Photography

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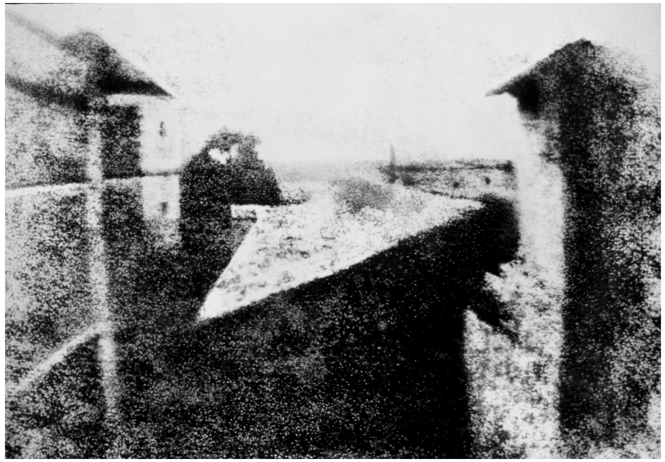
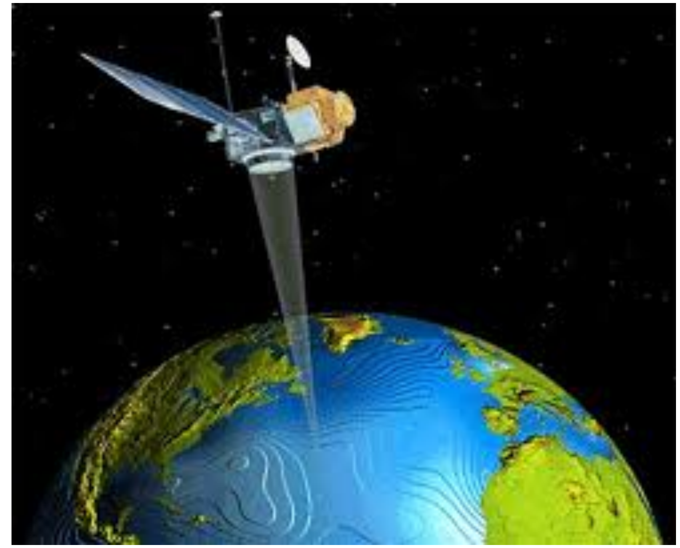
N.Niépce



His first photograph in 1826

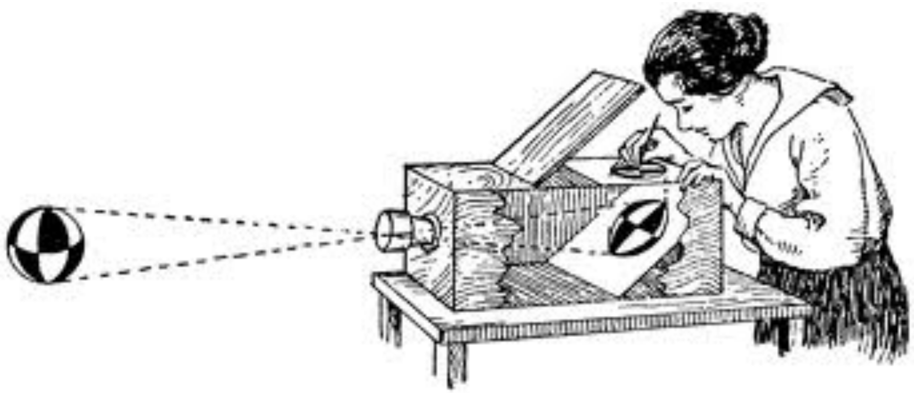


Remote sensing of the Earth from satellites

WHEN the French inventor Nicéphore Niépce took the first photograph in 1826, he could not have imagined the effect his creation would have on the world.

Today, photography is an essential part of the worldwide communications business, with newspapers and magazines relying on still pictures more than ever.

And in the world of science, photography plays a vital role in fields ranging from astronomy and chemistry to biology and remote sensing of the Earth from satellites.

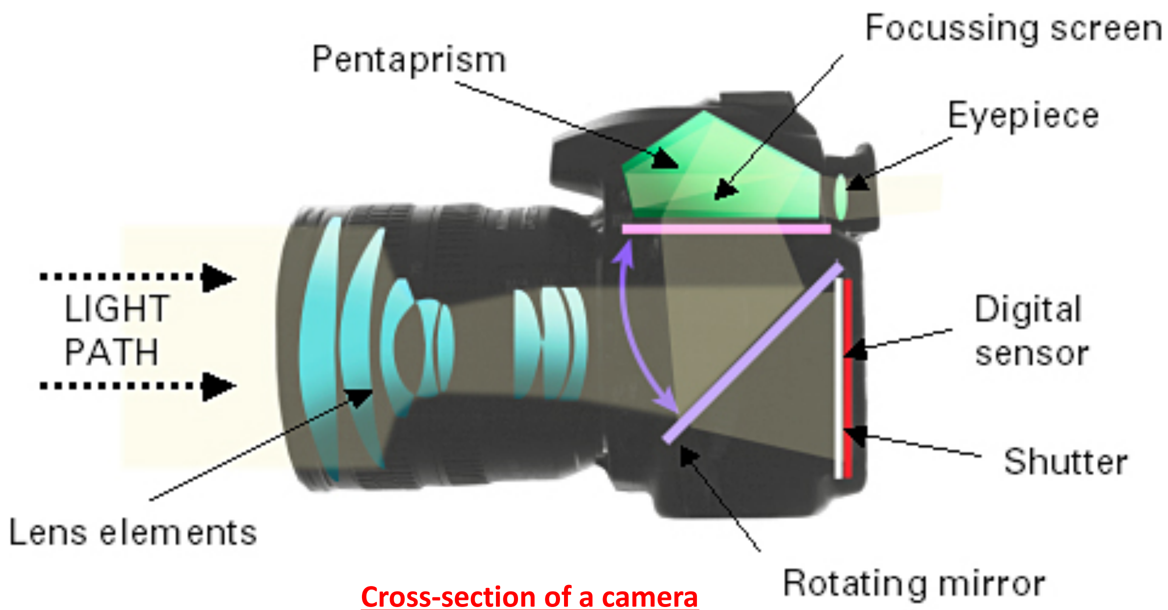


The camera obscura

Silver chloride salts : $AgCl$ before darkening

The origins of photography stretch back to the invention of the camera obscura, a darkened room with a hole in one wall through which images are projected onto the opposite wall.

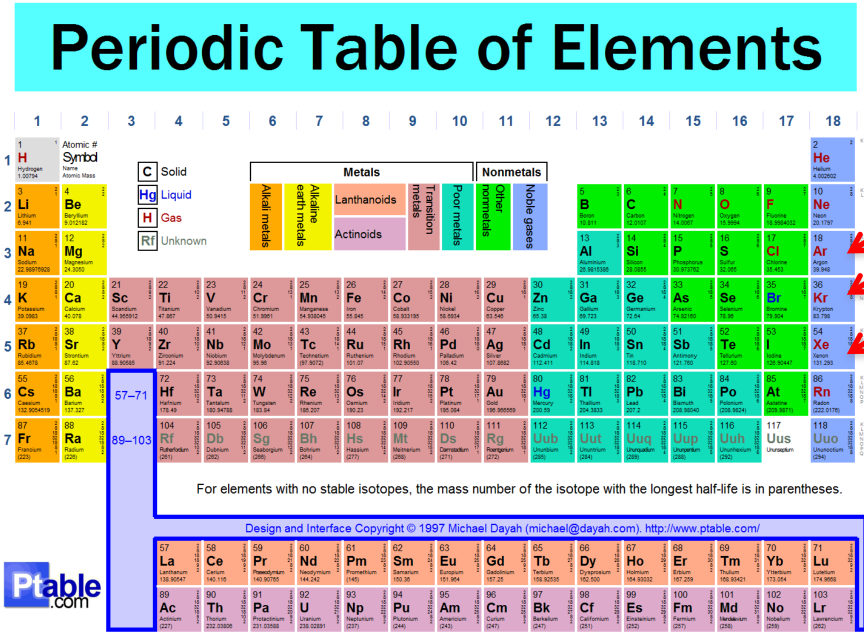
As far back as the 16th century, inventors knew that light could blacken certain silver salts, but they did not know how to make permanent images, or fix them, so that they would survive exposure to more light. This had to wait till the 19th century.



Cross-section of a camera

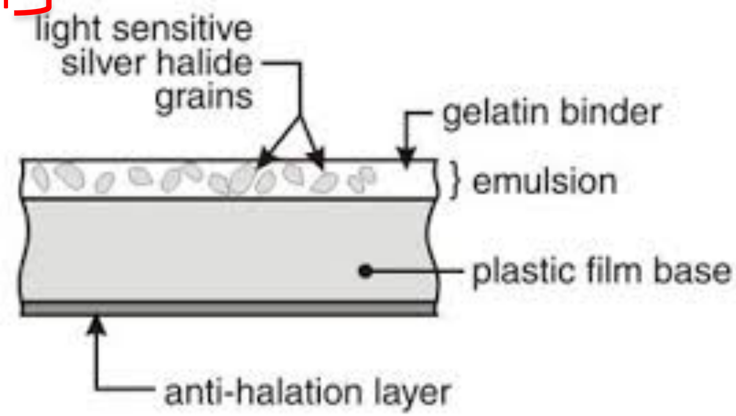
The device that makes photography possible is the camera - a miniature version of the original camera obscura.

This is essentially a light-tight box with a lens instead of a hole to let in the light, a means to control the amount of light entering the box, and a viewfinder. At the heart of any camera is the light-sensitive film that records the image.



Chloride Cl^-
Bromide Br^-
Iodide I^-
halides

Chlorine Cl
Bromine Br
Iodine I
halogens



Cross-section of a photographic film

Photographic film contains tiny crystals of silver halides, compounds made up of positively charged silver ions and negative ions of chlorine, bromine or iodine. These crystals are suspended in a thin layer of gelatine to form a light-sensitive emulsion, which is coated onto a transparent polymer base that gives the film its mechanical strength. These silver halide crystals are special because they are sensitive to light that hits them. Their sensitivity is limited to ultraviolet and blue light with wavelengths ranging from 300 nanometres to 500 nanometres, but by adding dyes it can be extended to cover the entire visible spectrum and beyond.

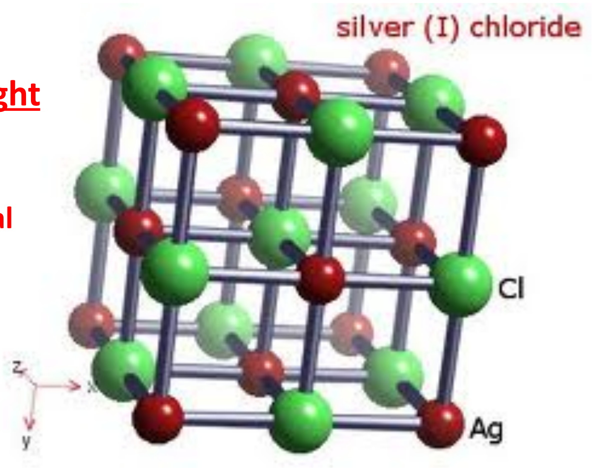
Chemical reactions induced by light

$Ag^+ + e^- \rightarrow Ag$

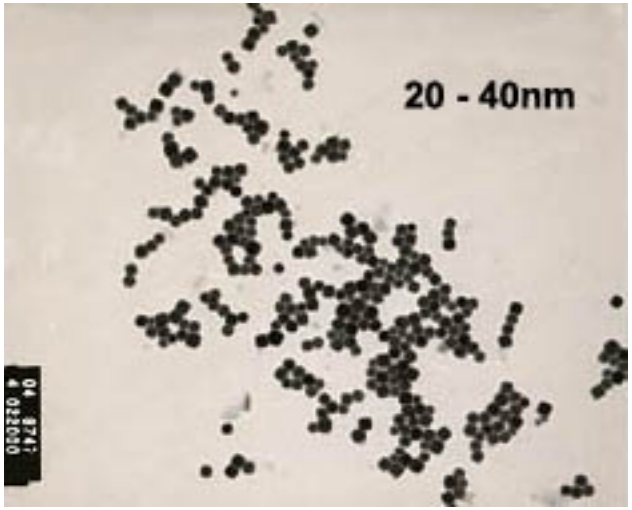
Reduction of silver ion into silver metal

$2\ Br^- \rightarrow Br_2 + 2\ e^-$

Oxidation of the bromide ion into the bromine gas

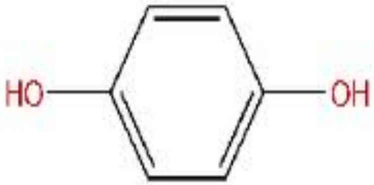


Lattice of the silver chloride crystal AgCl



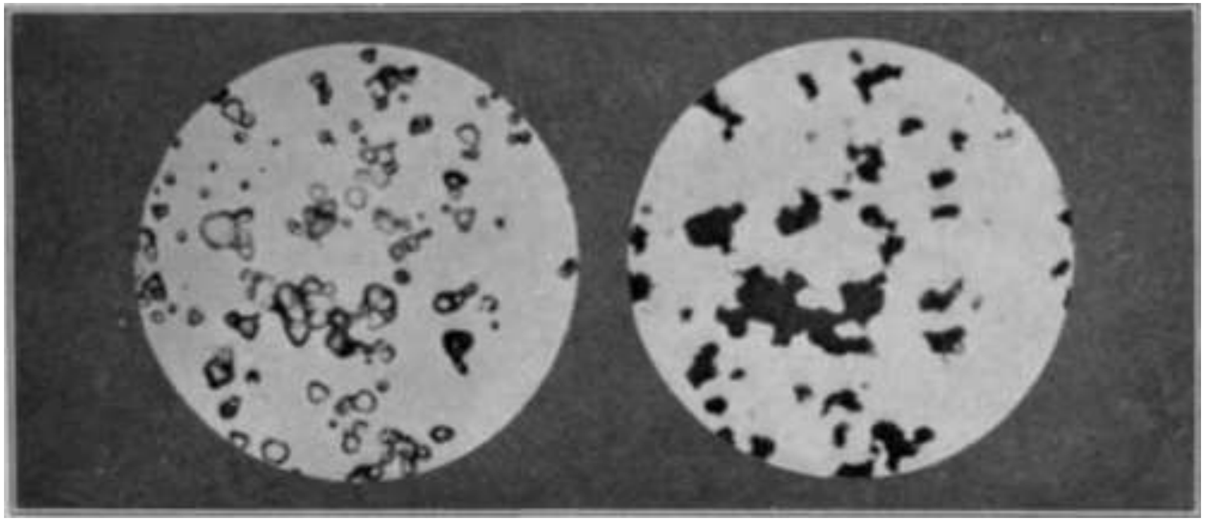
Metallic specks of silver forming the latent image

Exactly what goes on inside the crystals no one knows for certain, but most chemists now believe that photons kick electrons out of the crystal lattice. These electrons then join with positively charged silver ions to form a few atoms of metallic silver. Small amounts of halogen gases also form and migrate to the surface of the crystals, where they are absorbed by the gelatine. These gases play no further part in the photographic process. The important point is that the light has created a pattern of tiny metallic specks in the film known as the latent image.



Hydroquinone

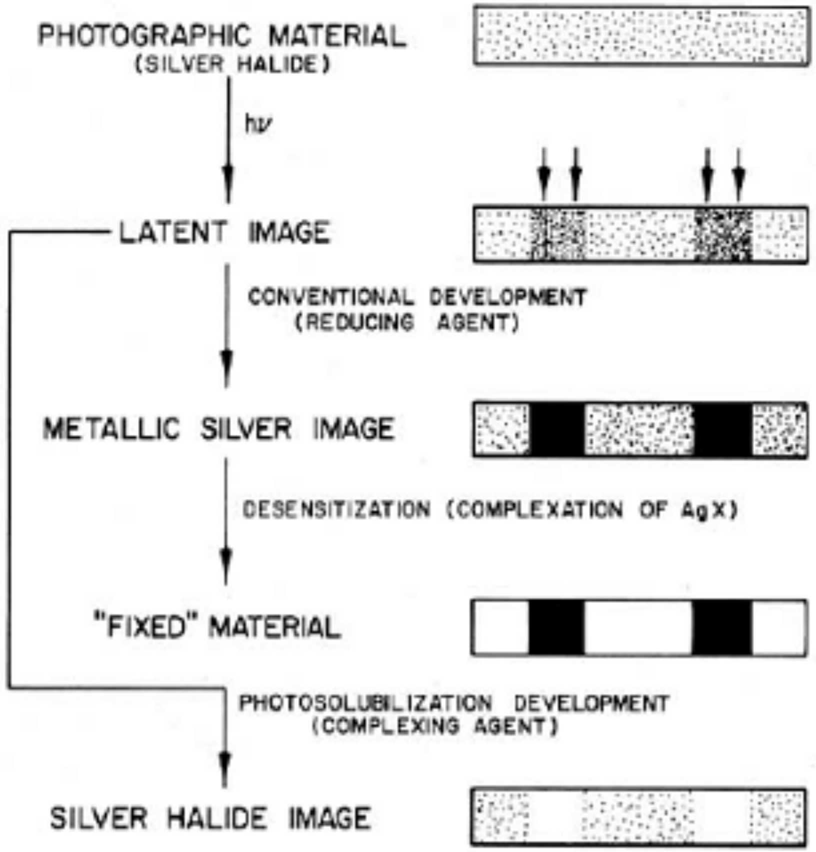
Developer



Action of developers forming large grain of metallic silver

At this stage, the latent image is invisible and must be developed in a photographic darkroom. The trick is to find a way of distinguishing between the crystals that contain metallic specks and those that don't. The chemicals that do this are known as developers - alkaline solutions containing weak reducing agents such as 1,4-dihydroxybenzene, better known in photographic circles as hydroquinone. Developers work by reacting with silver halide crystals to form large grains of metallic silver. Developers work much more effectively on crystals that already contain small specks of silver. So by careful control of the concentration, pH, temperature and time of the reaction, it is possible to stop the action of the developer when it has changed the exposed crystals to metal but has not yet begun to react with the unexposed crystals. Most films are sensitive to the whole visible spectrum so development must be carried out in total darkness.

The process of fixing



The next step is to remove the unexposed silver halide crystals in a process known as fixing. This is done with sodium or ammonium thiosulphate, chemicals that convert silver halide to soluble silver salts that can be washed away. The result is a dark pattern of metallic grains embedded in the gelatine, which exactly matches the pattern of light that fell on the film. Such an image, in which white appears black and vice versa, is called a negative.

Small grains ->
Less sensitive ->
High light conditions ->
Slow film ->
Smooth image

Large grains ->
More sensitive ->
Low light conditions ->
Fast film ->
Less smooth image

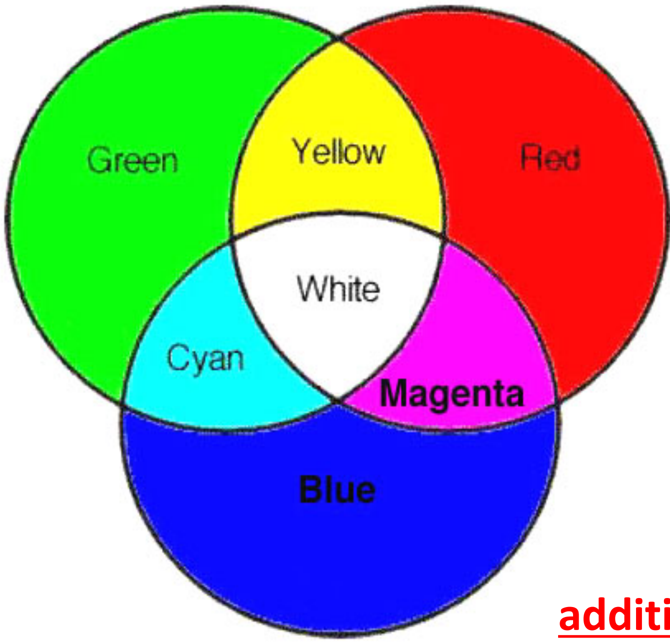
Generally, the size of the silver halide grains used in the film determines the sensitivity of the film to light. Large grains are more likely to be hit by light, so they make the film more sensitive. But a balance must be struck between the size of grains, the quality of image they produce and the light sensitivity required. When the film is developed and enlarged, large crystals in the negative show up in the final image. This is why images taken with films designed for low light conditions often look grainy. The light sensitivity of a film is known as its film speed: the "faster" the film the more light sensitive it will be. Film speed is measured by a scale determined by ISO, the International Organisation for Standards. So-called ISO numbers increase with the light sensitivity of the film. For example, an ISO 400 film requires half the light of an ISO 200 film in the same conditions. When the light is poor or when very fast exposures are required-in sports photography, for example-photographers generally choose ISO 400 film or faster. Slower films are less light sensitive-an ISO 50 film needs four times as much light as an ISO 200 film. But because they employ smaller grains they produce smoother images.

Flash lighting

Studio photographers can use flash lighting to boost the amount of light available, so they often choose slower films because they want high-quality images with plenty of fine detail.

Producing a print involves shining light through the negative onto paper coated with a thin layer of light-sensitive emulsion. The same process of developing, followed by fixing, then produces a positive black-and-white image on the paper.

Printing paper is only sensitive to blue, or blue and green light, so this stage can take place in yellow or red light.



additive synthesis

Figure 3. Additive colour mixtures of blue, green and red to produce cyan, magenta, yellow and white.

There are many different colours and shades, but the way the human eye perceives colour means that they can all be reproduced by suitable combinations of the three primary colours: blue, green and red. The combinations can be produced in two ways. The first, additive synthesis, adds the colours directly. So, for example, adding blue and green light of equal strengths produces the bluish-green colour called cyan, while adding red and green produces yellow, and red and blue makes magenta. Adding red, blue and green together produces white.

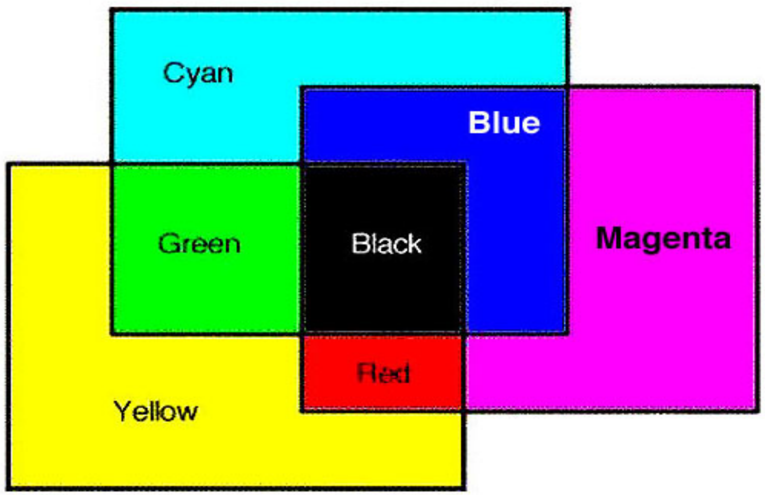
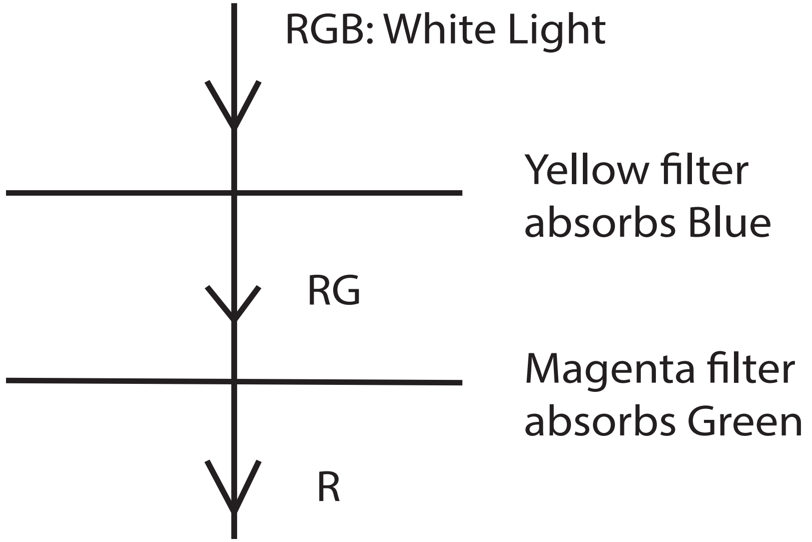


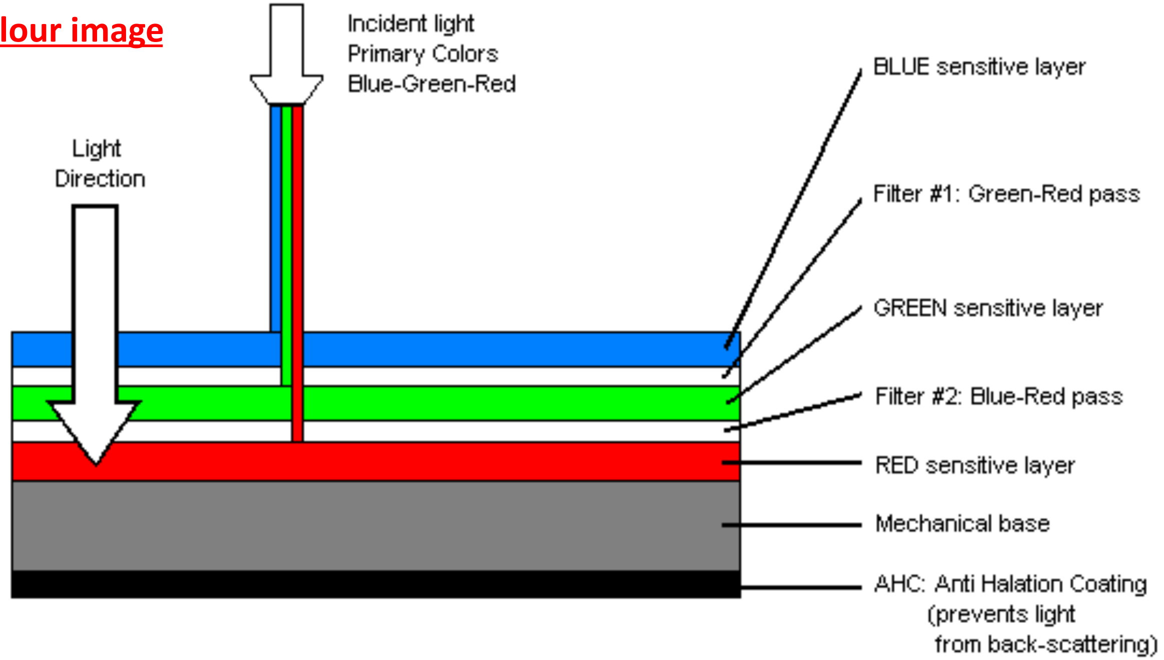
Figure 4. Subtractive colour mixtures of cyan, magenta and yellow to produce blue, green and red.



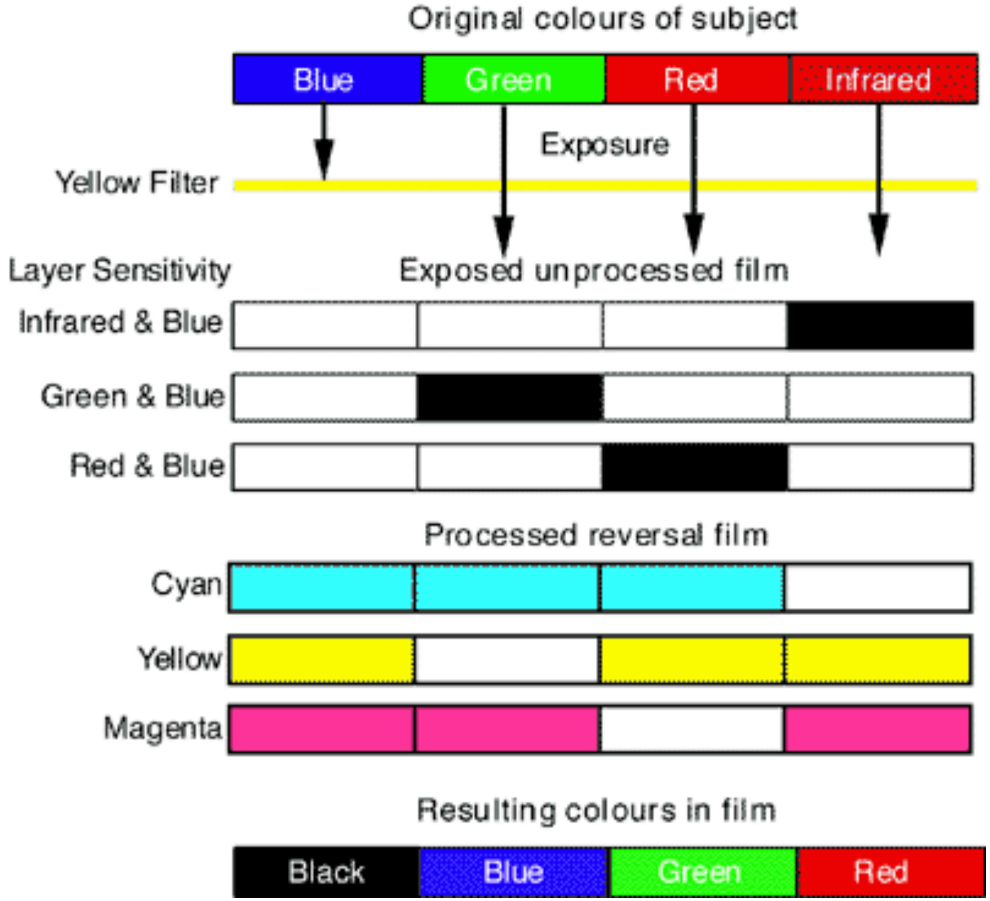
subtractive synthesis

The second option is to start with white light and use complementary filters to subtract the primary colours. Magenta filters hold back green light, cyan filters block red light and yellow filters absorb blue light. This process is called subtractive synthesis. To produce red light, all the blue and green must be removed from white light, which can be done with yellow and magenta filters. Creating green requires yellow and cyan filters. And so on.

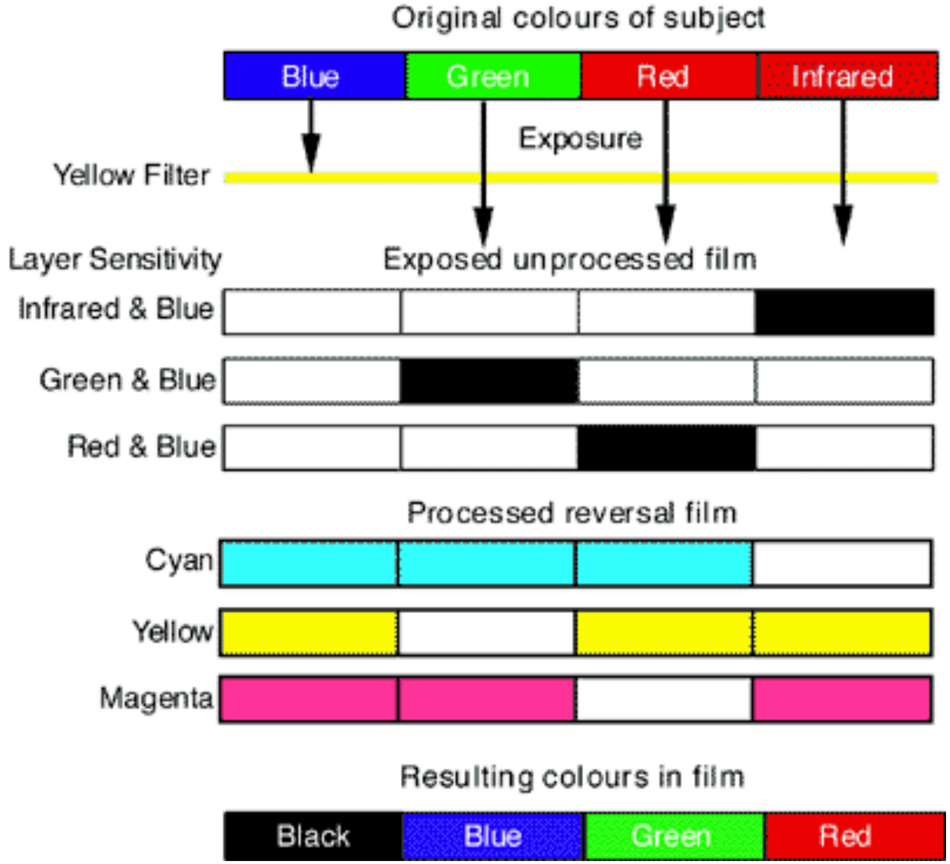
Formation of a colour image



To make a colour image, the light has to be divided into its constituent primary colours and the combination recorded on film. How can this be done on a single film? The answer is by using several thin layers of emulsion on top of each other and ensuring that each layer records a different primary colour. Colour films use three layers of emulsion, each one responding to a different colour. The top layer records any blue light that falls on it. Beneath this lies a yellow filter-the complement of blue-which absorbs any leftover blue light. The next layer contains dye sensitive to green, and below that is a layer sensitive to red. In this way, a full-colour image can be recorded with a single exposure.



Processing colour film is more complicated than black-and-white film. Each layer contains chemicals, which can be made to form a dye of a specific colour when silver halide crystals are converted to metallic silver. They are known as colour couplers. In a colour reversal process, which produces a positive transparency or slide, the first step is to develop a negative silver image in each layer of the film without triggering the colour couplers. The next step renders the rest of the silver halide in each layer developable.

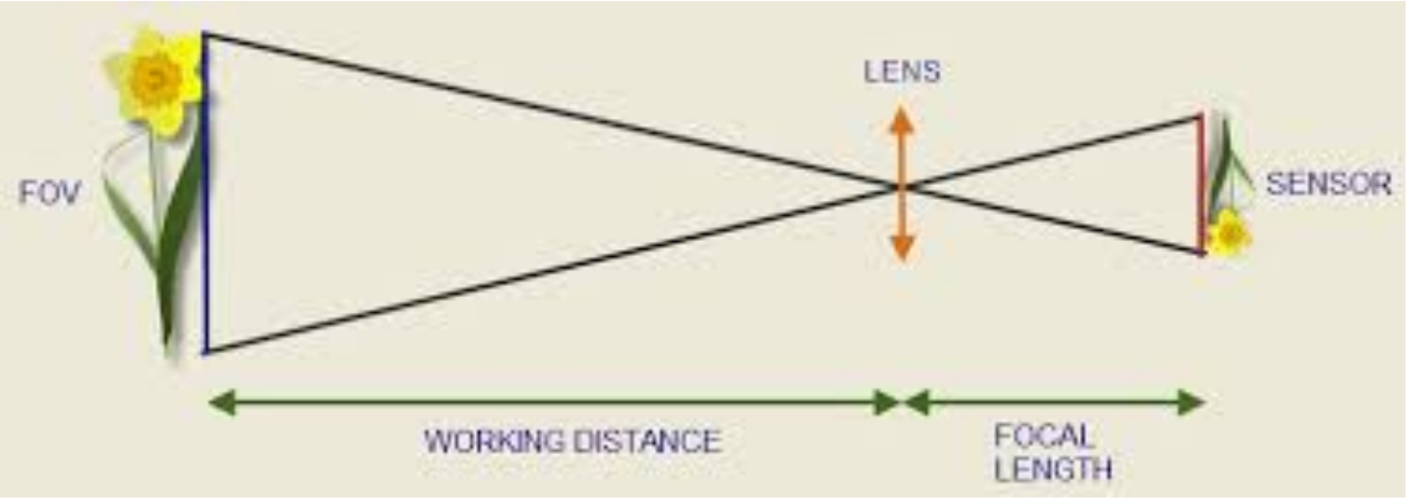


Colour development

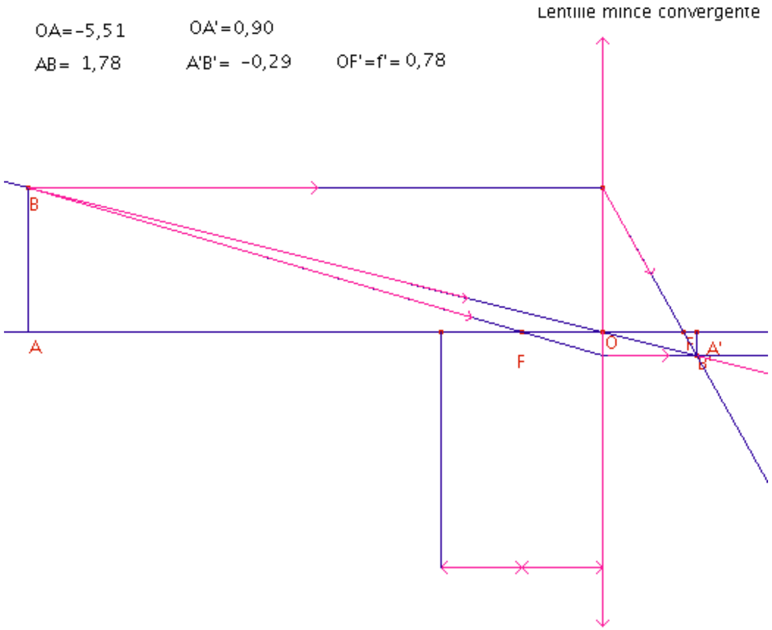
Then follows the colour development. This simultaneously produces a positive metallic silver image from the remaining silver halide in each layer along with a coincident dye image of the layer's complementary colour. Finally, the metallic silver is converted back into soluble silver salts that can be washed away. The result is a transparent film containing layers of yellow, magenta and cyan dyes.

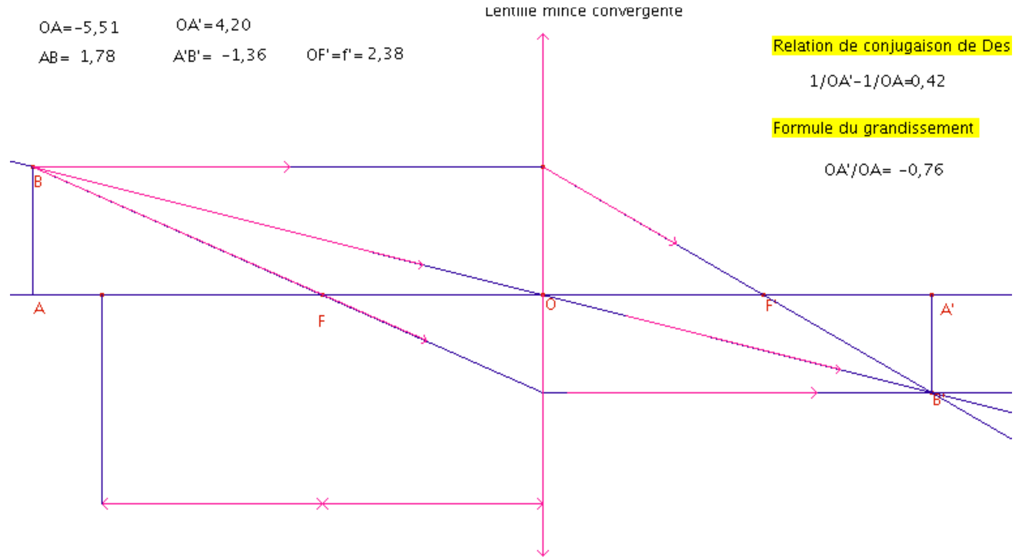
When white light shines through the film, the subtractive synthesis process forms a colour image. In colour negative film, the step that gives the positive image is omitted; otherwise the development is essentially the same.

Formation of an image on the image sensor



TO CAPTURE an image you need a camera and lens system. As well as acting as a light-tight container to hold the film, the camera must allow the photographer to frame the picture and control how much light the film is exposed to. Modern cameras often have flash units built in to provide extra light when needed. The camera's lens is designed to focus the image onto the film with as little distortion as possible. Camera lenses are designed to bend the rays coming from the object being photographed so that they converge towards the film plane. When the lens is focusing light from a distant source, the distance between the film plane and the optical centre of the lens is known as its focal length.





A wide-angle lens ->
Short focal length ->
Small and bright image
near the lens

A telephoto lens ->
Long focal length ->
Large but dim image
Far from the lens

In general, the longer the focal length, the larger the image that will appear at the focal plane. Wide-angle lenses have a short focal length. With some lenses the focal length can be adjusted, so that the photographer can zoom in on the subject.

Lenses and their f-numbers

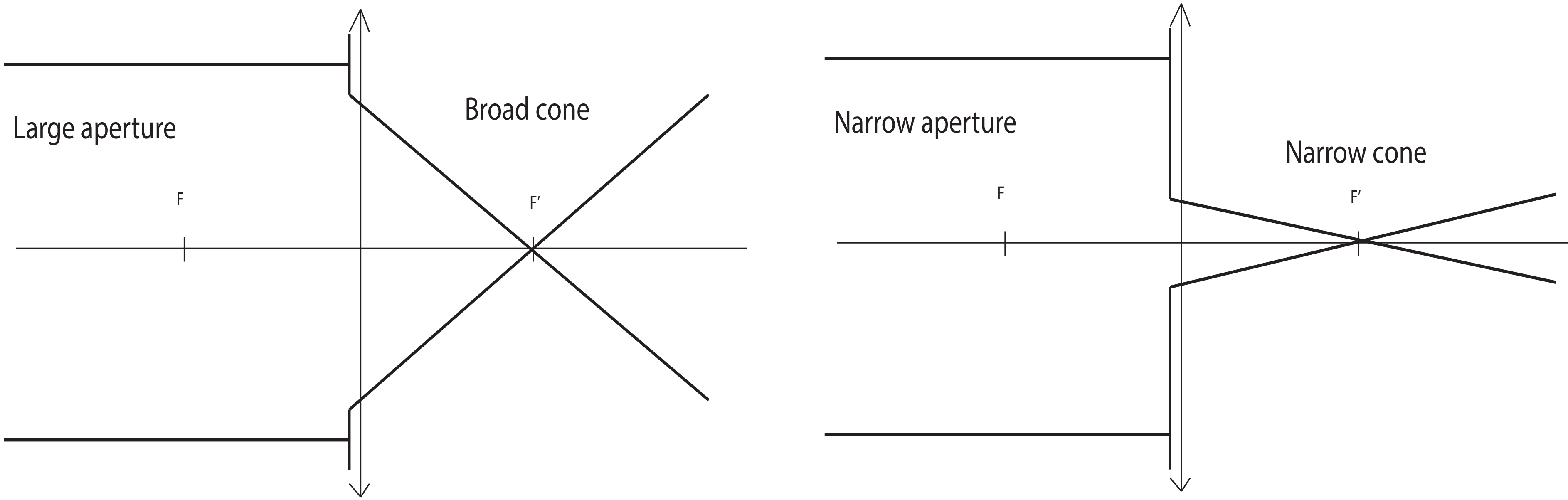
The amount of light that passes through the lens is controlled by an adjustable diaphragm, which works like the iris in the human eye. The area of the aperture of the lens is proportional to the square of its diameter. So the light striking the film is halved if the aperture's diameter is reduced by a factor of 1.4 (the square root of 2) , it is divided by four if the diameter is halved, and so on. The lens aperture is usually expressed as an f-number, obtained by dividing the focal length of the lens by its diameter. For example, a 100-mm lens with a diameter of 50 mm has an f-number of 100/50= 2. Reducing the size of the iris by a successive factors of 1.4 gives the sequence: 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32 etc. This sequence of adjustments, or stops, is marked on most lenses with adjustable diaphragms. Each stop halves the image brightness.

Large depth of field

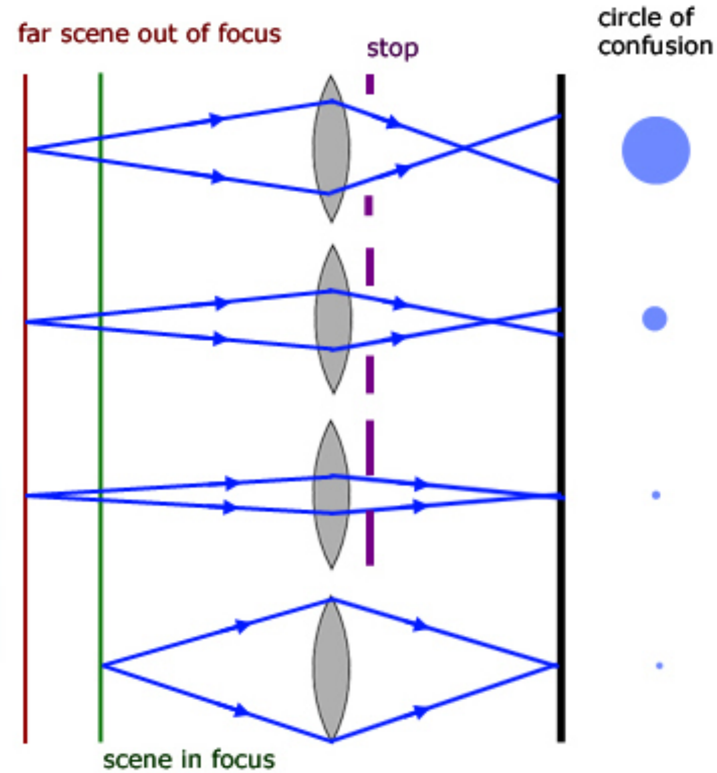
Short depth of field

The aperture also determines an important creative factor in photography, known as the depth of field. This is the distance in front of and behind the subject that appears in focus. For example, in landscape shots the depth of field usually stretches from the camera to the horizon, but in many portraits the subject's face appears sharp while the foreground and background are blurred.

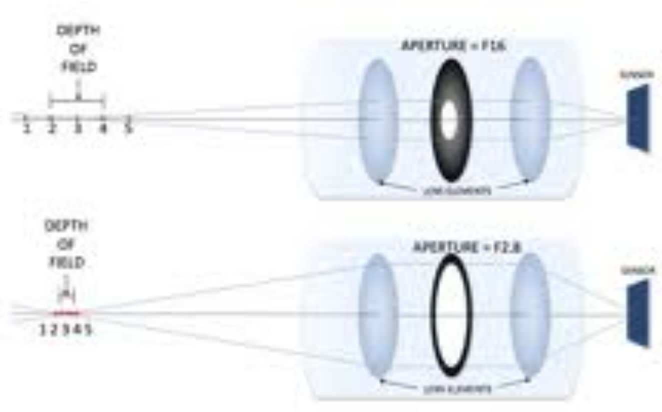
Size of the cone of light according to the aperture

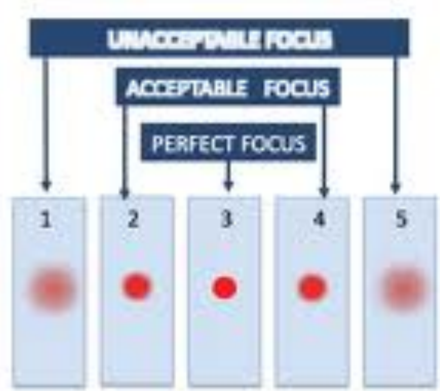


To understand what is going on, think about the way a lens brings light to a focus. First, rays that are parallel when they enter the lens are bent into a cone. When the aperture is large this cone is broad, but as the aperture is reduced it becomes narrower.



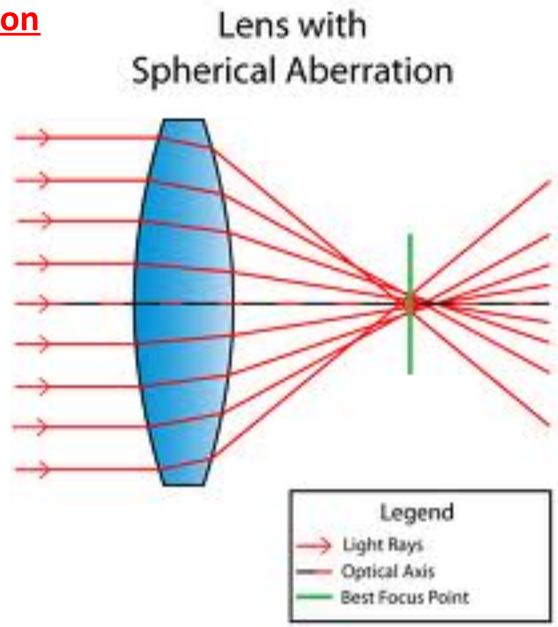
Circle of confusion





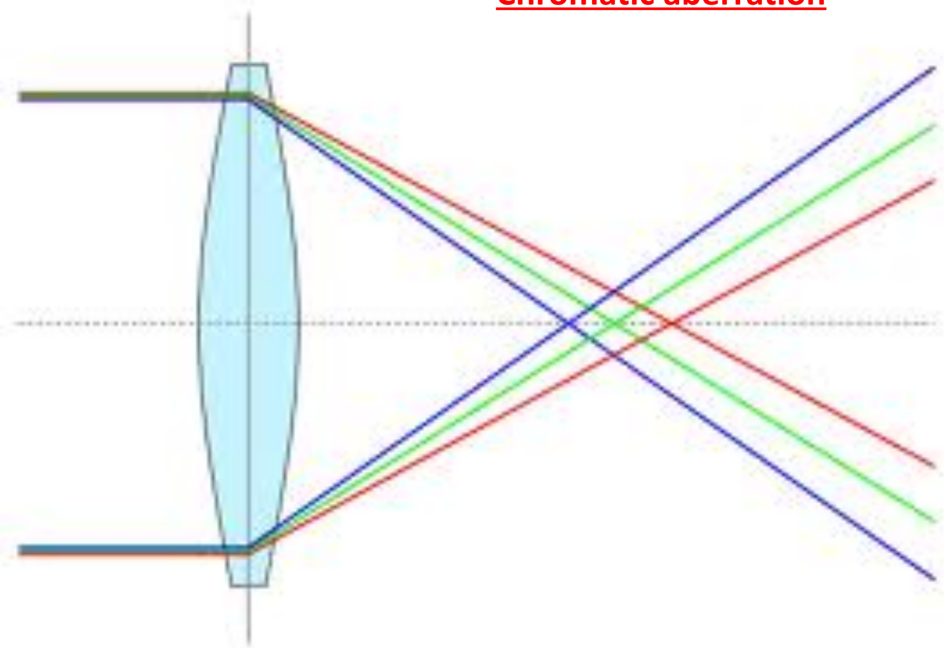
For the image to be in focus, the tip of the cone of rays must exactly touch the film plane. Well almost. In fact, the image appears in focus even if the tip of the cone is slightly in front of or behind the film. Instead of a point at the film plane, the cone forms a tiny circle known as a circle of confusion. Only when the circles reach a certain size does the image appear blurred. With the tip of the cone a given distance from the film plane, the size of the circles of confusion are determined by the aperture. This is why a large aperture leads to a shallow depth of field while a small aperture gives a wide depth of field.

Spherical aberration

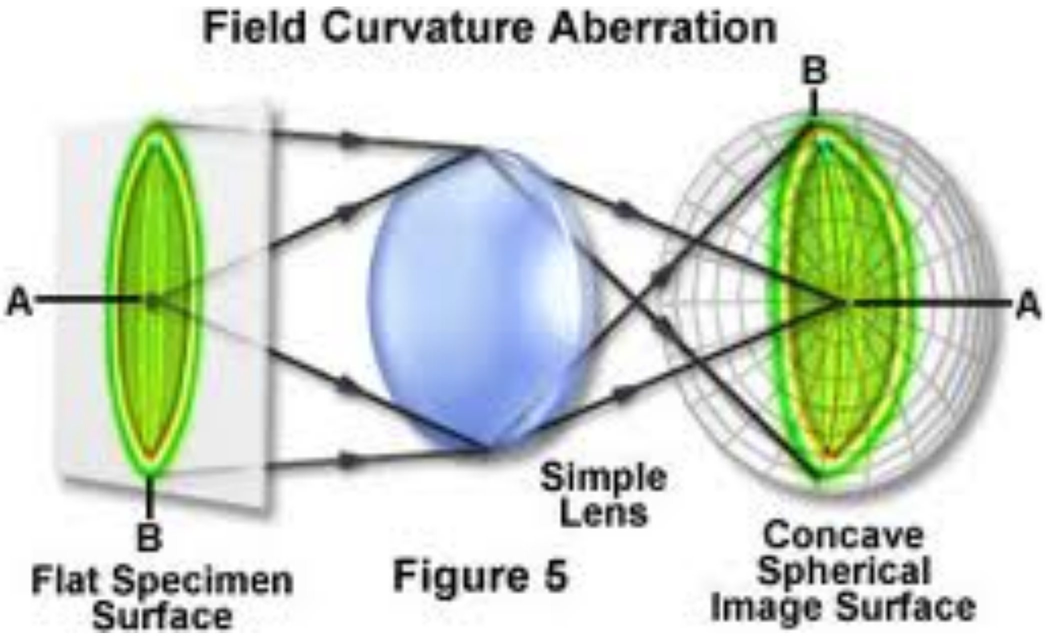


The aperture can affect the quality of the image in other ways, too. Simple convex lenses, with spherical outer surfaces, produce remarkably poor images. One reason for this is that different parts of the lens focus light to different points, a problem known as spherical aberration. The wider the aperture the worse this problem becomes. Lens designers spend a lot of effort trying to correct spherical and other types of aberration. Most camera lenses are made up of several lens elements, both positive and negative, which together reduce aberrations to a minimum.

Chromatic aberration



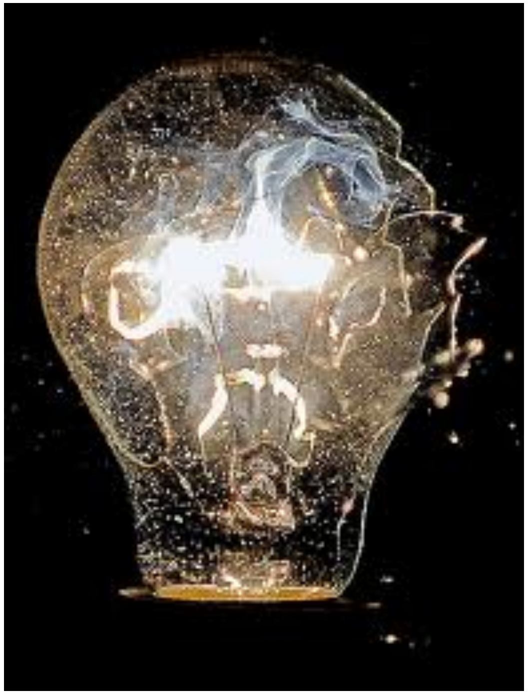
Chromatic aberration occurs because lenses focus blue light more strongly than red light. In simple devices like cheap toy telescopes this gives rise to colour fringes. But by combining lenses of different strengths made of different types of glass it is possible to cancel out this effect. Combination lenses in which different colours are bent by the same amount are called achromats or apochromats.



Lenses may also produce images that are focused not onto a flat surface like a film, but only onto a curved surface. This is known as curvature of field. Curvilinear distortion results in straight lines appearing to bulge outwards (barrel distortion) or inwards (pincushion distortion). Most lenses suffer from this defect to a small extent but in the case of a fisheye lens it is deliberately uncorrected. The benefit in optical performance is an enormous angle of view, typically 180° .

A tripod to steady the camera and avoid blurry images of moving objects

Images may also appear blurred if the camera or the subject move while the film is being exposed. Camera shake is a common problem in low-light conditions, when a long exposure is needed to form an image on the film, and with long focal-length lenses. In either case, a tripod can be used to steady the camera.

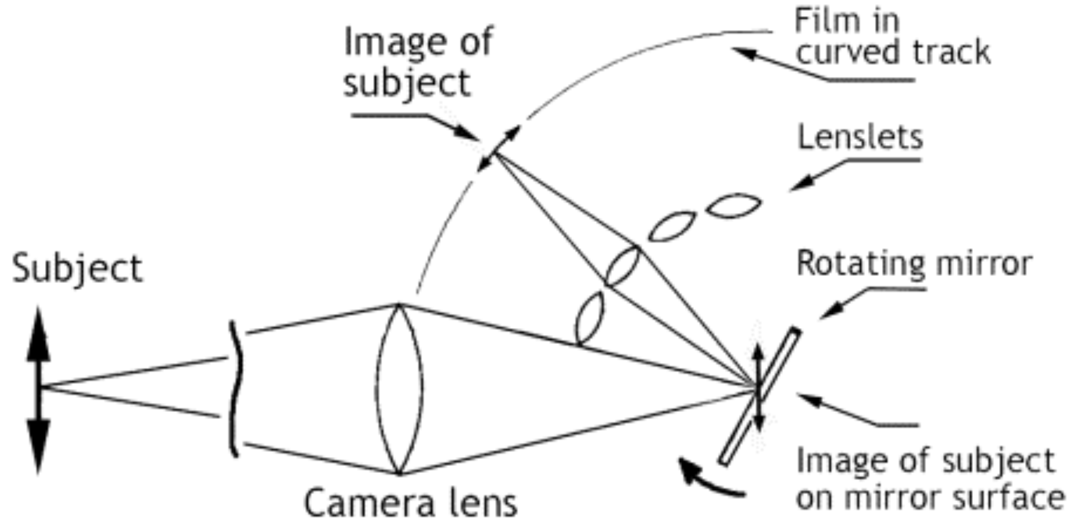


Light bulb shattering

Ballon bursting

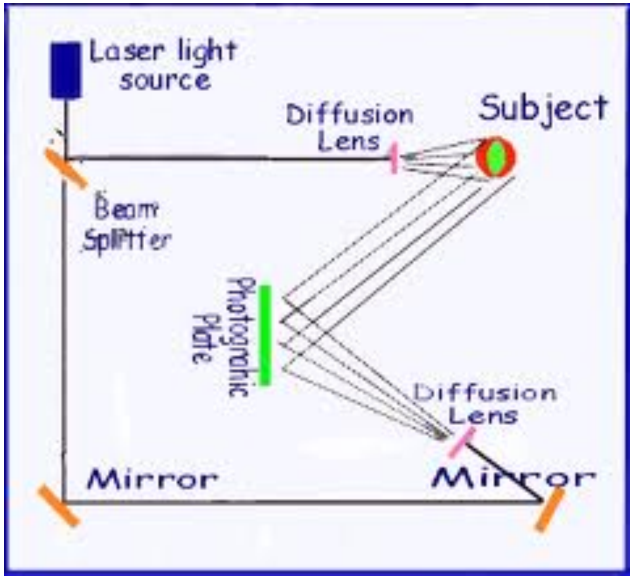
The length of the exposure is controlled by the light-tight shutter placed between the lens and the film, which opens for just long enough to let in the light needed to form an image on the film. How long this is depends on the lighting conditions, the lens aperture and the film speed. Many modern cameras can be set to open the shutter for intervals ranging from 1 second to about 1/2000 second. It is possible to make much shorter exposures. An electronic flash gun can produce enough light to expose the film in a burst that lasts for a mere 1/20 000 second. This can produce spectacular images, such as light bulbs shattering or balloons bursting.

Grasshopper leaping. Taken with a 5d mk2 and a 100mm macro, high speed flash and triggered with the single infrared beam from Triggersmart The beam was set 500mm apart with a single beam 5mm above the Grasshoppers head set on auto mode.

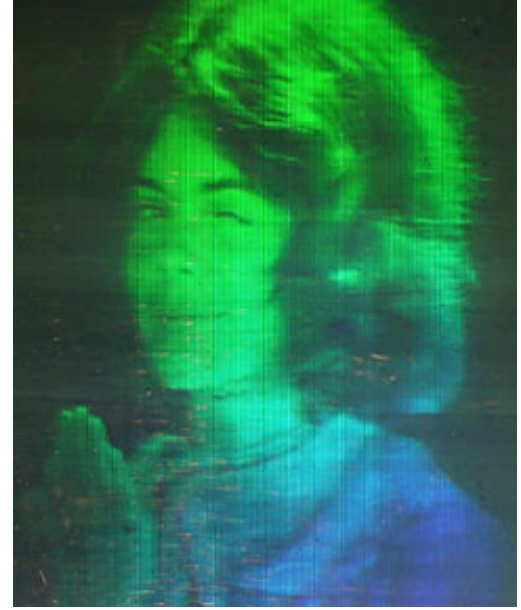


Use of a rotationg mirror as a shutter

To synchronise the flash with the event being recorded, photographers sometime use infrared trigger beams and electronic switches. While flashes are good for single exposures, they need time to recharge and so are unsuitable for a sequence of shots in quick succession. A way round this is to use a rotating mirror as a shutter. Each exposure lasts only for the period in which the mirror reflects light towards the film. With a small mirror rotating several thousand times a second it is possible to produce a rapid series of exposures only a few microseconds long. These short exposures mean that the subjects must be lit by a powerful light source such as a laser.



Holographic setup



Hologram

Lasers can produce short exposures themselves. Some lasers can produce pulses that last for only 10^(-15) seconds, which is short enough to freeze the motion of molecules during a chemical reaction. This does not produce a pictorial image but a set of data that researchers use to work out what is going on. Lasers can produce spectacular visual images too, particularly when they are used for holography. Holograms are recordings of the interference pattern created when two beams of laser light meet. A simple holographic setup consists of a laser beam and a semi-silvered mirror that sends half the beam towards a sheet of photographic film, leaving the other half to reflect off the subject onto to the film. The resulting interference pattern can be recorded on the film in the same way as ordinary light patterns. Viewing this pattern with the original laser creates a three-dimensional view of the subject.

Record of shock waves produced by bullets

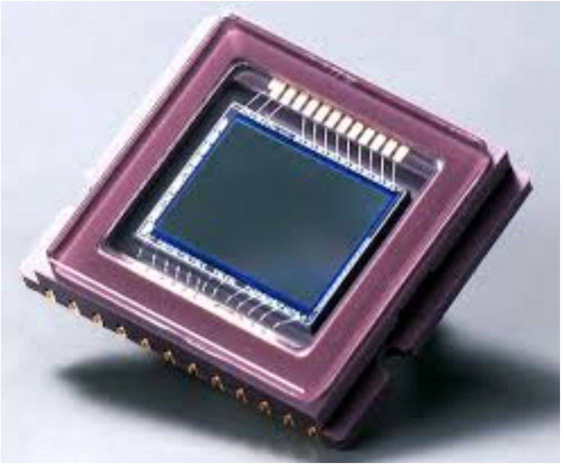
A schlieren photography of someone sneezing

With another photographic technique, it is even possible to record the shock waves produced by bullets and other fast-moving objects. Known as schlieren photography, from the German word meaning streaks, the technique relies on the fact that shock waves bend light more strongly than the surrounding air. This makes it possible to separate the light that has passed through the shock wave from the rest. And since hot air has a similar effect, schlieren photography can be used to image people sneezing and even the thermal currents surrounding the human body.

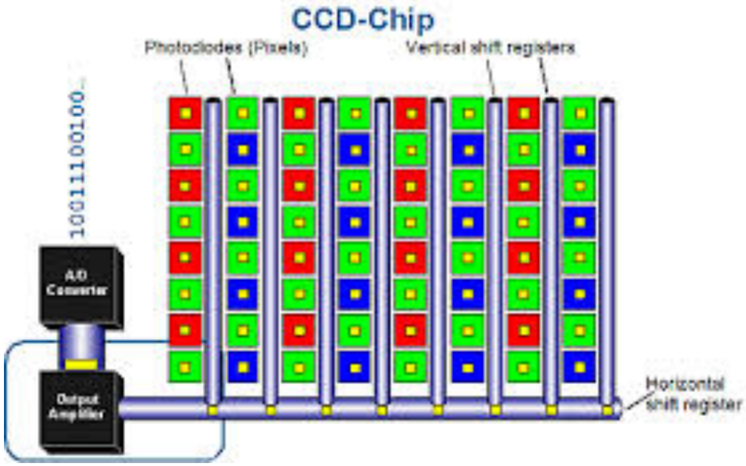
Photography of a tree taken in Infrared

Neither is photography limited to the visible spectrum. With specialist emulsions, or using ordinary film and filters, it is possible to use X-rays, ultraviolet and infrared light to gain a new perspective on everyday objects and scenes. In the near infrared (light with a wavelength between about 700 nanometres and 900 nanometres), the world looks very different. The sky and water appear black because they do not reflect much infrared radiation while grass and leaves reflect strongly and so appear a ghostly white.

Without doubt, Niépce would have been astounded.

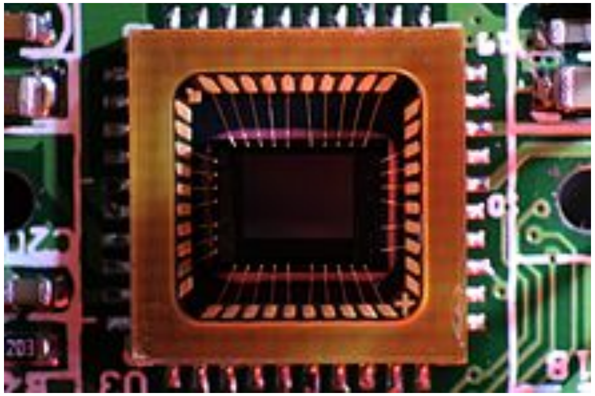


A CCD



An array of CCDS

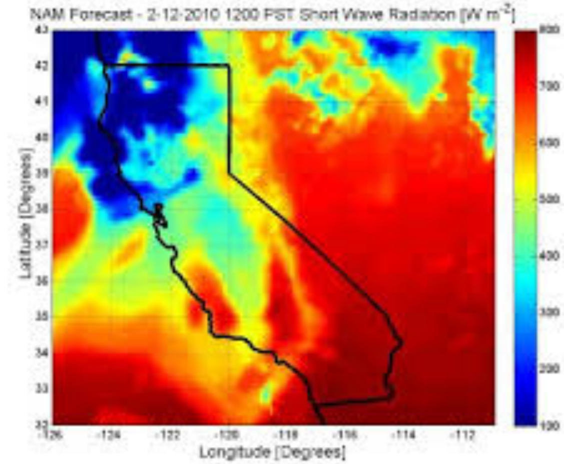
Photographic film is not the only way to record an image. Electronic devices that are capable of recording the light hitting them are now common. The main type, called charge-coupled devices (CCDs), produces an electronic signal that is proportional to the amount of light hitting it. By arranging a number of CCDs in an array, the signal from each CCD can be used to control the brightness of a pixel on a computer screen. In this way it is possible to record an image and this is exactly how digital video and still cameras work.



CCD

The problem is that a large number of CCDs is required to build up a high-resolution image. A basic laptop computer screen has an array of 480 by 640 pixels-a total of 307 200 pixels-and cheap digital cameras have roughly the same number of CCDs. But this gives an image with a low resolution compared with conventional photographs. If each silver halide grain is thought of as a pixel, one frame of a 35 mm film will have around 20 million pixels. The best CCD arrays have around 4 million pixels and are extremely expensive. But in future, high quality CCD chips should be available that rival the quality of photographic film.

A satellite equipped with electronic cameras



A thermal photography of the Earth in Infrared

In the meantime, there are some purposes for which the lower resolution of electronic images is more than made up for by their incredible flexibility. Electronic images can be fed straight into a computer, to be analysed or sent simply and cheaply over the Internet. Electronic cameras are also more reliable than conventional ones because they have fewer moving parts, and scientists in particular have begun to rely on them. A good example is in remote sensing. In the 1960s, satellites used photographic film to take pictures of the Earth's surface from space. When the film was used up it was jettisoned in a protective canister into the Earth's atmosphere and caught in mid-air by an aircraft. Clearly, this was a cumbersome, risky and time-consuming procedure. Today, however, most imaging in space is done using electronic cameras and the results are transmitted to Earth by radio. Although these images are not as detailed as those that film can manage, they can be much more easily measured, enhanced and manipulated on computer.

Development of electronic imaging techniques

News organisations are also beginning to make more use of electronic imaging techniques. An electronic image can be recorded and sent across the world in seconds. Conventional images take many minutes to develop and many hours, even days, to send around the world by courier.

In the past, storing electronic images has been difficult because of the huge amount of data they contain. But rapid advances in electronic memory technology mean that this is changing. It is already possible to store 30 low-resolution shots or more on a single floppy disc that can be bought in any high street.

But it is too early to write off conventional imaging entirely. It will be many years before electronic images match the quality that is possible with silver halide photography at a reasonable price.

Photography as we know it may not be immortal, but reports of its death are certainly premature.