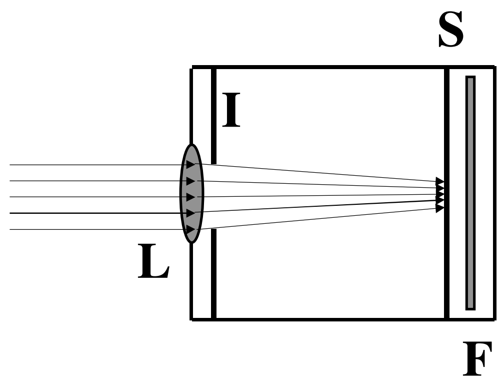
You need to learn the concepts and formulae highlighted in red. The rest of the text is for your intellectual enjoyment, but is not a requirement for homework or exams.

Chapter 5
PHOTOGRAPHY

THE CAMERA

The oldest, preserved, black and white photograph, or heliograph, was taken by Joseph Nicéphore Niépce in 1826. Soon after followed Daguerre (from which the "daguerreotype" name for old photographic plates on glass) and Henry Fox Talbot with the "calotype" process. The camera is the easiest to understand of the optical instruments. The key parts that form a camera, either a simple or a very sophisticated one, are shown in the schematic diagram on the right. These are:



- ***The lens*** **L** produces a *real image* of the object one wishes to photograph on the film. It is usually mounted on a barrel cap that can move so that the distance between the film and the lens can be adjusted for focusing.
- ***The shutter***, **S** (normally closed) opens for a small interval of time to allow light from the object to enter the camera.
- ***The iris aperture*** **I**, or ***f-stop***, is an adjustable aperture (hole or orifice) located near the lens. It controls the amount of light that enters the camera.
- ***The film*** **F** consists of a base, a polymer sheet, coated with a light sensitive *emulsion*, usually microscopic crystals of silver specks dispersed in gelatin.
- When light strikes the emulsion, the specks are modified. Chemical treatment of the emulsion, including *developing* and *fixing*, transforms the modified crystals into microscopic silver halide crystals, which are black, and removes the non-modified crystals. Let us now look in detail at the operation of the various parts.

FOCUSING THE CAMERA

Focusing the camera means adjusting the distance between lens and film so that the *real image* of the object being photographed is located on the film plane, not in front or behind it. Why is that important? Consider a point object being photographed. If the camera is not focused properly the light rays will not converge to a point on the film but will produced a fuzzy spot with larger size. The picture will be blurred.

Let us consider as an example a simple *35 mm camera*. This size refers to the film: 35 mm wide, and 24 mm high. The focal length of the lens is most commonly f = 50 mm. If you wish to photograph a far away mountain, the object distance is very, very large. When the object distance is more than 100 times greater than the focal length of the lens

(5 m in this case), photographers call it "infinity" and use the standard mathematical symbol for infinity: ∞.

When the object is very far away, in the lens formula, we can write:

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o} \qquad o = \infty \qquad \text{then} \qquad \frac{1}{o} = \frac{1}{\infty} = 0 \qquad \text{and} \qquad i = f$$

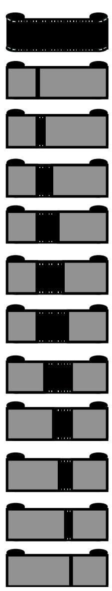
In other words, if o is very large $\frac{1}{o}$ is very small and can be neglected, and the image distance is equal to the focal distance. Using a lens with focal distance 50 mm, the film, and the image, must also be at 50 mm from the lens, to take a photograph of a mountain.

Suppose now that you want to take a close-up picture of a flower about 2 feet away.
2' ≈ 0.5 m   o = 0.5 m = 500 mm
f = 0.05 m = 50 mm

Using the lens formula again:

$$\frac{1}{f} = \frac{1}{i} + \frac{1}{o} \qquad \frac{1}{i} = \frac{1}{f} - \frac{1}{o} = \frac{1}{50} - \frac{1}{500} = \frac{10-1}{500} = \frac{9}{500} = 0.018 \quad \text{and} \quad i = 55.55 \approx 56 \text{ mm}$$

The distance between lens and film must be 56 mm. As you see, a very small motion of the lens, 56 - 50 mm = 6 mm, (about 1/4 inch) is all that is needed to focus from infinity to 0.5 m (two feet). Thanks to this small variation necessary to focus objects at any distance, cameras can be small and portable.



The Shutter, or, better defined, ***focal plane shutter***, is a double curtain mechanism that lies right in front of the film, i.e. in the focal plane. Initially both curtains cover the film (frame 1 in the sequence shown here). When you press the button to take a photograph, the first curtain starts moving across the whole film width, exposing the film to the light entering from the lens. After a certain time (the ***exposure time***) the second curtain starts moving in the same direction as the first curtain, covering the film again. For short exposures the two curtains move together, keeping a constant distance between them. Each point in the film is exposed for the same time (6 time-steps in this sequence schematically represented on the left). In real cameras the curtains move continuously, not in steps. The sequence reported in the figure is a simplification.

All cameras have a set of numbers to indicate the ***exposure time***, that is, the time that each point on the film is exposed to light, as the shutter curtains move in front of the film. The exposure times are usually: 1000, 500, 250, 125, 60, 30, 15, 8, 4, 2, 1, B, T meaning $1/1000^{th}$, $1/500^{th}$ of a sec, $1/250^{th}$ of a sec, etc.…down to 2 meaning 1/2 second and 1 meaning 1 second. Notice that the times the photographer has at his disposal form a sequence of factors of approximately 2.

Exposure time in seconds	***1***	***1/2***	***1/4***	***1/8***	***1/15***	***1/30***	***1/60***	***1/125***	***1/250***	***1/500***	***1/1000***
Geometric progression	1	1/2	1/4	1/8	1/16	1/32	1/64	1/128	1/256	1/512	1/1024

Exposure times vary by factors of 2. For each step to the right the exposure time doubles, to the left it is one half. This is not perfectly accurate, as you can see by comparison with the geometric progression, but it's very close. We will see how this is very useful to select appropriate settings to capture the desired photographs.

B, for bulb, usually means the shutter is open when the button is pressed, and closes when the button is released. When the camera is set on T, for time, the shutter is opened by pressing the button and is closed by pressing it again.

CHOOSING THE EXPOSURE TIME

If the object to photograph is moving, the photograph can be blurred because the object moved while the shutter was open. The distance moved is the speed × time, $d = v \times t$. A track star running a four-minute mile travels at a speed of 7 m/sec. If your camera is set to 1/100 sec the runner moved during the exposure time, and the photograph looks quite blurry.

$$7 \text{ m/sec} \times 1/100 \text{ sec} = 0.07 \text{ m} = 7 \text{ cm}$$

A person walking at 1 m/sec moves 1 cm in 1/100 sec. this is acceptable for some photographs.

If the object is stationary and the camera is held by hand, one can use a maximum exposure time of 1/60. For a longer exposure time, necessary for example at dusk, special attention is required not to move the camera. If the camera moves, the image of the stationary object moves on the film and the image will again be blurred. At 1/60 there is no blurring problem for any hand-held camera. At 1/30 sec holding your breath and leaning against the wall may be enough; for longer times, 1/15 sec or 1/2 sec, the camera must be held by a tripod or set on a table or car top.

CHOOSING THE APERTURE

The iris aperture, is a hole or orifice located immediately after the lens. It is made of many thin metal blades pivoted on the rim so that the diameter of the hole is adjustable. Cameras normally do not show the diameter of the aperture. What is shown printed on the lens mounting are the various ***f numbers***, mathematically represented by the symbol ***f/***. The diameter of the iris aperture is calculated by:

$$f/ = \frac{f}{Diameter}$$

where f is the focal length of the lens, Diameter is the diameter of the iris aperture, or the effective diameter of the lens portion being used. The sequence of ***f numbers*** or ***f/*** on the aperture adjustment control is normally:

f/	***1***	***1.4***	***2***	***2.8***	***4***	***5.6***	***8***	***11***	***16***	***22***	***32***	***45***

For example, if a camera has a lens with 50 mm focal length and the aperture is set at an f number of 4 (this is written ***f/4, not f/=4***), then the diameter is 50 mm / 4 = 12.5 mm.

What happens when you change the f number by two steps, from f/4 to f/8? That is, 4 to 5.6 and 5.6 to 8. A photographer calls this change "two stops", because *aperture stop* is the colloquial name for the iris aperture. The diameter of the aperture is changed in our example from 50/4 = 12.5 mm to 50/8 = 6.25 mm.

So changing the aperture by 2 steps changes the diameter by a factor 2. The ***area*** of the aperture changes by a factor of 4 (because the area of a circle is proportional to the radius squared).

Changing the aperture by 1 step changes the diameter by a factor 1.4

$$\frac{2.8}{2} = 1.4; \frac{4}{2.8} = 1.4; \frac{5.6}{4} = 1.4; etc. \text{ and the area by a factor } 1.4 \times 1.4 = 2.$$

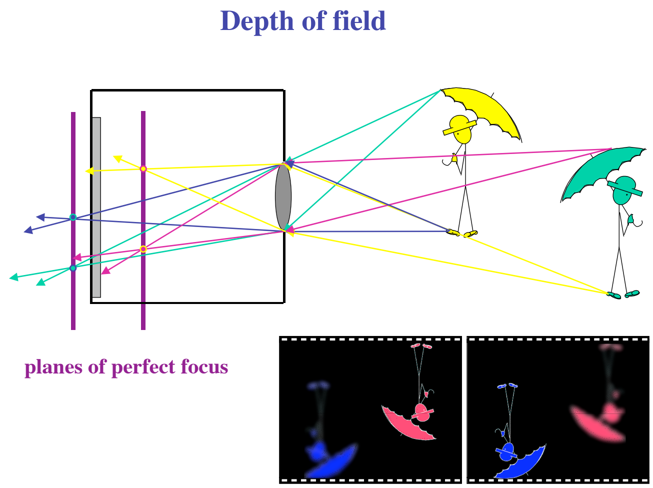
Each f/ step changes the lens area by a factor of 2, and the amount of light on the film by a factor of 2.

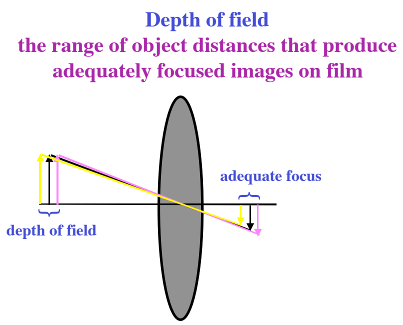
Besides its primary function of controlling the amount of light entering the camera, the value of the f number chosen affects another aspect of the picture: ***the depth of field***.

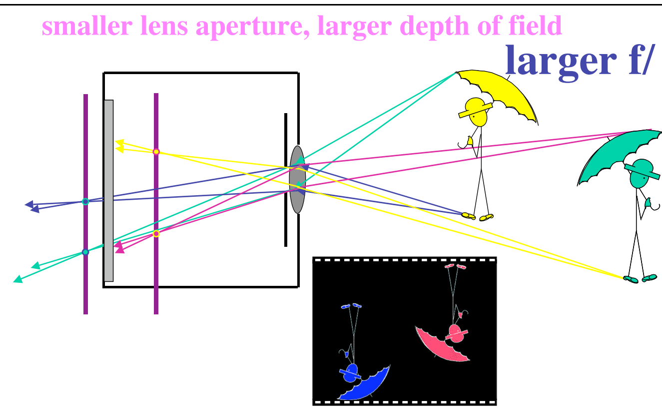
DEPTH OF FIELD

Suppose you are taking a photograph of an object 4 m away from the camera. You will naturally adjust the lens so that the object is in perfect focus. Objects farther away (background) say 5, 7, 8 …m away will be out of focus i.e. increasingly more and more blurred. The same will be true of objects closer by (foreground) at say 3, 2, 1 m. Now, if the f number is large (small diameter) you will find that objects at say 10 m and 3 m are in acceptable focus, i.e. they are not too blurred, but objects farther away than 10 m or closer than 3 m are blurred on the photograph - we say that the ***field*** extends from 3 to 10 m and that the ***depth of field*** is 7 m.

Large f numbers give large depths of field, and conversely, small f numbers give small depths of field. The reason is easy to see. Consider an object whose real image is not on the film but behind it, as the green man with the umbrella in the diagram on the right: the object is ***out of focus***. The yellow man, instead, is focused in front of the film, and is also blurry on the plane of the film. If we adjust the focus to the green man the yellow man is completely out of focus, and vice versa. The two resulting negatives will appear as shown here.







As you can see in the diagrams above, taking a photograph with the aperture wide open (or no aperture, see top right) nearby and further objects are in focus on the planes of perfect focus. The magenta and yellow rays from the far object (green man) cross on the first plane of perfect focus, and by the time they reach the film they are diverging again, so the image of the green man will be bigger and blurred on the film. The blue and green rays from the close object (yellow man) converge after the film, and are also bigger and blurred on it. When closing the aperture (bottom right), ***the planes of perfect focus do not move***, they are still in front and behind the film, but only rays that enter the lens at small angles from the optic axis enter the lens, and both blue and magenta rays diverge very little: the image of far and close objects is small enough on the film, and the focus is acceptable. The negative in this case shows both men in focus.

large depth of field
(large f/)

small depth of field
(small f/)

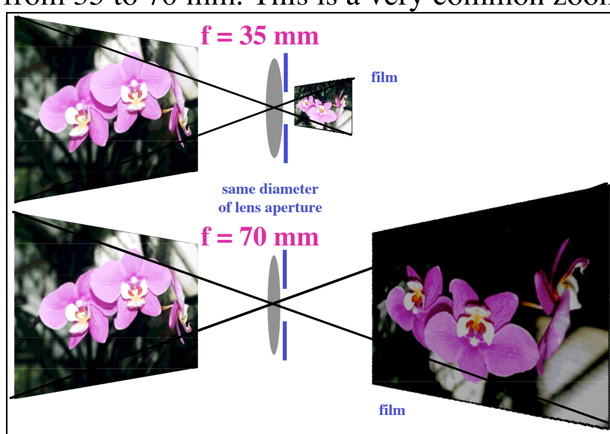
The two photos on the left were taken with identical exposure times and lenses, but with different f numbers. The top image shows flowers well in focus in the foreground (nearby flowers) and the background (far away flowers). In the bottom image a smaller f number selects only flowers at a very specific distance to be perfectly in focus. Flowers closer and farther than that distance appear blurred.

Why f number?

There is a perfectly reasonable question you may ask. And it would sound as: "I understand why you need an aperture to control the amount of light entering the camera. I also understand that steps of a factor of 1.4 in diameter correspond to steps of a factor 2 in the area of the aperture. But why not simply tell the diameter of the aperture instead of talking about the mysterious f number?"

The answer is the following: ***the amount of light on the film depends on the amount of light per square millimeter on the film not on the total amount of light***.

An example will clarify this point. Consider for instance a piece of paper with some orchids printed on it, photographed by two lenses with focal lengths of 35 mm and 70 mm (or simply by the same camera, with a zoom that allows to adjust the focal length from 35 to 70 mm. This is a very common zoom).



The illuminated area on the film is 4 times larger for the photograph taken with the 70 mm lens. If I want the same illumination on the film, I must have 4 times more light coming in through the lens. Therefore the diameter of the iris aperture behind the lens must be twice as large for the 70 mm lens than it is for the 35 mm lens. In other words, the f number must be the same! You may switch lenses, or zoom in, and keep the same exposure time if you also keep the same f number.

All lenses with the same f/ transmit the same amount of light on the film. This is quite convenient if you are using a zoom, and change the focal length of the lens: you do not need to recalculate the exposure time!

THE FILM

You can buy films of many types, made by many manufacturers. Let us start with black and white (B&W) film, for simplicity. Color film will be explained in Chapter 8. All B&W films are coated with an emulsion of silver grains, which darken when illuminated. The more light they are illuminated by, the more they darken. That is why the film produces negative images, which are then inverted again into positive images when printed. Films differ by several properties, listed below.

- ***Spectral Sensitivity***
  Some films are sensitive to blue and green light only (orthochromatic), others are sensitive to red light also (panchromatic). Special films are made to be sensitive in the infrared or the ultraviolet. Most black and white films you can buy are panchromatic.

- ***Contrast***
  Suppose that you take a picture of a person wearing a relatively dark shirt, so that the light coming from the person's face is ten times stronger than the light coming from the shirt. If the developed film will show a dark face (inverted!), ten times darker than the shirt, we say the contrast is normal. If the image of the face on the film is more than ten times darker, we say the negative has high contrast. If it is less than ten times darker, the negative has low contrast.

- ***Grain***
  The size of the original silver halide crystals and the method of development determine the final size of the silver specks that form the negative image on the film.

- ***Speed***
  Different films require different amounts of light to produce the same amount of darkening on the negative. A "fast" film requires a small amount of light. If a film requires a lot of light to darken it, it is called a "slow" film.

  The speed of films is measured in ***ISO*** (International Standard Organization). The ISO units replaced the A.S.A. (American Standards Association) and the DIN (Deutsche Industrie Norme) units, and have been adopted in all countries. The diagram below shows several ISO speeds commercially available.

Film speeds (ISO)

they *also* vary by factors of 2

50 100 200 400 800 1600 3200

slow film **fast film**

Film speed, Sensitivity ("more light") →

Notice above, that ISO rating is inversely proportional to the amount of light required to produce a certain standard black on the negative image. Doubling the ISO number (by using a faster film) you can reduce the amount of light you let into the camera by 1/2.

It may seem a good idea to buy the fastest film, so that you can take photographs also in dim conditions of light, but you have to be careful: the fastest films (e.g. ISO 1000) have much larger grain size. Therefore the photograph printed on 4" x 6" paper may appear acceptable, but if you try to enlarge it, it appears grainy, and has low resolution. Fast films also have lower contrast, and lower tonal range, that is, fewer graylevels in black and white, and fewer color tones in color photography.

PUTTING IT ALL TOGETHER: *TAKING A PHOTOGRAPH*

As we have seen, there are three numbers to take into consideration:

1. The exposure time:

1 1/2 1/4 1/8 1/15 1/30 1/60 1/125 1/250……..

← **I increases by factors of 2**

2. The f number:

f/1 1.4 2 2.8 4 5.6 8 11 16 22 32 45

← **I increases by factors of 2**

3. The film speed:

50 100 200 400 800 1600

Film speed, Sensitivity ("more light") →

For each one of these three parameters, the most relevant variable is the amount of light on the film, or illumination ***I***. The arrows in the sequences above indicate in which direction I increases. Again, varying the ***exposure time***, the ***f number*** or the ***film speed*** by ***one step*** varies ***I*** by a factor of ***two***. This is quite convenient, and greatly simplifies all calculations to be done before taking a photograph.

Once you have the film in the camera the film speed cannot be changed, so you are left with the exposure time T and the f number f/ with which you can play. The total amount of light I that falls on the film depends on:

$$I = \frac{L \times T}{(f\,/)^2}$$

where L is the amount of light reflected by the object being photographed and transmitted by the camera lens. The f number of the lens is given by $f\,/ = \dfrac{f}{Diameter}$.

Let us assume we are taking pictures outside. Since we cannot change the amount of sunlight reflected from the object towards the lens, all we can play with is T and f/. A picture taken at 1/60 sec and f/8 will have the same exposure as one taken at 1/250 and f/4. Here is why:

1/60 $\rightarrow$ 1/125 $\rightarrow$ 1/250 is two steps ***less*** light on film

8 $\rightarrow$ 5.6 $\rightarrow$ 4 is two steps ***more*** light on film

Decreasing the exposure time from 1/60 to 1/250, *decreases* the amount of light by a factor of 4. So we compensate by opening up the aperture by two stops and *increasing* the lens area by a factor of 4.

Are these two pictures the same? The answer is no. The picture with f/8 has a larger depth of field. A tree 10 m away, and the mountain 1000 m away are both in focus but the child jumping off the tree is blurred because of the long exposure time. In the second picture the child is not blurred but the mountain in the background is.

f-number f/1 1.4 2 2.8 4 5.6 8 11 16 22 32 45

I increases by factors of 2 ←

→ **Less light on film**
BUT: increasing depth of field

exposure time 1 1/2 1/4 1/8 1/15 1/30 1/60 1/125 1/250……..

I increases by factors of 2 ←

→ **Less light on film**
BUT: captures movement better

In synthesis, a larger f number requires a longer exposure time. A large f/ gives less light on the film, but has the advantage of an increased depth of field. A short exposure time gives less light on the film, but has the advantage of capturing movement. The diagram at the bottom of the previous page summarizes all parameters. ***This diagram is of fundamental importance to take photos, to do the homework and to pass the exam. Please understand how it works accurately.***

The exposure meter gives the photographer two numbers: an f/ and a corresponding exposure time, and tells the photographer that a photograph in those particular conditions of light it measured, will be well taken if he will use those settings. On the other hand the photographer is not bound to use those settings only: he can use any other combination of f/ and T that produce the same amount of light on the film. If he will increase the f/ he'll obtain a better depth of field, but will need to increase the exposure time. Same for capturing movement: shorter exposure time, lower f/. You must have noticed by now, that starting from the "good" settings given by the exposure meter, we are moving ***to the right*** on one sequence and ***to the left*** on the other.

Let us look at an example.

The exposure meter tells us that the "good settings" for a photograph are f/22 and exposure time T = 1/30 second.

f-number f/1 1.4 2 2.8 4 5.6 8 11 16 22 32 45

exposure time T 1 1/2 1/4 1/8 1/15 1/30 1/60 1/125 1/250……..

We do not have a tripod with us, and need to choose a much shorter T, say 1/250 sec. to avoid blurring of the photograph (hand-shaken, when T is longer than 1/60 sec).

f/1 1.4 2 2.8 4 5.6 $\boxed{8}$ 11 16 22 32 45

T 1 1/2 1/4 1/8 1/15 1/30 1/60 1/125 $\boxed{1/250}$…….

We have moved 3 steps to the right on the exposure time sequence (3 steps less light on the film, or 2 x 2 x 2 = 8 times less light), therefore we must move to the left on the f/ sequence (3 steps more light). The new photograph is now taken with f/8 and T = 1/250 sec. The disadvantage is a smaller depth of field.

Let's now look at a slightly more complicated case, in which all 3 parameters are changed.

A photograph is well taken with 1600 ISO film, f/5.6 and T = 1/125 sec.

1600 ISO film **f/1 1.4 2 2.8 4 5.6 8 11 16 22 32 45** **T 1 1/2 1/4 1/8 1/15 1/30 1/60 1/125 1/250……..**
We want a better depth of field, therefore we want to increase the f/ to f/8. But we ran out of film, and the only film in our bag is 200 ISO. This is a much slower film, that requires much more light than the 1600 ISO we had before. Lower sensitivity of the film is conceptually equivalent to "less light on the film", and we have to compensate for this loss by increasing the amount of light on one or both of the other two parameters.
1600 ISO film ⟶ **200 ISO film** **f/1 1.4 2 2.8 4 5.6 8 11 16 22 32 45** **T 1 1/2 1/4 1/8 1/15 1/30 1/60 1/125 1/250……..**
We did 3 steps less light by changing film speed, 2 steps less light by changing the f/, we therefore need to compensate by increasing T by 5 steps. **The new exposure time is T = 1/4 sec**. The disadvantage is blurring if the camera is hand-held.

Digital Photography

Many believe that digital photography will completely replace chemical based photography within a few years. Digital photography has certainly made its presence felt in the industry, and it is conceivable that a large segment of the amateur point-and-shoot market will indeed be mostly served by digital cameras, and a large segment of photojournalism is already covered by digital equipment. Yet conventional films still have a considerable advantage when it comes to overall resolution, contrast, and tonal range of the image. While digital cameras have the ability to equal 35 mm and even medium format photography, at least with scanning systems, we must not forget the incredible possibilities offered by large format systems. Digital photography is still in its infancy and currently is trying to parallel the capabilities of conventional film materials. In particular resolution, tonal range, and contrast that can be obtained with digital photography are all still much inferior to those of film photography. However, it is so convenient to use a digital camera that more and more people are abandoning film photography, myself included. Not having to buy the film, bring the negatives to a photo studio to develop and print, pick them up later, store the photos, and never have them handy when they are needed…… much easier with files on a computer! This is a shame, because there is a definite loss in the final quality of the photographs.

Current films are substantially better than the ones available only ten years ago. Several companies are currently experimenting with a new type of color film that could, in the near future, become ten times faster than current films, without too much loss in color fidelity, resolution and contrast. Continued research will lead to further improvements, and these will keep film photography competitive. Film and digital photography will complement each other, as they already do, and will coexist. Photography and film, as we know them, will certainly change, but they will not disappear.