A centenary, G.Lippmann, Nobel prize of Physics 1908 **for colour photography**

[**DOI** 10.1051/epn:2008601]

P.Ranson, **R.Ouillon** and **J.-P.Pinan-Lucarré**
Physique des milieux denses, IMPMC, CNRS UMR 7590, Université P & M Curie, 140 rue de Lourmel, 75015 Paris, France

One century ago, on December 10 (1908), the Royal Swedish Academy of Sciences awarded the Nobel prize for physics to Professor Gabriel Lippmann of the Sorbonne for his interference-based method to reproduce colours by photography.

The basis of colour photography

Since ancient times, man has wanted to keep images of his surrounding environment on various recording media. These images are first "imprinted" in the human retina through the light coming from the objects and analyzed by the brain. Following this idea, man tried to produce faithful copies of these images using the arts of sculpture, drawing, painting and, since a century ago, the art of photography. The original images are coloured. But the colour receptors of the retina, the retinal cones, are not very good frequency analysers for the light waves. Cones can be divided into three sets of receptors whose maximum spectral sensitivity are centred in three domains: blue (~ 425nm), green (~ 535 nm) and red (~ 570 nm). Then, in a first approach, it will be sufficient, using the art of photography, to use photographic plates whose properties are similar to those of the retina. In usual colour photography, this was done until now by using mainly the subtractive three-colour techniques and at present, with the supremacy of digital camera technology, by using the additive ones. The aim of these methods is to mimic the colour sensations which occur in the human eye.

The interference method of Gabriel Lippmann [1] follows a completely different route. This is a pure physical process based on the properties of the standing-wave pattern, which gives in principle a faithful and unalterable reproduction of the true spectral composition of the radiation. In the art of colour photography, the Lippmann process was not an epoch-making invention, in spite of its elegance. But this method has been a convincing illustration of the theory of harmonic plane wave interferences in optics and was to give rise a century later, with the advent of laser sources, to the modern applications of the Lippmann-Bragg effect.

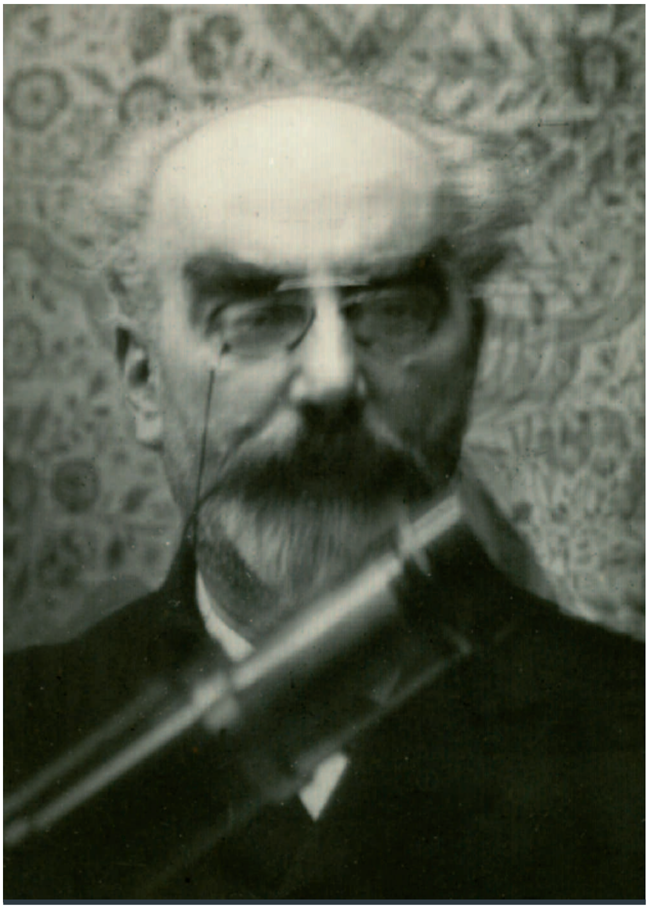
Who was Gabriel Lippmann?

Gabriel Lippmann (see Fig.2) was born of French parents at Hollerich (Luxembourg) on August 16, 1845. As a student at the Ecole Normale Supérieure (Paris), he decided upon a university career and held successively the chairs of mathematical-physics (1883) and of physics (1886) at the Sorbonne. He became head from 1886 until his death in 1921 of the famous L.R.P.S. "Laboratoire des Recherches Physiques de la Sorbonne", in which he finalized his interference colour photography. The Lippmann plates which illustrate this article come from this laboratory, which closed with the creation of the University Pierre et Marie Curie (Paris VI) in 1968.

The best known among the collaborators and students of Lippmann at Sorbonne were the Nobel Prize winners Pierre Curie (Physics, 1903) and Maria Sklodowska-Curie (Physics 1903 and Chemistry 1911).

1810-1848 The earliest colour recording processes [2]

In 1666, Isaac Newton has shown that white light is made up from a continuous set of monochromatic components, whose various visible colours from purple to red are displayed under dispersion by a glass prism. The first attempts to record and fix these "homogeneous" or "pure" colours on a solid flat surface dates back to the beginning of the XIX° century, that is twenty years earlier than the discovery of photography by the pioneers Nicephore Nièpce (~ 1826) and Louis Jacques Mandé Daguerre (1836). We can quote the studies of Johann T. Seebeck (1810), who used a saturated paper with silver chloride in water as an aid to print the various colours of the solar spectrum. These experiments were carried out by Sir John Herschell, Nièpce Saint Victor and Poitevin, but finally the best results were obtained by Edmond Becquerel with sensitized silver surfaced plates of Daguerreotypes. Becquerel showed that a well-polished silver plate, coated with a thin layer of silver chloride, coloured up under light with a colour corresponding to that of the original. He then obtained the famous Becquerel heliochromes (1838-1848) of which few have survived: no method was found to fix colours on the plate, and furthermore ►



◄ **FIG. 1:** A bunch of flowers (Lippmann plate 9x12 cm). Flowers photographs are perfectly suited to be taken by the Lippmann process. On this plate, we notice the various flower colours and the very nice reflection of light on the glazed vase.

► **FIG. 2:** Black and white image (13.6x18 cm, "plaque autostéréoscopique") showing Professor G.Lippmann in his study behind a telescope. A vertical-stripes pattern is visible on the image. This pattern, which is put in front of the glass plate, allows an observer to see a three-dimensional image when looking the plate from a judicious distance. This method was finalized by Eugène Estanave from 1908 in the laboratory of G. Lippmann at the Sorbonne.

◀ **FIG. 3: The great border (Tapis vert) in the Versailles grounds (Lippmann plate 9x12 cm). This is an archival image! The great border begins at the Latone bath and goes down towards the Apollon bath. In the background we see the great canal of about one mile long.**

▸ they fade in light. However, this method also failed to attract attention for twenty years, although it was most likely the first success of interference photography based on the creation of a standing-line pattern by reflection of light on the silver layer! At least this is the explanation for the origin of Becquerel's coloured images given by Wilhem Zenker in 1868.

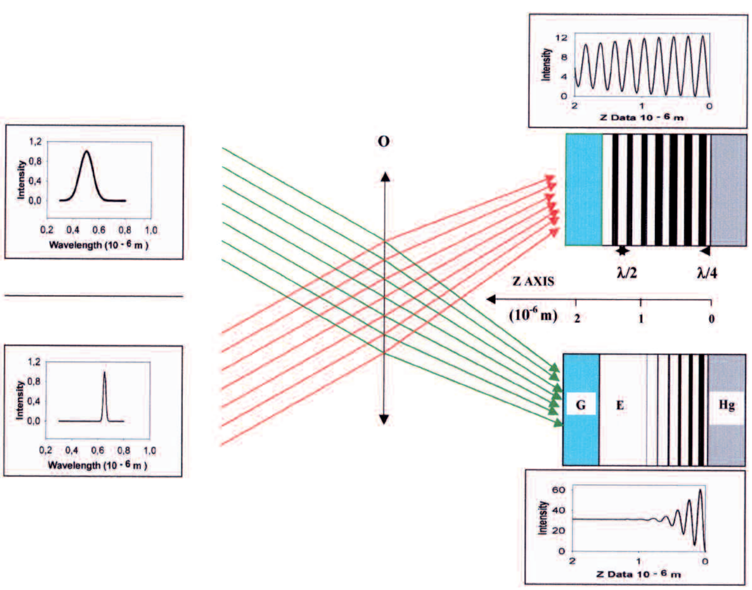
1861-1895: Three-colour photographic pictures, first attempts [2, 3]

Colour photography enjoyed a new boom after James Clerk Maxwell established in 1859 that all colours visible to the human eye may be produced by mixing the light of the three primary colours red, green and blue (RGB), in appropriate proportions. In 1861 Maxwell took the first permanent colour photograph using such additive process, by making three separate white and black photographs through red, green and blue filters (after the plates were developed into negatives, they were reversed into positives, and then each projected through the filters with which they were taken, with a careful superposition on the projection screen). But colours may be also obtained by subtraction from white light by dyes or pigments. In such subtractive processes, the most common set of primary colours is cyan, magenta, yellow and black (CMYK). The first theoretical studies (1869) and experiments (1877) using subtractive processes for colour reproduction were performed by Charles Cros and Louis Ducos du Hauron.

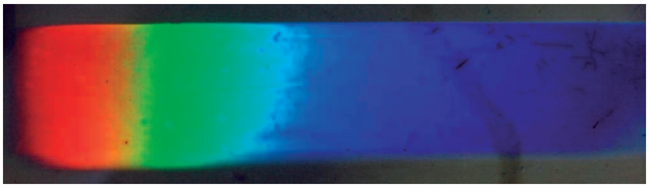
1891: The interference process of Gabriel Lippmann: a standing-wave process for colour production [1-6]

In all these earlier techniques at the end of the XIXth century, the colour production required chemical pigments or dyes, which were inserted in filters or in sensitive layers in the course of the photographic process. However, the response of these materials to light and their preservation with time were not well controlled. The idea of Gabriel Lippmann was only to use physical properties of light for colour production. He focused his study upon the accurate relation between the frequency spectrum of an incoming light wave and its colour. The challenge was to imprint the densely spaced harmonic waves contained in a natural colour as a *permanent mark* in a photosensitive layer, and afterward to reproduce from this mark the corresponding colour (by analogy with acoustic waves in the phonograph, a device for recording and replaying sound which was theoretically imagined by Charles Cros and achieved by Thomas Alva Edison in 1877).

A standing-wave pattern created in a photosensitive layer may realise this imprinted mark. The layer consists of a dispersion of silver halide in gelatine. The standing-wave pattern is obtained by reflecting the object's light back onto itself using a mirror (Fig.4). To provide a close contact between the reflecting material and the photosensitive layer, the ingenious method was to use a mercury mirror. After the photographic processes of development, fixation and drying, parallel mirror planes made up of Ag particles are located at the antinodal planes of the standing wave pattern.



◀ **FIG. 4: Lippmann's process of colour photography. In colour photography, any coloured object is analysed in terms of a great number of light sources, each having its own continuum spectrum within the limits of a certain spectral interval Δλ. In Lippmann's process, the radiation of each source is focused by camera lens (O) on the photographic plate as usual (G glass support, E light-sensitive layer), but in addition it is reflected back by a mercury mirror (Hg) lying on the reverse side of the light-sensitive layer (E). As a result of the superposition of the incident and of the reflected radiation, a standing wave pattern is created above the reflection surface. After exposure and development, a system of flat metal mirrors is formed in the photo-sensitive layer. In the figure, two different standing wave pattern are shown: the first originates from a narrow spectral band red source (λ=0.65 µm, Δλ≈0.02 µm) and the second from a broad spectral blue source (λ=0.5 µm, Δλ≈0.1 µm). In the first configuration the system of lamina fill up all the layer's depth, in the second configuration we see that the lamina system extends only a few hundred nanometer into the layer (E). When being illuminated by an incident natural white light, the imprinted metallic lamina system selects from the white light and reflects back to an observer the radiation of only the monochromatic components which took part in the registration process.**



▲ **FIG. 5:** A solar spectrum (Lippmann plate 6.5x8.5 cm, exposure time from 30 min up to 2 hr).
The solar spectrum or the graphite arc electric spectrum are the first records of colours by means of the interference process. Apparently it took Lippmann twelve years of experimental work from 1879 on to make emulsions with grains fine enough to record the standing wave pattern generated in the plates. The successful demonstration of the Lippmann process giving permanent and brilliant colour, *Colour Photography*, was communicated to the Paris Academy of Sciences in December 1891.

For an incoming monochromatic light of wavelength λ_0 (in vacuum), these planes are spaced from one another at distances d equal to half a wavelength in the layer ($d = \lambda_0/2n$, with n the refractive index of the photosensitive layer). Their spatial distribution may extend over several µm.

When the light is not monochromatic, the distribution of intensities in the standing wave pattern becomes uniform at a short distance from the mercury mirror due to the overlapping of the individual "monochromatic" standing waves contained in the light. Consequently the distribution of the silver particles will also become uniform.

Nevertheless, in either case, whatever the spatial expansion is, the metallic lamina pattern will behave as a frequency-selective reflector for the light waves. Subjected to the vibrations of a *white light source with a continuous spectrum*, it will reflect back with an appreciable intensity only those monochromatic components which have been involved in the imprinting process (a consequence of constructive *interference processes*, which may also be analyzed in terms of the *Bragg effect*). Consequently, the method is theoretically suitable for the reproduction of natural colours.

In modern optics language, we can say that the Lippmann process amounts to a double Fourier transformation: At the recording stage, the Fourier transform of the spectrum of the light is imprinted in the intensity profile of the standing-wave. At the reproduction stage, another Fourier transform is carried out, restoring the initial light composition.

Putting the Lippmann process into practice proved to be difficult. Several requirements must be fulfilled by the photosensitive layer:

- It must have very good transparency, since the incident radiation crosses all the layers (generally of few micrometers deep) before striking the mirror.
- It must be "grainless", in other words: have grains of silver halide of very small size, $s \leq 10$ nm. This is necessary, first to obtain a high spatial resolution for the standing-wave pattern [for blue light at $\lambda_0 = 450$ nm, the interfringe pattern is $i = \lambda_0/2n = 150$nm] and secondly to generate negligible noise by diffusion or scattering.
- It must be made isochromatic (by addition of suitable chemical sensitizers) so as to accurately reproduce the distribution of amplitudes in the broad frequency spectrum that issues from natural coloured objects. This last point is the key point of the Lippmann process.

In the Lippmann process, the reproduction of a coloured image results from the reflection of white light upon a set of silver metallic laminae, and then is function of a sum of local *amplitude* reflectance r created inside the plate during the recording process by each monochromatic vibration. Lippmann defines isochromatism as a response r which depends only on the amplitude of vibrations but not on their frequency. This statement is explained in detail in the theoretical article published by Lippmann in 1894 [7]. After several years of technical improvements in the emulsion's quality (in collaboration with Auguste and Louis Lumière, the inventors of the autochrome plates), brilliant and accurate images were produced. They display vivid colours one century later (see Figs 1-3-5-7) and some of them showing sites that are well known possess archival value.

And yet, why has the Lippmann process never gained widespread popularity...?

In the recording stage [8], the Lippmann process has some drawbacks. The plates (which need a reflecting mirror) are not very practical. Due to the use of an ultrafine-grain silver halide emulsion, the length of exposure (one minute in sunlight) is too long for a portrait. In addition, it is impossible to make duplicate copies of the images.

▼ **FIG. 6:** Photograph of a young man (Lippmann plate 9x12 cm)
One of the main drawbacks of the "grainless" Lippmann emulsion for usual photography is its very low sensitivity. Only few photographs of persons or animals have been taken by means of this process.

In the image viewing stage, the plates need to be lit and viewed from the correct angle to reflect the true colours, and their projection is a difficult task.

Also, after 1910, the more convenient autochrome additive process of the Lumière brothers would become, for almost 20 years, the dominant colour process.

As for Lippmann, he spent time to investigate the optical three-dimensional imaging devices in the art of photography. On March 3rd, 1908 he proposed the use of a series of small convex lenses (a fly's-eye lens array) at the picture surface instead of the opaque barrier lines of the Estanage method (see Fig.2). This was announced to the French Academy of Sciences under the title "La Photographie Integrale". Finally, Estanave carried out the theoretical concepts of Lippmann in 1925.

The revival of the Lippmann ideas

Fifty years after being awarded the Nobel Prize, the initial Lippmann ideas were taken up again with the development of imaging techniques that involved recording standing waves in a thick (≈15 µm) photosensitive layer (Denisyuk volume holography [9], 3D colour holography [10], optical data storage in micro-fibers [11]...). In these techniques the two interfering waves come from a coherent laser source and reach the holographic layer *from opposite directions*, then forming a reflection hologram. In three-dimensional imaging, one of the two waves is incident perpendicular to the layer (the reference beam), crosses the layer and is reflected back by the object under study (the object beam). To make a single-line reflection grating, the object is replaced by a plane mirror.

Accurate studies for “Modeling the Lippmann Colour Process” [12,13] were performed in order to improve the performances of high-resolution Lippmann type emulsion used in holography. Nowadays, the elaboration of a photosensitive layer of high-transparency and an increase in sensitivity are in progress [14,15].

▼ FIG. 7: The Luxembourg Palace in Paris (Lippmann plate 9x12 cm). This photography gives a faithful colour reproduction of the Luxembourg Palace with its gardens, one century ago.

Very simple and practical realisations are the modern holographic filters (notch filters) which are fabricated by recording throughout a photosensitive medium the interference pattern formed between two mutually coherent laser beams. Their use for eliminating the strong laser signal and the Rayleigh line has resulted in a simplification and improvement of performance of routine Raman instruments [16].

About the authors

Pierre Ranson, **Robert Ouillon** and **Jean-Paul Pinan-Lucarré**, have specialised in Raman scattering, and have made their main research studies on phonon relaxation in molecular crystals. They began their university career in the year 1960 in the LRPS at Sorbonne, the laboratory managed seventy years ago by Professor Lippmann. It was their Director of thesis, R. Dupeyrat, who has devoted time to the preservation of the set of Lippmann plates forming now the UPMC collection. Pierre Ranson, Robert Ouillon and Jean-Paul Pinan-Lucarré, now in retirement, carry on this task.

Acknowledgements

The images of Lippmann plates which illustrate this paper have been taken by Alain Jeanne-Michaud, engineer at the IMPMC laboratory (University Pierre et Marie Curie). He used a digital camera and a sky light illumination. In figure 6, the portrait, the Lippmann plate is shown with its protector frame recovered with a matt black paper. In the other figures, the frame has been suppressed in the images. ■

References

[1] G. Lippmann, *Comptes Rendus à l'Académie des Sciences* **112** (1891), 274

[2] P. Connes, *J.Optics* (Paris) **18** (1987), 147

[3] W. Alschuler, 2002, *31st Applied Imagery Pattern Recognition Workshop*, D.H.Schaefer Ed., 3

[4] J.M.Fournier, *J.Optics* (Paris) **22** (1991), 259

[5] J. M. Fournier, *Journal of Imaging Science and Technologie* **38** (1994), 507

[6] R. Ouillon, J.-P.Pinan-Lucarré, P.Ranson, *B.U.P.* **100:883** (2006), 459

[7] G. Lippmann, *J.de Phys.* 3° série, **3** (1894),97

[8] P. Hariharan, *Journal of Modern Optics*, **45:8** (1998) 1759

[9] Y. N. Denisyuk, *Fundamentals of Holography*, *State Optical*, *S.I. Vavilov Institute*, *Leningrad* (1978), 26

[10] H. I. Bjelkhagen, *Holography, Art and Design, 2002, London Conference* www.holography.co.uk/conference/bjelkhagen/CON2HIB1.pdf

[11] A. Labeyrie, J. P. Huignard, B. Loiseaux, *Opt.Letters* **23** (1998), 301

[12] H. Nareid, H. Pedersen, *J.Opt.Soc.Am.* **8** (1989), 257

[13] M. Jäger, H. Bjelkhagen, M. Turner, in *Practical Holography XVIII: Materials and Applications.T.H.Jeong and H.Bjelkhagen, eds., Proc.SPIE* 5290 (2004), 306

[14] Y. Gentet, P. Gentet, *Holography 2000, T.H.Geong and W.K.Sobotka, eds., Proc.SPIE* 4149 (2000), 56

[15] J. Belloni, *C.R. Physique* **3** (2002), 1

[16] J. Barbillat, B. Roussel, E.Da Silva, *J.Raman Spectrosc.* **30** (1999), 745