HOLOGRAPGY

The [Hungarian](https://en.wikipedia.org/wiki/Magyars)-[British](https://en.wikipedia.org/wiki/British_people) physicist [Dennis Gabor](https://en.wikipedia.org/wiki/Dennis_Gabor)  was awarded the [Nobel Prize in Physics](https://en.wikipedia.org/wiki/Nobel_Prize_in_Physics) in 1971 "for his invention and development of the holographic method".

Holograph is two steps process of recording and reconstruction of images which retain amplitude (intensity) and phase information using highly coherent laser light.

The development of the [laser](https://en.wikipedia.org/wiki/Laser) enabled the first practical optical holograms that recorded 3D objects to be made in 1962 by [Yuri Denisyuk](https://en.wikipedia.org/wiki/Yuri_Denisyuk) in the Soviet Union and by [Emmett Leith](https://en.wikipedia.org/wiki/Emmett_Leith) and [Juris Upatnieks](https://en.wikipedia.org/wiki/Juris_Upatnieks" \o "Juris Upatnieks) at the [University of Michigan](https://en.wikipedia.org/wiki/University_of_Michigan), USA. Early holograms used [silver halide](https://en.wikipedia.org/wiki/Silver_halide) photographic emulsions as the recording medium.

Several types of holograms can be made. Transmission holograms, such as those produced by Leith and Upatnieks, are viewed by shining laser light through them and looking at the reconstructed image from the side of the hologram opposite the source.

[Specular holography](https://en.wikipedia.org/wiki/Specular_holography) is a technique for making three-dimensional images by controlling the motion of specular glints( or small flash of light) on a two-dimensional surface. The image is made of many specularities (reflection) and has the appearance of a 3D surface-stippling made of dots of light. It works by reflectively or refractivity manipulating bundles of light rays, whereas Gabor-style holography works by diffractively reconstructing wave-fronts.

Most holograms produced are of static objects but systems for displaying changing scenes on a holographic [volumetric display](https://en.wikipedia.org/wiki/Volumetric_display) are now being developed.

Holograms can also be used to store, retrieve, and process information optically.

How it works-

Holography is a technique that enables a light field (which is generally the result of a light source scattered off objects) to be recorded and later reconstructed when the original light field is no longer present, due to the absence of the original objects.

**Laser**

In laser holography, the hologram is recorded using a source of [laser](https://en.wikipedia.org/wiki/Laser) light, which is very pure in its color and orderly in its composition. Various setups may be used, and several types of holograms can be made, but all involve the interaction of light coming from different directions and producing a microscopic interference pattern which a [plate](https://en.wikipedia.org/wiki/Photographic_plate), film, or other medium [photographically](https://en.wikipedia.org/wiki/Photography) records.

In one common arrangement, the laser beam is split into two, one known as the [object beam](https://en.wikipedia.org/wiki/Signal_beam) and the other as the [reference beam](https://en.wikipedia.org/wiki/Reference_beam). The object beam is expanded by passing it through a lens and used to illuminate the subject. The recording medium is located where this light, after being reflected or scattered by the subject, will strike it. The edges of the medium will ultimately serve as a window through which the subject is seen, so its location is chosen with that in mind. The reference beam is expanded and made to shine directly on the medium, where it interacts with the light coming from the subject to create the desired interference pattern.

Like conventional photography, holography requires an appropriate [exposure](https://en.wikipedia.org/wiki/Exposure_(photography)) time to correctly affect the recording medium. Unlike conventional photography, during the exposure the light source, the optical elements, the recording medium, and the subject must all remain perfectly motionless relative to each other, to within about a quarter of the wavelength of the light, or the interference pattern will be blurred and the hologram spoiled. With living subjects and some unstable materials, that is only possible if a very intense and extremely brief pulse of laser light is used, a hazardous procedure which is rare and rarely done outside of scientific and industrial laboratory settings. Exposures lasting several seconds to several minutes, using a much lower-powered continuously operating laser, are typical.

**Apparatus**

A hologram can be made by shining part of the light beam directly into the recording medium, and the other part onto the object in such a way that some of the scattered light falls onto the recording medium. A more flexible arrangement for recording a hologram requires the laser beam to be aimed through a series of elements that change it in different ways. The first element is a [beam splitter](https://en.wikipedia.org/wiki/Beam_splitter) that divides the beam into two identical beams, each aimed in different directions:

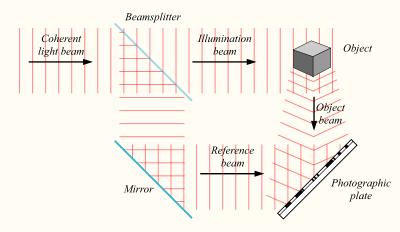
* One beam (known as the *illumination* or *object beam*) is spread using [lenses](https://en.wikipedia.org/wiki/Lens_(optics)) and directed onto the scene using [mirrors](https://en.wikipedia.org/wiki/Mirror). Some of the light scattered (reflected) from the scene then falls onto the recording medium.
* The second beam (known as the *reference beam*) is also spread through the use of lenses, but is directed so that it doesn't come in contact with the scene, and instead travels directly onto the recording medium.

Several different materials can be used as the recording medium. One of the most common is a film very similar to [photographic film](https://en.wikipedia.org/wiki/Photographic_film) ([silver halide](https://en.wikipedia.org/wiki/Silver_halide) [photographic emulsion](https://en.wikipedia.org/wiki/Photographic_emulsion)), but with a much higher concentration of light-reactive grains, making it capable of the much higher [resolution](https://en.wikipedia.org/wiki/Optical_resolution) that holograms require. A layer of this recording medium (e.g., silver halide) is attached to a transparent substrate, which is commonly glass, but may also be plastic.

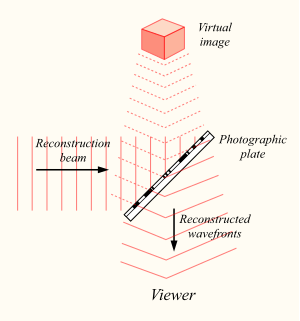
**Process**

When the two laser beams reach the recording medium, their light waves intersect and [interfere](https://en.wikipedia.org/wiki/Interference_(wave_propagation)) with each other. It is this interference pattern that is imprinted on the recording medium. The pattern itself is seemingly random, as it represents the way in which the scene's light *interfered* with the original light source — but not the original light source itself. The interference pattern can be considered an [encoded](https://en.wikipedia.org/wiki/Encoded) version of the scene, requiring a particular key — the original light source — in order to view its contents.

This missing key is provided later by shining a laser, identical to the one used to record the hologram, onto the developed film. When this beam illuminates the hologram, it is [diffracted](https://en.wikipedia.org/wiki/Diffraction) by the hologram's surface pattern. This produces a light field identical to the one originally produced by the scene and scattered onto the hologram.



Recording of Hologram



Reconstruction of Hologram

**Comparison with photography**

Holography may be better understood via an examination of its differences from ordinary [photography](https://en.wikipedia.org/wiki/Photography):

* A hologram represents a recording of information regarding the light that came from the original scene as scattered in a range of directions rather than from only one direction, as in a photograph. This allows the scene to be viewed from a range of different angles, as if it were still present.
* A photograph can be recorded using normal light sources (sunlight or electric lighting) whereas a laser is required to record a hologram.
* A lens is required in photography to record the image, whereas in holography, the light from the object is scattered directly onto the recording medium.
* A holographic recording requires a second light beam (the reference beam) to be directed onto the recording medium.
* A photograph can be viewed in a wide range of lighting conditions, whereas holograms can only be viewed with very specific forms of illumination.
* When a photograph is cut in half, each piece shows half of the scene. When a hologram is cut in half, the whole scene can still be seen in each piece. This is because, whereas each point in a [photograph](https://en.wikipedia.org/wiki/Photograph) only represents light scattered from a single point in the scene, *each point* on a holographic recording includes information about light scattered from *every point* in the scene. It can be thought of as viewing a street outside a house through a 120 cm × 120 cm (4 ft × 4 ft) window, then through a 60 cm × 120 cm (2 ft × 4 ft) window. One can see all of the same things through the smaller window (by moving the head to change the viewing angle), but the viewer can see more *at once* through the 120 cm (4 ft) window.
* A photograph is a two-dimensional representation that can only reproduce a rudimentary three-dimensional effect, whereas the reproduced viewing range of a hologram adds many more [depth perception cues](https://en.wikipedia.org/wiki/Depth_perception) that were present in the original scene. These cues are recognized by the [human brain](https://en.wikipedia.org/wiki/Human_brain) and translated into the same perception of a three-dimensional image as when the original scene might have been viewed.
* A photograph clearly maps out the light field of the original scene. The developed hologram's surface consists of a very fine, seemingly random pattern, which appears to bear no relationship to the scene it recorded.

Physics of holography a better understanding of the process, it is necessary to understand [interference](https://en.wikipedia.org/wiki/Interference_(optics)) and [diffraction](https://en.wikipedia.org/wiki/Diffraction). Interference occurs when one or more [wavefronts](https://en.wikipedia.org/wiki/Wavefronts" \o "Wavefronts) are superimposed. [Diffraction](https://en.wikipedia.org/wiki/Diffraction) occurs when a wavefront encounters an object. The process of producing a holographic reconstruction is explained below purely in terms of interference and diffraction. It is somewhat simplified but is accurate enough to give an understanding of how the holographic process works

A [diffraction grating](https://en.wikipedia.org/wiki/Diffraction_grating) is a structure with a repeating pattern. A simple example is a metal plate with slits cut at regular intervals. A light wave that is incident on a grating is split into several waves; the direction of these diffracted waves is determined by the grating spacing and the wavelength of the light.

A simple hologram can be made by superimposing two [plane waves](https://en.wikipedia.org/wiki/Plane_wave) from the same light source on a holographic recording medium. The two waves interfere, giving a [straight-line fringe pattern](https://en.wikipedia.org/wiki/Interference_(optics)#Between_two_plane_waves) whose intensity varies sinusoidally across the medium. The spacing of the fringe pattern is determined by the angle between the two waves, and by the wavelength of the light.

The recorded light pattern is a diffraction grating. When it is illuminated by only one of the waves used to create it, it can be shown that one of the diffracted waves emerges at the same angle as that at which the second wave was originally incident, so that the second wave has been 'reconstructed'. Thus, the recorded light pattern is a holographic recording as defined above.

**Complex objects**

To record a hologram of a complex object, a laser beam is first split into two beams of light. One beam illuminates the object, which then scatters light onto the recording medium. According to [diffraction](https://en.wikipedia.org/wiki/Diffraction) theory, each point in the object acts as a point source of light so the recording medium can be considered to be illuminated by a set of point sources located at varying distances from the medium.

The second (reference) beam illuminates the recording medium directly. Each point source wave interferes with the reference beam, giving rise to its own sinusoidal zone plate in the recording medium. The resulting pattern is the sum of all these 'zone plates', which combine to produce a random ([speckle](https://en.wikipedia.org/wiki/Speckle_pattern)) pattern as in the photograph above.

When the hologram is illuminated by the original reference beam, each of the individual zone plates reconstructs the object wave that produced it, and these individual wavefronts are combined to reconstruct the whole of the object beam. The viewer perceives a wavefront that is identical with the wavefront scattered from the object onto the recording medium, so that it appears that the object is still in place even if it has been removed{\displaystyle \left|U\_{\text{O}}+U\_{\text{R}}\right|^{2}=U\_{\text{O}}U\_{\text{R}}^{\*}+\left|U\_{\text{R}}\right|^{2}+\left|U\_{\text{O}}\right|^{2}+U\_{\text{O}}^{\*}U\_{\text{R}}}{\displaystyle T=kU\_{\text{O}}U\_{\text{R}}^{\*}+k\left|U\_{\text{R}}\right|^{2}+k\left|U\_{\text{O}}\right|^{2}+kU\_{\text{O}}^{\*}U\_{\text{R}}}, {\displaystyle U\_{H}=TU\_{\text{R}}=kU\_{\text{O}}\left|U\_{\text{R}}\right|^{2}+k\left|U\_{\text{R}}\right|^{2}U\_{\text{R}}+k\left|U\_{\text{O}}\right|^{2}U\_{\text{R}}+kU\_{\text{O}}^{\*}U\_{\text{R}}^{2}}[real image](https://en.wikipedia.org/wiki/Real_image) of the object in the space beyond the holographic plate being used to make a hologram

To make a hologram, the following are required:

(a)a suitable object or set of objects. part of the laser beam to be directed so that it illuminates the object (the object beam) and another part so that it illuminates the recording medium directly (the reference beam), enabling the reference beam and the light which is scattered from the object onto the recording medium to form an interference pattern

(b)a recording medium which converts this interference pattern into an optical element which modifies either the amplitude or the phase of an incident light beam according to the intensity of the interference pattern.

(c)a laser beam that produces [coherent](https://en.wikipedia.org/wiki/Coherence_(physics)) light with one [wavelength](https://en.wikipedia.org/wiki/Wavelength).

(d)an environment which provides sufficient mechanical and thermal stability that the interference pattern is stable during the time in which the interference pattern is recorded

These requirements are inter-related, and it is essential to understand the nature of optical interference to see this. [Interference](https://en.wikipedia.org/wiki/Interference_(optics)) is the variation in [intensity](https://en.wikipedia.org/wiki/Intensity_(physics)) which can occur when two [light waves](https://en.wikipedia.org/wiki/Light_waves) are superimposed. The intensity of the maxima exceeds the sum of the individual intensities of the two beams, and the intensity at the minima is less than this and may be zero. The interference pattern maps the relative phase between the two waves, and any change in the relative phases causes the interference pattern to move across the field of view. If the relative phase of the two waves changes by one cycle, then the pattern drifts by one whole fringe. One phase cycle corresponds to a change in the relative distances travelled by the two beams of one wavelength. Since the wavelength of light is of the order of 0.5 μm, it can be seen that very small changes in the optical paths travelled by either of the beams in the holographic recording system lead to movement of the interference pattern which is the holographic recording. Such changes can be caused by relative movements of any of the optical components or the object itself, and also by local changes in air-temperature. It is essential that any such changes are significantly less than the wavelength of light if a clear well-defined recording of the interference is to be created.

Thus, the laser power, recording medium sensitivity, recording time and mechanical and thermal stability requirements are all interlinked. Generally, the smaller the object, the more compact the optical layout, so that the stability requirements are significantly less than when making holograms of large objects.

Another very important laser parameter is its [coherence](https://en.wikipedia.org/wiki/Coherence_(physics)#Temporal_coherence).]This can be envisaged by considering a laser producing a sine wave whose frequency drifts over time; the coherence length can then be considered to be the distance over which it maintains a single frequency. This is important because two waves of different frequencies do not produce a stable interference pattern. The coherence length of the laser determines the depth of field which can be recorded in the scene. A good holography laser will typically have a coherence length of several meters, ample for a deep hologram.

The objects that form the scene must, in general, have optically rough surfaces so that they scatter light over a wide range of angles. A specularly reflecting (or shiny) surface reflects the light in only one direction at each point on its surface, so in general, most of the light will not be incident on the recording medium. A hologram of a shiny object can be made by locating it very close to the recording plate.

**Hologram classifications**

There are three important properties of a hologram which are defined in this section. A given hologram will have one or other of each of these three properties, e.g. an amplitude modulated, thin, transmission hologram, or a phase modulated, volume, reflection hologram.

**Amplitude and phase modulation holograms**

An amplitude modulation hologram is one where the amplitude of light diffracted by the hologram is proportional to the intensity of the recorded light. A straightforward example of this is [photographic emulsion](https://en.wikipedia.org/wiki/Photographic_emulsion) on a transparent substrate. The emulsion is exposed to the interference pattern, and is subsequently developed giving a transmittance which varies with the intensity of the pattern – the more light that fell on the plate at a given point, the darker the developed plate at that point.

A phase hologram is made by changing either the thickness or the [refractive index](https://en.wikipedia.org/wiki/Refractive_index) of the material in proportion to the intensity of the holographic interference pattern. This is a [phase grating](https://en.wikipedia.org/wiki/Grating_equation) and it can be shown that when such a plate is illuminated by the original reference beam, it reconstructs the original object wavefront. The efficiency (i.e., the fraction of the illuminated object beam which is converted into the reconstructed object beam) is greater for phase than for amplitude modulated holograms.

**Thin holograms and thick (volume) holograms**

A thin hologram is one where the thickness of the recording medium is much less than the spacing of the interference fringes which make up the holographic recording. The thickness of a thin hologram can be down to 60 nm by using a topological insulator material Sb2Te3 thin film.

Ultrathin holograms hold the potential to be integrated with everyday consumer electronics like smartphones.

A thick or [volume hologram](https://en.wikipedia.org/wiki/Volume_hologram) is one where the thickness of the recording medium is greater than the spacing of the interference pattern.

**Transmission and reflection holograms**

A transmission hologram is one where the object and reference beams are incident on the recording medium from the same side. In practice, several more mirrors may be used to direct the beams in the required directions.

Normally, transmission holograms can only be reconstructed using a laser or a quasi-monochromatic source, but a particular type of transmission hologram, known as a rainbow hologram, can be viewed with white light.

In a reflection hologram, the object and reference beams are incident on the plate from opposite sides of the plate. The reconstructed object is then viewed from the same side of the plate as that at which the re-constructing beam is incident.

Only volume holograms can be used to make reflection holograms, as only a very low intensity diffracted beam would be reflected by a thin hologram.

Examples of full-color reflection holograms of mineral specimens: