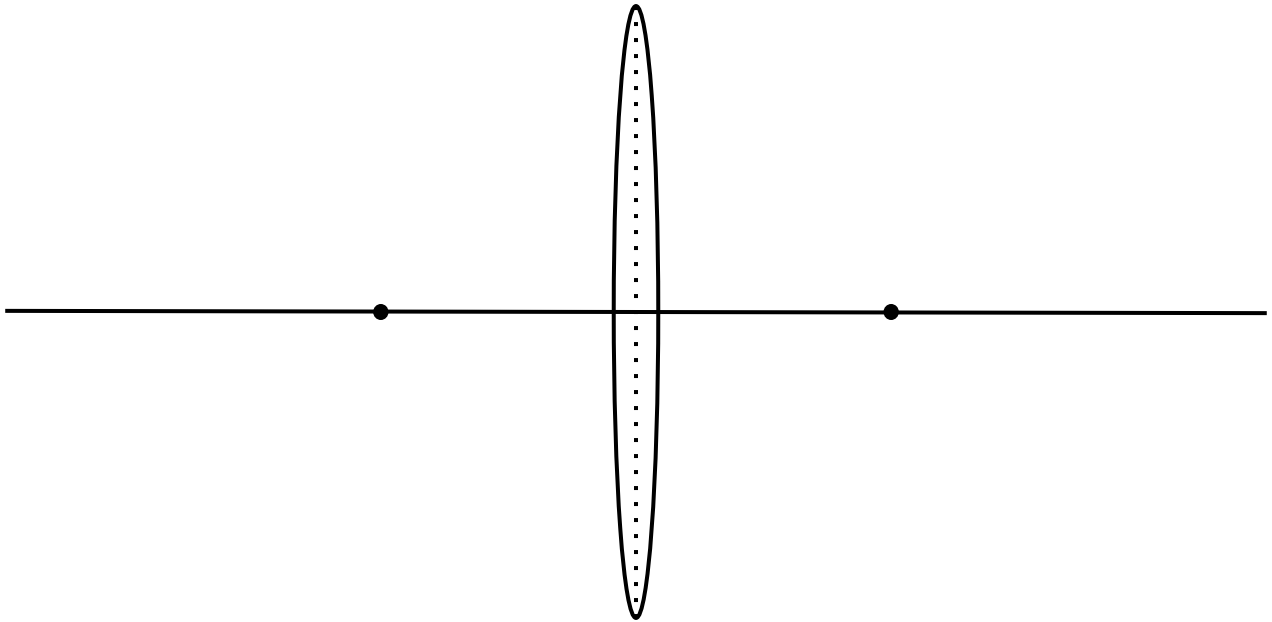
Ideally, place the image sensor where the generated image is in focus.

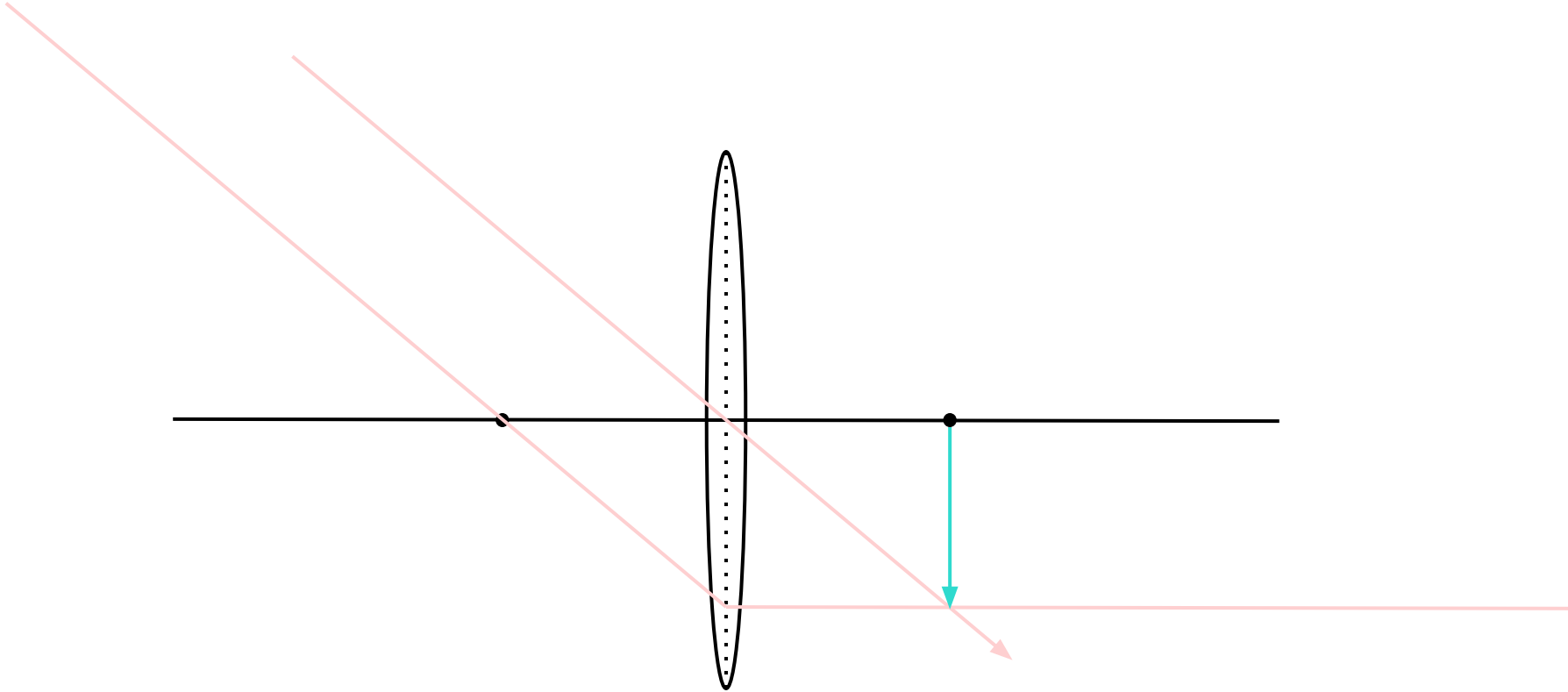


To find this point analytically, use the Thin Lens Equation.

$$\frac{1}{f} = \frac{1}{z_i} + \frac{1}{z_o}$$

Q1



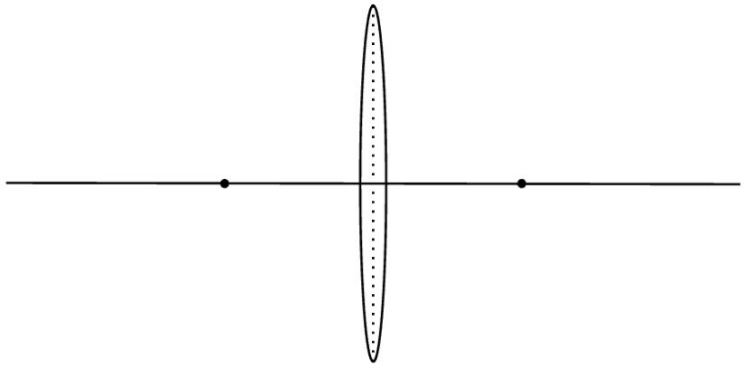


1.1, 1.2 Blood Moon

1 Blood Moon

The following diagram shows the optical axis, focal points, and thin lens of a camera that was used to photograph the recent total lunar eclipse. Assume the moon is a distance of infinity away from the camera.

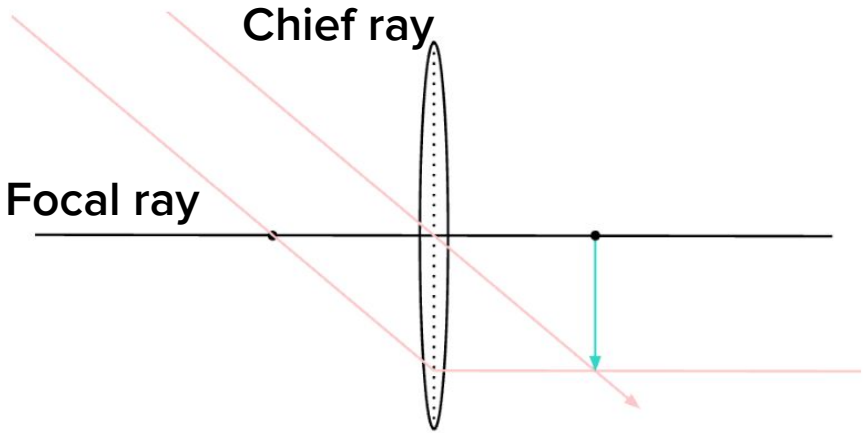
1. Draw the *focal ray*, which is the ray extending from the moon through the focal point of the thin lens. Recall that the focal ray exits the thin lens parallel to the optical axis.
2. Draw the *chief ray*, which is the ray extending from the moon through the center of the thin lens. Recall that all rays extending from an object at infinity are parallel to one another.



1.1, 1.2 Blood Moon

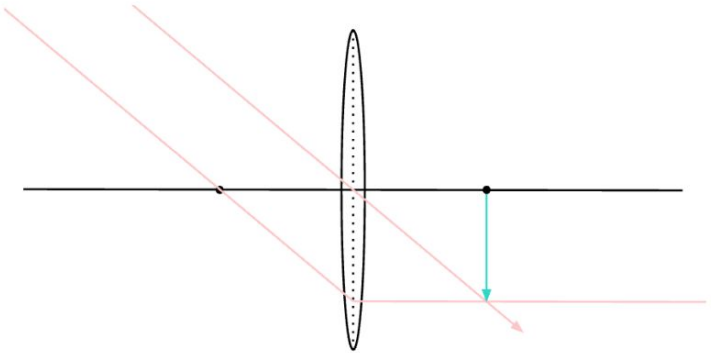
Solution:

Observe the image in turquoise.



1.3 Blood Moon

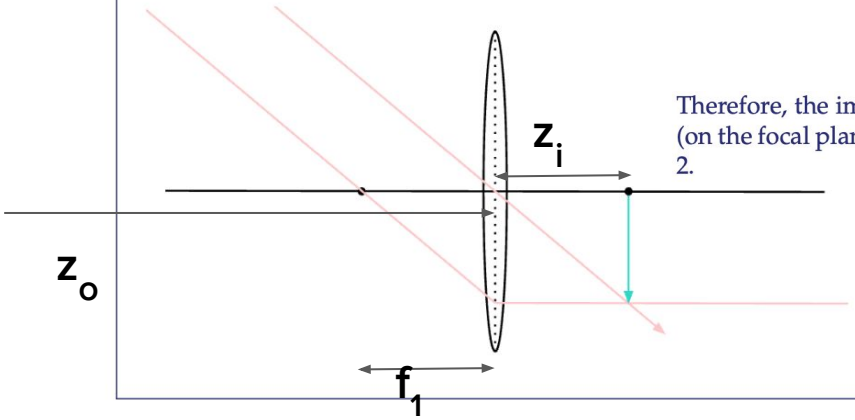
Observe the image in turquoise.



3. The focal length of this thin lens is f_1. Calculate the distance between the lens and the image of the moon that is formed by the lens.

1.3 Blood Moon

Observe the image in turquoise.



Solution: Use the Thin Lens Equation.

$$\frac{1}{f_1} = \frac{1}{z_i} + \frac{1}{z_o} = \frac{1}{z_i} + \frac{1}{\infty} = \frac{1}{z_i}$$

Therefore, the image forms at $z_i = f_1$. The image sensor is placed a distance of f_1 behind the lens (on the focal plane of the lens). This result could have also been found graphically from parts 1 and 2.

3. The focal length of this thin lens is f_1. Calculate the distance between the lens and the image of the moon that is formed by the lens.

1.4 Blood Moon

4. To achieve a clear photo of the moon, what should the distance between the lens and the image sensor be? What might occur if the distance is any smaller? What about any larger?

1.4 Blood Moon

4. To achieve a clear photo of the moon, what should the distance between the lens and the image sensor be? What might occur if the distance is any smaller? What about any larger?

Solution: The distance between the lens and the image sensor should be the same as the distance between the image formed by the lens and the lens, which is f_1. Any smaller or any larger of a distance, the rays will not be converged, and the image will be blurry.

1.5 Blood Moon

5. Let's now repurpose this lens as the *objective lens* of a telescope. In addition to the objective lens, a telescope has an *eyepiece lens*. The job of the eyepiece lens is to make the intermediate image formed by the objective lens appear infinitely far away to the viewer.

   The eyepiece lens has a focal length of f_2. Where should it be placed, relative to the objective lens?

Diagram not to scale

1.5 Blood Moon

5. Let's now repurpose this lens as the *objective lens* of a telescope. In addition to the objective lens, a telescope has an *eyepiece lens*. The job of the eyepiece lens is to make the intermediate image formed by the objective lens appear infinitely far away to the viewer.

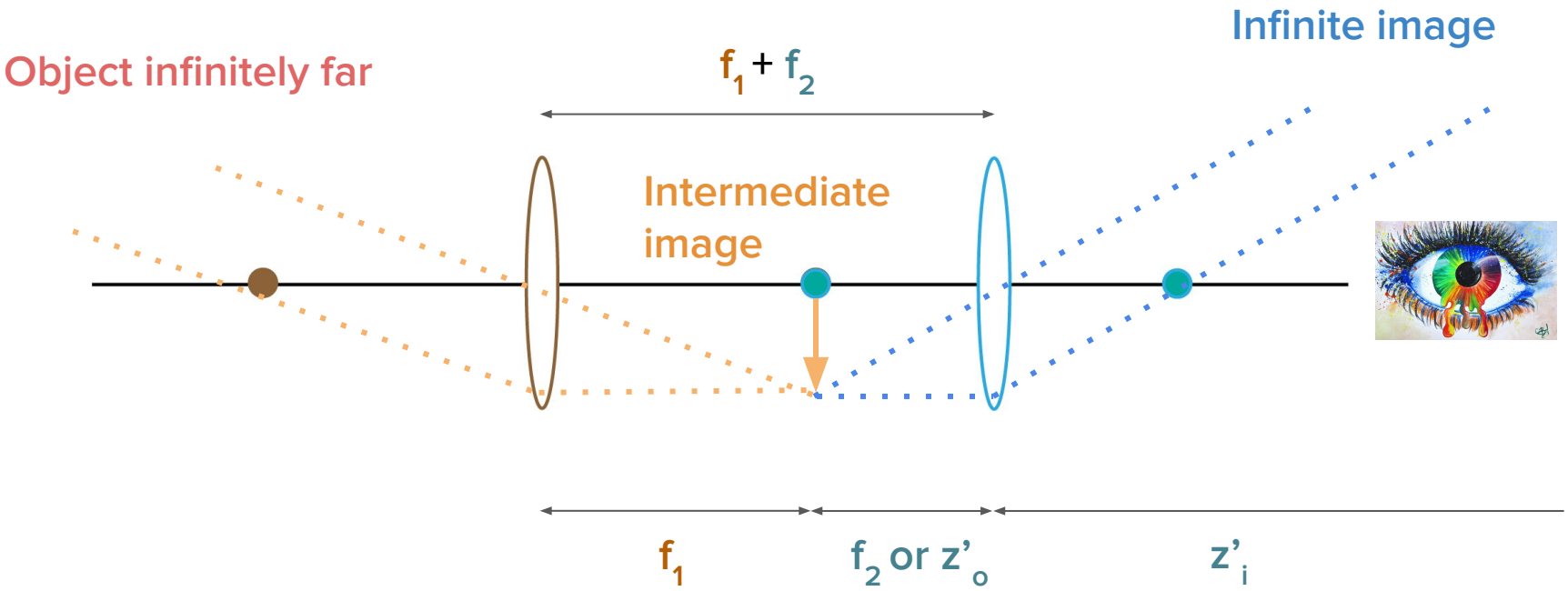
   The eyepiece lens has a focal length of f_2. Where should it be placed, relative to the objective lens?

Solution:

$$\frac{1}{f_2} = \frac{1}{z_i'} + \frac{1}{z_o'} = \frac{1}{\infty} + \frac{1}{z_o'} = \frac{1}{z_o'}$$

Therefore, the distance between the intermediate image and the eyepiece lens, z_o', is equal to f_2. So the eyepiece lens should be $f_1 + f_2$ behind the objective lens.

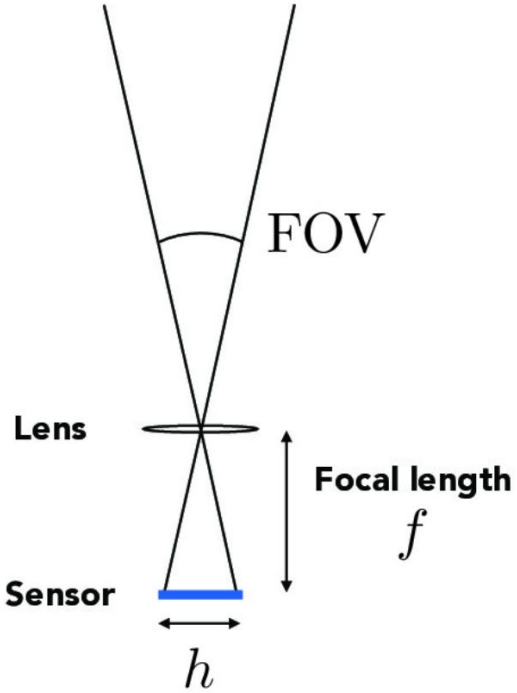
1.5


Object infinitely far
$f_1 + f_2$
Infinite image
Intermediate image
f_1
f_2 or z'_o
z'_i

Cameras & Lenses

Field of View

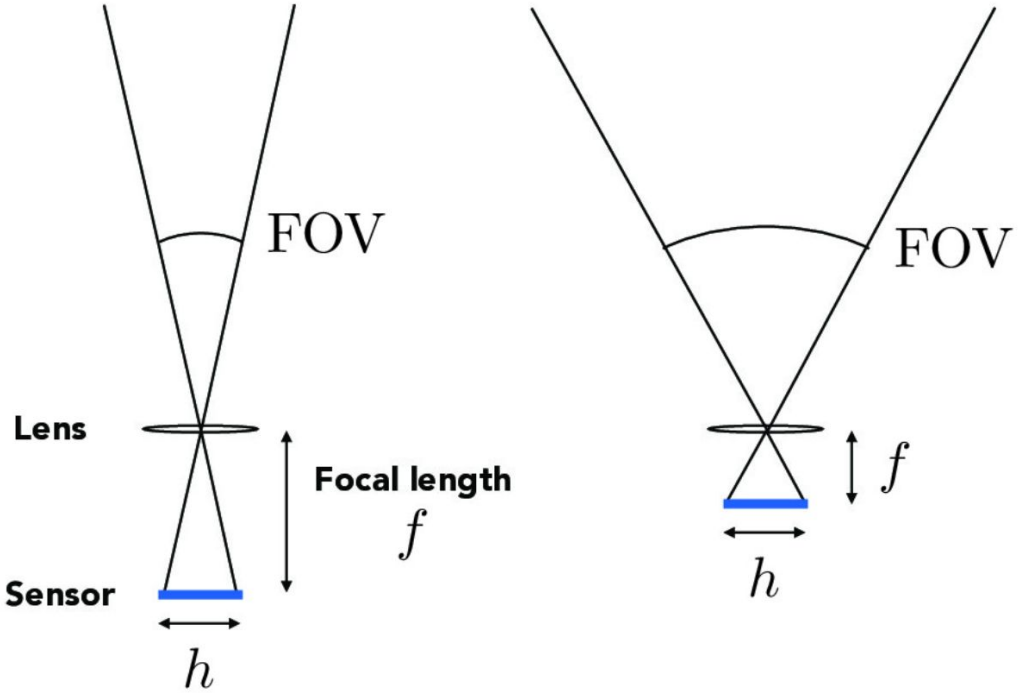
- FOV = angle of scene that camera lens can captured.



When calculating field of view, assume the lens is focused at infinity!

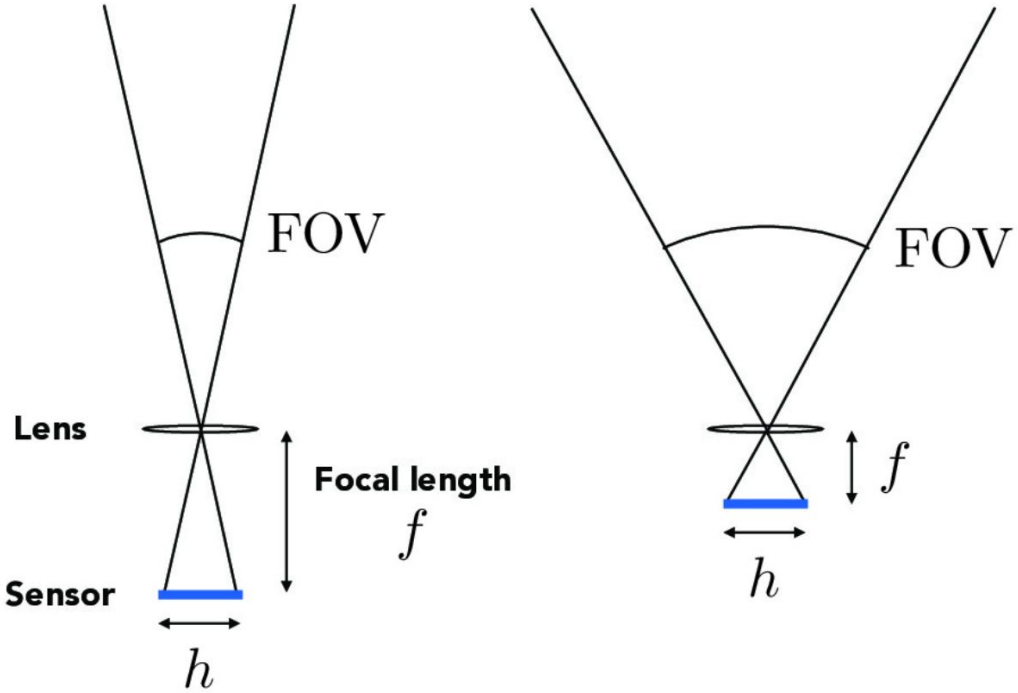
Field of View

- FOV = angle of scene that camera lens can captured.
- For fixed sensor size, smaller focal length → larger FOV!



Field of View

- FOV = angle of scene that camera lens can captured.
- For fixed sensor size, smaller focal length → larger FOV!
- $\text{FOV} = 2 \arctan\left(\frac{h}{2f}\right)$

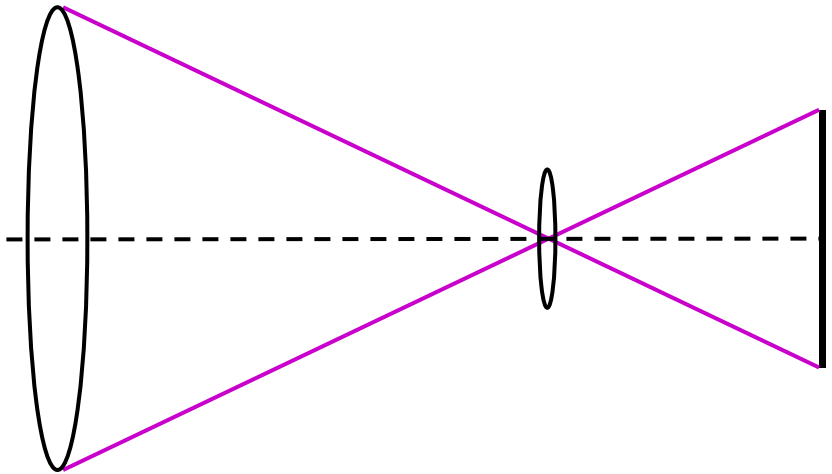


Question 2

2.1 Raine's Field of View

Raine is doing a photoshoot. His camera has a sensor height of 36 millimeters and a focal length of 50 millimeters. A bunny sits a little ways away.

1. Label the sensor height, focal length, and field of view (FOV) of Raine's camera.



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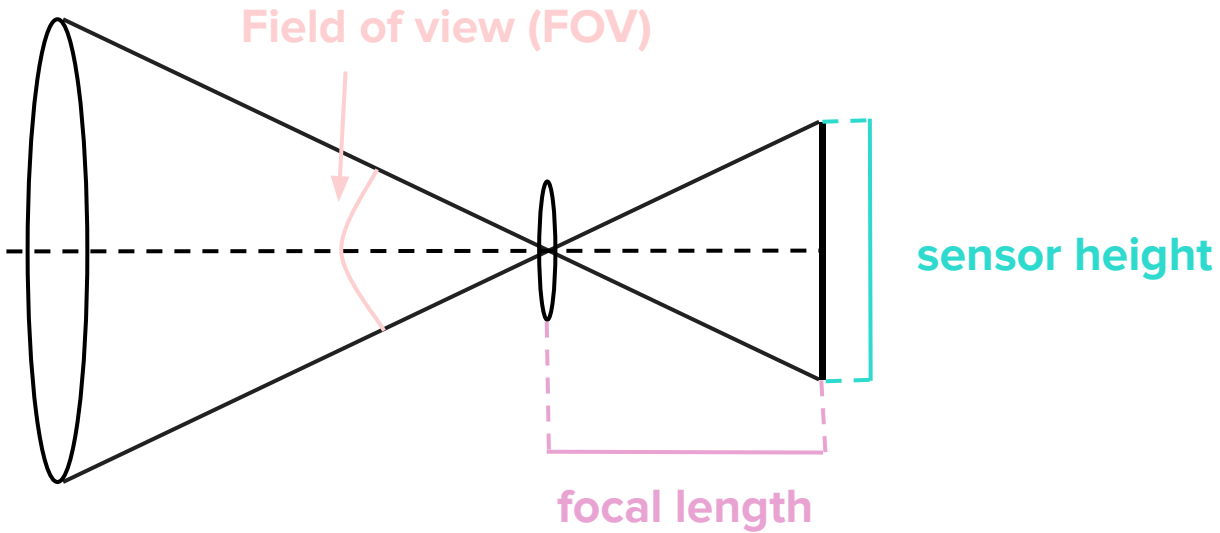
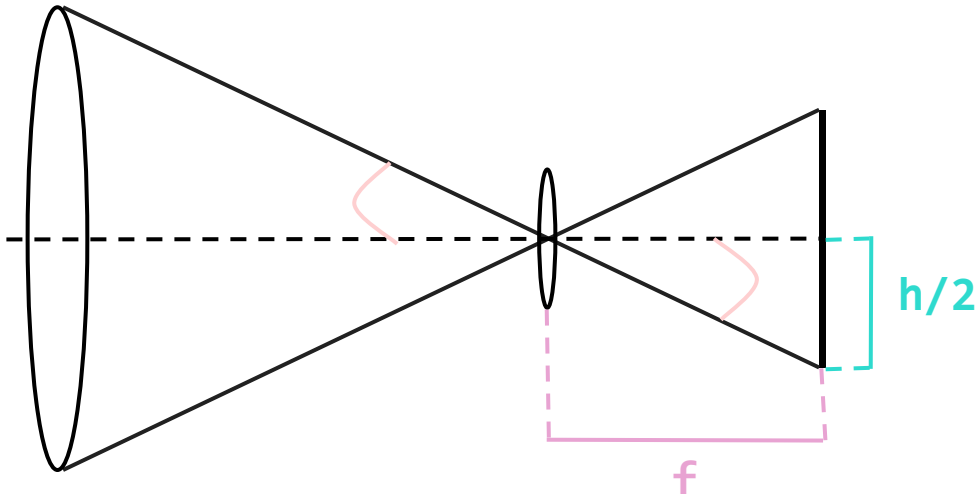


2.2 Raine's Field of View

2. Write an expression for the FOV of Raine's camera in the vertical direction.



2.2 Raine's Field of View

2. Write an expression for the FOV of Raine's camera in the vertical direction.

h: height of sensor

Hint! $$\text{FOV} = 2 \arctan\left(\frac{h}{2f}\right)$$

f : focal length

Solution:

$$2\arctan\left(\frac{36\text{ mm}/2}{50\text{ mm}}\right) = 2\arctan(0.36)$$

2.3 Raine's Field of View

3. Raine snaps a picture of the bunny, who is 20 centimeters tall. In the image, the bunny's height is one-ninth of the height of the image. Calculate the horizontal distance from the bunny to Raine's camera.

2.3 Raine's Field of View

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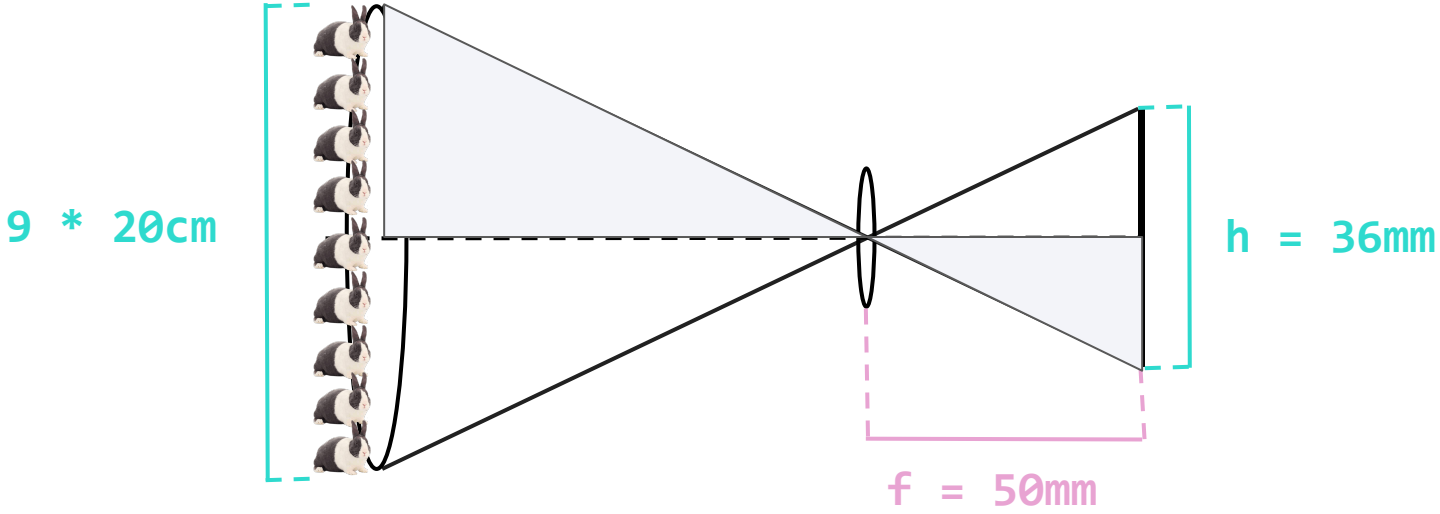

These triangles are similar!

2.3 Raine's Field of View

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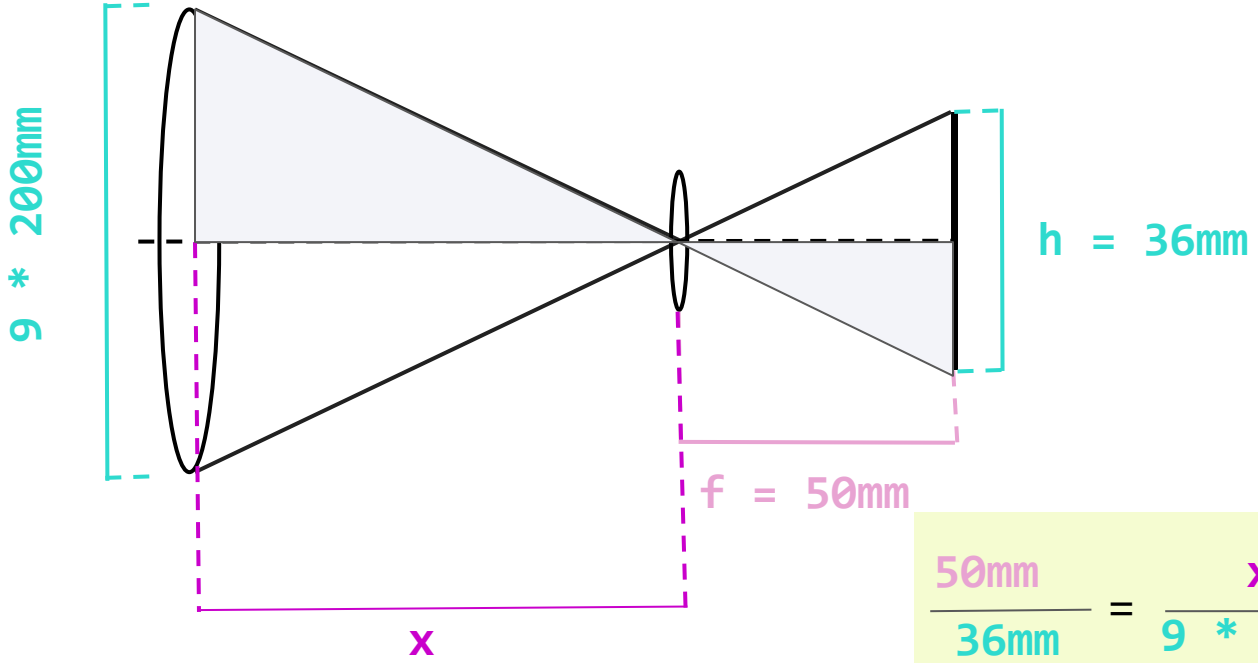
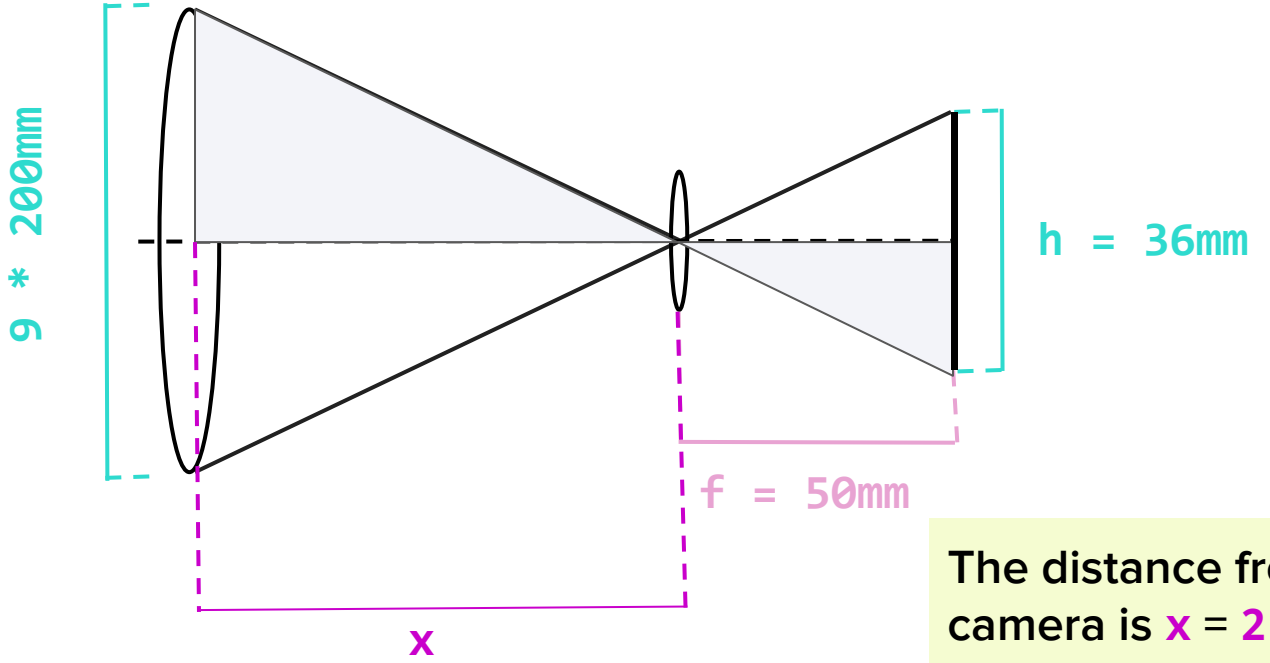


$$\frac{50\text{mm}}{36\text{mm}} = \frac{x}{9 * 200\text{mm}} \longrightarrow x = 2500\text{mm} = 2.5\text{m}$$

2.3 Raine's Field of View

3. Raine snaps a picture of the bunny, who is 20 centimeters tall. In the image, the bunny's height is one-ninth of the height of the image. Calculate the horizontal distance from the bunny to Raine's camera.



The distance from the bunny to Raine's camera is $x = 2.5m$.

2.3 Raine's Field of View

3. Raine snaps a picture of the bunny, who is 20 centimeters tall. In the image, the bunny's height is one-ninth of the height of the image. Calculate the horizontal distance from the bunny to Raine's camera.

Solution: We are given that $h_o = 20$ cm, $h_i = \frac{h}{9} = 4$ mm, and $f = 50$ mm. Furthermore, the image is focused on the sensor plane, so $z_i = f$.

By similar triangles,

$$\frac{z_o}{h_o} = \frac{f}{h_i}.$$

Therefore,

$$z_o = f \cdot \frac{h_o}{h_i} = 50 \text{ mm} \cdot \frac{20 \text{ cm}}{4 \text{ mm}} = 2.5 \text{ m}.$$

Raine's image sensor is 2.5 meters away from the bunny.

2.4 Raine's Field of View

4. Raine wants the bunny to take up a larger fraction of the vertical space of the image. Assume his camera's sensor height is fixed, and he doesn't want to move for fear of disturbing the bunny. How can he adjust his camera's *focal length* to achieve the desired effect? How is focal length related to FOV?

2.4 Raine's Field of View

4. Raine wants the bunny to take up a larger fraction of the vertical space of the image. Assume his camera's sensor height is fixed, and he doesn't want to move for fear of disturbing the bunny. How can he adjust his camera's *focal length* to achieve the desired effect? How is focal length related to FOV?

Solution: Raine can increase the focal length, which narrows his camera's FOV, thus resulting in the bunny taking up a larger fraction of the vertical space of the image. Focal length and FOV are inversely related.

2.5 Raine's Field of View

5. Now, assume Raine's position and focal length are fixed. How can he adjust his camera's *sensor size* to achieve the desired effect? How is sensor size related to FOV?

2.5 Raine's Field of View

5. Now, assume Raine's position and focal length are fixed. How can he adjust his camera's *sensor size* to achieve the desired effect? How is sensor size related to FOV?

Solution: Raine can decrease the sensor height, which narrows his camera's FOV in the vertical direction, thus resulting in the bunny taking up a larger fraction of the vertical space of the image.

Sensor size and FOV are directly related.

2.6 Raine's Field of View

6. Finally, assume Raine's position is fixed. Which of the following configurations for his camera results in the bunny taking up the largest fraction of vertical space?

   (a) 36 millimeters tall sensor and 50 millimeters focal length lens.

   (b) 12 millimeters tall sensor and 18 millimeters focal length lens.

   (c) 24 millimeters tall sensor and 8 millimeters focal length lens.

2.6 Raine's Field of View

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   (b) 12 millimeters tall sensor and 18 millimeters focal length lens.

   (c) 24 millimeters tall sensor and 8 millimeters focal length lens.

Hint! $\text{FOV} = 2 \arctan\left(\frac{h}{2f}\right)$

Solution: B. Recall that the field of view can be computed as an angle:

$$\text{FOV} = 2\text{arctan}(\frac{h}{2f})$$

where h is the sensor size and f is the focal length.

Using this expression, we see that (a) has FOV $2\text{arctan}(\frac{36}{100})$, (b) has FOV $2\text{arctan}(\frac{12}{36})$, and (c) has FOV $2\text{arctan}(\frac{24}{16})$. (c) has the largest FOV at approximately 56.31 degrees, whereas (a) has FOV 19.8 degrees and (b) has FOV 18.43 degrees.

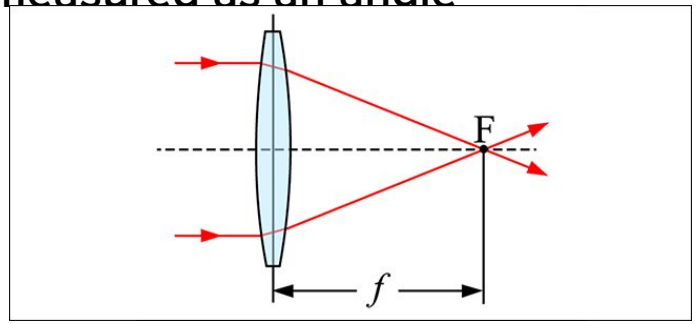
1.1 Terminology

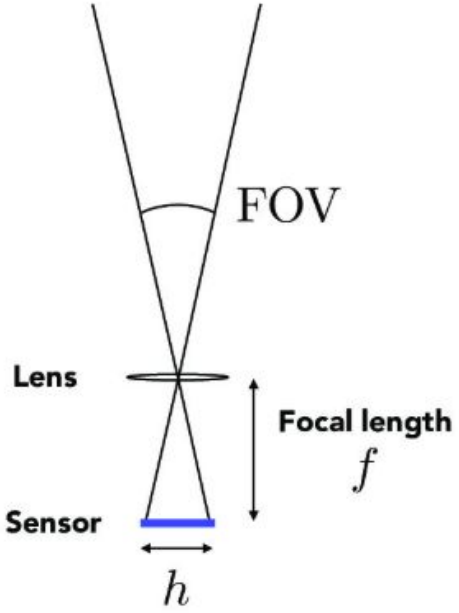
Focal length:

- distance between the center of a lens and the point at which parallel light rays from infinity at brought into focus

Field of view:

- the extent of the scene that is visible to the camera's sensor, measured as an angle

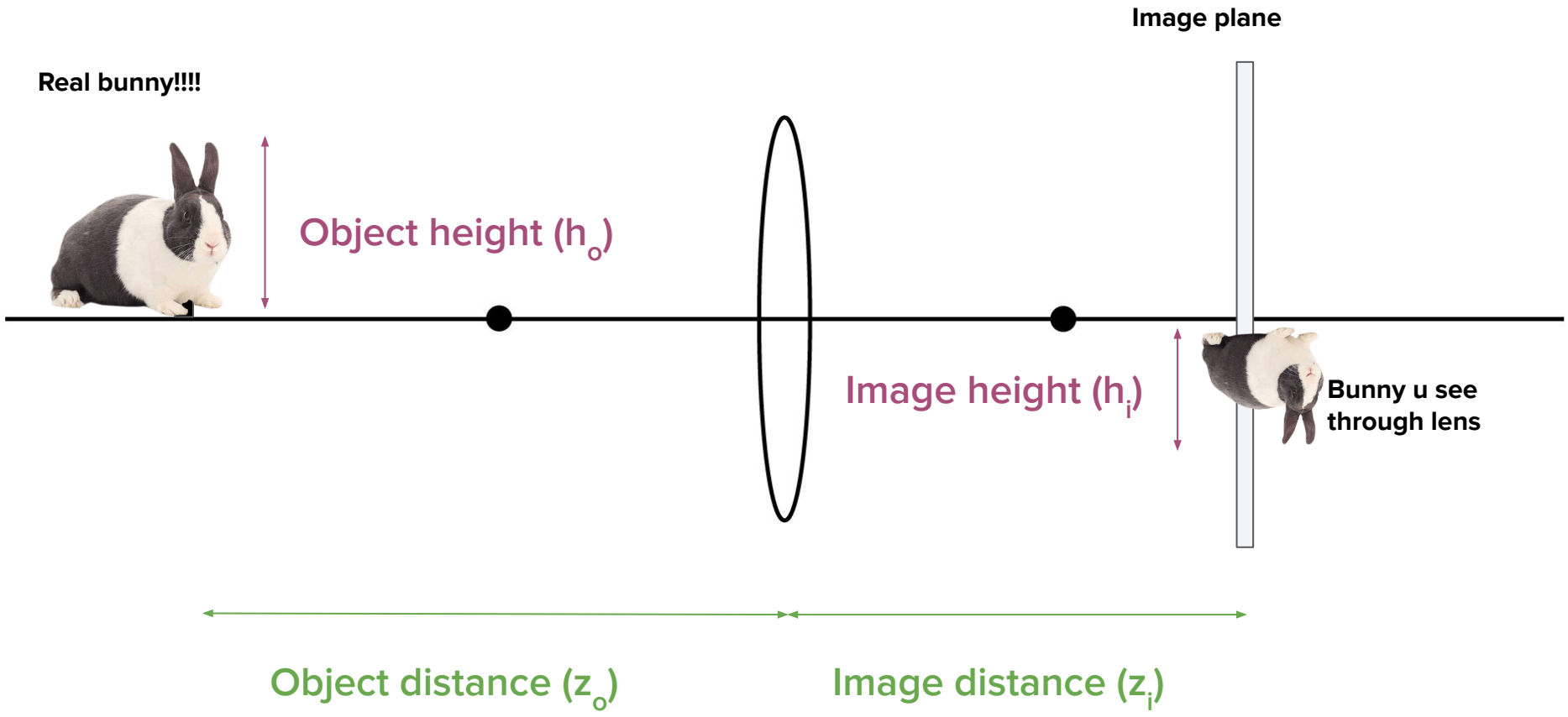




Exposure

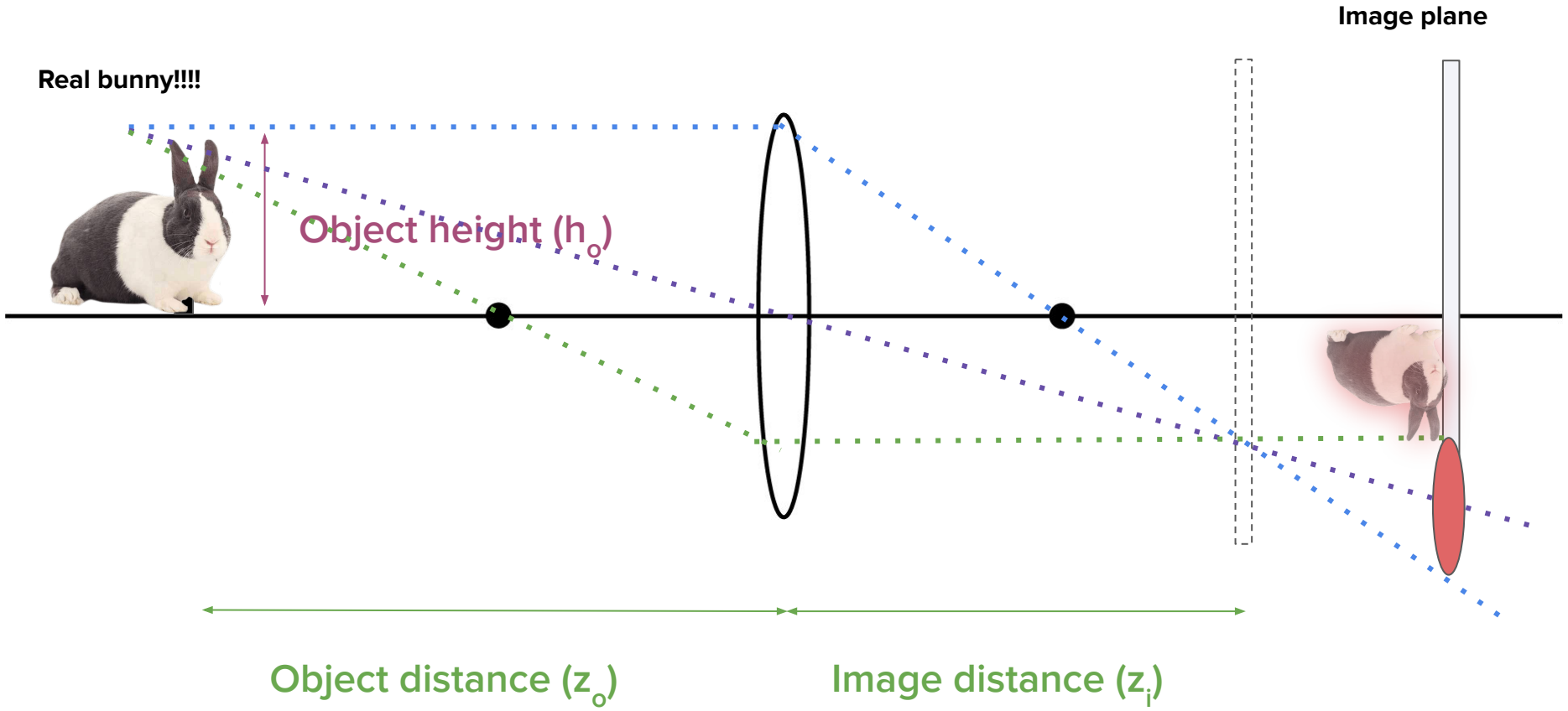

-2 , 1 , 0 , 1 , 2+
-2 , 1 , 0 , 1 , 2+
-2 , 1 , 0 , 1 , 2+
Exposure
= Irradiance
x Time
x Gain

An aside: circles of confusion (aka blur)



An aside: circles of confusion (aka blur)

If the image plane is not at z_i,
bunny on image plane appears blurry!
(Circle of confusion)

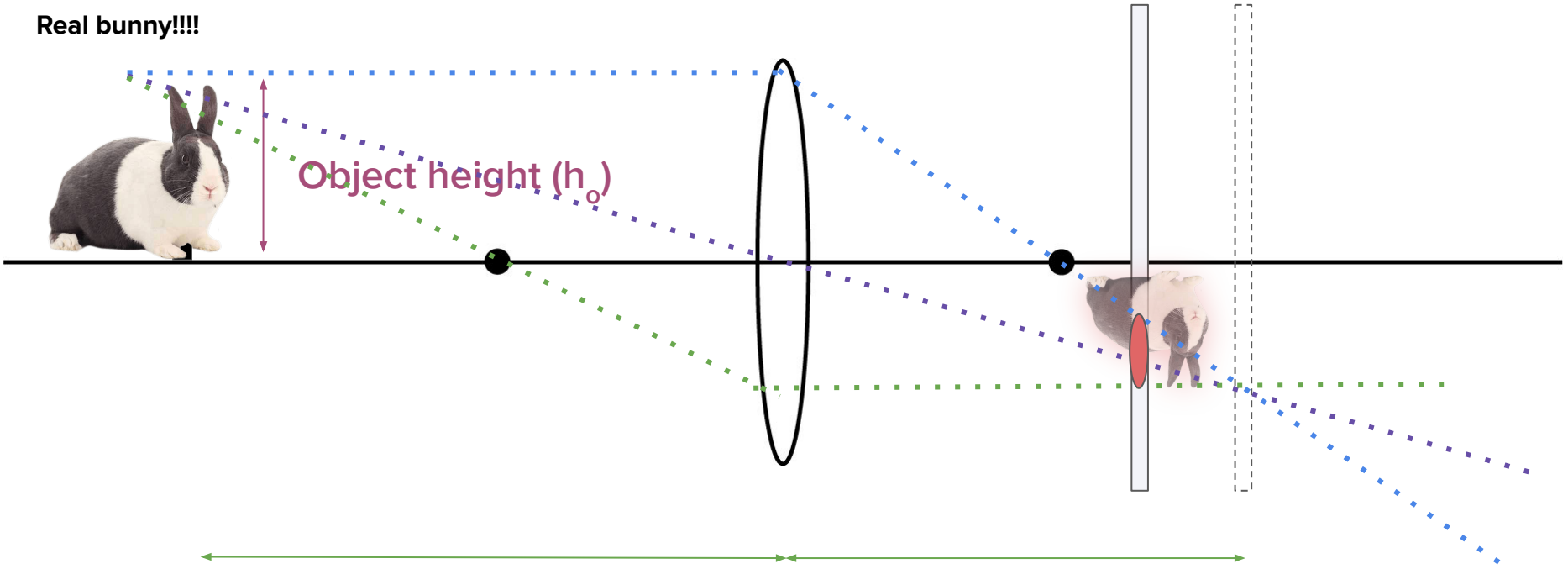


An aside: circles of confusion (aka blur)

If the image plane is not at z_i,
bunny on image plane appears blurry!
(Circle of confusion)

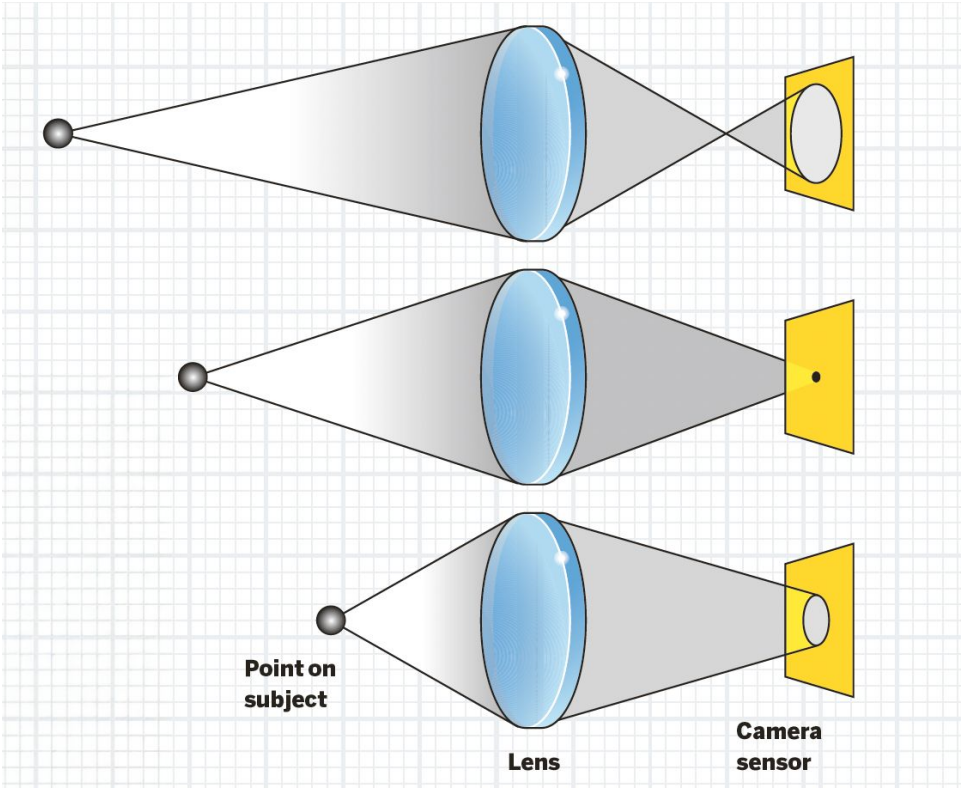
Image plane

Real bunny!!!!



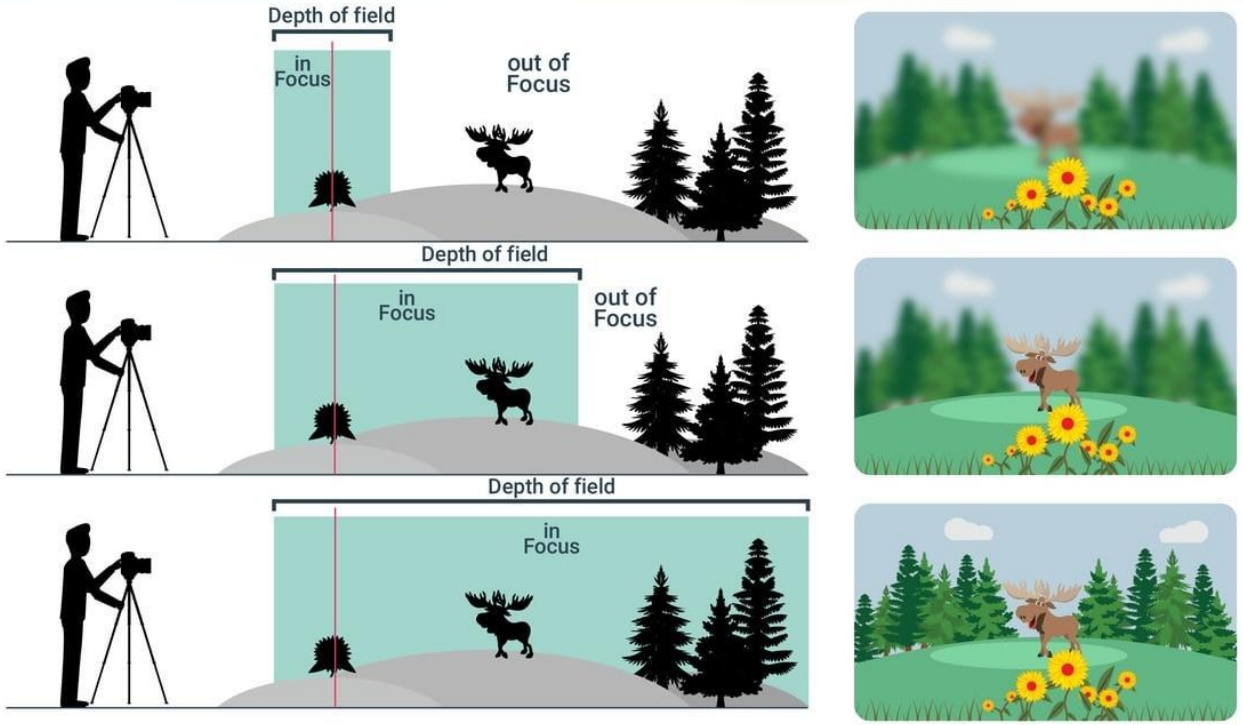
An aside: circle of confusion

- Optical spot caused by cone of light not coming to focus
- Aka blurring!



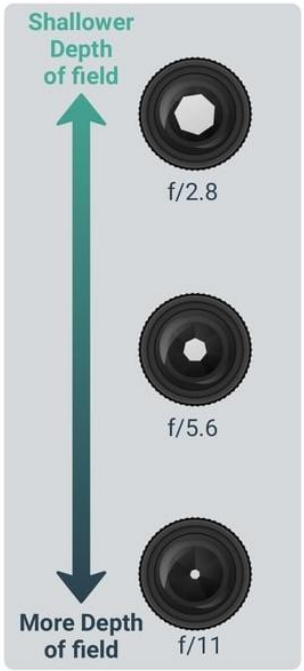
An aside: depth of field

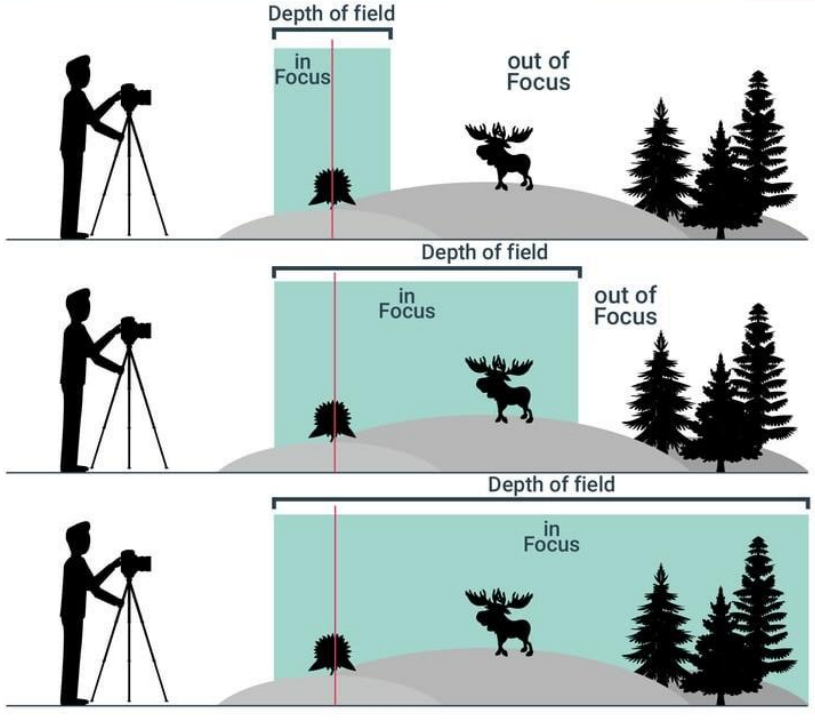
- Set maximum size circle of confusion.
- Depth of field = depths with blur less than this size.

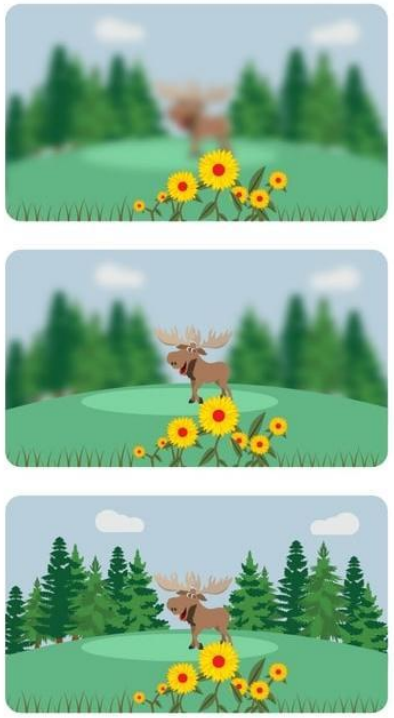


An aside: depth of field

Smaller aperture → more concentrated rays → reduces blur → larger depth of field!

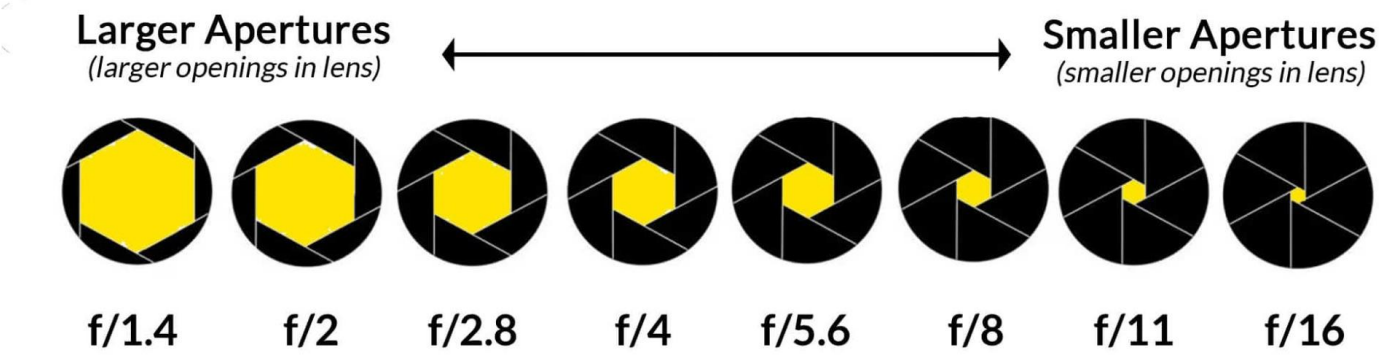






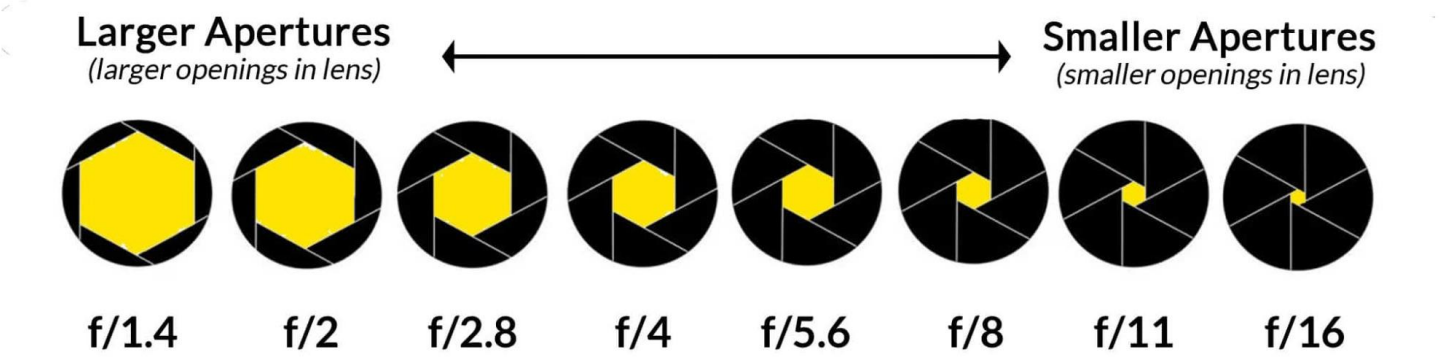
Exposure = irradiance x time x gain

- Control irradiance with aperture.



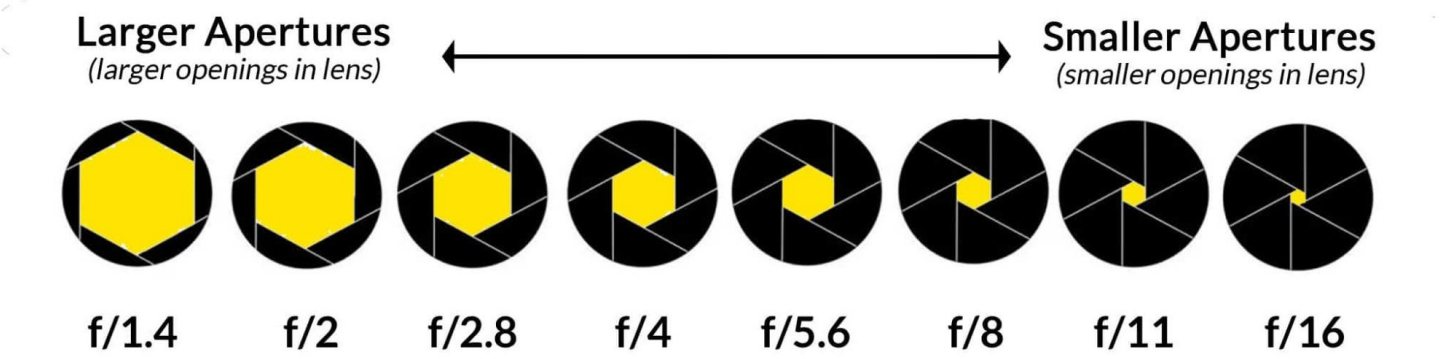
Exposure = irradiance x time x gain

- Control irradiance with aperture.
- Larger aperture → more shallow depth of field.



Exposure = irradiance x time x gain

- Control irradiance with aperture.
- Larger aperture → more shallow depth of field.
- Larger aperture → more light = higher irradiance.



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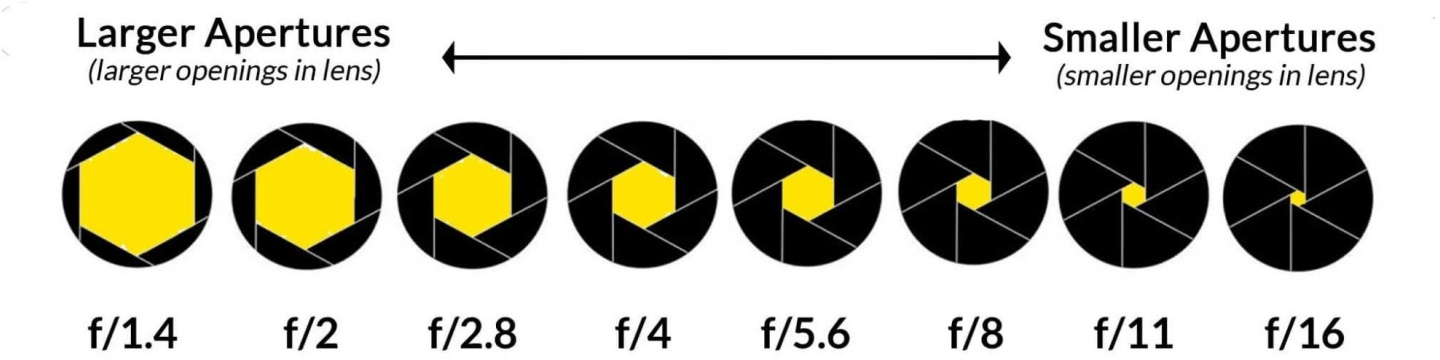
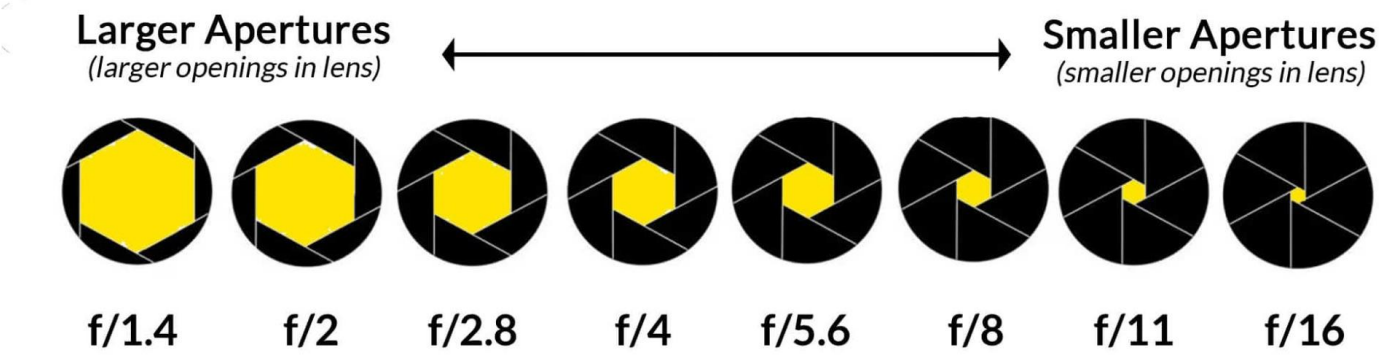
- F-number = focal length / diameter of aperture.



Exposure = irradiance x time x gain

- Control irradiance with aperture.
- Larger aperture → more shallow depth of field.
- Larger aperture → more light = higher irradiance.
- F-number = focal length / diameter of aperture.
- Change in F-number is a “stop”: e.g. stop down F/1.4 lens to F/4.

Note on notation. An F-number of 4.0 is written as *f/4.0*.
(This is not a fraction!)

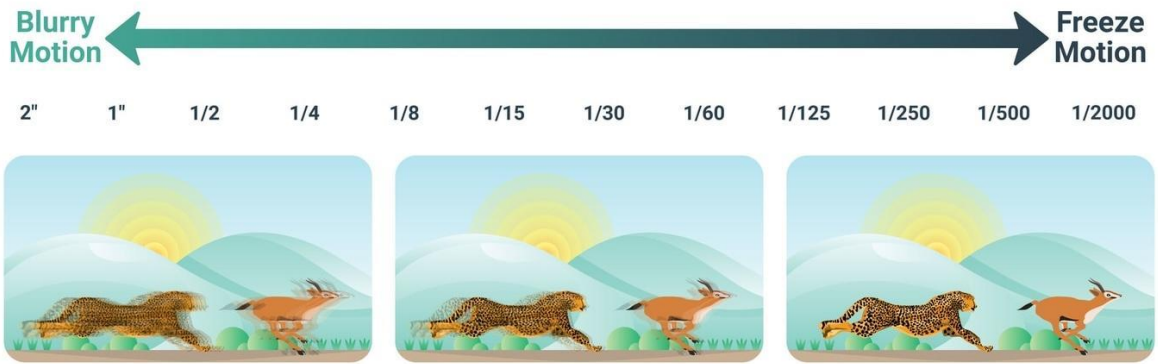


Exposure = irradiance x time x gain

- Shutter duration: time (seconds) the camera sensor is exposed to light when taking a photo.
- Shutter speed = reciprocal of shutter duration.

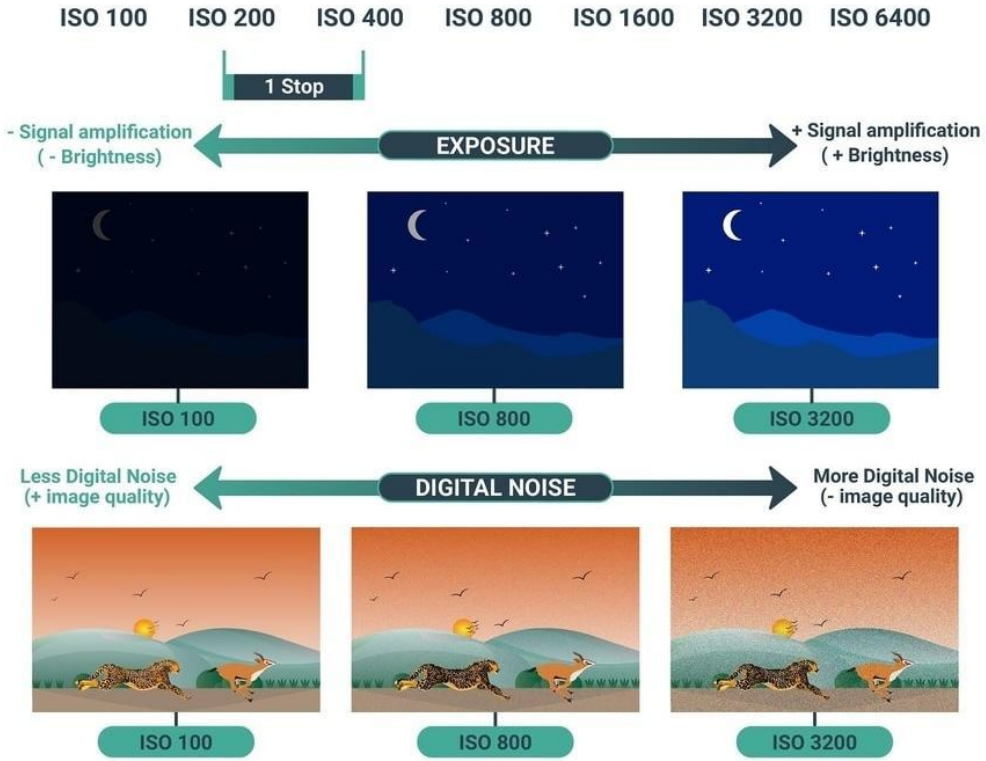
Exposure = irradiance x time x gain

- Shutter duration: time (seconds) the camera sensor is exposed to light when taking a photo.
- Shutter speed = reciprocal of shutter duration.
- Side effect: Increased shutter duration → increased motion blur.



Exposure = irradiance x time x gain

- ISO: sensor's sensitivity to light.
- In digital cameras, represents how much light is amplified.
- Higher gain introduces more noise



Question 3

3.1 Exposé of Exposure

3 Exposé of Exposure

James's camera supports several aperture, shutter duration, and ISO gain settings:

- Aperture: f/1.4, f/2, f/2.8, f/4, f/5.6, f/8, f/11, f/16.
- Shutter duration: Anything longer than 1/4000 seconds.
- ISO gain: 100, 200, 400, 800, 1600.

1. James's camera is currently on the following settings: aperture f/5.6, shutter duration 1/100 seconds, and ISO 200. In each part, leaving all other factors equal, select the new setting that allows James to double the exposure of images he captures.

   (a) Aperture (b) Shutter duration (c) ISO gain

3.1 Exposé of Exposure

1. James's camera is currently on the following settings: aperture f/5.6, shutter duration 1/100 seconds, and ISO 200. In each part, leaving all other factors equal, select the new setting that allows James to double the exposure of images he captures.

   (a) Aperture (b) Shutter duration (c) ISO gain

Solution:

(a) Each $\sqrt{2}$ increase in aperture doubles the amount of light. Thus, James can step up the aperture to f/4.0.

(b) Doubling the shutter duration doubles the exposure. Thus, James can double the duration to 1/50 seconds.

(c) Doubling the ISO gain doubles the exposure. Thus, James can double the ISO gain to 400.

3.2 Exposé of Exposure

2. James is now taking a shot in extremely bright light, where the correct exposure is equivalent to an aperture of f/8 with a shutter duration of 1/1000 seconds at ISO 100. He is taking a portrait of a person, and aesthetically would like to blur the background as much as possible without changing the exposure. Help James select his camera settings!

   (a) Aperture (b) Shutter duration (c) ISO gain

3.2 Exposé of Exposure

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   (a) Aperture (b) Shutter duration (c) ISO gain

Solution: Blurring the background requires a shallow depth of field, which is achieved by using the largest possible aperture. To allow this while maintaining correct exposure, we adjust the following settings:

(b) Minimize the shutter duration: We shorten the exposure time to 1/4000 seconds, reducing the amount of light reaching the sensor by $4\times$.

(c) Minimize the ISO gain: 100 is already the minimum, so no change is required.

(a) To maintain the same exposure level, we must increase light intake by 2 stops. This means opening the aperture from f/8 to f/4, which is supported by James's camera. (Each step up in f-stop doubles the light, so $f/8 \to f/5.6 \to f/4$.)

3.3 Exposé of Exposure

3. James has had a long day of photography and takes his last shot in the evening. The correct exposure is equivalent to an aperture of f/8 with a shutter duration of 1/8 second at ISO 100. This shot is a landscape, and aesthetically James would like to maximize the depth of field without changing the exposure.

   A rule of thumb in photography is that the shutter duration should be at least as fast as the inverse of the focal length of the lens to avoid motion blur due to hand-shake. James's camera has a 32 mm focal length lens, so make sure to choose a shutter duration at most 1/32 seconds.

   What camera settings should he choose?

   (a) Aperture (b) Shutter duration (c) ISO gain

3.3 Exposé of Exposure

3. James has had a long day of photography and takes his last shot in the evening. The correct exposure is equivalent to an aperture of f/8 with a shutter duration of 1/8 second at ISO 100. This shot is a landscape, and aesthetically James would like to maximize the depth of field without changing the exposure.

   What camera settings should he choose?

   (a) Aperture (b) Shutter duration (c) ISO gain

Solution: Maximizing the depth of field is achieved by using the smallest possible aperture. To allow this while maintaining correct exposure, we adjust the following settings:

(b) Maximize the shutter duration: 1/32 seconds (decrease by 2 stops from 1/8 seconds).

(c) Maximize the ISO gain: 1600 (increase by 4 stops from ISO 100).

(a) To maintain the same exposure, we decrease the aperture by 2 stops from f/8 to f/16. (Each step down in f-stop doubles the light, so $f/8 \to f/11 \to f/16$.)

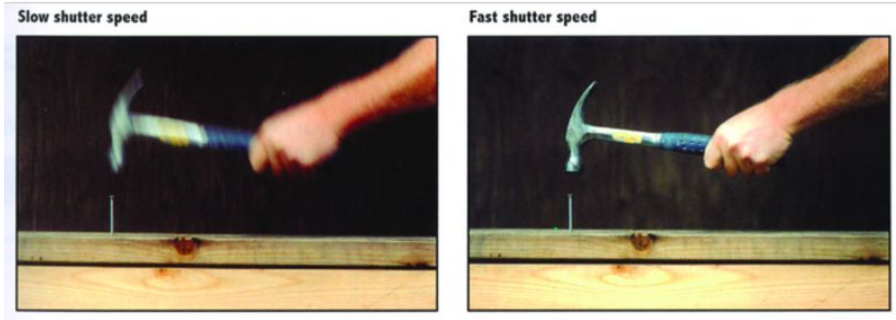
1.1 Terminology

Exposure:

- determines how light or dark an image will appear
- determined by three settings: aperture size, shutter speed, and ISO (gain)

Shutter speed:

- how quickly the shutter opens and closes for the sensor to capture light
- the reciprocal of the how long the shutter is open for during a capture



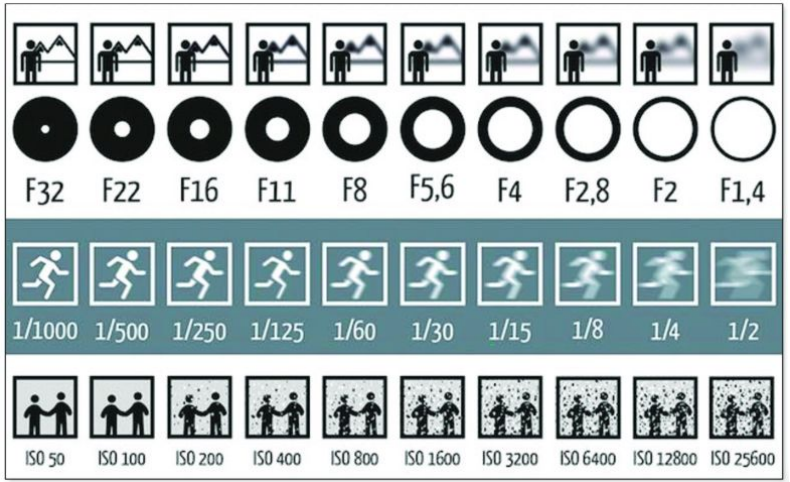
1.1 Terminology

Aperture:

- the size of the opening through which light enters the camera and hits the sensor or film

F-stop:

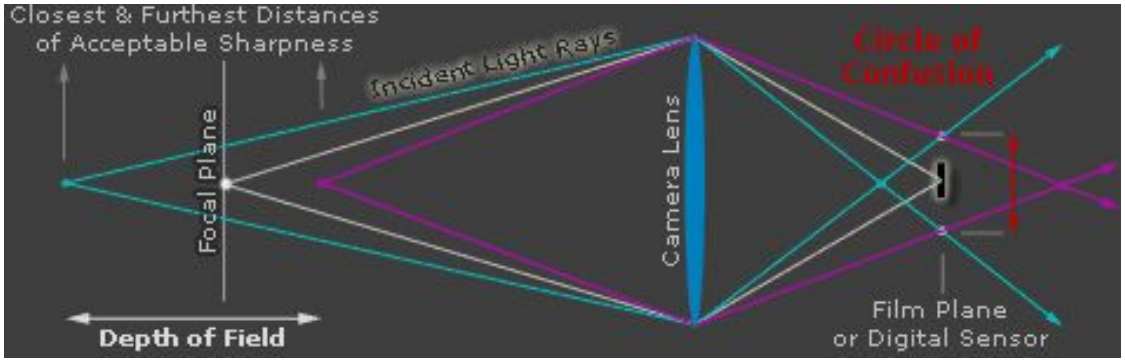
- the ratio between the focal length and aperture size for a given camera configuration (f = d/A)



1.1 Terminology

Circle of confusion:

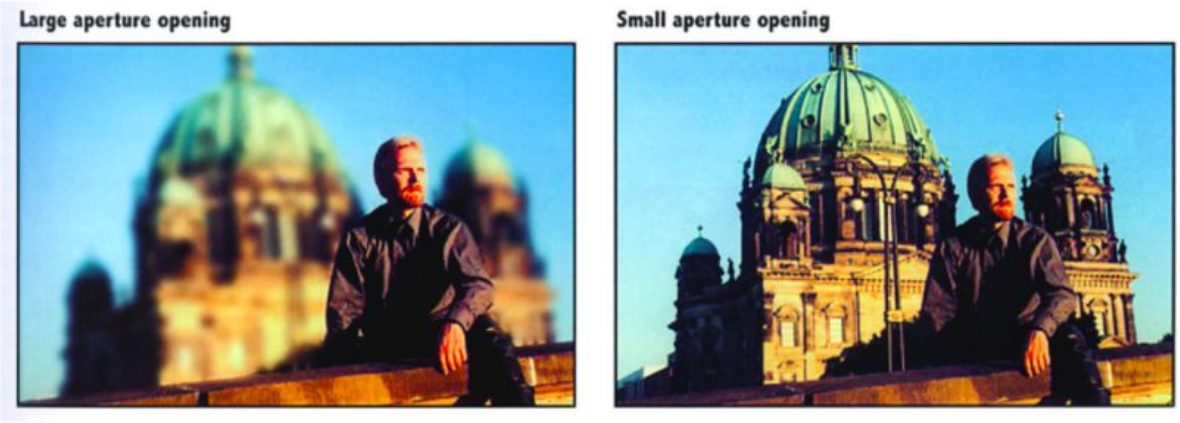
- a spot caused by a cone of incoming light rays from a lens that do not come into perfect focus
- the less in focus, the larger the circle of confusion

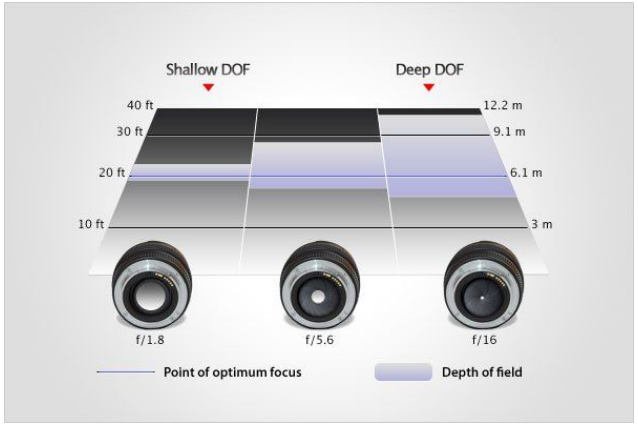


1.1 Terminology

Depth of field:

- the range of depths that are in focus for a given camera configuration
- = the farthest depth in focus - the closest depth in focus





Larger aperture, smaller depth of field

1.1 Terminology

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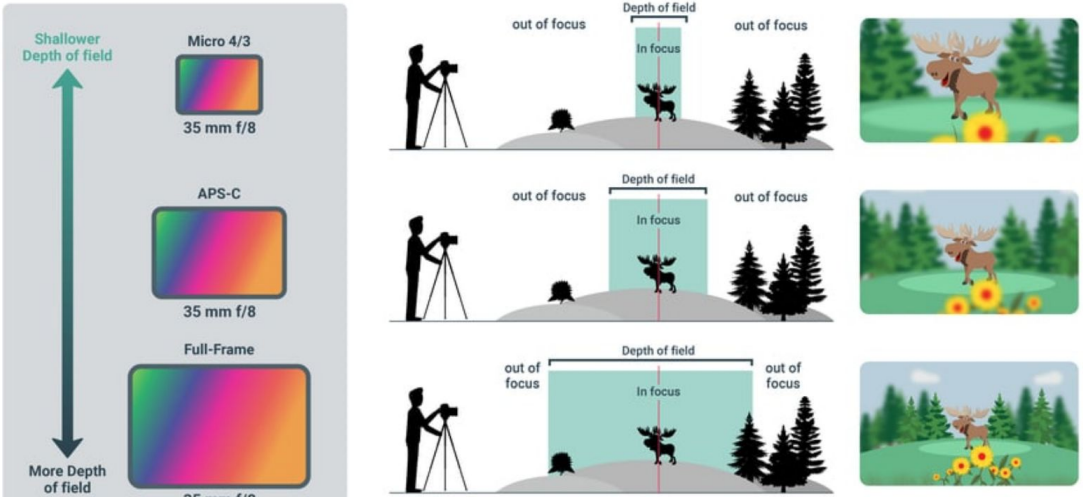

Larger sensor, larger depth of field

1.2 Configurations and Effects

1) How are focal length and field of view related? For a fixed sensor size, what effect does increasing the focal length have on the field of view? (Hint: Triangles)

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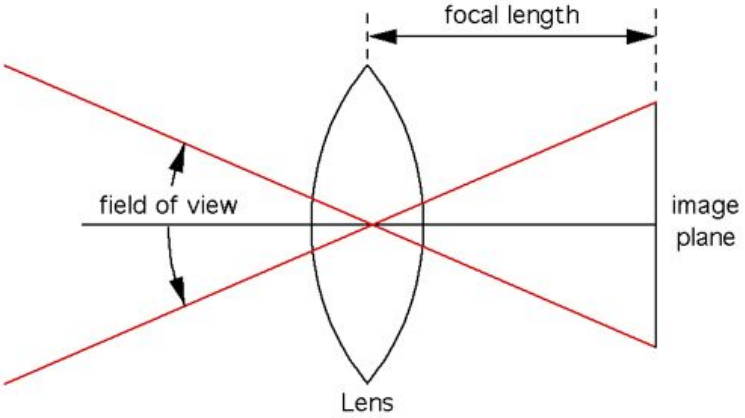
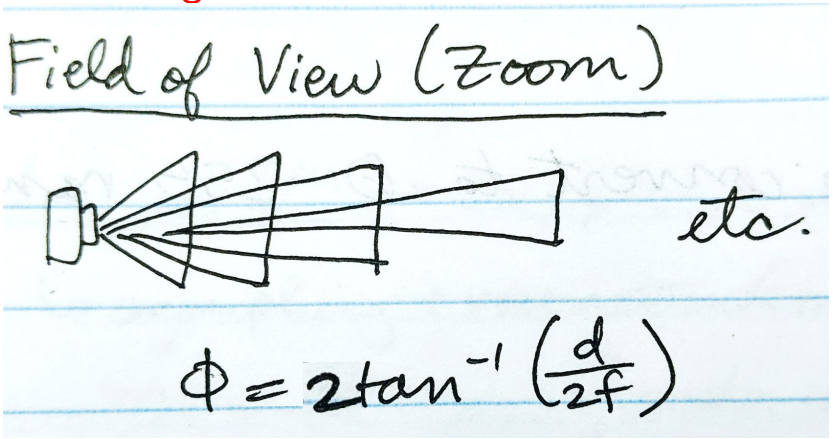
Solution: Focal length and field of view are inversely related. A shorter focal length results in a wider field of view, while a longer focal length results in a narrow field of view





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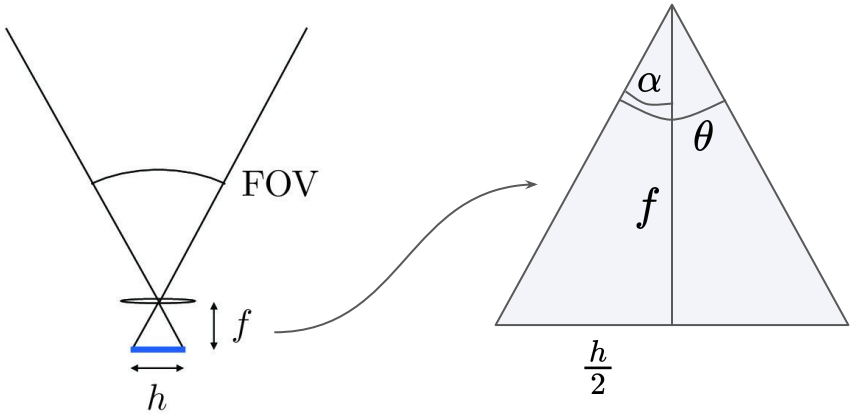


$$\theta = 2 * alpha = 2arctan(\frac{h}{2f})$$

1.2 Configurations and Effects

2) An image captured with a 50mm focal length is considered to have a ”normal” field of view. What about an image taken with a 15mm focal length? How about 150mm focal length? Do these types of images have special names?

1.2 Configurations and Effects

2) An image captured with a 50mm focal length is considered to have a ”normal” field of view. What about an image taken with a 15mm focal length? How about 150mm focal length? Do these types of images have special names?

Solution: An image taken with a relatively shorter focal length such as 15mm is called wide angle. An image taken with a relatively longer focal length such as 150mm is called a tele

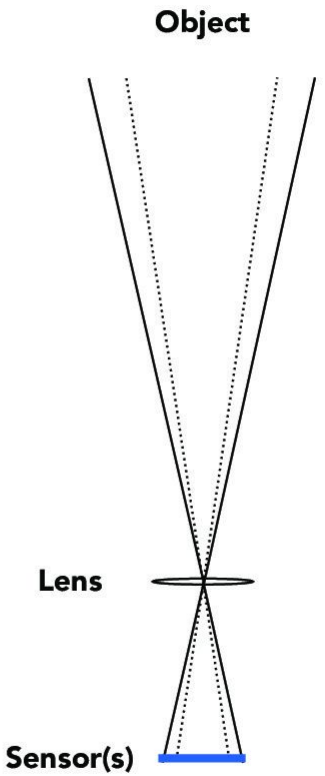
1.2 Configurations and Effects

4) How are sensor size and field of view related? What happens to the field of view if I don’t move my sensor, but increase its size? What about decreasing its size?

1.2 Configurations and Effects

4) How are sensor size and field of view related? What happens to the field of view if I don't move my sensor, but increase its size? What about decreasing its size?

- Solution: Sensor size and FOV are directly proportional
- Larger sensor size will result in a larger field of view, and vice-versa.



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5) If my F-number is increasing, then what can I deduce about the size of my aperture and/or my focal length?

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- Larger sensor size will result in a larger field of view, and vice-versa.

5) If my F-number is increasing, then what can I deduce about the size of my aperture and/or my focal length?

- Solution: F-number := the ratio of focal length to aperture size.
- F-number is increasing → focal length is increasing relative to my aperture size
    a. I increase my focal length while holding aperture size constant
    b. I decrease my aperture size while holding focal length constant

1.2 Configurations and Effects

6) To help reduce motion blur when I capture photos, I can increase the shutter speed of my camera (which reduces the amount of time the sensor is exposed to light). What are the tradeoffs of doing so? What can I do to mitigate the tradeoffs?

1.2 Configurations and Effects

6) To help reduce motion blur when I capture photos, I can increase the shutter speed of my camera (which reduces the amount of time the sensor is exposed to light). What are the tradeoffs of doing so? What can I do to mitigate the tradeoffs?

Solution: Exposure = product of (exposure time * irradiance)

Increasing shutter speed reduces exposure time → overall exposure value is lower

Images will be darker in exchange for reducing motion blur. To counteract this, we can attempt to boost the amount of irradiance falling on the sensor by increasing the size of our aperture by a proportional amount.

1.2 Configurations and Effects

7) How are depth of field and aperture size related? What happens to the depth of field if I reduce the size of my aperture? What else happens if I reduce the size of my aperture?

1.2 Configurations and Effects

7) How are depth of field and aperture size related? What happens to the depth of field if I reduce the size of my aperture? What else happens if I reduce the size of my aperture?

Solution: Depth of field and aperture size are inversely related.

Smaller aperture size → larger depth of field (a larger range of depths in the image will be in focus), and vice versa

However, aperture size is directly proportional to exposure → reducing the aperture size will increase depth of field at the tradeoff of having a darker image

1.2 Configurations and Effects

8) Briefly explain why photographers must choose between depth of field and motion blur for moving objects.

1.2 Configurations and Effects

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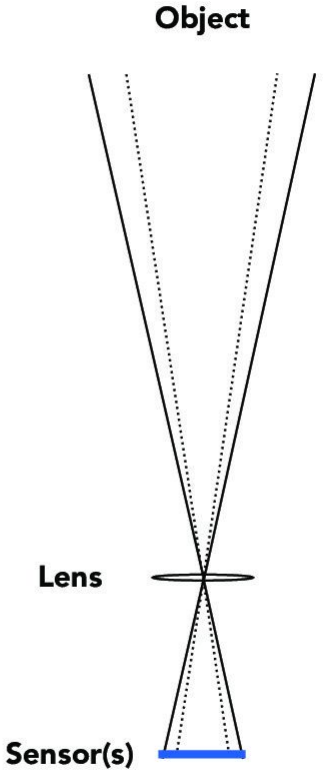
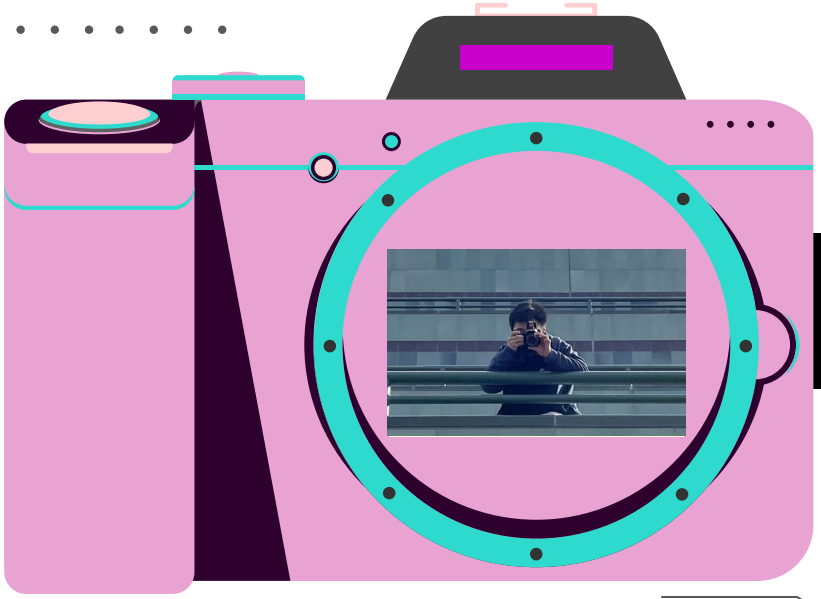
Solution: To gain better depth of field, photographers must reduce their aperture. However, this means that less light will reach the sensor.

To maintain roughly the same amount of exposure that the sensor gets, photographers must decrease their shutter speed (i.e. slower speed), which could introduce motion blur. The opposite tradeoff also holds true.

Relationships

- Depth of field <> aperture
  - Inversely related
  - Smaller angle → smaller CoCs and larger depth of field.
- Exposure <> aperture
  - Directly related
  - Larger area for light to enter → more light entering
- Sensor size <> field of view
  - Directly related
  - See diagram →
- Focal length <> field of view
  - Inversely related
  - Closer sensor → light from wider angles will hit



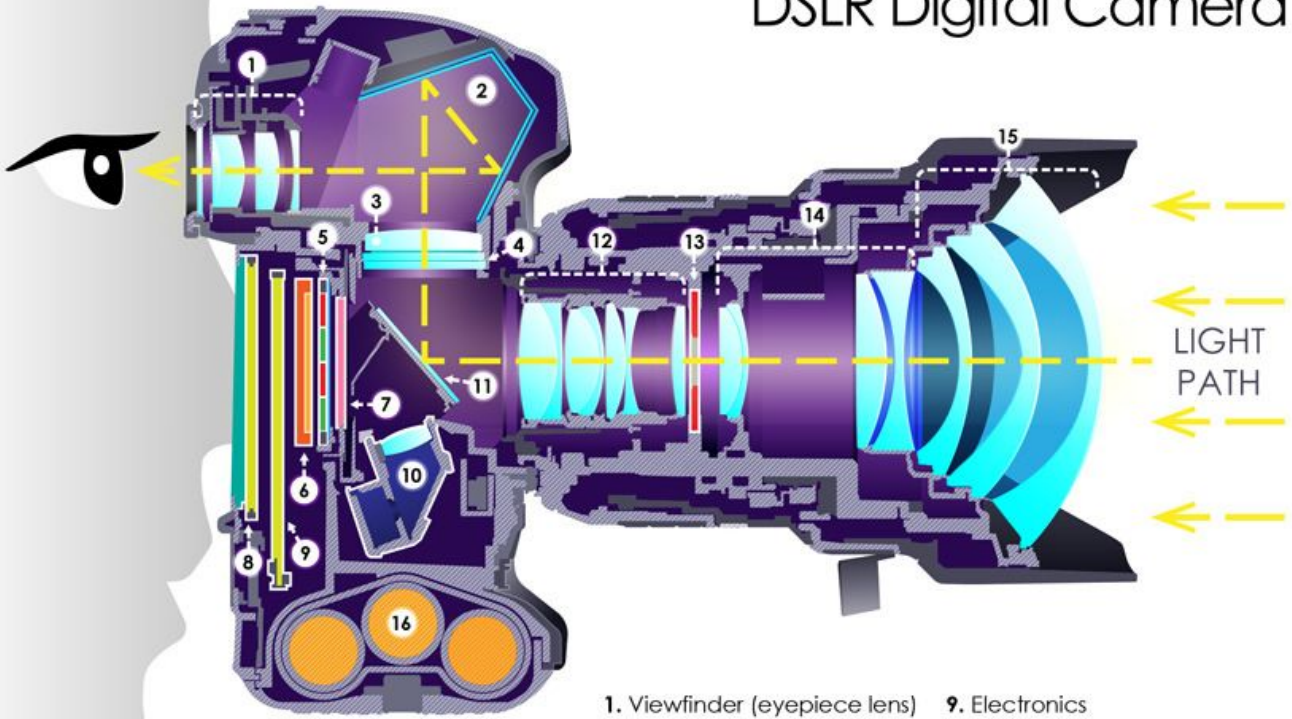


The Fake Camera Discussion

Definitely am not reusing this

How does a camera work?

DSLR Digital Camera



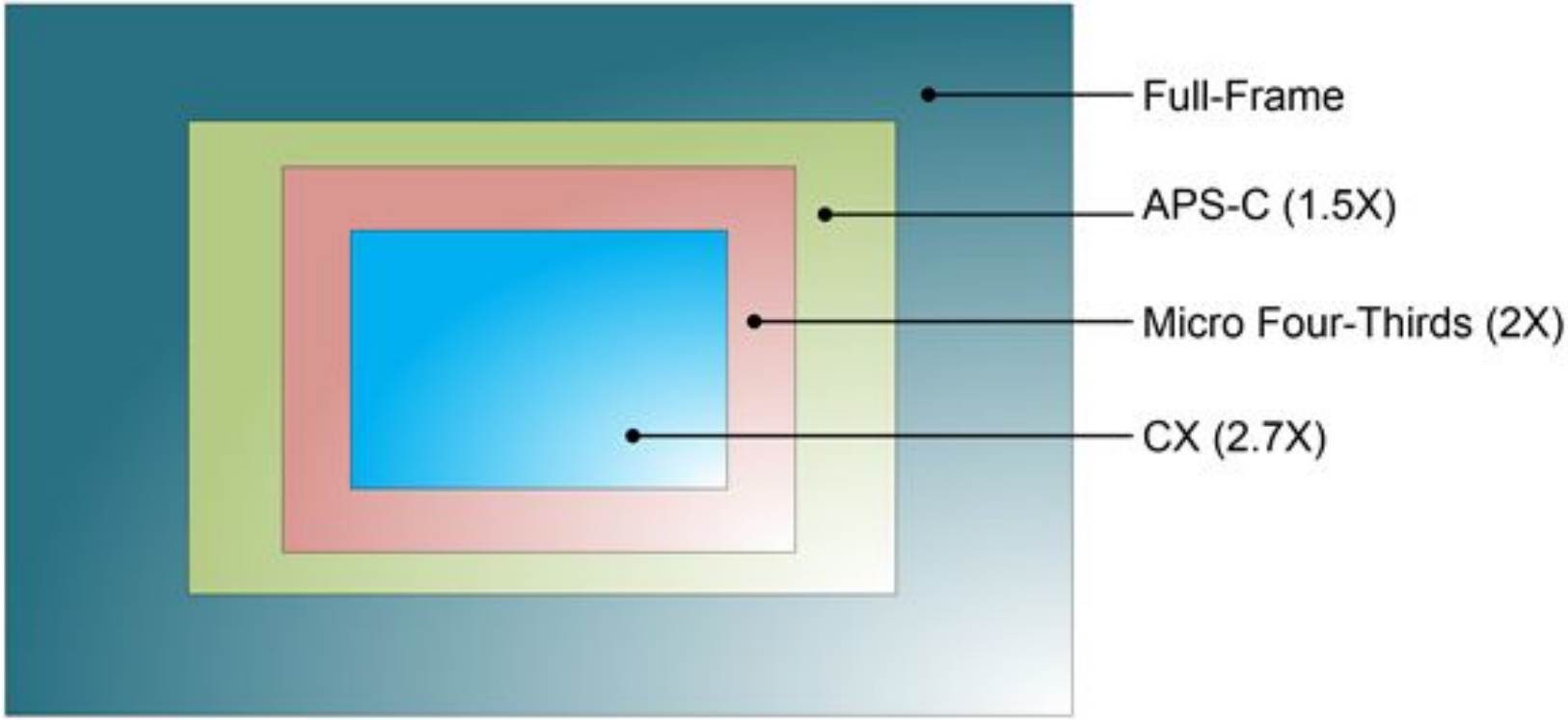
1. Viewfinder (eyepiece lens)
2. Pentaprism
3. Focusing screen
4. Condenser lens
5. Color and infrared filter
6. Digital sensor
7. Shutter
8. Display
9. Electronics
10. Autofocus system
11. Reflex and relay mirror
12. Focusing elements
13. Aperture
14. Zoom elements
15. Front line gathering elements
16. Batteries

Camera Sensor Sizes

CAMERA SENSOR SIZE COMPARISON CHART

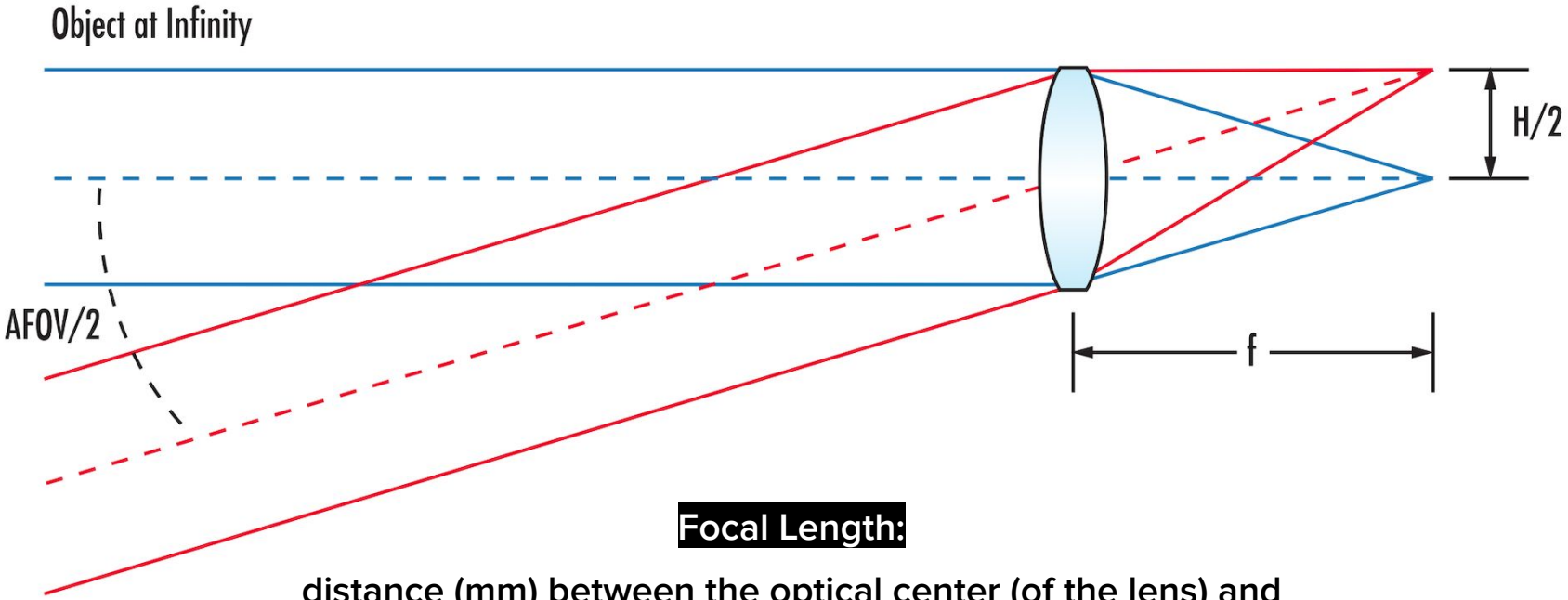
	MEDIUM FORMAT	FULL-FRAME	APS-C	MICRO 4/3	1"	1/2.55"
PICTURE						
SENSOR SIZE	53.0 X 40.20 MM	35.00 X 24.00 MM	23.6 X 15.60 MM	17.00 X 13.00 MM	12.80 X 9.60 MM	6.17 X 4.55 MM
CROP FACTOR	0.64	1	1.52	2	2.7	5.62
CAMERA						

Camera Sensor Sizes



Camera Sensor Sizes

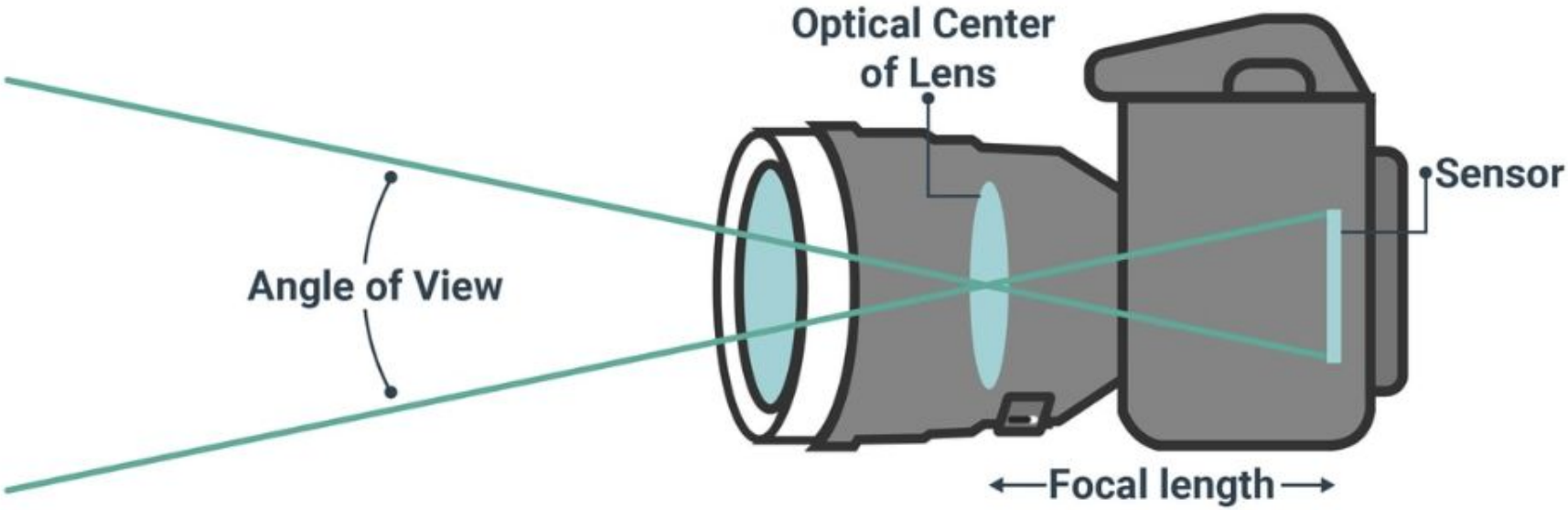
Focal Length



Focal Length:

distance (mm) between the optical center (of the lens) and the camera sensor

Focal Length

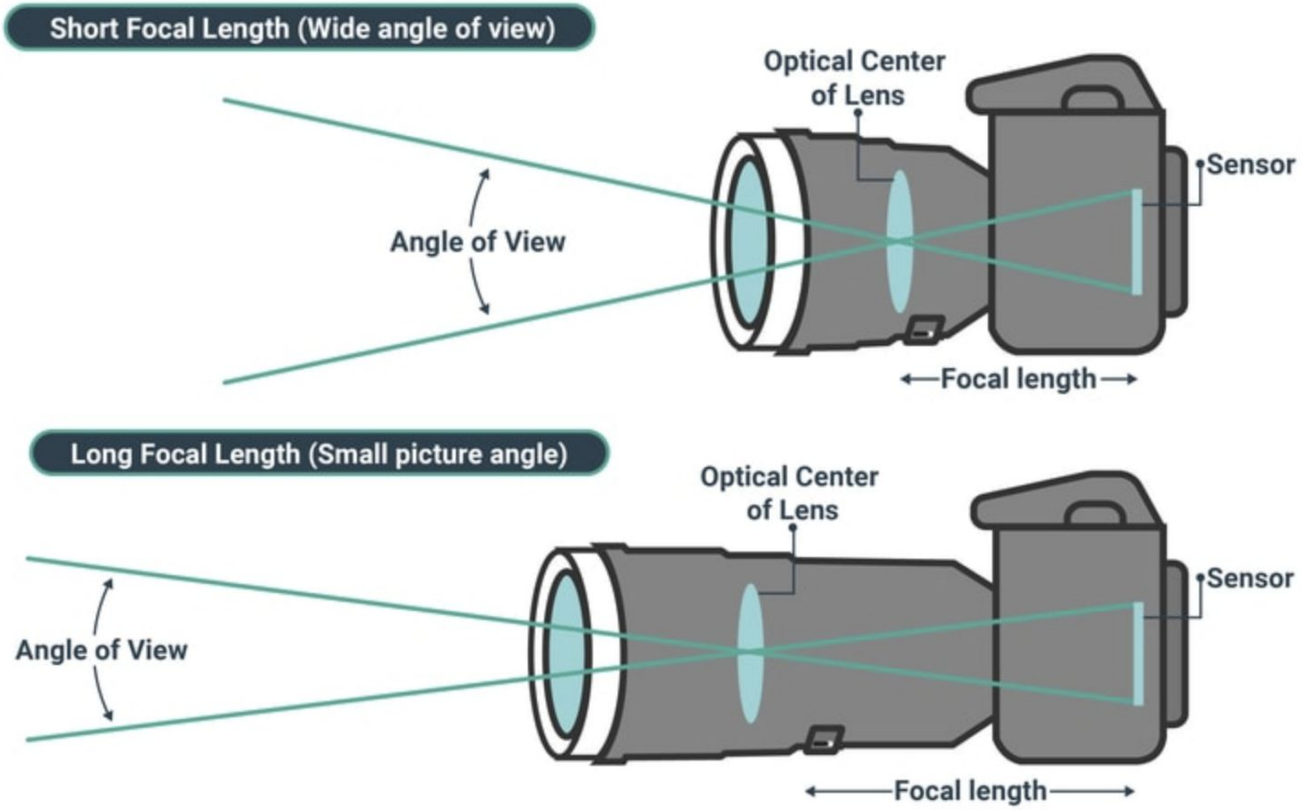


Angle/Field of View:

angular extent of the observable world

that is visible to the camera

Focal Length



Focal Length

A longer focal length *generally* means a longer lens*

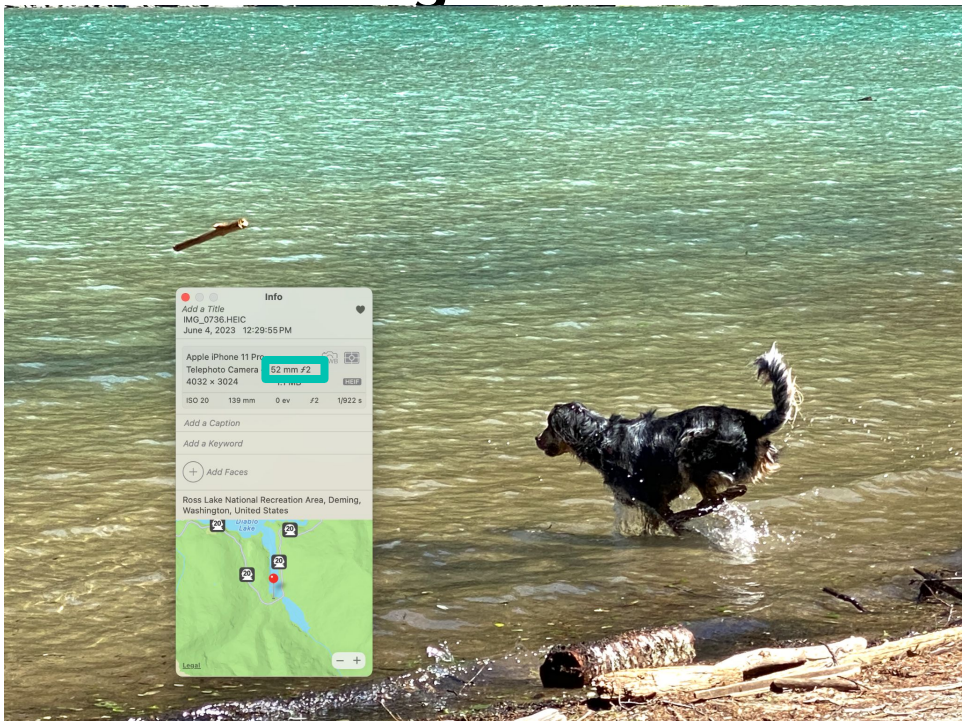
** assumes all other variables held constant, many exceptions apply*

Focal Length

A longer focal length *generally* means a longer

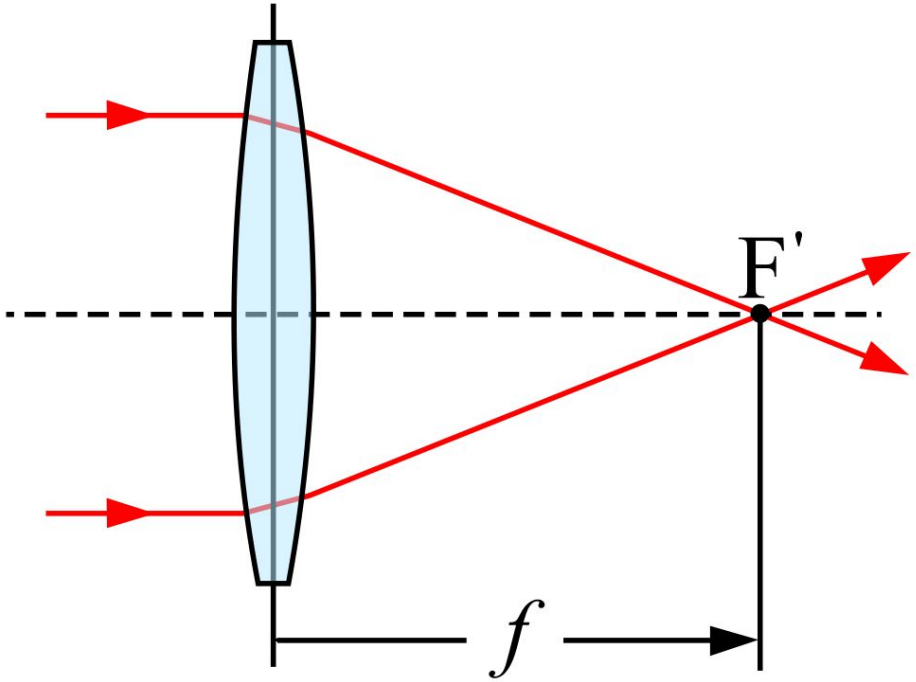
** assumes all other variables held constant, many exceptions apply*

Sensor Sizes and Focal Length

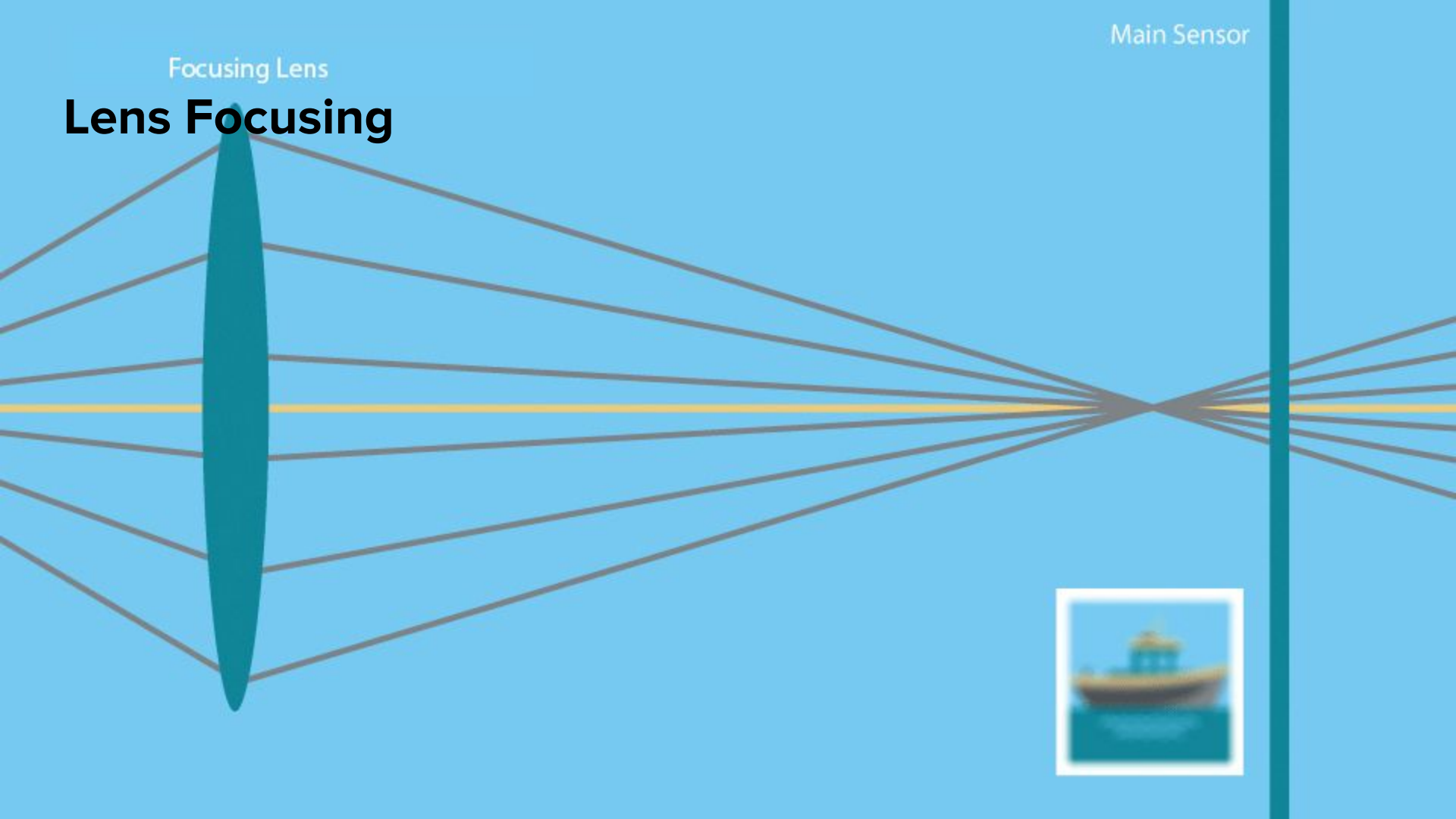


Focal Length is typically converted to full frame equivalent

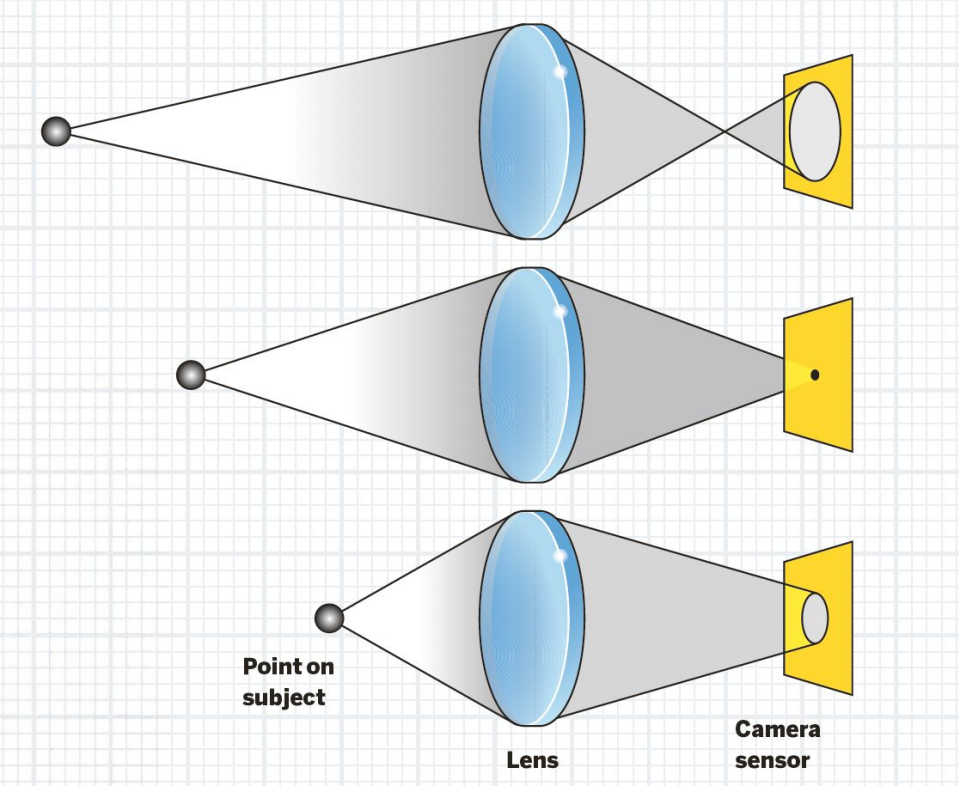
Focusing



Lens Focusing



Out of Focus: Circle of Confusion

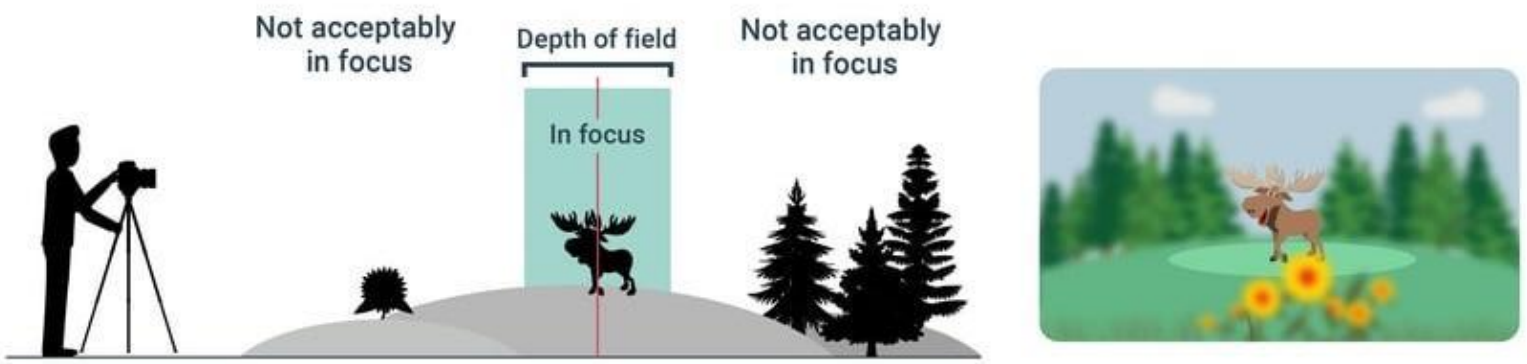


Circle of Confusion:

optical spot caused by a cone of light rays from a lens not coming to a perfect focus

(aka blurring)

Depth of Field



Depth of Field:

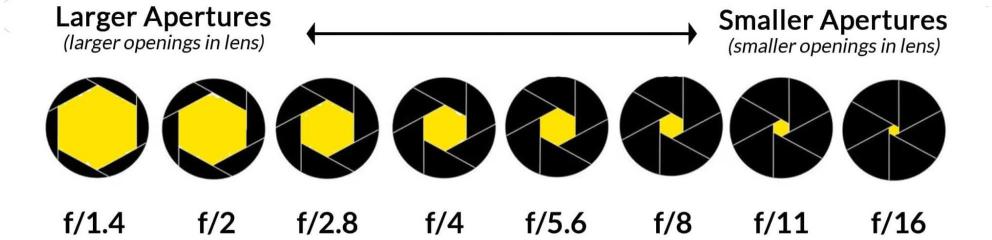
the range of depths that is acceptably “in focus” or “sharp”

Aperture

Aperture:

the opening in a camera lens that allows light to enter the camera and onto the sensor

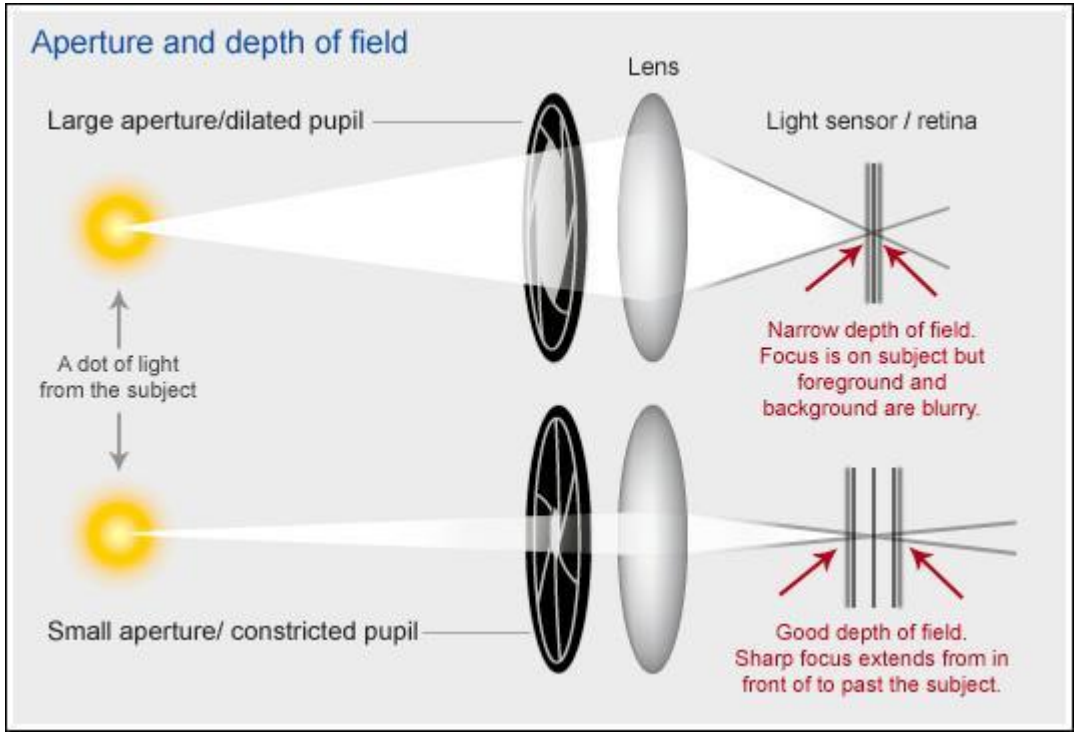
1. Controls amount of light
2. Controls depth of field



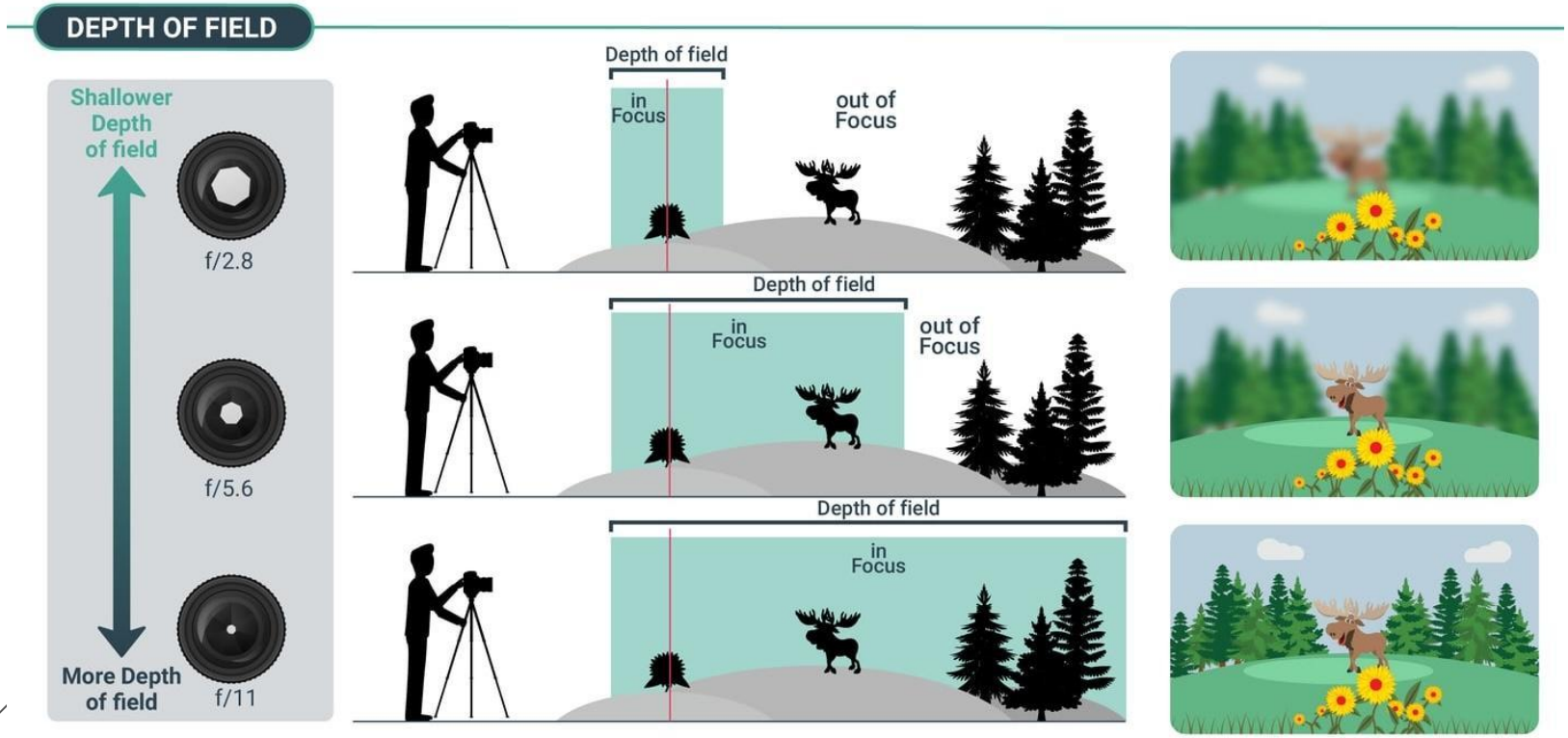
Measured in **f-stops:**

lens focal length divided by diameter of aperture opening

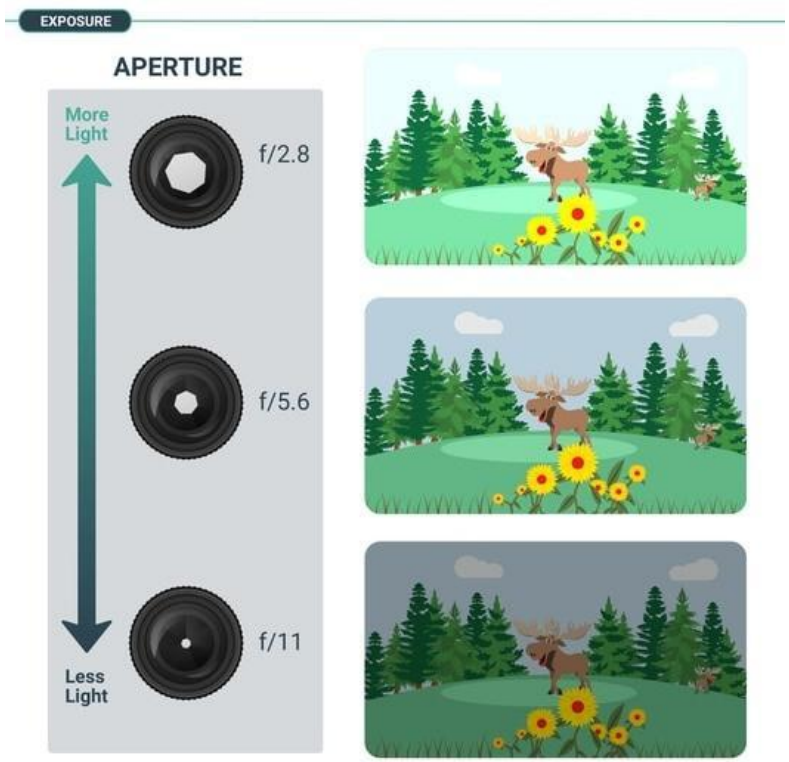
Aperture: Controlling Depth of Field



Aperture: Controlling Depth of Field



Aperture: Controlling Exposure



Each √**2** decrease in f-stop

halves

the amount of light

(also known as a “full-stop” of light)

Small Apertures for Large DoF

Wide Aperture Lens are generally better...

Shallow DoF is desirable for subject isolation

More light means superior low light performance

You can always “step-down” or reduce your aperture, but not up!

… but are much bigger…

… and more expensive!

RF50mm F1.8 STM

SKU: 4515C002

$199.99

In Stock

FREE Standard Shipping

RF50mm F1.2 L USM

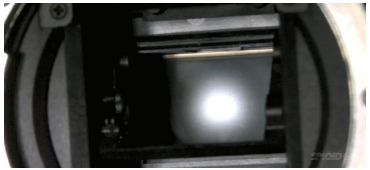
SKU: 2959C002

$2,299.00

In Stock

FREE Standard Shipping

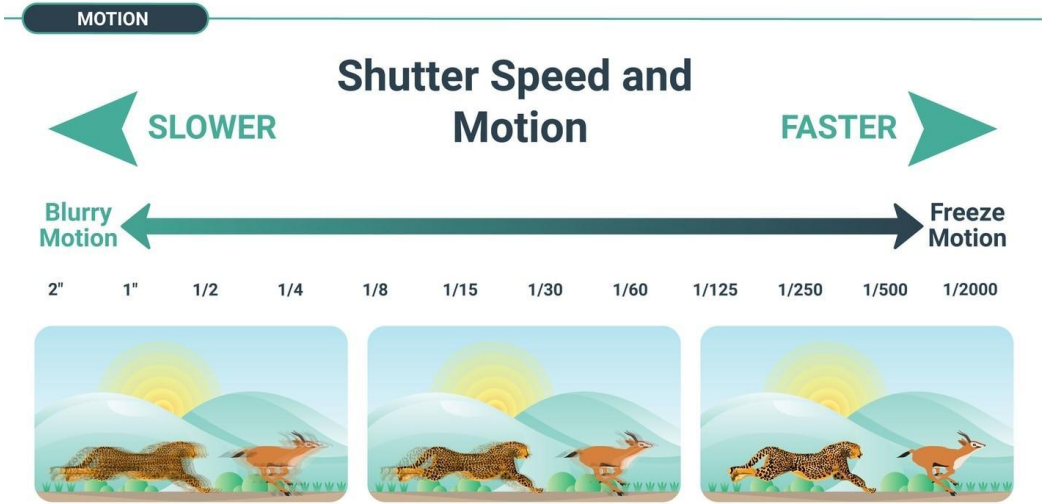
Controlling Exposure: Shutter Speed



Shutter Speed:

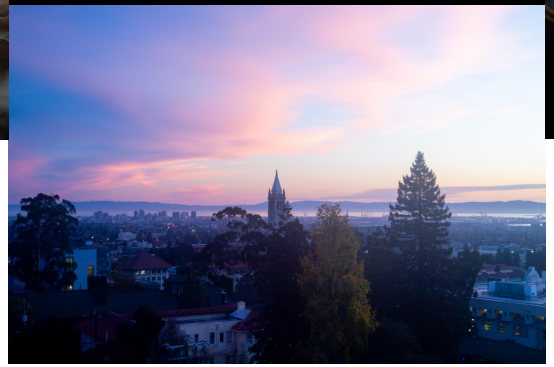
length of time (in seconds) the camera sensor is exposed to light when taking a photograph

1. Controls amount of light (linearly)
2. Controls motion blur



Slow Shutter Speed Photography

Capturing Motion Blur



Fast Shutter Speed Photography

Capturing Action

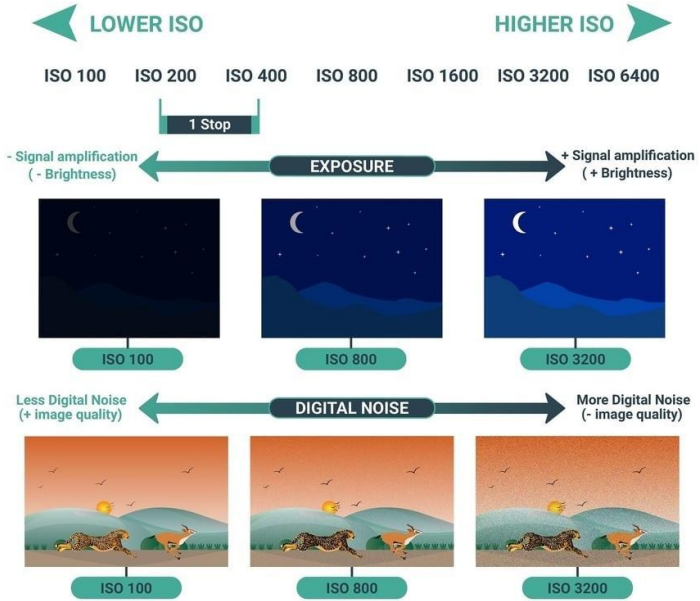
ISO (gain)

ISO:

(International Organization for Standardization):

sensor's sensitivity to light

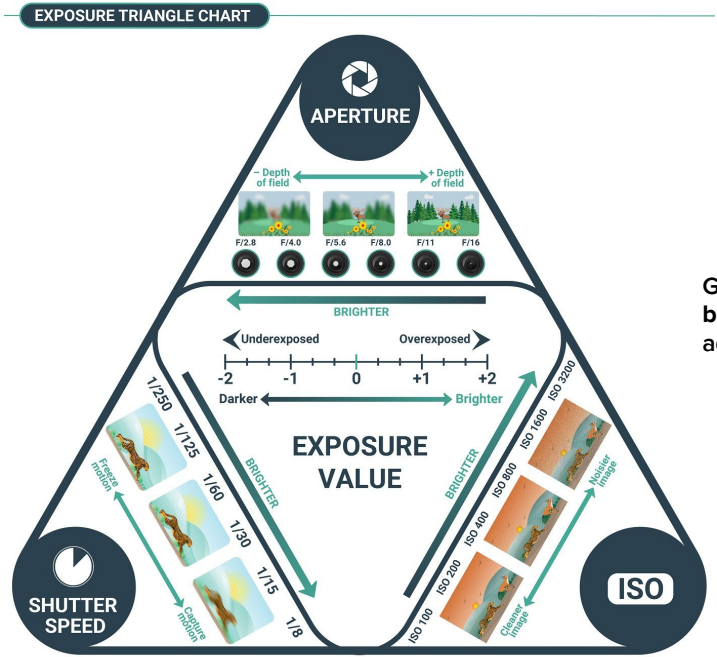
(In digital cameras, represents how much input light is amplified)



Exposure

Exposure:

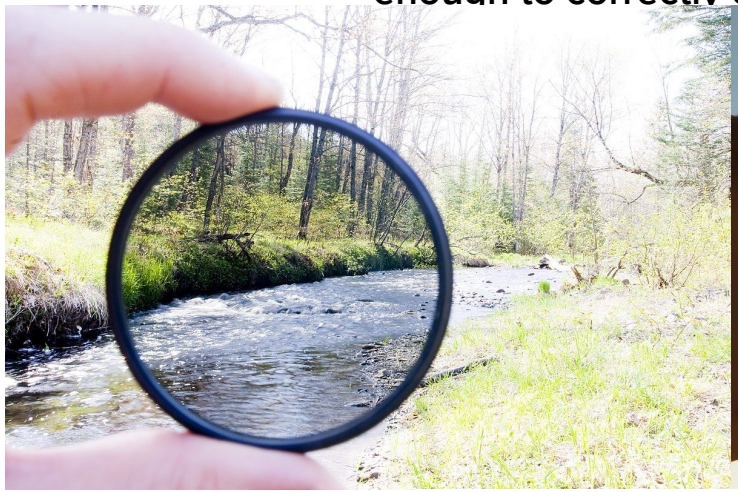
overall brightness of a captured image



Generally, **choose desired motion blur and depth of field first**, then adjust ISO accordingly

Advanced Exposure: ND Filters

Sometimes you can’t lower your ISO far enough to correctly expose your image



Question 4

4 You Might Not Believe Your Eyes...

A camera has an ideal thin lens with a 50 millimeter focal length and f/4.0 F-number. It is focused at optical infinity, so the image sensor is placed at the focal plane. A firefly floats 1 meter in front of the camera lens.

1. Calculate z_i, the horizontal distance between the lens and the image formed of the firefly. Does the image form in front, on, or behind the image sensor?

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Hint: recall the thin-lens equation

$$\frac{1}{f} = \frac{1}{z_o} + \frac{1}{z_i}$$

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Focal length — Object distance — Image distance

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Focal length = 50mm
Object distance = 1000mm

$$\frac{1}{f} = \frac{1}{z_o} + \frac{1}{z_i}$$

Focal length | Object distance | Image distance

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$$\frac{1}{f} = \frac{1}{z_o} + \frac{1}{z_i}$$

Focal length = 50mm
Object distance = 1000mm

$$\frac{1}{50} = \frac{1}{1000} + \frac{1}{z_i}$$

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Focal length = 50mm
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$$\frac{1}{50} = \frac{1}{1000} + \frac{1}{z_i}$$

$$\frac{19}{1000} = \frac{1}{z_i}$$

$$\frac{1000}{19} = z_i$$

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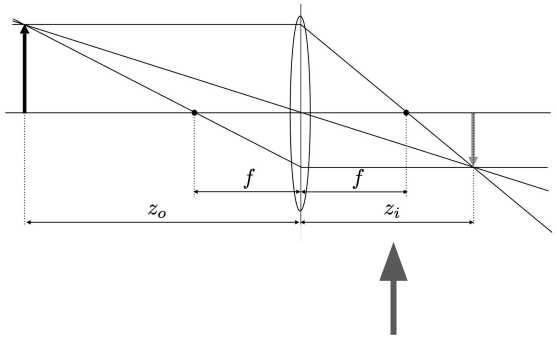

Recalling this figure, the image forms behind the image sensor.

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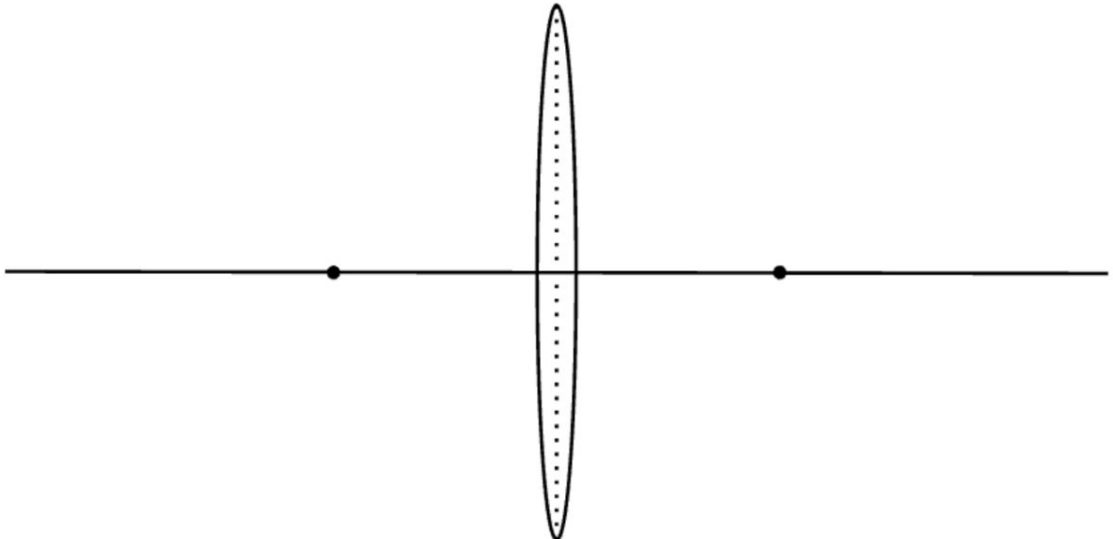
2. Draw a ray diagram representing this problem. In your diagram, include the firefly, lens, image sensor, and rays from the firefly passing through the lens. Label the focal lengths (f), the distance from firefly to lens (z_o), and the distance from the lens to where the image of the firefly converges (z_i).

   (Your drawing does not need to be to scale.)



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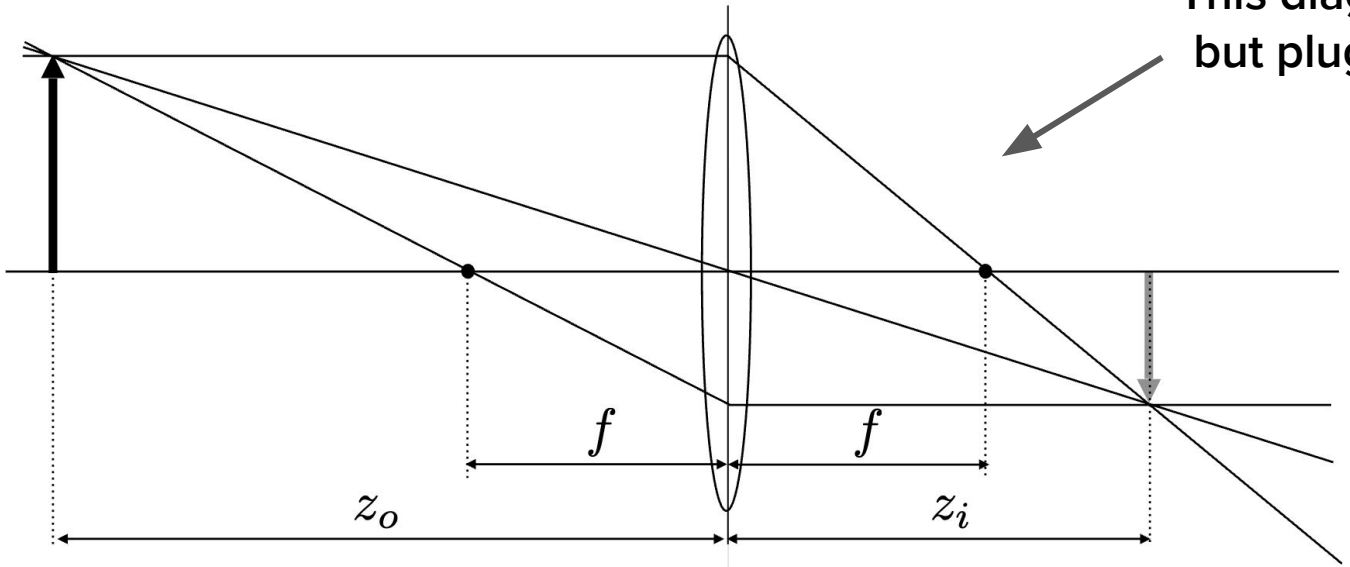
This diagram is a hint, but plug in what you know!



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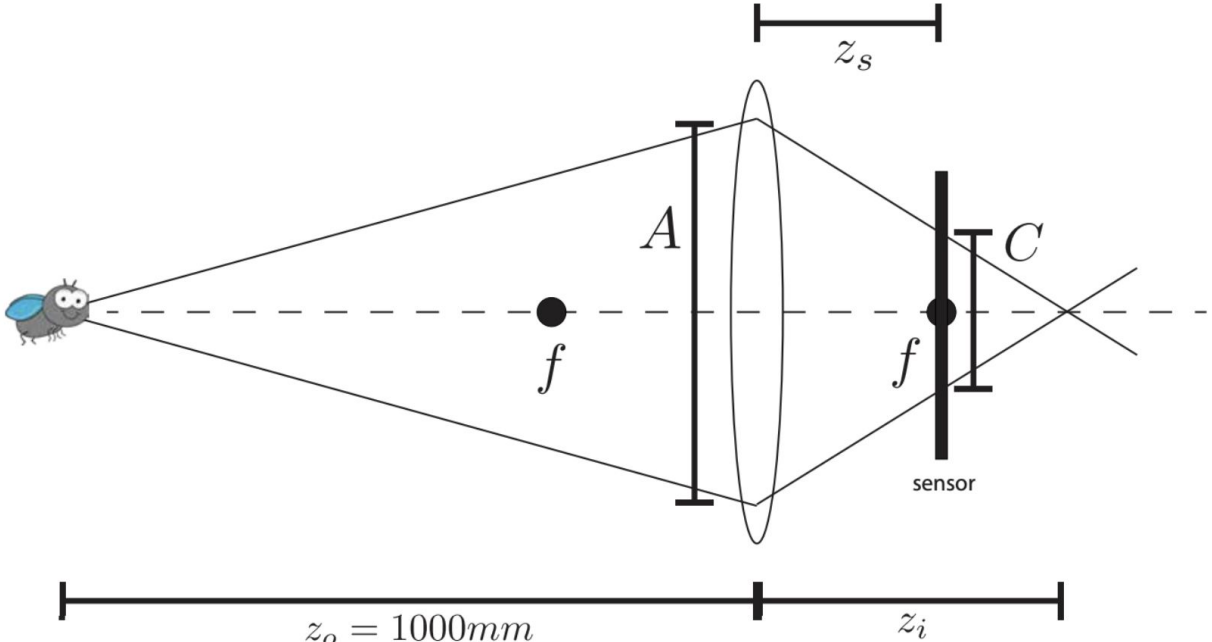

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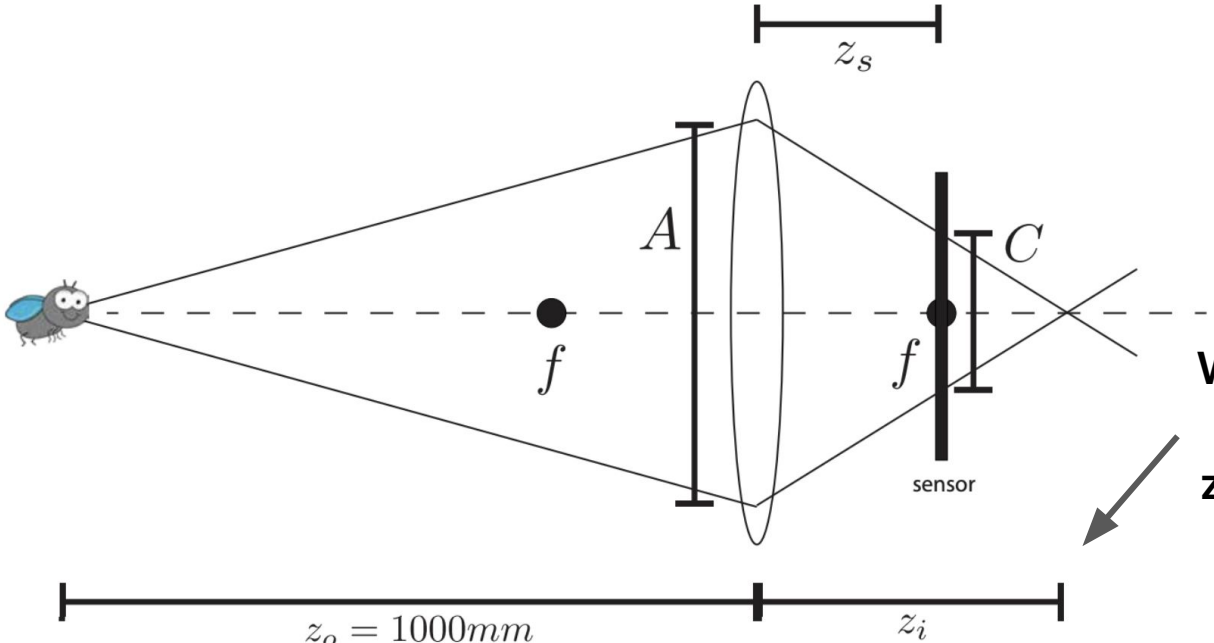

We note that zi>zs, because zi=1000/19=52.6..., which is > f=50

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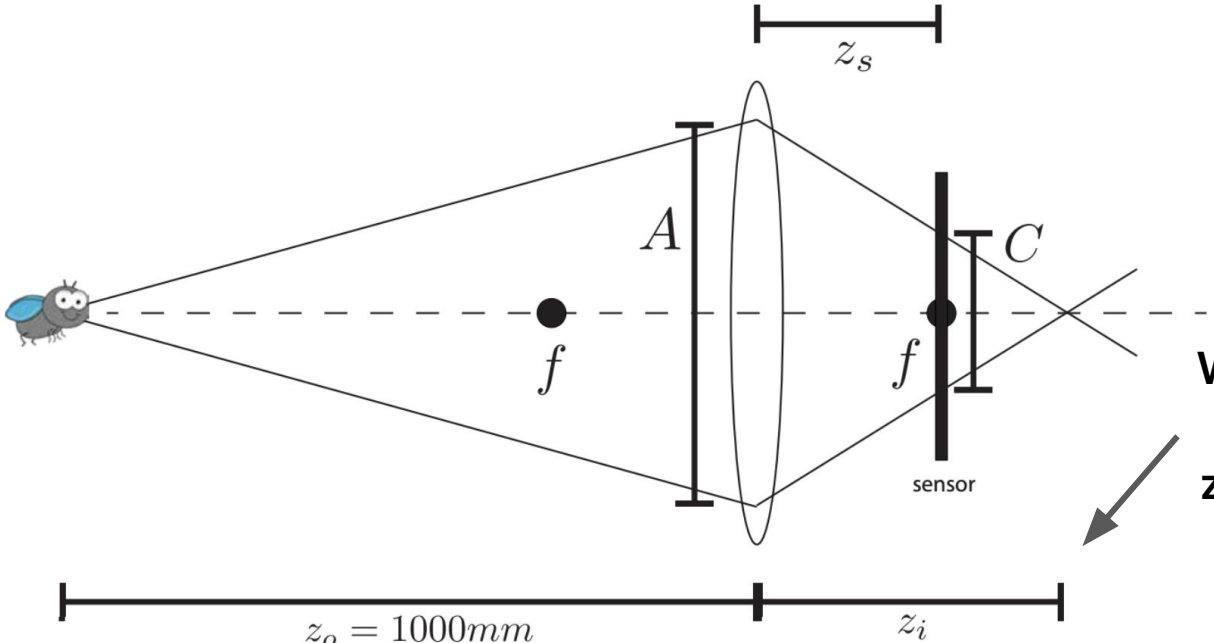

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3. Recall that F-number is the ratio of focal length to aperture diameter. What is the aperture diameter of the lens, A, in millimeters?

Definition: F-Number of a Lens

- **The F-Number of a lens is defined as the focal length divided by the diameter of the aperture**

F-Number = focal length / diameter

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Solution: $A = f/4.0 = \frac{50 \text{ millimeters}}{4.0} = 12.5 \text{millimeters}.$

F-Number = focal length / diameter
diameter = focal length / F-Number

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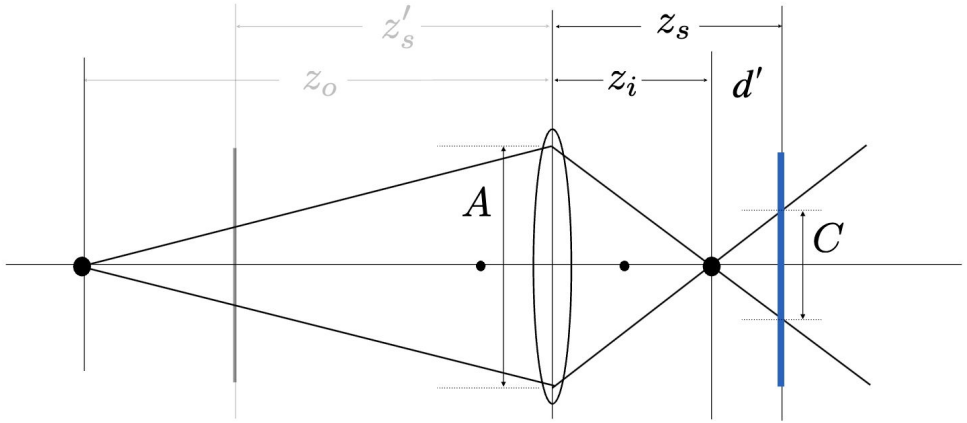
4. C is the diameter of the circle of confusion formed on the image sensor. Calculate C using A, z_i, z_o, and f. (Hint: can you spot any similar triangles?)



Circle of confusion is proportional to the size of the aperture

$$\frac{C}{A} = \frac{d'}{z_i} = \frac{|z_s - z_i|}{z_i}$$

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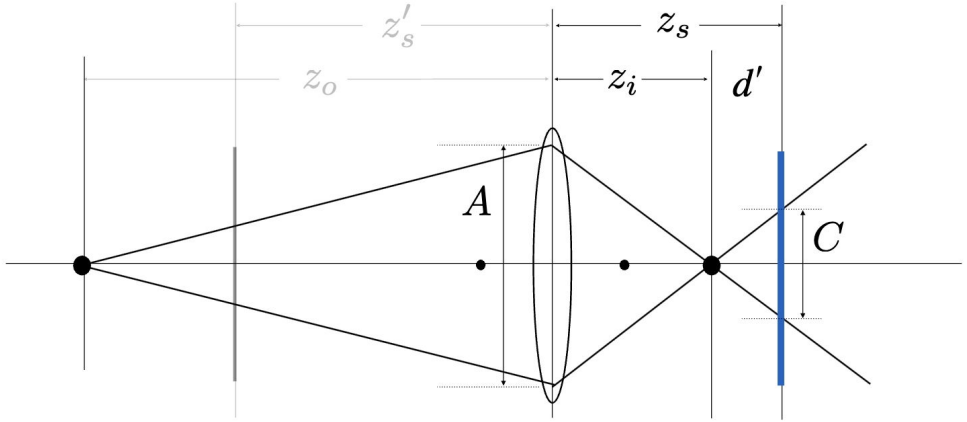

We can rewrite **d' = zi-f** from the previous problems.

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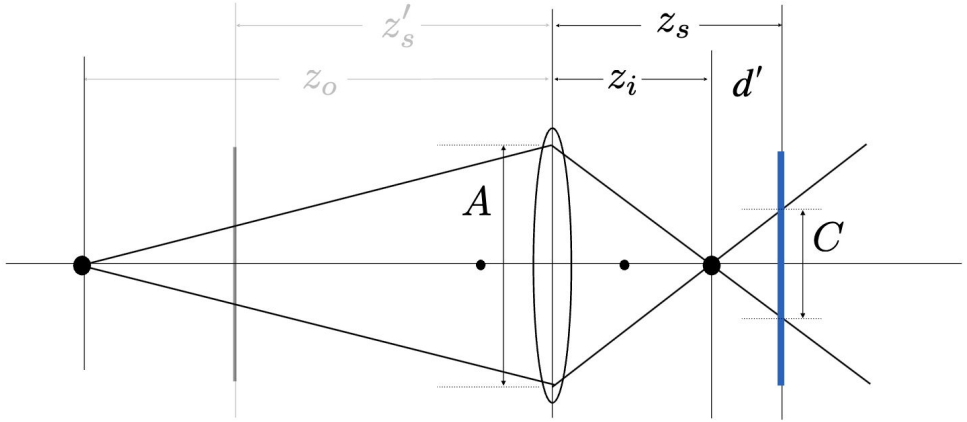

We can rewrite d' = zi-f from the previous problems.

$$\frac{C}{z_i - f} = \frac{A}{z_i}$$

Circle of confusion is proportional to the size of the aperture

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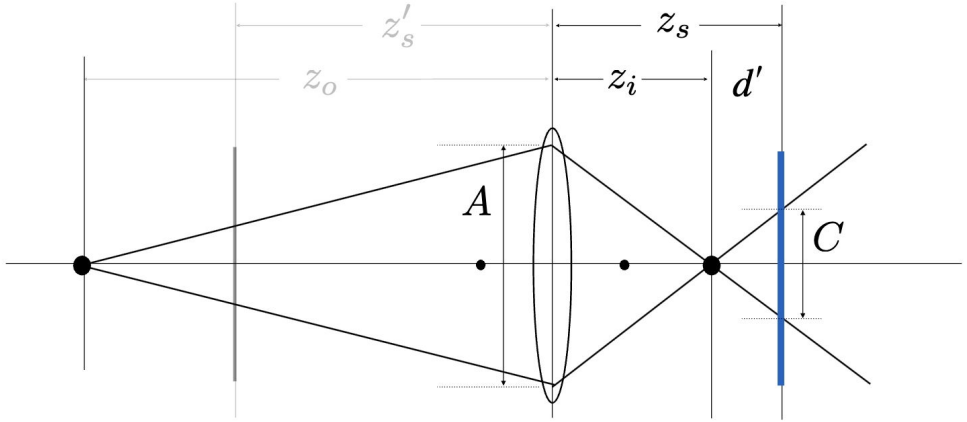

We can rewrite d' = zi-f from the previous problems.

$$\frac{C}{z_i - f} = \frac{A}{z_i}$$

$$C = \frac{A(z_i - f)}{z_i}$$

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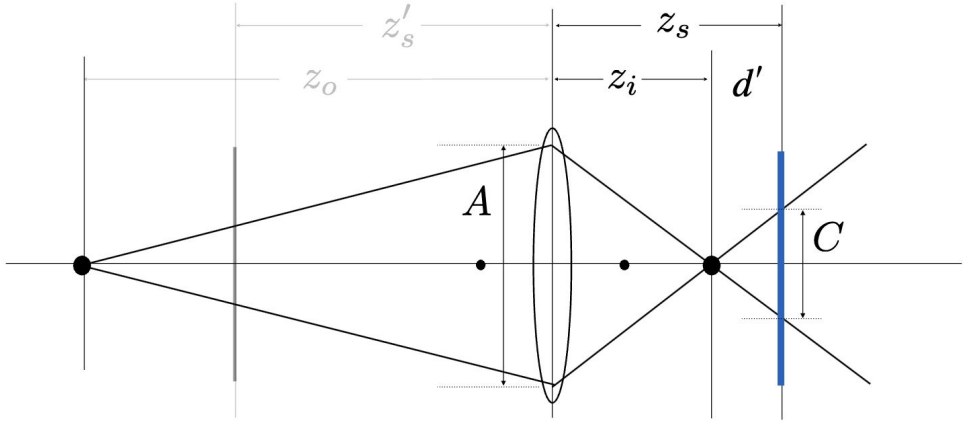
4. C is the diameter of the circle of confusion formed on the image sensor. Calculate C using A, z_i, z_o, and f. (Hint: can you spot any similar triangles?)



Circle of confusion is proportional to the size of the aperture

$$\frac{C}{A} = \frac{d'}{z_i} = \frac{|z_s - z_i|}{z_i}$$

We can rewrite d' = zi-f from the previous problems.

$$\frac{C}{z_i - f} = \frac{A}{z_i}$$

$$C = \frac{A(z_i - f)}{z_i}$$

$$C = \frac{12.5(1000/19 - 50)}{1000/19}$$

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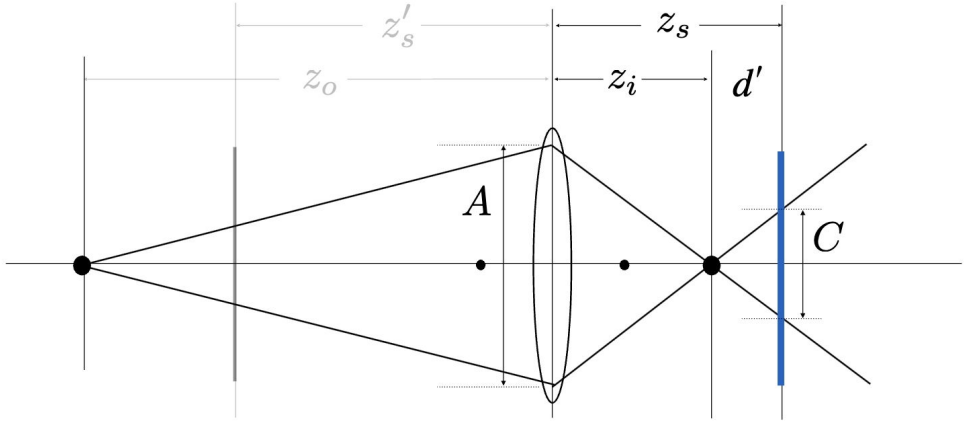

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$$C = 12.5(1 - \frac{50}{1000/19}) = 0.625 \text{ mm}$$

Let’s Take Attendance.

- Be sure to select Week 09 and input your TA’s secret word 😉
- Any feedback? Let us know!