Akademie múzických umění v Praze
Filmová a televizní fakulta

Adrian Aregger

New Means of Photography

Final Theoretical Dissertation Bachelor Degree Project

Prague, 2016

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The author states that she based her work only on the sources and literature named in the Acknowledgments and that the Dissertation is original text of her own.

Abstract

This thesis gives an overview over the different wave bands of the electromagnetic spectrum (EMS) beyond human perception and the means to capture them, as well as their use in science, industry and art.
With the revelation of light being an electromagnetic wave and the discovery of the EMS in the late 19th century, technology made an unprecedented leap, revealing the light beyond human perception. Todays technology is able to visualise the light of different wavebands with shorter wavelength than the visible spectrum, such as micro waves and infrared radiation, as well as the bands of longer wavelengths like ultraviolet, x- and gamma radiation. There are scientific fields, such as archeology, astronomy or geology, that make use of the special characteristics of each band, industries that use them for improving products and artists, that discovered the unique worlds. In this thesis a brief summary of the historical events and theoretical background needed for understanding the wavebands of infrared, ultraviolet, x- and gamma radiation and its applications.

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1. Introduction

Human vision is an astounding feat of evolution. Processing all the visual data the visual cortex is the largest system in the human brain underlining just how important sight is to the human body. Yet the electromagnetical waves that our eyes are able to detect, make up only a very small portion of the whole wave spectrum. It is trapped in a very thin slice of perception. It is seeing less than a 10 trillionth of what could be theoretically perceived. There are radio waves, microwaves, X-rays and gamma rays passing through the human body, but it is mostly unaware of it, becauset biological receptors were not evolved for picking it up.

What this means is that human experience of reality is constrained by biology. Photography is curtailed by those limits. A true document of events in time, that the brain is so evasive of, approximated as much as possible over years of inventions and development. From the early beginnings in black and white primarily in the blue and ultraviolet realm to the accurate colour representation and spectral filtering in modern sensors. Yet there is this technology developing, that allows for a new perception of the world, unseen by humans. scientist, forensics and atronomers reach for those invisible domains to discover previously undiscovered stars or traces at a crime scene thought to be invisible. Why doesn't the general population use this technology? Why don't photographers try to discover new ways of seeing the world?

Over the course of the following thesis I first set the overall basis for understanding the electromagnetic radiation and then examine more in depth various aspects of light and other bands; what it is, how it behaves and how it can be captured.

2. Theory

2.1 Brief history of light and optics

The following chapter will give a brief overview of the 3000 year old history of optics.
Mirrors are probably the first optical device conceived by men and are already mentioned in the old testament where it mentions pouring "Woman's mirror", water into a bronze sink:

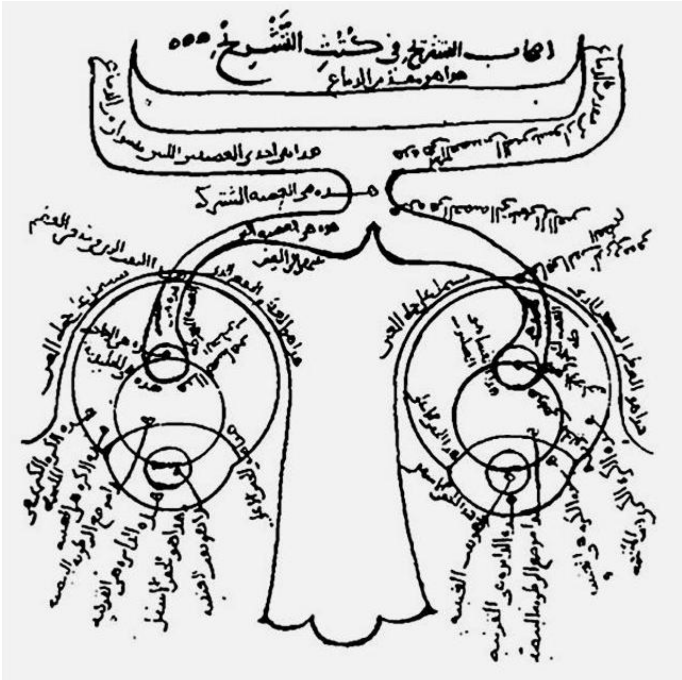
> He made the basin of bronze and its stand of bronze, from the mirrors of the ministering women who ministered in the entrance of the tent of meeting.
>
> Exodus. 38.8

Mirrors manufactured out of polished obsidian were found in modern-day Turkey and can be dated back even further to around 6000 BC. [En06]
Other references to optical devices can be found in ancient texts such as in the comedy "The clouds" by Aristophanes (424 AD) where a Burning Glass, a collective lens used to set fire, is described. In "The Republic" Plato mentions around 380 BCE the visual "breaking" of objects immersed into water and Senecca described the use of a glass orb filled with water for enlargement and it is likely that artist during that time were using it for filigree work.
Many ancient philosophers such as Pythagoras, Demolcrit, Empedocles, Plato or Aristotle pondered the nature of light. The fact that light moves in straight lines were as well understood as the laws of reflection, described by Euclid in 300 AD in his opus "Catoptrics". Aristotle hypothized light as the disturbence of an all surounding element called aether a theory that would be expanded upon again in the 19th century.

After the dawn of the Roman empire (476 AD) discoveries and research came to a halt in Europe and the centre for intellectuality and studies shifted to the middle east. In the country which is now modern-day Iran, a scholar named Ibn Al-Haztham or Alhazen (1000 PD) made significant contributions to optics via his book Kitab al-Manazir (book of optics) in which he described laws of reflection, the camera obscura, different sorts of mirrors and especially the anatomy of the eye (Fig. 1).

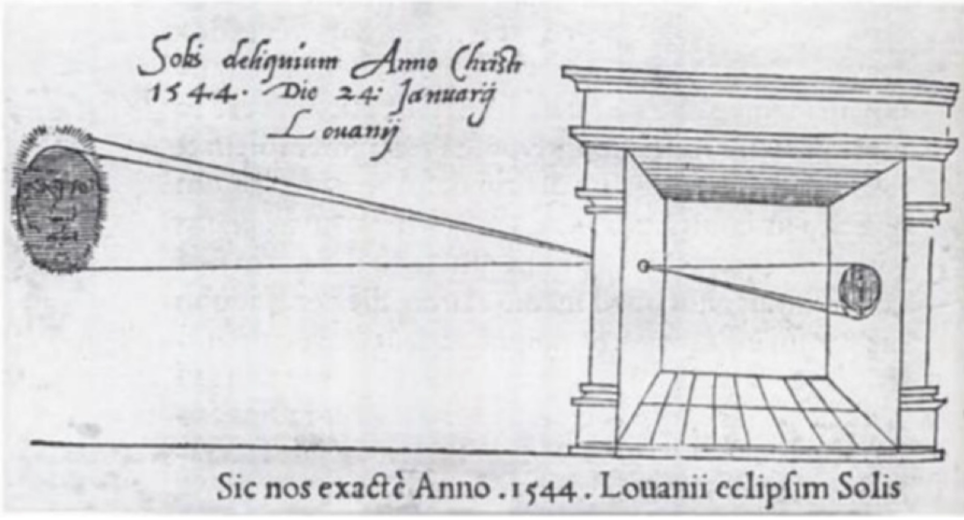
> The act of vision is not accomplished by means of rays emitted from the visual organ ... vision is accomplished by rays coming from external objects and entering the visual organ.
>
> Alhazen [AR72]

Ibn Al-Haytham had used a camera obscura in his extensive optical experiments and compared it to the eye. Thus, he realised that if the light rays, orthogonal to the curved surface of the crystalline lens, continued, they would project an inverted image on the back of the eye. (Fig. 1)
At the end of the 13th century Europe slowly awoke from hibernation and Alzahen's texts were translated



[Fig. 1] Alzahen's description of the human visual system.

into Latin, again scholars began to theorise about light and optics.
Leonardo da Vinci (1452-1519), influenced and inspired by the texts of Alzahen describes the camera obscura (Fig. 2), which Giovanni Battista della Porta (1535-1615) published 1558 in "Magica Naturalis" and brought to a wide audience.
It is unclear who can be credited with the invention of the telescope. While a monk named Roger Bacon (1215-1294) is often attributed with coming up with its concept, Hans Lippershey (1587-1619) first handed in a patent that describes such an invention. Galileo (1564-1642) heard of this novelty and built his own version while Johannes Kepler (1571-1630) not only described the exact way of functioning Galileo's telescope but improved on it (Keplerian telescope).
In his opus “Dioptrice” describes Johannes Kepler (1571-1630) the total reflection and was able to closely approximate the law of refraction for thin lenses. He further describes the first order of systems with small lenses and the exact way of functioning for both his and Galileo's telescope. Willebrod Shell (1591-1626) discovered in 1621 the long needed law of refraction and thus the door for modern optics was opened.
Still the exact nature of light was unclear and in the 17th century increasingly under debate. While in the 11th century Ibn Al-Haztham had argued light to be a particle ray René Descartes (1596-1650) described and popularized the idea of light as a pressure wave that moves through an universal medium similar to Aristotle’s aether.
The phenomenon of diffraction, the bending of light’s straight course by passing an obstacle seemingly supported the wave theory and has first been documented first by Prof. Francesco Maria Grimaldi (1618-1663). He observed lines of light inside the shadow of a pole, lit by a small light source.
Robert Hook (1635-1703) Christian Huygens (1629-1695) and much later Augustin-Jean Fresnel (1788-1827) expanded on the mathematical wave model of light and could theoretically show refraction as an effect



[Fig. 2] Earliest known illustration of a camera obscura. The legend translates: 'Observing solar eclipse of 24 January 1544.'

of waves moving at different speeds depending on material it passes through.

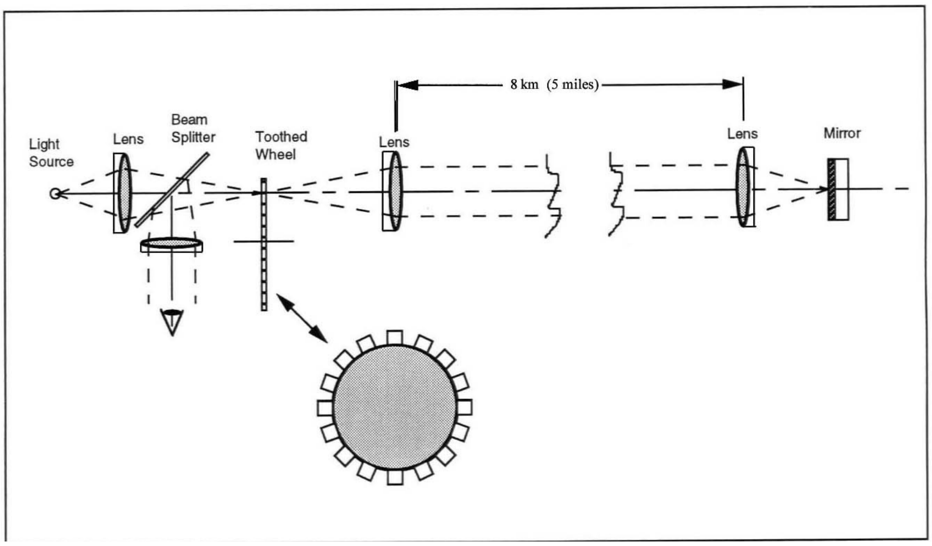
Isaac Newton (1642-1726) was opposed to wave theory and argued that the perfectly straight lines of reflection were indicative of the particle nature of light. In his opus „Opticks" he described light as a stream of small discrete particles named „corpuscles" giving rise to the popularity of his corpuscular theory. Further „Opticks" rejected the notion that light was fundamentally white and instead concluded that it was indeed the summation of all colors. He also clearly stated that colors were not an inherent property of light but instead a sensation of the mind. While Isaac Newton seemed to have won the debate over the nature of light in the 18th century, Thomas Young proved light to be a wave in 1806 via his now famous double-slit experiment.

Many believed light to have infinite speed - a theory that dates back to Aristotle. The first substantial definition of the finite speed of light was developed by Armand Hippolyte Fizeau (1819-1896). He constructed a mechanism of a rotating cog wheel and a mirror placed exactly 8633m away (Fig. 3). A short pulse of light was let through the individual openings of the wheel and reflected back. Looking through the cog wheel and adjusting the speed of rotation, he was able to observe the absence or presence of the reflection. By knowing these factors he calculated the speed of light to be approximately 315300 km/s and his colleague Jean Bernard Leon Foucault (1819-1868) later on proofed, that the speed of light is dependent on the penetrated material.

James Clerk Maxwell (1831-1879) discovered the fundamental connection between light and electromagnetism and described it in four equations. Those equations unified phenomenon that were thought to be seperate such as electro statics, magnetism, visible light, ultraviolet light and infrared red light which made his equations one of the most important contributions in the history of physics. His theory was later conclusively proven right by Heinrich Hertz in 1887.

Although the wave character of light had been proven still two fundamental problems remained.

First light still produced some particle characteristics namely the photoelectric effect first discovered by



[Fig. 3] Concept of Fizeau's construction for meassuring the speed of light.

Hertz and Hallenwachs in 1887 in where a metal exposed to light emitted electrons. Secondly the question of the medium for light to travel through remained very much unsolved. Although a medium in the form of aether had been proposed such an element had yet to be discovered. Further consequence of such a medium would have been that the speed of light would depend on the speed of the aether. Yet in all experiments the speed of light remained constant. This meant that either the aether was sticking to the surface of the earth and did not move independently of it or a new theory had to be found.

It wasn't until 1900 that Jules Henri Poincaré dared to state:

> "Whether the ether exists or not matters little – let us leave that to the metaphysicians. ... After all, have we any other reason for believing in the existence of material objects? That, too, is only a convenient hypothesis; only, it will never cease to be so, while some day, no doubt, the ether will be thrown aside as useless."
>
> 1889, H. Poincaré [Po89]

In 1905 Albert Einstein presented his "Special Theory of Relativity" in which he independently denied the hypothesis of the aether as well.

> The introduction of a "luminiferous ether" will prove to be superfluous inasmuch as the view here to be developed will not require an "absolutely stationary space"... that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body.
>
> 1905, A. Einstein [Ei05]

Bothe issues were eventually resolved by Einsteins idea of quantised light (later called photons) in 1905 for which he received the nobel prize and the introduction of Einsteins special theory of relativity which showed that Maxwells equations did not need a medium. [AT11][He09][JR88]

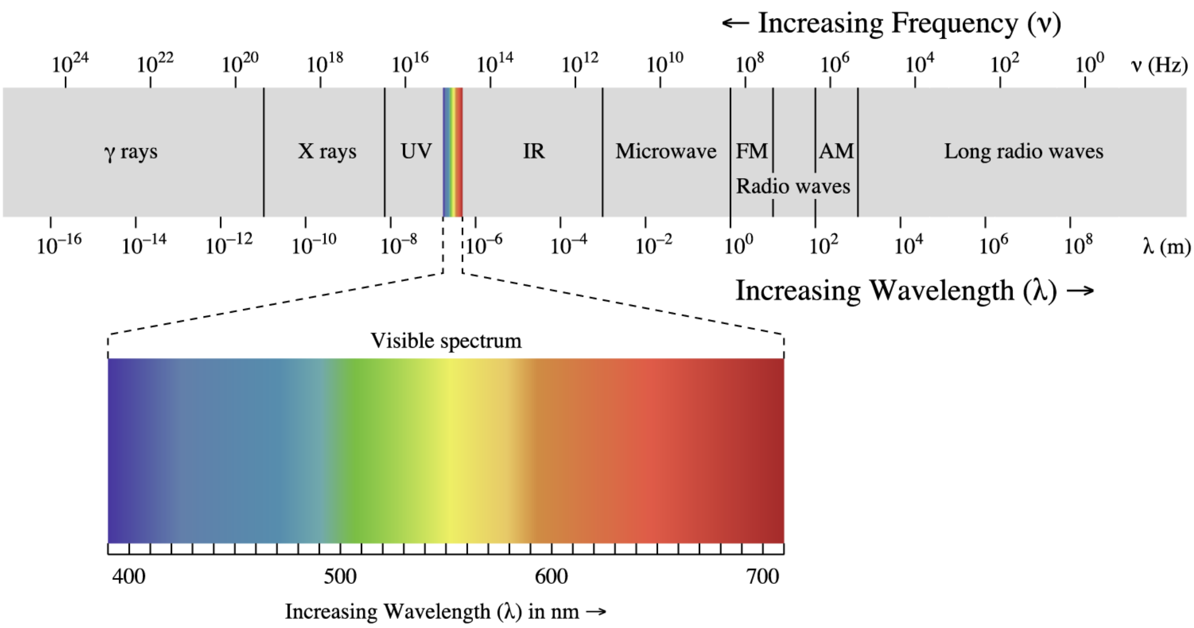
2.2 Electromagnetic Radiation

Modern physics defines light as part of the electromagnetic radiation (Fig. 4), which consists of photons, particles with different frequencies, that inhabit both, the laws of waves as well as the laws of particles. The shorter the frequency, e.g. the closer to gamma rays, the more photons behave like particles and the longer the frequencies the more like waves.

The base property of every particle is its localisability: it exists in a defined, very limited area of space. The key component of a wave on the other hand is, that it cannot be localised. A classical developing wave stands for a self-sustaining disruption of a carrier medium, which moves through space and transports energy and impulse.

The units used to measure electromagnetic radiation is either the frequency (Hertz), the energy (electron volts) or the wavelength (meters) and differs on the applied field. The spectrum is divided into approximately 8 sections. Each section shows different properties and is bound to a certain range of frequencies . The smallest measurable photons are gamma rays, subatomic radiation up to a wavelength of 10 picometer (10^{-11}m), although this is rather only a rule of thumb than a definition. Radioactive decay of an atomic nuclei is referred to as gamma radiation no matter its energy. The next longer instance than gamma rays are x-rays. Together with the gamma rays it shares the properties of penetration: because of their subatomic scale, they are capable of passing through solid material. This attribute weakens with increased frequency and stop around 10nm of wavelength, where the ultraviolet segment begins. The photons up to the visible realm, e.g. 400nm or violet, hence the name, don't quite have the piercing factor, yet it is still strong enough to kick electrons out of orbit and cause effects like the sunburn.

Light itself is described as a narrow part of the electromagnetic spectrum, which ranges from the sometimes



[Fig. 4]   Spectrum of the Electromagnetic Radiation

kilometres long radio waves to the atomic and even subatomic gamma rays (Fig. 4). It begins at approximately 400nm with red light the goes through green at 500nm, blue at 600nm and finally violet at around 700nm, which marks the endpoint of light. The Oxford dictionary describes it as follows:
A kind of radiation including visible light, radio waves, gamma rays, and X-rays, in which electric and magnetic fields vary simultaneously.
Just beyond the visible in the electromagnetic spectrum is the infrared up to approximately a millimetre wavelength. It is where the sun emits the most radiation and heated bodies radiate. The longer wave band are Microwaves. Moving along the spectrum to longer wavelengths, the microwave region. Water molecules are heated by the absorption of microwave radiation, therefore its use in microwave ovens to heat food and beverages. Radio waves, discovered by H. Hertz in 1887, have very long wavelengths (from 0.3 metres to many kilometres). Their frequency range is very large and extends to about 10 9 Hz. Radio waves have no effect on the body, i.e. they cannot be seen or felt, although they can readily be detected by radio and television receivers. Radio frequencies are used in astronomy and are captured by radio antennas. Otherwise radio waves are used for transmitting telephone communications, guiding aeroplanes, in speeding radars and in remote sensing. [AT11] [He09][Ja88][Ra06][Ra99]

2.3 Visible Light and colours

The definition of light, according to the Oxford Dictionary is:

> The natural agent that stimulates sight and makes things visible.
>
> Oxford Dictionary [Ox16]

Light is defined in modern physics as a photon, visible to the human eye. Frequencies, such as infrared and Ultraviolet therefore do not conform to this definition, even though they are based on the same particle, the photon.
The Bohr model of an atom states, that there is a nucleus, consisting of neutrons and protons, as well as there are layers of electrons orbiting around the nucleus. Those electrons vibrate at a certain frequency. When a photon hits this an electron with the same frequency, the photon is absorbed and the electron is set into vibrational motion, which is then converted into thermal energy. If the material is reflective, the photon's and electron's frequencies do not match, the photon sets the electron into short vibration, then the energy is remitted as light. A transparent material the vibrations of the electron is passed to a neighbouring electron throughout the depth of the material. Such frequencies of light waves are said to be transmitted. Each material is a mixture of those properties and electrons at different frequencies.
In general materials three types of properties: reflectance and transmission. The colour of the objects is largely due to the way those objects interact with light and ultimately reflect or transmit it the a sensor. When light hits an object the photons of certain frequencies are absorbed and the rest is either transmitted or re-

flected, which will contribute to the appearance of the material. If an object absorbs light at all frequencies except that of green, e.g. it reflects or transmits only photons with the frequency around 520-560nm, then it will appear to be green. Black materials absorb most of the visible frequencies, whereas white reflects the majority. Transparent materials may absorb photons of certain frequencies, but transmit and reflect the rest. [He09][Ja88][Ra06][Ra99][AT11]

2.4 Filters

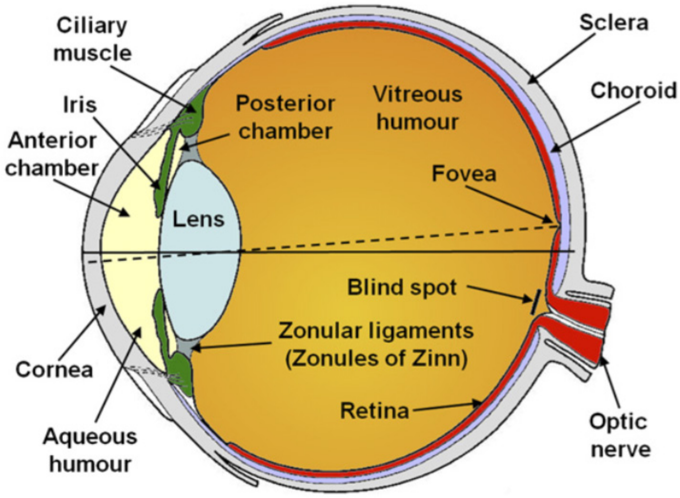
An optical filter can either be absorptive or change the interference. Their purpose is the filtering of the spectral band of unwanted frequencies otherwise transmitted by the optical system. The characteristics of filters corresponds with their transmission properties. The colour depends on the transmitted wavelength and most naming corresponds with the wavelength cut-off region, e.g. Y52 transmits beyond 520nm. For proper exposure, the amount of absorbed light, depending on the density and transmission frame of the filer, has to be compensated and is expressed in a filter or exposure factor as a multiplication such as x4 or a negative Exposure Value (EV), i.e. -2EV. [Ra99]

In black and white photography filters help to alter the tonal reproduction. As rule of thumb it can be assumed that a filter lightens subject colours of its own colour and darkens those of complementary colour. Haze penetration in telephotography is improved by orange or red filters, restricting photography to longer wavelengths which are scattered less.[Ra 99] Colour photography uses filters most notably for accurate colour representation, i.e. control the white balance through colour temperature filters. Each colour film is produced for certain light colour temperatures expressed in Kelvin (k), such as candle light at 2800k or daylight at 5600k. With the use of filters the light can be adjusted for the film in use. A daylight film in combination with a blue filter will produce accurate colour reproduction in candle light scenarios. For both kinds of photography a neutral density filter can be used to limit incoming light uniformly across the spectrum.

The orientation of light wave vibration is completely randomised, giving unpolarised light. If the vibrations are restricted to one particular plane, called the plane of polarisation, the light is then considered polarised. Polarised light can be produced by a polarising filter. Reflected light is partially polarised and can be dimmed by placing a polarising filter at the right angle in front of the sensor. The sky, 90 degrees to the sun is rendered the darkest through a polarising filter, but gets bright the closer it is pointed towards the sun or 180 degrees to the sun. [AT11] [Ra99]

2.5 Human Vision

The eye (Fig. 5) and camera share a lot of similarities. The cornea and the pupil bundle and focus light, like a lens and the iris itself acts like the aperture, adapting the opening diameter to varying light situations. The light then hits one of two differently shaped sensors - rods and cones - on the retina, similar to a digital sensor

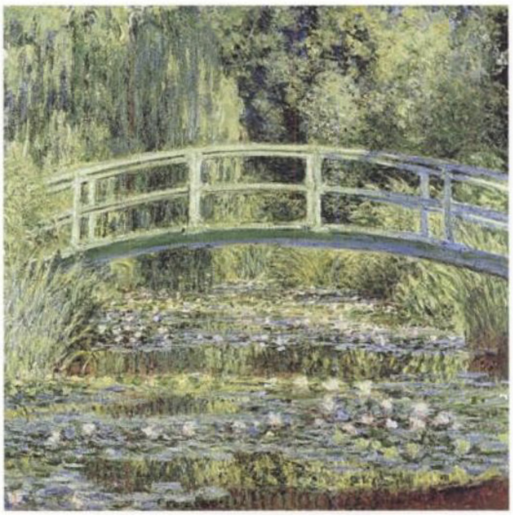


[Fig. 5] Cross-section through the human eyeball.

chip or analog colour film. A nerve system in front of the sensors then bundles in the blind spot and delivers electric impulses to the brain, the processor on a camera or computer. Yet vision is complex, rendering a 3D, full colour perception, while a camera is rather simple and believed to be unbiased. Perception is a collaboration of the eye and the brain, where the eye provides observation data from the retina and the brain is responsible for the interpretation, influenced by culture, experience and prejudices, which results in details being added or ignored from the perception. [Gr66][Co70][So77]
Rods outnumber cones by a factor of about 20, e.g. 120 Million rods to 6 Million cones, and are responsible for sensing pure luminance changes. [AT11] They are active at dim light situations and are clustered throughout the whole inside of the eye, but actually more prominent towards the side and front. Hence in bad light situations it is easier to see things if not looking directly at them. Cones on the other hand detect colour and come in three variations, each responsible for one of the three primary colours, e.g. red, green and blue. They are especially grouped in a hexagonal pattern around the fovea. When light hits those sensors a chemical reaction is triggered and an electric impulse is formed. The data from the cones reaches the brain immediately and unaltered, whereas that of the rods is grouped up and averaged. The brain then tries to make sense of this data and we end up with our vision. What we define as vision is therefore nothing else than the brain making sense of a constant stream of electric impulses.[AT11][Ra06]

Our vision is quite limited in the frequency range between 400-700nm, whereas the lens and cornea filters out the upper range and the rods and cones don't react to near-infrared photons. [AT11] The high-energy UV light accelerates the darkening of the lens by age and turns it visibly brown until the age of 70 and as well damages photo receptors, decreasing the sensitivity. Through the adaption of the brain these changes remain invisible. A cataract, an extreme of normal ageing of the lens and inability of the brain to compensate, affected the french impressionist painter Claude Monet's (1840-1926) style over the years, showing a visible shift in blues and greens to yellows and browns (Fig. 6, Fig. 7). When almost turned blind at the age of 82 he had the lens of his right eye removed, leaving his left still impaired with a strong cataract. The removal of the the

yellow lens resulted in a sudden increase of visible blue colours, which contrasted to the brown world spectated in his left eye. It is believed that he tried to express this sensation by painting the same landscape with each eye individually (Fig. 8, Fig. 9). [BK+98]
On December 1st 2014 an international team of scientist released a paper on the human eye's ability to see infrared light under certain conditions. Based on the observation of researchers, that they were sometimes able to see green flashes when operating an infrared laser, the research was initiated. "They were able to see the laser light, which was outside of the normal visible range, and we really wanted to figure out how they were able to sense light that was supposed to be invisible," said Frans Vinberg, PhD. [PV+14] The resulting conclusion is, that the eye's pigments react, in the rare occasion that two infrared photons hit it at the same time, and produce a signal. This means that the eye is theoretically able to see wavelengths of up to 1000nm.



[Fig. 6] Top: Monet, C.: Le bassin aux nympheas.
[Fig. 7] Bottom: Monet, C.: Nymphéas: Le pont Japanais.

[Fig. 8] Top: Monet, C.: La maison vue du jardin aux roses.
[Fig. 9] Bottom: Monet, C.: La maison vue du jardin aux roses.

3. Defining Photography

There are many definitions of photography, the etymology dictionary defines the term as follows:

> The word "photography" was coined by Sir John Herschel (1792-1871) from the Greek roots φωτός (phōtos), genitive of φῶς (phōs), "light" and γραφή (graphé) "representation by means of lines" or "drawing", together meaning "drawing with light". It won out over other suggestions, such as photogeny and heliography. Neo-Anglo-Saxonists prefer sunprint; and sun-picture was an early Englishing of the word. The verb, as well as photography, are first found in a paper read before the Royal Society on March 14, 1839.
>
> Online Etymology Ditionary [Ha16]

The Oxford Dictionary:

> A picture made using a camera, in which an image is focused on to light-sensitive material and then made visible and permanent by chemical treatment, or stored digitally [Ox16]

Radiometry and Photometry are scientific disciplines concerned with the measurement of electromagnetic radiation. Radiometry is concerned with the measurement across all frequencies of the electromagnetic spectrum and therefore includes ultraviolet, visible and infrared light as well. Photometry, by contrast, deals with the measurement of radiation as it is perceived by the human visual system and therefore only deals with visible light, wavelengths 360-770 nm.

There are thus three factors, need to be fulfilled to become a photograph or be considered photography:

- The presence of light as a carrier of information.
- A camera.
- A sensitive material to receive and store such information.

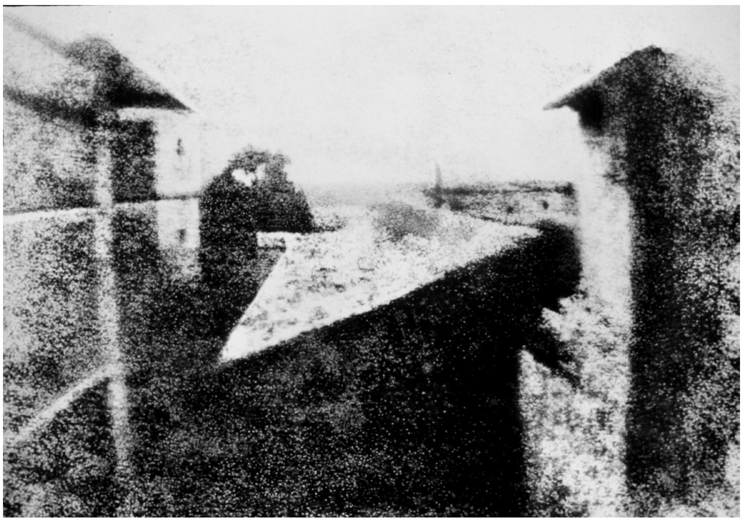
3.1 Camera

The camera obscura, a dark chamber where only a small opening would let light in, was the earliest form of a camera. This devices dates back to the ancient Chinese and ancient Greek, which uses a pinhole or lens to project scenes from the outside upside-down onto a viewing surface.
The Arab scholar Ibn al-Haztham published in his book of optics the construction of the first pinhole camera and is credited with the invention of the camera obscura. He realised, that the smaller the opening the sharper the image.
Before the invention of the photographic process, pictures were hand traced to be preserved and cameras were the sizes of small rooms, by the time of Niépce they had been scaled down to handheld portable dimen-

sions. In 1800 Thomas Wedgwood (1771-1805) made first attempts to combine the camera obscura with the newly discovered photosensitive materials but as he reported the images were to faint and he had no way to make them last, as Humphry Davy reported:

> The images formed by means of a camera obscura have been found too faint to produce, in any moderate time, an effect upon the nitrate of silver. ... No attempts that have been made to prevent the uncoloured part of the copy or profile from being acted upon by light have as yet been successful.
>
> 1802, H. Davy [Li73]

Approximately 1826 Nicéphore Niépce (1765-1833), a French physicist, famously created the first permanent photograph of his window view with his very small handmade camera (Fig. 10), in its most basic form a sliding wooden box with lens attached to allow for a sharper and brighter projection.[Ge86] Both Daguerre and Talbot used very simple camera designs as well, consisting of two nested boxes. The rear box was able to move back and forth for focusing had a ground glass projection screen. The lens had a fixed aperture and exposure time was manually controlled by covering it with a cap. Daylight and a fast film allowed for a smaller camera and hand-held exposure. The shorter exposure time lead to the invention and implementation, first separate then inside the lens, of a mechanical shutter. 1888 George Eastman first offered to sale his Kodak camera. A very simple box camera, that came pre-loaded with enough film for around 100 pictures and that had to be sent back to the factory for extraction, development and restocking. In 1900 he introduced the Kodak Brownie to the wide masses and pioneered the concept of the snapshot. By 1900 every fourth person in Britain, at the time with a population of four million, was estimated to have a camera [He65] Even though cameras existed, that made use of 35mm cinema film at 1912, it took until 1925 for Leitz's small Leica rangefinder camera that spawned immediate popularity and copies of design, due to it's portability, rapid action and lightness. It was especially significant in the development of documentary and photo-journalism. 1938 the first autoexposure camera with built in exposure meter, the Kodak Super Six-20, was introduced, but steep



[Fig. 10] " View from the Window at Le Gras." First known permanent image recorded by Nicéphore Niépce.

component prices and the outbreak of the second world war refrained its success. [Co78] It took until the 1960s for built in light meters and automatic exposure became widespread.
The first digitally scanned image was taken in 19757 and Satellites were equipped with Charge-Coupled Device (CCD) array sensor already by 1976, but it would take another 12 years to be scaled down and built into cameras. Until then cameras were increasingly digitised and equipped with chips to do calculations. 1989 Fuji introduced the first portable true digital camera, but it was a commercial failure. With the invention of compressed image files (Jpegs) in 1987 and the improvement technologies, digital camera sales began to flourish around 1999, when a lot of big companies went on producing their own digital camera system. Since 2003, digital cameras have outsold film cameras and are now implemented into any cellphone or electronic devise. [AT11][He09][Ja88][Re95]

3.2 Photosensitive Material

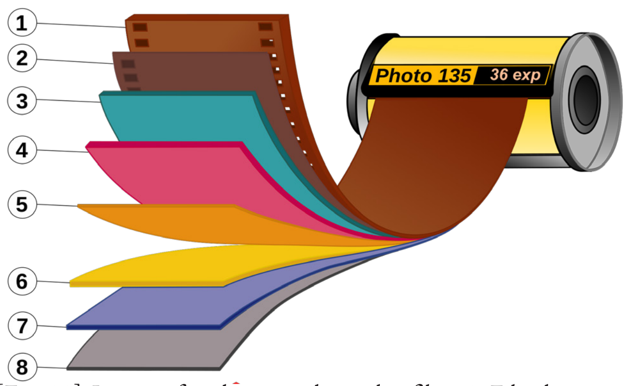
Thomas Wedgwood was the first one to combine leather treated with silver nitrate and the camera obscura. He build up on the early experiments by Wilhelm Homberg (1652-1715) describing the darkening of silver nitrate after exposure to light in 1694. The production of a latent image by Niépce was done with bitumen on pewter. Niépce met Louis-Jacques-Mandé Daguerre in 1826 and they soon joint forces in the studies of photosensitive material until Niépce's death in 1833. Daguerre continued and soon abandoned the asphalt prints that Niépce used for the much faster silver chloride coated on silver backing, which produced invisible exposures until developed by mercury steam and made permanent with common salt. He produced the first permanent negative picture in 1837 and sold it to the french government in 1839 as the Daguerrotype. The long exposure time of approximately 20min for one picture, made it impractical for portrait photography or any sort depicting a moving subject. 1840 Henry Fox Talbot (1800-1877) presented his Calotype process, a latent negative photograph produced on a faster reacting silver iodide film on paper and the use of hyposulfite of soda as a fixer. Even though the exposure time was a fraction of the daguerrotype's, it lacked the precision and detail. Frederick Scott Archer(1813-1857) experimented with collodion as a binder for silver halides on glass to improve the calotype and published his findings 1851 as the wet collodion or just wet plate process. Paired with the albumen printing process introduced by Louis Désiré Blanquart-Evrard (1802-1872) in 1850 it resulted in becoming the basis of the most commercially successful and universally practiced process in the 19th century until it was eventually replaced by the gelatine emulsion plate in the 1880s. The gelatine plates could be acquired pre-coated, had controlled sensitivity and could be developed later at a more convenient location. The concept of flexible film dates back to the calotype, but it didn't succeed until the mid-1880s that Eastman Dry Plate Company introduced a celluloid-based, paper backed roll of film and Eastman Transparent Film in rolls and sheets of clear, flexible nitrocellulose in 1889. This allowed for taking multiple pictures on a single roll of film.
Throughout the 1880s manufactures focused on increasing the sensitivity of the gelatine emulsions, as it was

primarily sensitive to the ultraviolet, violet and blue wavelengths, characteristics they shared with all previous photographic processes. The increase in spectral sensitivity was not only important to decreasing exposure time, but essential to the development of colour photography. Already in the 1850s colour daguerrotypes by Levi Hill (1816-1865) or in 1877 a similar process called heliochromes by Niépce de St. Victor (1805-1870) were introduced, but had little success. However, in 1861 James Clerk-Maxwell (1831-1879) made a celebrated demonstration of additive colour synthesis, generating interest in finding a way to extend sensitivity of collodion plates for full-colour photography. For Maxwell's demonstration Thomas Sutton (1819-1875) then made three negatives through red, green and blue filters of a colourful ribbon, which were then projected through the same filters, resulting in a "full-colour" image. In the 1870s Adolph Braun, Hermann Wilhelm Vogel, and Frederic Ives conducted promising experiments using dye sensitising emulsions with eosin and chlorophyll, increasing the spectral response to green and some yellow colours. By the 1890s isochromatic gelatine emulsions were produced with extended range to deep oranges, but it took until 1903 for Agfa to create panchromatic films with its sensitivity to the entire visible spectrum. The important experiments with isochromatic and panchromatic emulsions were a great help in making colour-assembly prints from separation negatives or experimental additive colour plates.

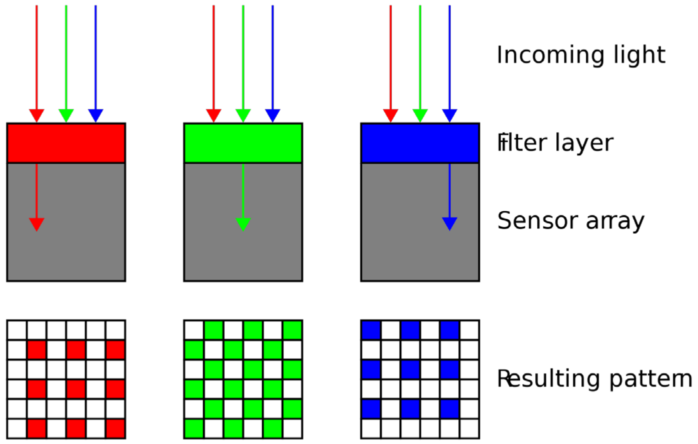
These materials were the basis for modern materials, and their structures and properties have been refined rather than dramatically changed. A carrier material is coated with a photosensitive material, such as silver halides and encased in a light-tight container. Upon exposure to light, photons agitate the silver halide crystals and rearrange them. A developer liquid then bond chemically with the agitated crystals and form a black grain. The fixer finally removes the unbound crystals and leaves a developed negative, where the densest concentration of grains are the areas exposed the most to light.

Colour film is produced by stacking three layers of photographic emulsions upon each other and colour filters in between (Fig. 11). Each layer becomes therefore responsible for one primary colour. In development the filters are removed and the layers are paired with equivalent dyes. [AT11][Ge86][Pe13] [Ja88]

3.3 Camera Sensor



[Fig. 11] Layers of a photographic color film. 1. Film base; 2. Subbing layer; 3. Red light sensitive layer; 4. Green light sensitive layer; 5. Yellow filter; 6. Blue light sensitive layer; 7. UV Filter; 8. Protective layer.



[Fig. 12] Concept of an image sensor with the bayer pattern.

The spectral response of silicon sensor technology ranges from around 300nm to 1100nm, limited at the upper end by the penetration depth of photons.[DA09] Cameras produced for the consumer, have a sensor market have a filter placed in front of the sensor, limiting the incoming radiation to the visible spectrum. Back-illuminated sensors are chips specially arranged imaging elements to increase the amount of light captured and thereby improve low-light performance. Used primarily for low-light security cameras it found its way into the consumer market. Additionally the sensitivity is increased in the ultraviolet region up to around 200nm.

A Change-Coupled-Device (CCD) is a light sensitive sensor that maps incoming light in a two dimensional matrix. It is built up similar to a analogue colour photography film. Where silver-halides are replaced with silicon segments arranged in a Bayer-pattern (Fig. 12), each pixel corresponding to one of the three primary colours. [PR15f] Since the average human vision is at its peek performance in the green frequencies, the are twice as many green pixels on each chip, than blue or red. Each pixel has a filter of one of those primary colours placed in front. Each pixels on the sensor produces an analogue signal after being struck by a photon. The signal is then transformed on the chip to a digital signal with discrete numbers, that then form the values on the screen.

The Complimentary Metal Oxide Semiconductor (CMOS) is a different technology of digital photo sensors, emerged approximately the same time as the CCD sensor, but found its way into the consumer market not long ago. Whereas the CCD outputs an analogue signal the CMOS technology converts, amplifies and corrects noise on the chip and returns a digital signal. These functions increase design complexity and reduce the area available for light capture. The CCD chip also reads each pixel at once, while a CMOS has a rolling shutter, scanning pixels from top to bottom consequently.

Different variations of sensors exist. Sigma's Faveon technology makes use of the fact, that each wavelength penetrates the silicon to different depths. Values are captured for all three colours for every pixel. This allows for high quality and detail in colour representation. Fuji Film's X-Trans sensor does not rely on the Bayer pattern, which is prone to moiré, a asymmetrical arrangement of pixels eradicate this effect and eliminate the need for a anti-aliasing filter, which improves the sharpness. [AT11][Ed16][Lo16][Pc10]

3.4 Lightfield Camera

First proposed in 1908 by Gabriel Lippmann, calling it an 'integral camera', the concept of a light field camera or , consisting of an array of glass beads placed on the focus plane onto a photographic emulsion. Traditional cameras only record a two dimensional representation of a scene. Each glass bead, nowadays mostly hexagonally arranged micro lenses, acts as another lens or eye and forms an image from its point of view, resulting in an arrangement of pictures and views depending on the number of beads. Recent developments in high resolution sensors, gives way for digital implementation of such technologies. By capturing multiple views at the same time from different angles, parallax shift can be analysed and the angle of photon incidence calculated. This leads to a number of uses such as depth map extraction, 3D modelling, refocusing and slight change of angle including parallax shift all from a single image. Since peering behind and object is possible, foreground objects could possible be removed. Current limitations are the resolution of the sensors and further research be conducted. [Ha13][PR15n]

The basic concept and mathematics behind it are applicable to interesting technologies. Adobe Systems is working on an estimated 100 mega-pixel camera, with a special compound lens made of 19 smaller lenses (Fig. 13), each resulting in an individual focal point.[Ro07] With the use of the appropriate software, the individual viewpoints of each small lens can be extracted. The advantage of having such technology in the lens instead directly on the sensor would make switching between traditional and light field photography possible. Using special software the light field picture could then be analysed and the focus as well as point of view be changed. It should be expected, that the transition between viewpoints is not too smooth, since images in between would have to be calculated. Lytro, a light field specialised camera producer potentially targets video production of virtual reality films.

The technology is now about to be reversed into light field display granting a 3D view from different angles for each person looking at it.[WL+12] Recent proof of concepts make the display even emulate different material surfaces and realistic reaction based on lighting. [GZ+14]

[Fig. 13] Adobe's concept for a lightfield lens.

4. Infrared

In 1800 the astronomer Sir William Hershel (1738-1822) discovered the infrared radiation (IR). As the name suggests the band lies directly beneath the visible red light.
Between 1 mm and 750nm lies the realm of IR Photons. They border to the Microwaves at higher and red light at the lower end of the visible light spectrum. It is where the sun emits most of its radiation, but is invisible to the human eye. There are a few animals though, that are able to see further into the infrared spectrum than we do. Certain families of snakes, such as the pit vipers, the boas and pythons developed a natural thermal vision, that reacts to heat emissions from hot objects, as at all temperatures above the absolute zero point, -273°C bodies emit infrared radiation.[AT11][He09][Ra06]
The landscape in Figure 11 is photographed in the near IR, showing foliage (tree leaves, grass) strongly reflecting IR in the same way that snow reflects light.
With extended sensitisation, silver halide materials can record to 900nm but astronomers may hypersensitive special plates to some 1300nm. [Ra99] Digital silicon sensors are sensitive to IR up to 1100nm and actually peaking sensitivity at around 800nm, which is why an IR blocking filter is placed in front of the sensor. [DA09] If that weren't the case, the IR would throw off the metering of the sensor, resulting in an overall red hue and a loss in image quality, by the addition of an aberrated IR image.
Yet the outcome only becomes truly special if a IR Filter is added, blocking all the light, but IR. They come in different intensities identified by the cut off range in nanometers. With such a filter only a small portion of light is being let through, therefore the exposure has to be adjusted accordingly. Since the filter will block out most of the visible light, focusing and framing in an SLR has to be done prior to the attachment of the filter. There are two shapes of filter to buy; square or screw on filter. The advantage of a square glass is, that it can be slid into a holder in front of the lens, prior to shooting, making framing quicker to adjust. [Li16][[Rø04]
Infrared is recorded monochromatic on both film and photography, i.e. they are based on the amount of IR radiation. This is due to the fact that until recently no distinction was made between different infrared

[Fig. 14] Infrared Image recorded with the Sigma SD10 and B+W 093 filter.

wavelengths was made, but simply added up. In 2015 a new technology was devised, able to differ frequencies inside the infrared spectrum and allow for colour mapping similar to visible light photography. [AH+15]

4.1 Infrared Analogue vs Digital Photography

Digital Infrared photography (Fig. 14) differs substantially from film IR photography. Analogue infrared photography is known for its contrasty, black and white images with jet black skies and white clouds, deciduous trees glowing in strange brightness. One might think that it should be the same in digital cameras, yet the truth is, that infrared radiation is not only picked up by the red pixels on the sensor, but also the blue and green ones, decreasing the contrast drastically. The digital CCD, expecting photons in the range of the visible spectrum, is forced to make sense of the to us invisible IR rays, so they end up making colours where no perceivable to humans can exist.

The distinction has to be made between digital IR colour photography (DIR) (Fig. 15) and the analogue counterpart (AIR). There is no pure AIR, as the IR spectrum is perceived monochromatic and would have to be split into smaller bands, requiring filtration of those specific bands, which has not yet been achieved. Only false colour AIR exists, by sensitising filtering one emulsion layer to the IR spectrum. The colour film Ektachrome adds green and red bands to the ensuing colour image, but these are shifted upwards so green becomes blue, red is assigned green and the IR component rounds off the scene by being rendered as red.[Rø04]

Conventional silver halide materials are spectrally receptive to a wavelength of 680nm and the sensitisation deeper into IR causes loss of efficiency, typically by a factor of 10 per 100nm. It can potentially be extended up to a real limit of about 1240-1350nm, set by oxidation reactions. Photographic material available for IR recording such as the Kodak Technical Pan and the Illford SFX-200 film have extended bands to 900nm. A drawback is that the film must be loaded and unloaded in complete darkness, an inconvenience for location work. Some analogue cameras use a combination of IR emitting LED and detector to meter film frame advance. This will cause the IR film inside to be partially exposed, resulting in a foggy image.

4.2 Filters

Even though the sun emits the biggest fraction of its light in the IR range, the filter in front of the CCD sensor and added frequency sensitivity in film makes daylight wash out the IR image. An opaque filter that doesn't let any visible light through is therefore needed to limit incoming radiation to only the IR range. Since the frequency is lower to that of visible light, focus has to be adjusted when attaching a filter, since most lenses are tuned to green light. Fortunately most older lenses feature a red or orange indicator next to the focusing inscription, which is tuned for infrared focus. Once the subject is sharp without, the filter can be attached and the focus point on the lens moved to the orange dot for perfect infrared focus. The opaqueness of the lens prohibits focusing by eye anyways and forces it to be done prior to attachment, which is why a square filter or a one with a hinge, to allow it to be simply be swung away for normal usage, should be considered. Most modern cameras have such an improved ISO capability, that live-view through a filter can be managea-

[Fig. 15] Digital Infrared Image with switched blue and red channels.

ble, which means manual focusing and sometimes even contrast detection focusing is possible.

There is an extensive range of IR filters from various manufacturers. Ranging from the homemade film conversion to the square filters intended for professional daily use. A number in the naming of the filter mostly indicates, at what range the frequency cutoff will happen (A Hoya 89B will cut off at 890nm). Where the higher number is used for true IR images and lower numbers, such as the Hoya 72 for the near infrared range, letting some red light through already. Typically they come either as a round glass, that can be screwed on, a square one to be mounted in on holders or a gelatine sheet.

The easy IR solution is a cut piece of non-exposed, developed, E-6 film, placed in front of the lens or sensor directly. It results in some convincing IR images, although the emulsion and plastic will cause it to be on the softer size. Due to its size a 120 mm film will fit most purposes, since the thicker 4x5 film will blur the image too much.

An 87 is a typical black IR filter which scarcely lets any visible light through. Even the bright sun will only show as a dull red glow. They are best suited for film based systems and produce the typical "IR-Look". For most digital camera systems this filter is too dark though, to be used comfortably.

An 89B fits the digital realm much better, with extended response into the visible frequencies, it produces a mild infrared looking image.

Filters like the Wratten 87C and Hoya RM1000, are of denser material and therefore less suited for digital cameras, because if its likelihood of lower sensitivity to longer IR wavelengths. Nevertheless it can be mounted onto a digital system and produce amazing results, just the exposure time will increase accordingly.

A list of filters recommended for infrared photography: [Li16][Ra99][Rø04]

- Wratten 88A, 87(C), 87B, 87A
- Schott-Glass RG 715, RG 780, RG 830, RG 850, RG 1000
- B+W 093, 094
- Heliopan FS/EAN-FS 5715/571, 5780/578, 5830/583, 5850/585, 5100/510

- Hoya RM90, RM100

4.3 Lenses

For IR photography most lenses are suitable as they transmit adequately in the IR. Unfortunately aberration correction of chromatic errors does not extend into the IR band, reducing the sharpness notably. An issue is the occurrence of a central hot-spot in the image in DIR and AIR. This may happen due to small apertures or the zoom set to the widest setting and is a result of light bouncing in between rear-lens elements. Such phenomena are lens and camera specific, depending on different glasses and coatings. Both errors lead to the typical halo in IR images and can be pictorially attractive.

Generally a fixed focal length lens will do best, due to fewer lens elements inside and usually smaller threading. Older manual focus lenses are less prone to such effects, with the added benefit of having a infrared focusing indicator on most models.

Due to the longitudinal chromatic aberration conventional lenses usually focus the IR band more distant to the lens. A rule-of-thumb is to increase the lens extension by around 10% or if the lens features a red dot or line with an adjacent "R", the subject can be focused visually, then the focus transferred to this red line and then, after attaching the IR filer, exposed. Alternatively Hasseblad provides IR focusing correction tables for their lenses. Another simple method is to focus through a deep red filter and then closing the aperture sufficiently for an increased depth of the field, but increased exposure time. In any case a pinhole camera is not affected by all those problems. A cap in front of the camera, with a small hole drilled through, aluminium foil glued on, pierced and a filter placed in front will suffice as a substitute. [Li16][Rø04][Re95]

4.4 Light Sources

Sunlight will most probably be the primary source of IR light, but any flash and incandescent lamp will also emit in this range. For closed rooms an IR emitting incandescent lamp might lead to some tropical conditions, so the heat should definitely be taken into consideration.

An old copy of the Kodak "Infrared and Ultraviolet Photography" book (1961) suggest, that IR can be used to photograph self-illuminant objects as cool as 250 degrees C.

The photographers Weegee (1899-1968) with his series "At the movies" and Kohei Yoshiyuki (1946-) with his depiction of nocturnal park life in japan, both discovered infrared flashes to their advantage, as it allowed them to document people in intimate spaces without their knowledge. [Rø04][Po47d]

4.5 Photographic Application

In forensics and archaeology infrared photography found its way as a tool to study worn, burnt or faded documents, the distinction between pigments, dyes or inks which seem similar to the eye, and the verification of authenticity or it is used for discovering or emphasising almost invisible residue of previous layers of paint or artistry and for verification of authenticity. Foma, the Czech photographic material producer, sold a lot

of special, black and white infrared film to India, because of the effect, that skin tends to look super smooth and white.
IR spy satellites are looking for secret missile launches, other IR satellites for diseases spread in agriculture or they gaze in the universe looking for answers to our origin. There are thermal seeking, IR controlled, missiles.
During the 1930s and 1940s Germans conducted studies in indirect infrared photography. A relatively simple process, in which a membrane is coated with a thin layer of oil and a infrared image focused on that membrane evaporates the oil to extend, depending on the intensity of the light, giving a change in the interference colour, which can be photographed. Attempts were made especially to display the heat radiation and distribution of ship's funnels or airplane exhausts, since the several seconds exposure limits the use drastically. [Po47]
It is used in forest surveys to distinguish between coniferous and deciduous trees. It is also possible to detect the presence of disease in plants and pollution in rivers and other bodies of water.
Ecologists often utilise infrared photography when completing aerial studies. A 1975 aerial ecological survey used infrared film to produce accurate maps of the area's benthic algae, shore line and drainage pattern. The infrared film was most sensitive to low concentrations of algae and highlighted active plant areas. Another aerial investigation in 1998 used infrared photography to find homes in Australia that were at risk of yellow fever mosquito (Aedes aegypti) infestation. [Li16]
In astrophysics infrared is frequently discover new celestial objects. Since stars emit radiation whose frequency changes relative to their velocity, sometimes they are only visible in the infrared spectrum. Without infrared radiation this star cluster would not have been visible, along with other objects such as clouds of particles around stars, infrared galaxies, interstellar molecules, cool stars, brown dwarfs and planets. [Lo16]
In military for a number of tasks. One of the military's primary uses of infrared is for target acquisition. Camouflaged objects can be hard to detect by normal cameras, whereas infrared takes advantage of the particular, that foliage reflects infrared light and glows bright, exposing the camouflage.
In the second world war Germans invested into research of IR photography:

> The Germans made a very careful study of the applications of infrared photography to their war problems, and some details have now been released. With long-focus lenses and infrared photography they were able from France to observe the radar and other installations on the English coast near Dover, to study defenses and construction changes, convoys and ship movements in the harbors, muzzle flashes from British gun batteries and the location of the shell bursts from their own guns. Naturally, they could not penetrate mist and fog. There is no evidence that they had any infrared plates or films which were not known to the United States.
>
> 1947, Popular Photography [Po47]

Infrared photography is also used to find illegal drug farms easily from the air. Often, marijuana plants are

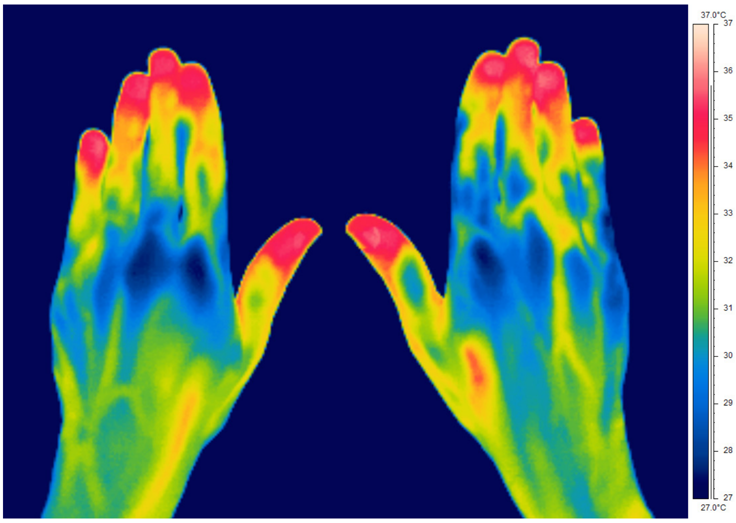
hidden within cornfields so that they are undetectable. However, colour infrared imagery clearly shows the marijuana plants in a different colour from the cornfields, making it easy to detect illegal drug growers.
French impressionist artist Pierre-Auguste Renoir's painting – Luncheon of the Boating Party – is one example of an artwork that was modified before the final version was painted. In his under drawing, Renoir readjusted every figure and transformed the sailboats and the railroad bridge radically. Without infrared photography, this important piece of art history would never have been known. [Ru96]
In the field of medicine, IR photography is particularly useful as infrared radiation can penetrate the skin, making problems such as varicose veins or venous blood easy to spot. Infrared is also used in dental photography because enamel shows up darker than dentin, the material that makes up the bulk of a tooth. [Li16]

Kohei Yoshiyuki attracted international attention with his exhibition "The Park", a voyeuristic documentary series about the park life in the 1970s Shinjuku and Yoyogi parks in Tokyo (Fig. 16.) When walking one night through the Chuo Park in Shinjuku, he noticed a couple on the ground and strangers creeping toward them. As it was dark he needed to find a way to light them without gaining their attention and found Kodak's infrared flash bulbs. Throughout the 1970s he photographed heterosexual and homosexual acts and their voyeurs. It addresses photography's unique capacity for observation and explores the boundaries of privacy. [Ge07]

[Fig. 16] Infrared photography from the series "The Park" by Kohei Yoshiyuki.

4.6 Thermography

Thermography forms an image (Fig. 17) using two atmospheric transmission 'windows' in the far infrared radiation of 3000-5000nm and 8000-14000nm and plays an important role in environmental studies and military applications. All bodies emit a certain amount of infrared radiation as a function of their temperatures. The higher the objects temperature the more black-body radiation is released.
Thermographic cameras tend to utilise a single colour channel that does not distinguish between different wavelengths, but instead colours the monochromatic image relative to the quantity of photons, e.g. low volume of photons is blue and the higher the more red and brighter.
Unlike the sensor in CCD and CMOS sensors, a thermographic sensor does not rely on silicon but on materials such as indium antimonide. The heat of sensor itself would overload it with information, consequently it has to be cooled down to 60k-100k (minus 213c – minus 173c). Although modern advancement allows for uncooled infrared detectors, which have a stabilised sensor temperature at around room temperature and detect changes of resistance, voltage or current, occurring at thermal radiation incidence.



[Fig. 17] Thermal pseudo color image.

5. Visible Light

Visible light is electromagnetic radiation in a narrow frequency span between 3.84 x 10^{14} Hz to ca. 7.69 x 10^{14} (781nm-390nm) Hz. It is created generally through the rearrangement of valence electrons in atoms and molecules. [He09]

In a glowing material, such as the glowing wire inside a light bulb or the fireball of the sun, electrons are projected in every direction and often crash into each other. As a result the so-called heat radiation is generated in a wide spectrum, which renders an important source of light. In a electric discharge of a gas-filled tube, atoms are agitated. They send off radiation of a specific frequency, which creates a thumb print, different and thus characteristic for every gas.
Newton was the first one to discover that white light is in reality a mixture of all colors of the visible light spectrum and that those created by the penetration of white light through a prism, are not created by it. For centuries it was believed, that the prism changes the light - Newton discovered that it simply split the light into its different components. What is considered white depends on the perception of the spectrum of daylight on earth, which declines faster on the violet end than on the red one. The sensors responsible for the perception of colours interprets white as a mixture of different frequencies, whereas the energy level of all parts are about the same. A not very limited number of frequencies added up, gives us the impression of more or less white. A sheet of paper for example shows light of a light bulb in a different white than daylight. This perception of white is influenced by many rays of different light.
The mixture of colour is a subjective physiologic and psychologic reaction to the different frequency bands between 781nm to 390nm in the order of Red, Orange, Yellow, Green, Blue, Violet. The perception of the colour itself is not a result of the light, but an electromechanical reaction of the eye and its interpretation by the brain. Different mixtures of frequencies, can evoke the perception of the same colour. A red ray (430 THz) which is added to a green ray (540 THz) results in a ray, by us perceived as yellow, even though the mixture contains no yellow light at all. The sensorial field seems to average the frequencies and views it as yellow. That's why the computer screens can function with only three basic colours. [He09][AT11]
Photography, by definition, depicts light from the visible band of the spectrum. Changes made to the arrangement of layers in a colour photography film, e.g. switching the red and blue layers and resulting colours, are defined as false-colour photography. As it is the case with Kodak's Aerochrome film, false-colour photography is not bound to the visible spectrum, but can be a multispectral arrangement ranging in astronomy from X-rays to microwaves.
Unlike false-colour photography where, two or more images of the same scene are combined, pseudo-colour images derive form one monochromatic image, that displays force or heat. This is then coloured for a better understanding with a gradient, leaving the choice of colours to the scientist and needs of the picture.

5.1 False Colour

A false colour image is per definition one that consists of two or more colour images, taken from the same camera mostly at differing wavelengths and superimposed on top of each other. False hereby does not refer to a fraudulent picture, but rather one that does not correspond to our reality, e.g. perception of the world. Technically speaking all cameras fall into that category, since none of them actually match our vision, but rather try to approximate it. Additionally the way to display each image is another alteration of colours, depending on the technology used. Yet a green tree on a normal photography will always be a green tree and similarly are other colours. False colour imply the deliberate alteration of colours for distinctively different tones, with either digital or photographic tools. In the scientific world this is applied to be able to catch the most important information of an image at a glance, aesthetics are not the priority in most case. Geologist and Biologist use it in aerial photography to observe changes or display certain vegetation on the ground.
Since there is no atmosphere blocking any wavelengths, the sensor can pick up on the whole range of incoming photons, which allows for more information to be gathered, analysed and some artistic freedom to be reigned in post production. One of the most famous applications are the pictures created by the Hubble space telescope and retouched by Zolt Levay.

> "The colors in Hubble images are neither 'true' colors nor 'false' colors, but usually are representative of the physical processes underlying the subjects of the images," he said. "They are a way to represent in a single image as much information as possible that's available in the data."
>
> 2008, Zolt Levay[At07]

[Fig. 18] *Vintage Violence,* false color photograph by Richard Mosse.

In the military field it was used to detect well hidden enemy troops, due to the fact, that their camouflage reflected less Infrared light than the vegetation around them.
Most commonly known to analogue photographers might be Kodak Aerochrome film, that records infrared into the red channel and outputs red as green and green as blue. This is only one example of a multitude of films that are and were available, and processes that can be done digitally. [At07]

5.2 Application

Richard Mosse is an Irish documentary photographer in Iran, Pakistan, Haiti, Iraq and Gaza until he decided in 2009 to fly to Congo. Sick of his previous work, he chose kodak's Aerochrome film, intended for various aerial applications, such as vegetation and forestry surveys, earth resources monitoring and camouflage detection and surveillance in military fields, as his new foundation for a documentary art project. The film is sensitive to infrared and renders it as red, whereas reds are pushed into green, greens into blue, and blues into black. In essence chlorophyll reflects most of the incident infrared radiation and appears to IR sensitive film as bright. The Kodak Aerochrome renders it in intensively kitschy pink shades. Congo's vast vegetation is and its ongoing, sparsely reported on war, rendered him a great contrast to overly masculine poses, behaviour and aspects of soldiers/war. The films potential to reveal the invisible, related to his ambition to make Kongo's mostly hidden humanitarian disaster visible (Fig. 18-20).
"I was really trying to bring these two incongruous notions together - to take two completely unrelated things, one, history of photography, and the other, the history of Africa, and to examine them in light of each other." [Fr13]

The pink pushes the viewer into this extraordinary space, way past the threshold of the imagination and into science fiction, something pulsating, nauseous.
"We don't see in pink, but we don't see in black and white either - whichever way you look at it, documentary photography is constructed way of seeing the world." [Fr13]

[Fig. 19] *Safe from Harm,* false color photograph by Richard Mosse

[Fig. 20] *Platon,* false color photograph of the congo river by Richard Mosse

Posing as a journalist, because the soldiers were utterly unresponsive to an artist, and with the help of a fixer he slowly gained access to the over 30 rebel groups in Congo. Over the span of 4 years he spent his last savings on film and development, living in catholic missions. He assembled and published the material in his book "Infra", which lead to international success and earning him the Deutsche Börse Photography Prize in 2012. "It is physically immersive and devastatingly beautiful, but all the time you are moving forwards towards the horror at its heart." [Fr13]

He followed up his success with the film installation in the biennale in Venice for Ireland, called "The Enclave". Over 2-3 years he tried to locate and buy rolls of 16mm Aerochrome film. Together with 39 rolls, each with capacity of around 11min, the filmmaker Trevor Tweeten and the composer Ben Frost he went to Congo a few more times to produce a installation of several looping clips. [Fr13][Da14]

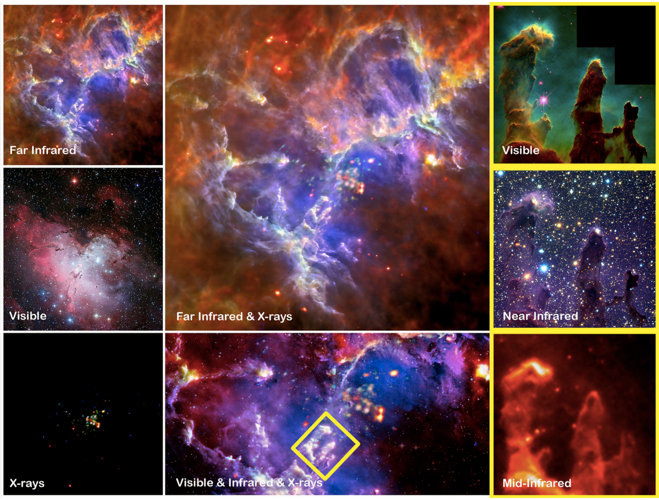
5.3 Multispectral

Astrophotography and Remote-Sensing are two fields, which utilises multiple slices of the electromagnetic spectrum to visualise different aspects of a scene. Celestial objects can radiate depending on various properties, such as heat, speed, chemical composition or gases and dust between the viewer and the object. There are formations only visible at certain parts of the spectrum and hidden to our limited vision. Since images are taken in a specific range of frequencies, they are captured as monochrome.

Multispectral imaging is the acquisition and combination of multiple slices into one composite, whereas the visual aspect is dependant on the operator and/or specific need for the images. (Fig. 21)

Hubbel's pictures of the universe are some of the most well known examples for such a technique. In 1995 Nasa released Hubble pictures of the Eagle Nebula., that became known as the "Pillars of Creation". (Fig. 22)

Its atoms emit light of specific wavelength, the hydrogen atoms and sulfur ions in the red / orange spectrum and oxygen in the greens. The telescope takes a picture for each atom emission slice and in the composite the blue channel of the final RGB image is assigned the oxygen picture, hydrogen the green and sulphur ions the red. More modern images include slices from gamma and x-ray radiation.[He08]



[Fig. 21] The Eagle Nebula through different wavelengths.

[Fig. 22] "Pilars of Creation," Multispectral image of the Eagle Nebula

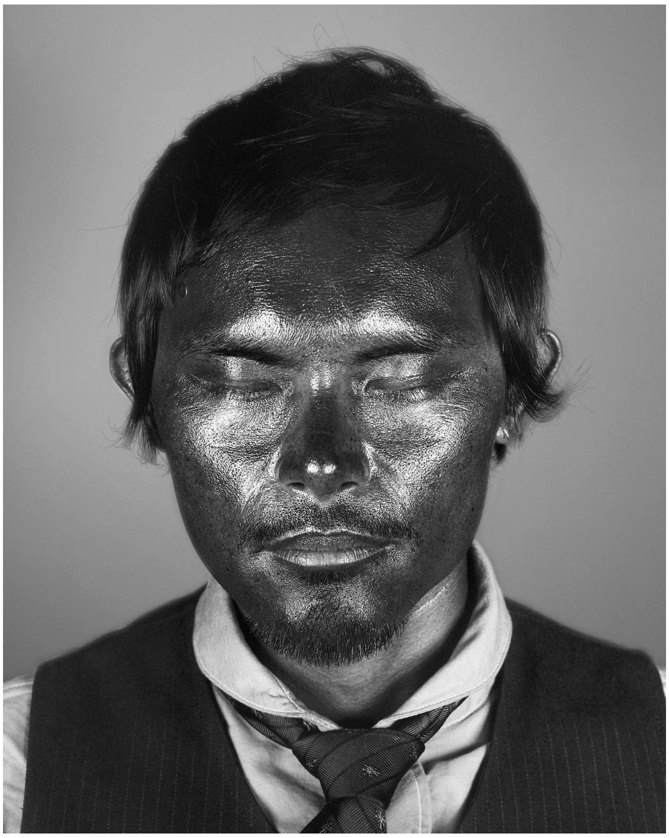
6. Ultraviolet

On the other side of the visible light spectrum, further past the violet light, begins the ultraviolet frequency. In the electromagnetic spectrum, ultraviolet radiation borders to the visible at around 8 x 109 Hz and 3 x 1016 on the other side. It was discovered by Johann Wilhelm Ritter (1776-1810). The UV photons emitted by the sun are strong enough to ionise atoms in the high altitude atmosphere, forming the Ionosphere. Additionally most chemical reactions produce photons in the UV span of the electromagnetic spectrum and can be initialised with radiation of such. Sun burn is due to the chemical reaction of the skin to UV radiation. Luckily our atmosphere carries Ozone (O3), which absorbs the majority of sun's radiation. If it would reach earth without being filtered out, it would be quite deadly to us. [He09]
The eye performs poorly at perceiving UV light, mostly due to the cornea and lens, which absorb photons of wavelengths below 300nm. Someone that had his lens removed, as a result of grey star for example, will be able to see deeper into the UV spectrum. Insects, for example the honey bees react to UV light as well as pigeons; They are able to see into this spectrum and it is believed, that they orient themselves to the position of the sun, who's UV radiation penetrates the sky even on cloudy day.[Rø04] Reindeers have been discovered to use UV light, down to 350-320nm, reflected of snow that causes painful snow blindness in humans to help them survive. Snow reflects up to 90% of incident UV light, which makes absorbing materials or patches, such as urine stains, vegetation or fur appear darker. [Bi07]

6.1 UV Photography

As tests show, digital cameras are not only able to record light from the UV spectrum, but adapts essentially the same characteristics as any film-based system. [Rø04] However the representation of colours differs from the analog counterpart, as there blueish tones are prominent and in digital the whole colour scheme shifts into the reds. What sets the digital camera apart when it comes to recording invisible radiation?

The CCD sensor not only records light from the ultraviolet end, but most often shows sensitivity down into the near-infrared spectrum as well. In fact, the IR sensitivity of the CCD is typically so high, an anti-IR filter has to be installed in front of the sensor's surface. In film the only spectral thorn in its side is the UV-radiation, which can be easily countered with a UV filter. A film emulsion can be sensitised to only a certain band in the spectrum, thus making the representation and process of capturing UV light a bit easier.
The opaque filters used for blocking visible light and passing UV usually have a secondary band frequencies they let through, which happens to be in the near-infrared spectrum. Since the sun emits more radiation in the IR frequencies than UV, IR contamination of pictures taken on CCD sensors are an actual issue.
The Bayer filter, which enables the CCD to read different colours at each pixel location, has not been designed for invisible light and breaks down when it comes to how UV and IR is recorded. The result is, that in UV photography, where one would expect a blueish tone, as the UV film displays, the CCD sensor renders a



[Fig. 23] UV portrait by Cara Phillips

different representation. Contrary to what one would expect the UV light mostly triggers red-sensitive pixels and at times even green ones. The problem then becomes imminent, when the, as red recorded IR hits the same pixel as the UV does and the camera has to handle the two widely separated bands of the spectrum. The software responsible for decoding the information flow of the CCD sensor may react in strange ways to the abnormal data captured. [AT11][Rø04] [Ra99]

6.2 Filters

In order to filter UV light, a visually opaque filter has to be installed in front of the lens, that blocks out any visible light. The filter is basically made up of silver particles deposited in gelatine and enclosed in protective glass, which makes the filter considerably thick and expensive. The relative low demand on those filters and the special purpose of these filters, tend to elevate the prices even further. As described already, the problem faced with UV photography is the additional region of transmittance in the near infrared region. For purists or forensics, that truly only want to focus on ultraviolet and shun any light rays of infrared, an additional IR-Block filter has to be installed in front of the lens.

Filters for digital UV photography are offered with a number of different options: [Rø04]

- Hoya U-360, quite thick glass, letting light through down to 330nm. Hoya delivers additional UV band-pass filters, like the U-330 and U-340.
- Nikon's special line of UV lenses, like the UV-Nikkor 105mm, come with Nikon FF filter. It can be

bought separately though. It is a thick glass filter which transmits slightly in the lower purple range and deep red.

- The Tiffen Hot-Mirror filter which reduces infrared, is best suited for digital cameras with high infrared responsiveness, to reduce contamination of such.
- For digital cameras with a lower sensitivity to IR, the Wratten CC20C filter cuts in some IR. In combination with any IR-blocking filters, it should work just fine.
- The Schott UG-11x, with its sophisticated coating technology, that further cuts down IR light and build up and improved on that is the "Venus" or Baader "U" filter. The substantial suppression of IR and reasonable price point, considering the specialised nature, is quite reasonable too.
- The contamination of IR, to be taken in consideration with the Nikon FF and Hoya U-330, is a problem, that should not be taken lightly. The images become less sharp, because the IR and UV focus on different levels and there is a significant loss of contrast. A B+W BG-38 or BG-40 are highly recommended to be used in addition to any UV filter.
- Tiffen 18A
- Wratten 18A
- B+W 403, 484
- Kodak 18A
- Hoya U360
- Schott-Glass UG 1, UG 3

Filters that block IR:

- Wratten 43/44(A)
- Schott-Glass KG 3
- B+W 489
- Heliopan FS/EAN-FS 8103/103

6.3 Lenses

Unless you are using a pinhole camera, most likely you will have to put a piece of glass between the sensor or film. In UV photography this is of importance, since most optical glass and even more so multi-coated (fn) lenses, do not let a lot of UV light through. There are special quartz lenses, produced for the sole purpose of recording wavelengths below 350nm for scientists, yet those are considerably expensive. Both Nikon and Canon have launched their own line of UV lenses, that let light between 350-400nm through. As a photographer that is not interested in the purity aspects of UV, this should suffice. Because of their special need nature, they as well do not come at a cheap price. It is possible to shoot UV with a normal lens, but because of the sensor's low sensitivity to this range and the coatings, that chances of actually capturing anything true are quite low. There are a few factors to consider when using or buying a normal lens for UV photography:

- A simple optical design with few lens elements.
- No cemented elements.
- No multi-coating on the lens.

For Nikon, the E-Series lens line match these criteria, which have a simple 4-5 element design. Since they are of some age, high production and low status, they should be available for cheap almost anywhere.
In addition enlarger lenses do as well let a lot of UV light pass and are thus a good fit, if one builds a mount for the camera, for taking UV photos. For the more inventive people fax lenses or apochromatic process lenses should do the job as well.
For most lenses, except the UV-Nikkor and similar quartz-based lenses, a significant shift in focus occurs. It has to be adjusted to focus closer to the subject than for visual photography. Also a degradation of optical quality has to expected, since the lenses were not manufactured for such wavelengths and effects like aberration will occur. To counteract and worry less about the focusing problems, stopping down the aperture helps. [AT11] [Ra99] [Rø04]

There is a gap between about 330nm, where glass starts to absorb, 230nm where the absorption of the emulsion starts to become a problem to 20nm where the X-radiation begins. Special Quartz or fluorite lenses will work for radiation up to 180nm after which mirror lenses or simple pinhole cameras have to be used. Ordinary photographic film can be used, the emulsion being coated with petroleum jelly or mineral oil, which fluoresces during exposure, giving a visible image, which the emulsion records. The jelly is removed using a solvent before processing.

6.4 Artificial Light Sources

As the sun emits a lot of IR light, quite suitable for film-based UV photography, for the digital realm it isn't really the best fit. Although, if there are no other options, a cloudy day might help, since some of the IR light will be filtered out by the atmosphere.
Artificial sources for UV light are mercury vapour lamps, xenon tubes, fluorescent tubes, black light and some halogen bulbs. Electronic flashes give off a good amount of UV light as well, especially if they lack a UV-screening coating. All UV-sources with continuous output will be damaging to your eyes, therefore never stare directly into the source. If needed, wear UV-protective goggles. [Rø]§

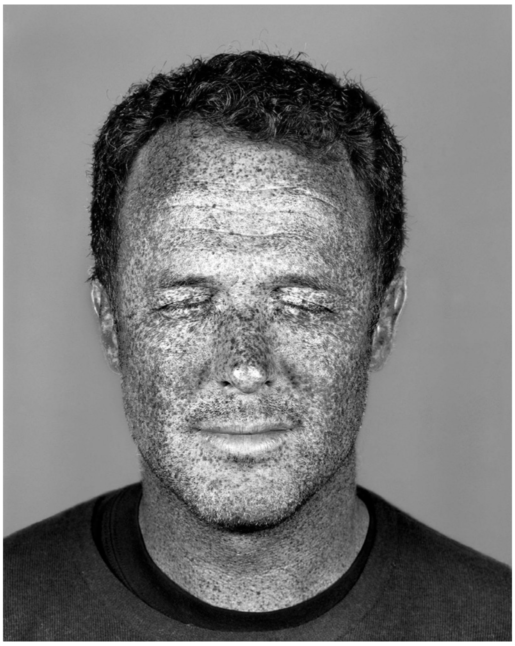
6.5 Camera & Film

As sensor technology evolves rapidly, it is hard to grasp or even form a good rule for finding a digital camera for UV photography. The only way is to test the camera with a filter. The more limiting factor of a camera's use for UV photography is the absorption of UV radiation by the lens, which can be countered by turning it into a pinhole camera.

Unsensitised silver halides react well with UV light, which was a problem in the early years of photography. By relinquishing the lens and with the addition of a filter any analogue camera can be turned into a reasonable UV camera. It has to be tested as to the nature of the used film material and light conditions, in order to determine correct exposure time.

6.6 Application

Similar to infrared, ultraviolet photography finds its way into to fields of science, forensics and medicine. In criminology and art history it is used to differentiate between paints, subsequent tempering and preceding versions. Also bodily fluid spills and fingerprints can be made visible with external ultraviolet lighting.
Most stars are relatively cool objects and radiate in the visible to near-infrared part of the spectrum. Ultraviolet is the signature radiation of hotter objects, as stars in their early or late stages of their evolution. Unfortunately this is filtered through the atmosphere of the earth and various clouds of gas and dust throughout the milky way.
Biomedical applications for ultraviolet are for instance in dermatology. Slight changes in pigments in the skin, especially involved with Melanin, show clearly when seen under UV. Unpigmented skin reflects ultraviolet strongly, whereas melanin absorbs it. The method is also very useful for enhancing surface detail of skin. There is virtually no penetration of ultraviolet into the tissues, therefore there is no scattering and sharper pictures result. Old traumatic lesions-scars, bruises, bite marks, etc.- may sometimes be revealed by the reflected ultraviolet method months after they have faded visibly.
"Ultraviolet Beauties" is a portrait series made in streets of Brooklyn by Cara Philips (Fig. 23-25). Inspired by unforgiving and straightforward medical photography, she lit willing pedestrians to be photographed under harsh UV light, intended to bring out every minuscule incongruity. The series is "Ultraviolet Beauties" to which she refers to as "anti-portraits" is a response to modern obsessions over elimination of quirks and imperfection.



[Fig. 24] UV Portrait by Cara Phillips

[Fig. 25] UV Portrait by Cara Phillips

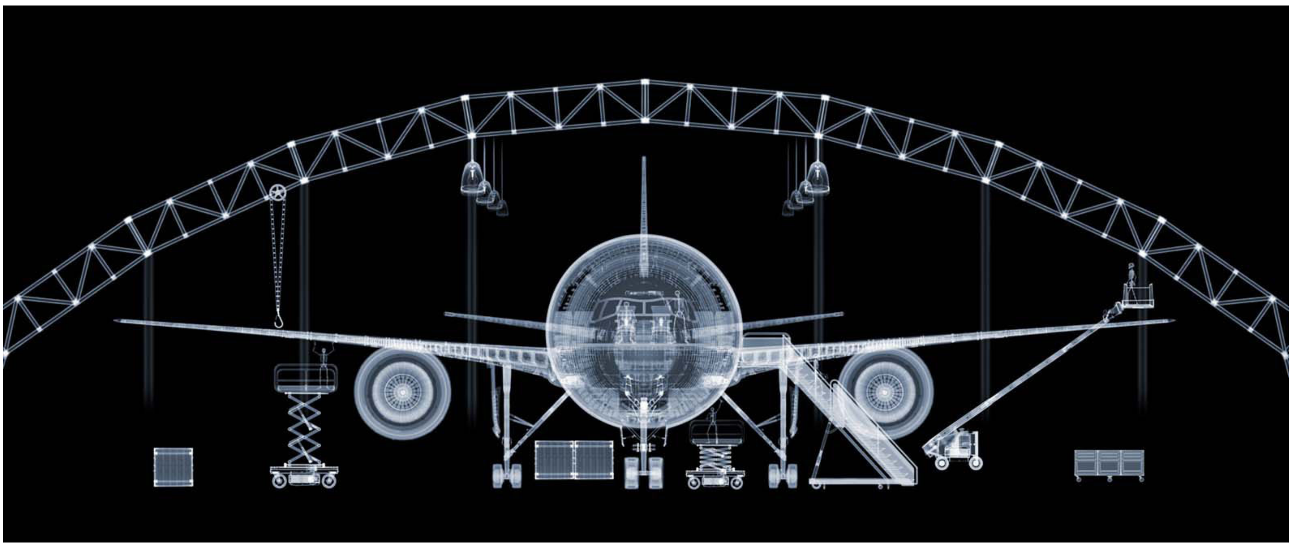
7. X- & Gamma Rays

The X-ray radiation was discovered more or less accidentally by Wilhelm Conrad Roentgen (1845-1923). It spans the frequencies from about 10nm to 0.01nm. The wavelength is quite narrow, mostly below the measurements of Atoms. Because of its high energy, single Roentgen-photons are capable, like little bullets, of causing effects in materials, which they can penetrate because of the particle like nature of the photons. A mechanism used to generate X-rays is the fast deceleration of loaded, hight velocity particles: If for example a ray of fast electrons hits matter, the so-called bremsstrahlung with a wide frequency spectrum. The cause of that is the deflection of electrons by bumping into the copper cores.

Through this electron bombardment atoms of the target can be ionised. If because of that an electron of the innermost, closely tied to core, electron is hit and projected out of orbit, the electron cloud returns to its original state by emitting a Roentgen-photon. Such emissions can only happen at certain wavelengths, which are specific to the structure of energy levels of the target atom; it is respectively called characteristic radiation.

Paul Villard, a French chemist and physicist, discovered gamma radiation in 1900 while studying radiation emitted by radium. Gamma rays typically have wavelengths less than 10 picometers (10−11 meters), which is less than the diameter of an atom. However, this is not a strict definition, but rather only a rule-of-thumb description for natural processes. Electromagnetic radiation from radioactive decay of atomic nuclei is referred to as "gamma rays" no matter its energy, so that there is no lower limit to gamma energy derived from radioactive decay. This means scanners can be used to detect gamma radiation of much lower energy than x-rays. In astronomy, gamma rays are defined by their energy (100 keV up to 10 TeV which is 10pm to 0.01pm), and no production process needs to be specified. [He09][Ra99]

A traditional X-ray or gamma ray image, as it is used for instance in cargo scanning, doesn't say much more than a shadow image. Until now the creation of lenses for high energy radiation was unsuccessful, but recently the use of mirrors are used to focus a ray. [DR13] Through x-radiation more resourceful images of a multitude of objects, ranging form the implosion of fusion particles to the cosmic rays of millions of degrees



[Fig. 26] Composites of X-rays of an airport hangar.

hot sources like stars, distant quasars and black holes, can be obtained. X-ray and gamma telescopes in orbit around earth deliver a stunning view into the depths of space. [Na14]

Homemade X-ray imaging is possible, but it is hard to find a source of radiation strong enough to be captured. The sun and stars only emit a fraction of the photons needed. One possibility is to build a belirium tube to emit strong radiation and plans for such can be found, yet it is not advisable due to health hazards. Another possibility is to finally find a personal use for the x-ray scanners at air ports. If there is a nuclear reactor close by or Chernobyl on the list of holiday destinations, the present radiation should suffice for some photographs. The probably easiest way is to get some sodium-free salt, that emit photons from decaying potassium-40 and use it as a source of radiation. It might take several months though. On Ebay it is fairly easy to find radium watch handles, which radiate x-rays and should be the best option, if handled with caution.
The light sensitivity of silver halides emulsions is confined to the range of wavelengths absorbed by silver halides. This includes blue and violet regions of the visible spectrum, the ultraviolet region and shorter wavelengths extending to x- and gamma radiation.
An instant film with a high ISO sensitivity wrapped in aluminium foil, to prevent light from entering, and the subject placed on top, will result in an image or rather a shadow of the subject.
With normal film this might be a bit more difficult, due to the thin layer of emulsion. X-ray and gamma-radiation is absorbed very little and it is necessary to apply a thick coating, containing a large amount of silver halide to obtain an image. This is normally applied in two layers, one on each side of the film base. At least the use of medium to large format or two layers of such are advisable. [Gr09]
Another possibility is to use a fluorescent material, such as heavy metal salts and rare earth salts, that reacts to high-energy radiation. The photons will run through the subject, altering their energy and then hit the screen, upon which a light flash is emitted. Most digital cameras nowadays can pick up this signal quite easily, yet the problem of finding a sufficient source of remains. In any case, such a screen decreases exposure time, by amplifying and transforming the indecent radiation to blue and/or green light, which also lowers the danger involved.

7.1 Backscatter X-ray

Unlike traditional x-ray radiography, where variation of transmission through a material is measured, backscattering, similar to photography, detects reflected radiation. It is a less destructive procedure, as fewer radiation is needed. The backscatter pattern depends on the material properties and is useful for imaging organic material. Applied fields are for instance whole body scanning at airports. The backscatter units tend to be a lot bulkier and expensive than traditional methods.
The atmosphere filters out most of the gamma radiation, natural radiation is therefore quite sparse and gamma radiation cannot be generated, which is why an external source is needed for imaging. As there is no aperture or lens to limit incident light, this technology is dependent on exposure time. There are two main

designs to control exposure time:

- The torch design has a radioactive source placed inside a shielded box, where either a hinge allows the shielding to be opened or the source is placed on a wheel inside the camera the can be turned to expose the material.
- In the calbe-based design a block of lead or depleted uranium with an S shaped tube cut through it. The radiating material sits in the curvature in the centre of the block and can be manually exposed by cranking a winch and pushing it out of the tube.

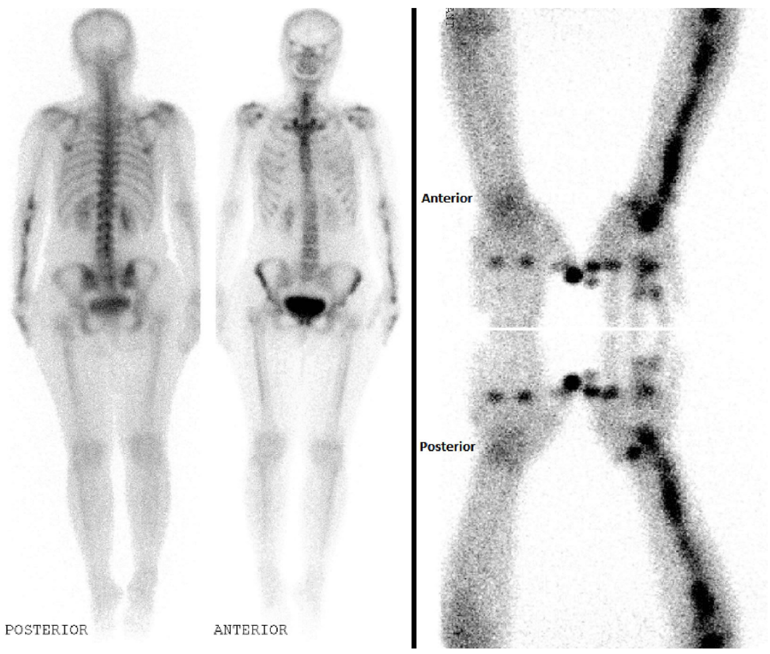
7.2 Scintigraphy

Scintigraphy is a form of medical diagnostic test used in nuclear medicine, wherein radioisotopes are infused into the subject and the emitted radiation is picked up by gamma cameras. As opposed to the SPECT and PET (Single-/Positron Emission Tomography), it only forms a two dimensional image and unlike X-ray photography no external radiation is sent through the subject.

The gamma camera, also called scintillation camera or Anger camera, consists of a flat crystal plane, that reacts, scintillates, to photons and emits a faint flash, which is then detected by a photomultiplier.

Unlike in photography, where only parts, depending on the aperture, hit the sensor, in scintigraphy 99% is attenuated, still large amount of radiation must be present for the the camera system to form a picture.

The best current camera system designs can differentiate two separate point sources of gamma photons located a minimum of 1.8 cm apart, at 5 cm away from the camera. The resolution decreases rapidly at increasing distances from the camera. [Ot05]

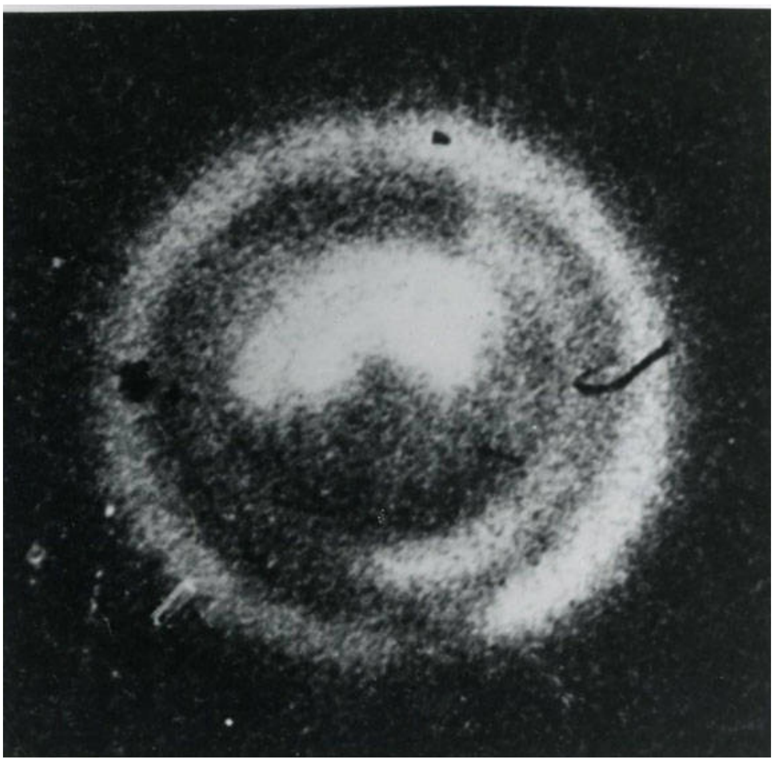


[Fig. 27] Scintigraph of the human body for medical analysis.

7.3 Application

Applied in various fields of science and medicine it cannot be often found, due to its properties. Radioactive material are dangerous to the human body, but needed as an external source of radiation for capturing. The transmissive behaviour instead of reflective as know from visible light changes the aspect and use of the medium. The transmissive qualities of different material becomes apparent, yet the it has to be exposed to the brute force of x-ray particles. Doctors of all sorts make use of that property to gaze at the inside of the body. As a preventive measurement air port security is equipped with machines to look through baggage and find eventually dangerous objects.
Astrophysicist examine the cosmic x-radiation, emitted by compact stars, such as black holes and neutron stars, usually objects at temperatures of 10^7-10^8 degrees Celsius.

> 1945 the U.S. public health authorities began x-raying the lungs of its entire population to battle tuberculosis. In order to x-ray the 130'000'000 pairs of lungs, special equipment was developed by Kodak. The plan was based on photofluorographs - or photographs of the dim image cast by x-rays on a fluorescent screen. To meet the photofluorography's need for extreme speed and precision, Kodak came up with the Kodak Fluro Ektar lens, f/1.5, 111mm. A product of internal studies, that embodies a rare-element glass and a low-reflection coating.
>
> 1945, Popular Photography[Po45]



[Fig. 28] First X-ray of the sun.

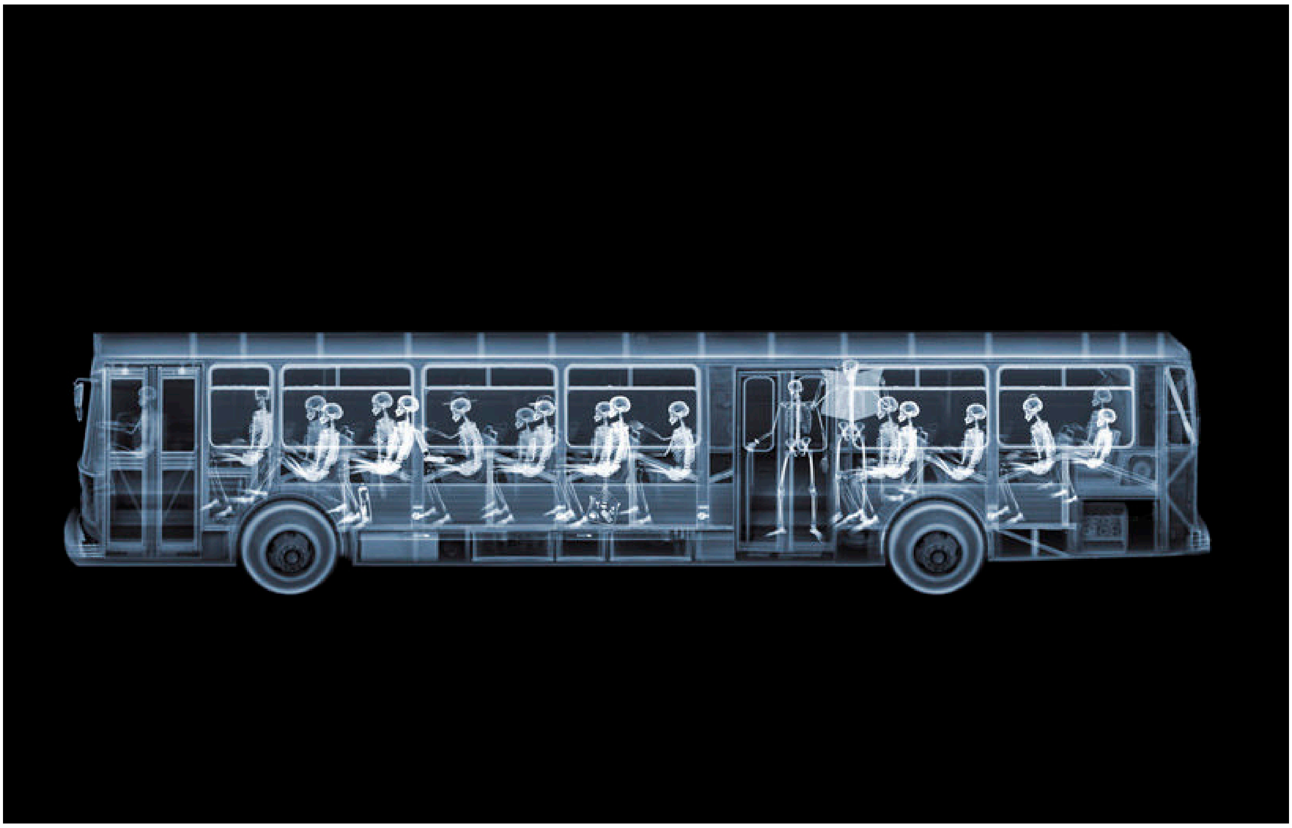
X-Rays and the radiation from radium continued to be used in industry as a means of checking the quality of metal structures and their behaviour in operation. Primarily spectacular, but interesting from the point of view of technique, was a radiograph of, 12 feet by 4 3/4 feet in size - the word's largest - of a Jeep, made by the university of Rochester and the Eastman Kodak Co. [Po47]
With increasing research in nuclear physics and high energy particles, because it was discovered, that photographic lenses absorb rather than project high-energy particles, pinhole cameras found their way into the scientific world.
The idea of imaging high-energy X-rays and gamma rays from the sun, black holes and exploding stars using pinhole cameras placed on space vehicles began in the late 1950s. The first soft X-ray pinhole photograph of the sun was achieved on April 19, 1960 (Fig. 28), when a set of pinhole cameras was flown on an Aerobee-Hi Rocket and the emulsion used was industrial Illford X-G film.

> Duration of exposure was 286 seconds. Peak altitude was 220KM. The camera was kept pointed at the sun ... There were actually eight cameras in the block, four of which survived the flight and impact. Two of the four were designed to produce photographs with a resolution of one-fifth solar diameter, the other two with one-tenth solar diameter. The camera producing the best picture utilised a pinhole which was 0.005 inch in diameter and was placed 6 inches from the film. In order to adapt pinhole photography for use in the x-ray region, it is necessary to prevent visible and ultraviolet light form striking the film. The pinhole was covered with a thin film of Parlodion (a type of nitro-cellulose). The Parlodion, in turn, supported an evaporated film of aluminium.
>
> 1963, R.I.Blake[BC+63]

The artist Nick Veasey is a british photographer that specialises in x-ray imaging. Ever since this first journey into the world of x-rays, Nick was hooked on it. The former advertising agent, makes his living with commercial x-ray photography (Fig. 26, Fig. 29, Fig. 30)

> "My girlfriend's father used to be a lorry driver. At one time he drove a lorry for a couple of days which contained thousands of cans of Pepsi, one of which had a ring-pull prize worth 100'000 pounds. I thought I'd try a scam. I decided to hire an x-ray machine from a local hospital to find the winning can. I never did find it, but it sparked off the ideas for the career I have today"
>
> -2001, Nick Veasey[Ho16]

Inspired by previous explorers, such as Man Ray and Moholy-Nagy, he ventures on and tries to push the format to its limits. Borrowing cargo x-ray scanners used to scan trucks on the US American / Mexican border, he scanned the biggest x-ray to date of a Boeing 777 in the hangar. Since the largest X-ray film is only 35.6 cm



[Fig. 29] Composites of X-rays of an airport hangar.

long, over 500 exposures were made, scanned, stitched together and populated with separately shot skeletons in Photoshop to create the final image.

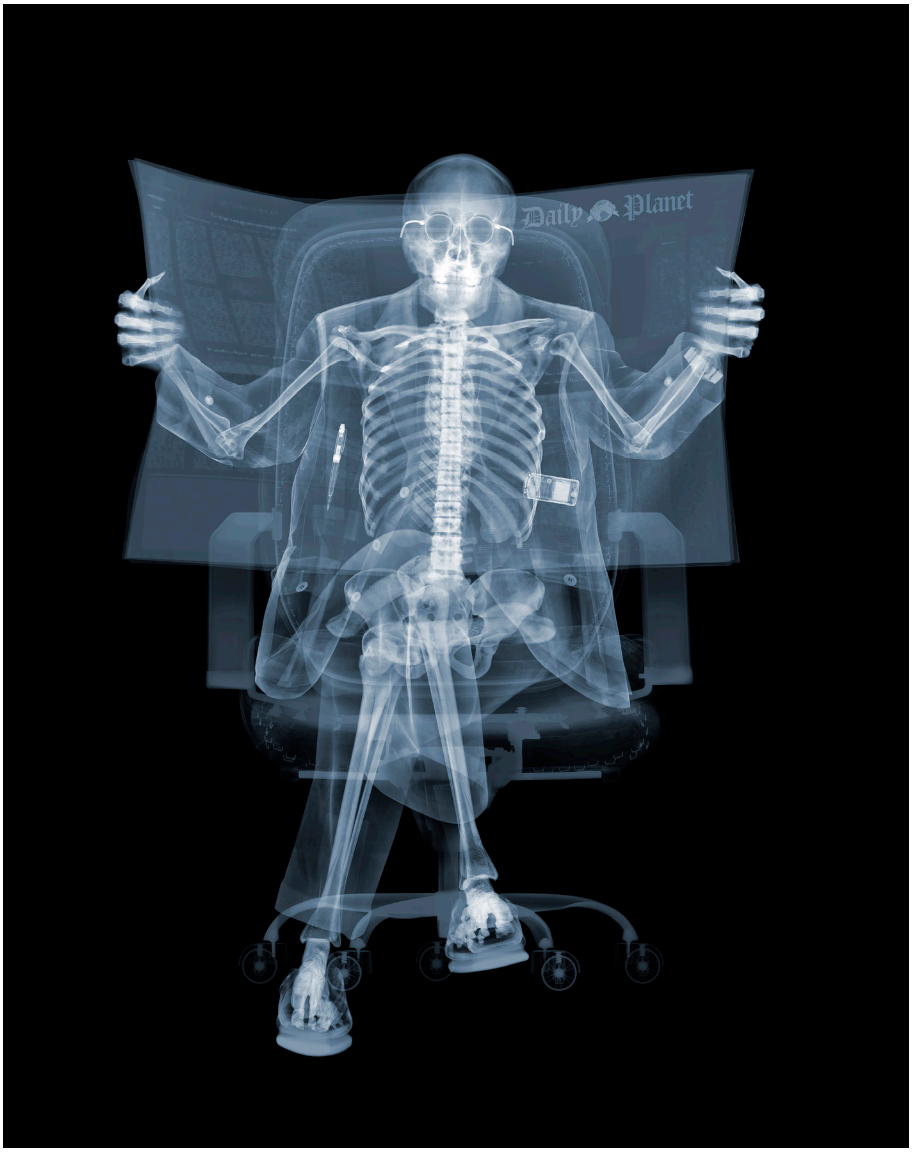
> "When I x-ray an object, the image on the film is exactly the same size as the object you are x-raying. It's like a photocopy"
>
> 2010, Nick Veasey[Le10]

While society is taught to concern itself with the alluring surface of things, Veasey uses X-ray to peel back those upper layers, often revealing a far more beautiful, and complex underside. The switch into x-ray photography, changed his view on the world, seeing everything with experienced radiologist's eyes. Most of the time he photographs everyday objects, of which over 4000 he has already scanned.

To get his pictures, Veasey uses industrial x-ray machines typically employed in art restoration, to examine oil paintings, electronics manufacturing, to inspect circuit board, and the military, to check tanks for stress fractures.
In order to minimise a patient's unhealthy radiation, doctors and radiologists make an exposure of a fraction of a second to create a blurry still. For a detailed result, Nick bombards his subjects sometimes over 12 minutes with radiation, impossible to try on living humans. Instead, for human forms, he uses skeletons in rubber suits, used by radiologists for training, or corpses, donated for scientific purposes and lasting only eight hours at maximum.
He has control over three aspects of the final outcome. The amount of radiation, which relates to the inten-

sity of available and artificial light, the exposure time and the distance to the subject. Since X-rays simply pass through glass and metal without being diffracted, there is no aperture to be controlled. The thicker the object, the more radiation is needed. The film is thicker than for usual photography, since there is emulsion on both sides of the carrier.
There are things which are technically unsympathetic to x-ray, generally x-rays and liquids don't mix very well, as it results in soft images. When he was x-raying seaweed, he dried them out first.

> "My work is real. X-Ray is an honest process. It shows things for what they are, what they are made of."
>
> 2010, Nick Veasey[Ho18]



[Fig. 30] X-ray by Nick Veasey of a reading man.

8. Conclusion

For the lifetime of human consciousness we tried to discover the nature of light. Grasp and define it in objective terms. From the early discoveries of its linear trajectory and origin to the debate over the wave or particle nature. Not too long ago we came to the conclusion, that was not only both, but also part of a much larger spectrum, the electromagnetic radiation (EMR). The EMR was divided into different sections, depending on the frequency, behaviour and origin. Visible light was defined as a small fraction of the spectrum between 400-700nm and the science of capturing and measuring those frequencies was named photography/-metry, which is a part of the radiography/-metry.

Photography is therefore bound to the boundaries of the human vision. A reasonable decision, as it was from its early days on meant as a tool to deliver a seemingly objective view on the world understandable to the majority of humanity, setting the familiarity and similarity of human vision as basis for a new language. Since the begging, we tried to approximate photographs to what we perceived. Pushing the sensitivity from UV to blue, green and later red. Developing technologies for trichromacy and perfecting its filtering and sensitivity to human perception. With the end of the millennium came the dawn of the digital age almost true caption of light according to our vision, only with slight variation.The quest of finding a natural vision, one unobstructed of unfamiliarity, giving an immediate response to the content and able to trigger our imagination into seeing the world in the picture at the time it was taken.
What we call "unnatural" is only a departure from human vision or a different interpretation of such. Finally it is based on the same physics and building blocks. Even though the initial natural response of the photographic emulsions were in the invisible UV field, effort was made to broaden and push the sensitivity according to our taste. Interesting is that monochromacy was and isn't as much of an issue as false colours or "unnatural" wavelengths. Maybe because the cones in the retina, active in low-light situations, are as well monochromatic and we are used to seeing the world as such sometimes. Yet not all monochromatic pictures appear natural, depending on the subject photographed, being more critical with portraits and more liberal with landscapes, sole blue or red sensitivity are perceived as unnatural, whereas green appears to be neutral. This corresponds to our distribution of colour sensitive rods, where green sensitivity is in surplus.
Trichromatic film may have brought another step towards "realism" or "naturalism", yet it should be thought of such with precaution. From the faint early stages of colour photography there was always a certain style involved with film and the later simulation or approximation in digital photography. Colour photography was and always will be a sole approximation of human vision, differing and driven by taste, until it is possible directly intercept and interpret the flow of neuronal information from the eyes to the brain.
Then again, the eyes could just be altered or replaced with another device, whose language we are able to understand. Altering isn't that uncommon, as mentioned Monet had his eye's lens removed which allowed him to see the previously filtered ultraviolet radiation. Mutations of the retina is common, that leads to bi-/

monochromatic vision.

A comparison of the eye to a film camera could be made, as the construction of the eye and camera are similar and temporal correlation plays an important role for the perception of the world. Temporal correlation may be thought of as the similarity between two or more successive pictures, where the brain discards any unnecessary information, e.g. looks primarily for changes, instead of perceiving the whole image every time. By doing so, less brain power is used to process the constant stream of information.

But vision is complex, while the camera is simple and believed to be unbiased. Human vision, gives a three-dimensional image in full colour, in the right lighting situations. The brain is responsible for the interpretation which is in turn influenced by culture, experience and prejudices, so detail may be added to or ignored for the final perception.

A yet still unsolved question is the storage of memories. Fact is though, that once we do store memory, it is never accurate, e.g. mostly distorted according to our perception, mood and impression of a particular event. Furthermore new events, that are alike any old ones are distorted by the comparison of the two and stored accordingly.

These (temporal factors) affect the memory record in that the previous history of exposure to light of the eye is important. Also to consider is the duration of an event and the non-integration of light by the retina (unlike photographic film), followed by the persistence of vision flicker frequency (fps in cinematic terms) and the presence of after-images. Finally, there is memory loss with time and the notorious unreliability of memory. So visual perception is a poor recording system when time is a significant parameter.

The photographic image does not always correspond to the memory of a subject, so that, for example, distant mountains may look less impressive in a photograph. On the other hand, visual perception is very good at side-by-side comparisons and can perform critical discriminations of colour, brightness and inhomogeneity. [Ka99]

Replacement of the eyes isn't just science-fiction either. Research has shown, that the brain is able to interpret many if not any information or stimulation given. Experiments were conducted in the 1950s, where blind people were seated in a special chair with a mechanism touching their back, which would translate a live feed from a camera into a grid of pressure stimulation. After some training and habituation, the blind people were able to see or rather perceive objects held in front of the camera. This experiment has been improved over the years and a device has been developed based on the same concept, just placed on the tongue. [BK03] The conclusion was made, that the brain was to be discerned as a plug-and-play computer, capable of calculating sense into any information stream. Vision itself, thus isn't much different to the tactile sense or acuesthesia, as it just builds the perception of the world, yet the defining factor is its stimulation by photons. The combination of the visual and tactile senses, would make artificial vision in different spectra possible. This would be forcing a new definition of visible light and photography as a consequence. [Ea15]

Technically the perception of any wavelength is possible nowadays. The resolution and quality of resulting pictures differs across the board, but progress is made constantly. The various characteristics of the different portions of the spectrum as well as the sheer size, makes the development difficult and the meaning of time to invest not always seen. Not long ago, a new sensor was developed, capable of the distinction of different wavelengths in between the infrared spectrum, allowing for a trichromatic colour representation.

UV was captured before visible light was, in fact photographic film is sensitive to light from IR into the x-radiation, which is why film shouldn't be carried through airport security. The naturally occurring radiation is hereby key factor and mostly limited to the imminent exposure of the sun and respectively the filtering of the atmosphere. As this celestial radiation is unequally prominent on the earth's surface, filtration is needed to see through only through a certain frequency. The piercing factors of x-radiation makes it prominent in all pictures taken, yet invisible, as the ration of x-rays to visible radiation is too big. A simple aluminium foil makes for a filter allowing none other than x-/gamma radiation through. External source of radiation is needed though, since it would take multiple years for an exposure of a single picture with the natural celestial radiation. Portable x-ray devices can be bought for the price of a small camera, yet the destructive nature of the higher frequencies should be taken into consideration.

Glass acts, like the lens in our eyes, as a natural filter of UV radiation, therefore either expensive quartz materials are needed for photography. The cheaper solution is omitting the lens and using a pinhole instead. UV transmitting filters are commercially available. Infrared is, because of its natural sensitivity of digital sensors and the relative ease of caption, the most popular radiography. A variety of filters can be obtained and older lenses even feature a special focus indicator for infrared radiation. Services are even offered, that transform cameras permanently into a IR capturing device, placing the filter directly onto the filter instead in front of the lens.

Since such technology is available to us in such variety and easy, shouldn't it be explored more? Seeing the world through different light, discovering new never seen before aspects. This a thrilling thought, that should revive the spirit of exploration as it did with the discovery of America in the 17th century. I see it as a task of any artist to peek into this world, leave behind the comfort of familiarity and seek for a new perception, even if this means the literal alienation of a scene by the use of false colour. The thrilling aspect of this new vision is its invisibility and even unimaginability of such a world. Our brain is incapable of imagining a colour it has not seen, giving the artist total freedom in interpretation.

9. Resources

9.1 Bibliography

[AH+15] Akselrod, G. M.; Huang, J.;Hoang, T. B.; Bowen, P. T.; Su, L.; Smith, D. R.; Mikkelsen, M. H.: *New technology colors in the infrared rainbow: Perfect absorbers capture specific wavelengths from the visible to the infrared spectrums*. Duke University, http://www.sciencedaily.com/releases/2015/11/151109141520.htm, 2015.

[AR72] Alhazen (Ibn al-Haytham); Risner, F..: *Opticae Thesaurus.* Per Episcopios, Basileae, 1672. pp. bk. 1, chap. 5, secs 14 & 23.

[AT11]

[At07] Atkinson, N.: *True Or False (Color): The Art Of Extraterestrial Photography*. http://www.universetoday.com/11863/true-or-false-color-the-art-of-extraterrestrial-photography, 2007.

[BK03] Bach-y-Rit, P.; Kercel, S. W.: *Sensory substitution and the human–machine interface.* TRENDS in Cognitive Sciences, Vol.7 No.12, 2003.

[BK+98] Backhaus, W.; Kliegel, R.; Werner, J. S.: *Color Vision: Perspectives from Different Disciplines.* Walter de Gruyter, Berlin, 1998.

[Bi07] Biotechnology and Biological Sciences Research Council: *Reindeer see a weird and wonderful world of ultraviolet light*. https://www.sciencedaily.com/releases/2011/05/110526064627.htm, 2016.

[BC+63] Blake, R.; Chubb, T.; Friedman, H.; Unzicker, A.: *Interpretation of X-Ray Photograph of the Sun.* ApJ, vol. 137, 1963, p. 3.

[BG01] Bolomey, J.; Gardiol, F.: *Engineering applications of the modulated scatterer technique.* Artech House, Boston, 2001, pp. 25-29.

[Co70] Cornsweet, T.: *Visual Perception.* Academic Press, New York, 1970.

[Co78] Coe, B.: Cameras: *From Daguerreotypes to Instant Pictures.* Crown Publishers, New York, 1978, p. 223.

[DA09] Darmont; Aphesa: *Spectral Response of Silicon Image Sensors.* White Paper, Aphesa, http://www.aphesa.com/downloads/download2.php?id=1, 2009.

[Da14] Davies, L.: *Richard Mosse: Congo's civil war, Interview.* The Telegraph, http://www.telegraph.co.uk/culture/photography/10734272/Richard-Mosse-Congos-civil-war-Interview.html, 2014.

[Ea15] Eagleman, D.: *Can we create new senses for humans?* TED, https://www.ted.com/talks/david_eagleman_can_we_create_new_senses_for_humans, 2015

[Ed16] Edmundoptics: *Imaging Electronics 101: Understanding Camera Sensors for Machine Vision Applications.* http://www.edmundoptics.com/technical-resources-center/imaging/understanding-camera-sensors-for-machine-vision-applications/, 2016.

[Ei05] Einstein, A.: *On the electrodynamics of moving bodies*. 1905, p. Ch. Introduction.

[Em67] Emming, J.: *Electromagnetic Radiation in Space*. Springer Netherlands, Dordrecht, 1967, pp. 134-137.

[En06] Enoch, J. M.: *History of Mirrors Dating Back 8000 Years.* University of California at Berkeley, Berkley, 2006.

[Fr13] Frieze: Richard Mosse: *The Impossible Image. Frieze Magazine,* https://vimeo.com/67115692, 2013

[Ge07] Gefter, P.: *Sex in the Park, And its Sneaky Spectators.* New York Times, Sept. 23rd 2007, pp. 37-38.

[Ge86] Gernsheim, H.: *A Concise History of Photography.* Courier Corporation, New York, 1986, pp. 8-22.

[Gr66] Graham, C.: *Vision and Visual Perception.* Wiley, New York, 1966.

[Gr08] Graves, L.: *Extreme X-Rays: Photographer Nick Veasey Takes You Inside ... Everything*. Wired, http://www.wired.com/2008/08/ff-xray/, 2008.

[Gr09] Gray, T.: *GRAY MATTER: DIY X-RAY PHOTOS,* Popular Science, http://www.popsci.com/diy/article/2009-11/gray-matter-diy-x-ray-photos, 2009.

[GZ+14] Glasner, D.; Zickler, T.; Levin, A.: *A Reflectance Display.* Harvard University; Weizmann Institute of Science, http://www.wisdom.weizmann.ac.il/~levina/papers/GlasnerEtal-ReflectanceDisplay-SIG2014.pdf, 2014.

[Ha13] Hamprecht, F.: *10.1 Light Fields | Image Analysis Class 2013*. Universität Heidelberg, https://www.youtube.com/watch?v=q_zVV89nU3g, 2013.

[Ha16] Harper, D.: *Photograph*. Online Etymology Dictionary, http://www.etymonline.com/index.php?term=photograph, 2016.

[He09] Hecht, E.: *Optik*. Oldenbourg, München, 2009.

[He08] Hester, J.: *Saving Hubble: How It Sees*. Pbs.org, http://www.pbs.org/wgbh/nova/sciencenow/0303/01-howi-nf.html, 2008.

[Ho16] Holland, M.: *Artist Spotlight: Nick Veasey*. Altpick, https://altpick.com/spot/veasey/veasey.php, 2016.

[JR88] Jacobson, R.; S. Ray; G. Attridge: *The Manual of photography*. Focal Press, London, 1988.

[Le10] Les photographes: *X-ray, The Curious Vision of Nick Veasey*. les photographes, http://www.lesphotographes.com/old-site/2010/07/20/x-ray-the-curious-vision-of-nick-veasey/, 2010.

[Li16] Life Pixel Infrared: *Digital Infrared Photography Primer*. http://www.lifepixel.com/infrared-photography-primer, 2016.

[Li73] Litchfield, R. B.: *Tom Wedgwood, the first photographer.* Duckworth and Co., London, 1903, pp. 191-192.

[Lo16] Lombry, T.: *Technique*. http://www.astrosurf.com/luxorion/menu-technique.htm, 2016.

[Ne04] Newton, I.: *Opticks*. Dover Publications, New York, 1704.

[Ni10] NIST: *Imaging Metrology*. Nist.gov, http://www.nist.gov/mml/mmsd/security_technologies/dietimage.cfm , 2010.

[Pr07] Prather, L.: *Tongue creates sight for blind: Visually impaired persons will be able to use device to sense images on tongue*. Wicab Inc., Truman State University Index, 2007, p.11

[Pe13] Peres, M. R.: *The Focal Encyclopedia of Photography.* Focal Press, Burlington, 2013.

[Ot05] O'Toole, M.: *Encyclopedia and Dictionary of Medicine, Nursing, and Allied Health*, Saunders, 2005.

[Ox16] Oxford Dictionary: *Photograph*. Oxford Dictionary. 2016.

[PV+14] G. Palczewska; F. Vinberg; P. Stremplewski: *Human eye can see 'invisible' infrared light*. Washington University in St. Louis, http://www.sciencedaily.com/releases/2014/12/141201161116.htm, 2014.

[Pc10] PCO AG: *Pixel size & sensitivity*. PCO AG, https://www.pco.de/fileadmin/user_upload/db/download/kb_pixel_size_sensitivity_20100721.pdf, 2010.

[Po89] Poincaré, H.: *Science and hypothesis.* Dover Publications, New York, 1889, p. Ch. 12.

[Po45] Popular Photography: *X-Ray by the Millions*. Popular Photography, no. 17, 1945, pp. 60-61.

[Po47] Popular Photography: *War Surplus*. Popular Photography, no. 20, 1947, pp. 138-140, 144.

[Po47d] Popular Photography: *Weegee (Arthur Felling).* Popular Photography, no. 21, 1947, p. 55.

[PR15f] Pound, M.; Riley, S.: *Capturing Digital Images (The Bayer Filter) - Computerphile.* https://www.youtube.com/watch?v=LWxu4rkZBLw, Feb. 2015

[PR15n] Pound, M.; Riley, S.: *Light-field Camera - Computerphile.* https://www.youtube.com/watch?v=rEMP3XEgnws, Nov. 2015

[Ra06] Raum, B.: *Licht und Farben.* Duden Paetec Schulbuchverl, Berlin, 2006.

[Ra99] Ray, S.: *Scientific photography and applied imaging.* Focal Press, Oxford, 1999.

[Re95] Renner, E.: *Pinhole photography.* Focal Press, Boston, 1995.

[Rø04] Rørslett, B.: *All You Ever Wanted to Know About UV and IR Photography.* http://www.naturfotograf.com/UV_IR_rev00.html, 2004.

[Ro07] Rostyslav, S.: *Adobe 3D Camera Demo by AudioBlog.fr.* https://www.youtube.com/watch?v=xu31XWUxSkA, 2007.

[Ru96] Russel, J.: *Renoir's Paradise, And Those Who Loved It.* The New York Times, Sept. 29th 1996.

[Sc16] Schiller, J.: *X-Rays Reveal the Beautiful Guts Inside Classic Motorcycles*. Wired, http://www.wired.com/2015/04/nick-veasey-xray-motorcycles/, 2016.

[Sh14] Shainman, J.: Richard Mosse - The Enclave - Jack Shainman Gallery. Jack Shainman Gallery, https://www.youtube.com/watch?v=RKO5LbOFjXg, 2014.

[So77] Sontag, S.: *On Photography.* Penguin Books, London, 1977.

[Te07] Texas Instruments: *Texas Instruments - 1966 First FLIR units produced*. Texas Instruments, http://www.ti.com/corp/docs/company/history/timeline/defense/1960/docs/66-first_flir.htm, 2007.

[UM04] University Of Montreal: *An Eye On The Tongue*. University of Montreal, www.sciencedaily.com/releases/2004/06/040603065225.htm, 2004.

[WL+12] Wetzstein, G.; Lanman, D.; Hirsh, M.; Raskar, R.: Tensor Displays: *Compressive Light Field Synthesis using Multilayer Displays with Directional Backlighting*. MIT, http://web.media.mit.edu/%7Egordonw/TensorDisplays/TensorDisplays.pdf, 2012

[WW02] Williams, P.; Williams, G.: *Reflected Ultraviolet Photography*. http://medicalphotography.com.au/Article_01/index.html, 2002.

9.2 Artwork

[Fig. 1] Alhazen (Ibn al-Haytham): *Illustration of the human visual system.* Illustration, Book of Optics (Kitab al-Manaztu), 1083.
[Fig. 2] Frisius, R. G.: *Observing solar eclipse of 24 January 1544.* Engraving, De radio astronomico et geometrico liber, 1545.
[Fig. 3] Walker, B.: I*llustration of Fizeau's experiment.* Optical Engineering Fundamentals, SPIE Press, Bellingham, 2008.
[Fig. 4] Ronan, P.: *EM spectrum*, Illustration, Wikipedia commons.
[Fig. 5] Allen, E.; *S. Triantaphillidou*: Anatomy of the human eyeball. The Manual Of Photography. Elsevier/Focal Press, Oxford, 2011.
[Fig. 6] Monet, C.: *Le bassin aux nympheas.* Oil on canvas, The Art Museum, Princeton University, 1899.
[Fig. 7] Monet, C.: *Nymphéas: Le pont Japanais*. Oil on Canvas, The Minneapolis Institute of Arts, 1912-22.
[Fig. 8] Monet, C.: *La maison vue du jardin aux roses.* Oil on canvas, Musée Marmottan, Paris, 1925.
[Fig. 9] Monet, C.: *La maison vue du jardin aux roses.* Oil on canvas, Musée Marmottan, Paris, 1925.
[Fig. 10] Niépce, J. N.: *View from the Window at Le Gras*. Oil-treated Bitumen, Harry Ransom Center, Austin Texas, 1826.
[Fig. 11] Voytek S.: *Photographic Film.* Illustration, Wikipedia Creative Commons, 2007.
[Fig. 12] Burnett, C. M. L.: *Bayer pattern on sensor profile.* Wikipedia Creative Commons, GFDL, 2006.
[Fig. 13] Georgeiv, T.; *Adobe LightField Camera Prototype #1.* Photography, Adobe Systems Inc, 2006.
[Fig. 14] Merril, S. P.: *Infrared photo of bending Cypress tree.* Infrared Photograph, 2006.
[Fig. 15] Aregger, A.: *Untitled*, Infrared Photograph, 2014.
[Fig. 16] Yoshiyuki, K.: Top Left: *Untitled*. Gelatin Silver Print, from the series The Park, 1973.
Top Right: *Untitled*. Gelatin Silver Print, from the series The Park, 1971.
Bottom Left: *Untitled*. Gelatin Silver Print, from the series The Park, 1979.
Bottom Right: *Untitled*. Gelatin Silver Print, from the series The Park, 1971.
[Fig. 17] Bath's Royal National Hospital: *Thermal image of patient's hands.* Thermograph, Bath's Royal National Hospital, 2013.
[Fig. 18] Mosse, R.: *Vintage Violence.* Infra, Aperture Foundation, 2012.
[Fig. 19] Mosse, R.: *Safe From Harm.* Infra, Aperture Foundation, 2012.
[Fig. 20] Mosse, R.: *Platon.* Infra, Aperture Foundation, 2012.
[Fig. 21] NASA; ESA; Herschel; PACS; SPIRE; Hill: *Multi-wavelength view of Messier 16.* Composite of different wavelength images, 1995.
[Fig. 22] NASA; ESA; STScI: *Pillars of Creation.* Photograph by the Hubble Space Telescope, NASA; ESA; STScI, 1995.

[Fig. 23] Philips, C.: *(untitled) ultraviolet #7.* Ultraviolet Photograph, Cara Philips, 2012.
[Fig. 24] Philips, C.: *(untitled) ultraviolet son #2.* Ultraviolet Photograph, Cara Philips, 2012.
[Fig. 25] Philips, C.: *(untitled) ultraviolet wife #1*. Ultraviolet Photograph, Cara Philips, 2012.
[Fig. 26] Veasey, N.: *Plane*. X-Ray image, C-Type Print, 2001.
[Fig. 27] Blake, R.: *First X-ray photo of the sun.* X-Ray Pinhole Photograph, Palace of the Governors Photo Archives, 1960.
[Fig. 28] Evren, B.: *Bone scintigraph.* Scintigraph, Inonu University, Turkey, 2012.
[Fig. 29] Veasey, N.: *Bus*. X-Ray Image, C-Type Print, 1998.
[Fig. 30] Veasey, N.: *Newspaper Man.* X-Ray Image, C-Type Print, 2008.