The origins of colour photography are typically traced to mid-nineteenth-century ‘three-colour’ processes based on a mixture of three primary colours. At the time, however, images produced by these means were pejoratively labelled ‘photographs in colours’ and not ‘colour photographs’ because they did not result solely from the direct action of light.

In 1891, the French physicist Gabriel Lippmann claimed to have developed a direct, ‘physical’ method of colour photography, which the French industrialists Auguste and Louis Lumière subsequently improved. This article charts the rise and fall of so-called ‘interferometric’ colour photography and evaluates Lippmann’s suppression of the chemical aspects of his work, in the context of his award of the 1908 Nobel Prize in Physics.

Keywords: Gabriel Lippmann; colour photography; nineteenth-century physical science; Auguste and Louis Lumière; Nobel Prize in Physics; wave optics

In 1908 the French experimental physicist Gabriel Lippmann (1845–1921) won the Nobel Prize in Physics ‘for his method, based on the phenomenon of interference, which permits the reproduction of colours by photography.’¹ Despite having been called ‘one of the greatest inventions of the nineteenth century’, his ‘interferometric’ method has been largely forgotten.² Historians tend to treat it as merely a dead end and usually trace the origins of colour photography to the 1860s, when the Frenchmen Charles Cros and (independently and more practically) Louis Ducos du Hauron proposed ‘indirect’ methods of colour reproduction based on combinations of three ‘primary’ colours.³

This historiography fails to account for regular denials by the nineteenth-century scientific and photographic press that indirect methods constituted potential solutions to the problem of reproducing natural colours.⁴ At about the time when Lippmann began his investigations, a

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basic ‘three-colour’ method consisted of taking three separate colourless negatives by successively transmitting incident light via three coloured screens complementary to the ones from which the positives were made.\textsuperscript{5} The latter were coloured with aniline dyes or coloured inks closely approximating the primary colours. When superposed, they produced a coloured image. In the press’s opinion, this method was based on false scientific principles and relied instead on the art of dyeing and on basic observations of colour blending. The choice of coloured screens and pigments was arbitrary and subjective. Nor could the screens filter the exact complements of these colours. Only a ‘direct’ method that exploited the ability of light to impress \textit{its own} colours directly upon matter could count as ‘colour photography’ or ‘photography in natural colours’ (\textit{photographie des couleurs}). Three-colour methods were consequently dubbed pejoratively ‘photography in colours’ (\textit{photographie en couleurs}). This distinction seems to have been employed universally by all parties interested in colour photography.\textsuperscript{6}

Lippmann claimed to have discovered the definitive, scientific solution to the (historical) problem of ‘colour photography’. His insistence on its comprehensible, physical nature has proven so successful that the few historians who have researched interferometric colour photography in any detail have ignored his (necessary) abandonment of the well-trodden paths of optical theory for the uncertain territory of chemical sensitization.\textsuperscript{7} The pioneering contributions of the (aptly named) Lumière brothers, Auguste (1862–1954) and Louis (1864–1954), to the development of a practical interferometric process have consequently remained largely unnoticed. This article describes the development by Lippmann and the Lumiéres of interferometric colour photography and the French reception of their work, and subsequently evaluates Lippmann’s bold claim in the context of his award of the Nobel Prize in Physics.

\textbf{Defined with precision}

Photographic pioneers had attempted to reproduce the colours of the spectrum because it was a simple, multi-colour, readily obtainable image (with a prism). Edmond Becquerel’s 1848 results were the most successful before Lippmann’s. On an extremely thin layer of an unidentified silver chloride compound he obtained an image of the solar spectrum. Like his predecessors, he attributed the appearance of colours to the specific properties of the sensitive layer and its means of preparation. These colours, however, proved impossible to ‘fix’, because any chemical process that prevented the further impression of light also destroyed the image.\textsuperscript{8}

By 1890, confidence in finding a direct means of reproducing natural colours remained low. Indirect processes were not even colour photography, and all attempts at finding some chemical preparation capable of fixation had failed. This was blamed on the almost total ignorance of the interaction of light with silver salts, critical to any photographic process. The American Carey Lea, an ‘acknowledged master’ of photochemistry, maintained in 1887 that the physical or chemical basis of the phenomenon remained unestablished.\textsuperscript{9} In a discussion of the chemical effects of light on matter, the premier English photochemist and a Fellow of the Royal Society, Captain William de Wiveleslie Abney, insisted pessimistically that the products of such action remained largely mysterious.\textsuperscript{10} Beyond the fact that that silver salts were known to absorb light and be coloured by it, nothing could be asserted reliably. He concluded that colour photography remained ‘a beautiful dream’, or more frankly, a ‘proven impossibility’.\textsuperscript{11}
After his appointment as Professor of Experimental Physics and Director of the Sorbonne research laboratory at the Paris Faculty of Science in 1886, Lippmann worked on an alternative approach. As an experimental physicist, he identified a scientific solution with one that duplicated the processes causing objects to appear coloured, rather than those through which the brain registers colour sensations. On 2 February 1891 he presented a note simply entitled ‘colour photography’ to the Académie des Sciences. He claimed to have resolved the same fixation problem that preoccupied the chemical tradition: how to obtain an image of the spectrum unalterable on prolonged exposure to light.

In contrast, however, Lippmann insisted that the wave theory of light entirely prescribed the requirements for reproducing natural colours and attributed his success to the comprehensibility of the physical theory: ‘instead of focusing on the so poorly understood chemical effects of light, I thought of using its physical properties, which are defined with precision.’\(^\text{12}\) He claimed merely to have altered two physical conditions of previous experiments: a reflecting surface placed in contact with the light-sensitive photographic emulsion, and the granularity of the silver salt. With monochromatic light, interference between the incident and the reflected light rays formed a system of fringes within the emulsion. He assumed that light had an effect only at the stationary maxima (positive or negative) where, after development, deposited silver formed a system of parallel laminae. The interval between them was equal to the interval separating two maxima: half the wavelength of the incident light (figure 1). Illuminating the developed plate with white light resulted in constructive interference only for precisely the wavelength of light corresponding to the incident one. Although each plane reflected only a small proportion of the incident light, the cumulative effect produced vibrant colour. Unless the size of the grains within the layer was small relative to half the wavelength, however, the laminae would simply collapse onto each other—hence the requirement for a continuous sensitive layer, or at least extremely fine grains. Lippmann’s theory predicted success whenever these two general conditions were fulfilled. There was therefore no need for the obscure physicochemical interactions of light to feature in an explanation of colour reproduction, nor to dwell on the means of preparing the working materials.\(^\text{13}\)

Figure 1. Diagram by Ch. Gravier indicating the formation of silver laminae ok and OK at the interference maxima of stationary waves. (Source: The Bodleian Libraries, University of Oxford, N. 1709 d.2, ‘Photography in colours’, *Amat. Photographer* (6 March), 163–164 (1891), at p. 164.)
Lippmann offered two observations to support this physical explanation of the origin of the spectral colours. First, they shifted towards the red end of the spectrum as the viewing angle became more oblique, like natural colours arising from interference phenomena. Second, moistening the plate caused the emulsion to swell. The colours disappeared because the distance between the silver layers increased to a value of half-wavelength beyond the infrared end of the visible spectrum. If the plates dried uniformly, the colours, beginning with red, reappeared sequentially at the violet end and appeared to move laterally across the spectrum before returning to their initial positions. He attributed the cause to the gradual reversal of the process. 14

In Lippmann’s opinion, the comprehensibility and generality of the physical theory guaranteed the status of his method as the definitive solution to the problem of reproducing natural colours. He claimed to have succeeded in reproducing the spectrum with three different standard transparent supporting materials, namely albumin, collodion and gelatin, and two different light-sensitive silver salts, formed on glass. In 1892 he announced further success with potassium bichromate. He regarded these particular results as even more persuasive because the reflecting laminae were produced in an entirely different way. The light impression rendered the organic material less hygrometric, resulting, when moistened, in the formation of a series of layers swelled with water. The periodic variation in reflective power reproduced the incident colours of the spectrum. 15 He henceforth routinely emphasized, ‘you get the colours by any chemical means which give you a fixed photograph, you are not obliged to take a silver salt.’ 16

This contrasted starkly with the specificity of chemical attempts at reproducing natural colours. Lippmann merely noted in passing that he had experimented with the same light-sensitive substances, developers, and fixatives, without admitting that he had actually modified standard photographic processes. Commercial gelatino-bromide and gelatino-chloride plates were unsuitable owing to their opacity and grain size. Optical theory offered no guidance on how to fulfil the requirement of fine grains; he admitted having ‘despaired for years of finding a proper method of making them.’ 17 He skirted over the essential chemical processes of plate manufacture because to him they merely supplied the means of fulfilling the necessary physical conditions. In other words, by presenting the purely physical aspects of his research as a general method of colour photography, he suppressed details essential to the creation of a practical interferometric process. 18

The main photographic apparatus consisted of a narrow three-sided U-shaped ebonite container E lined with rubber to form a good seal (figures 2 and 3). Two glass plates G and V were mounted on either side of the container, the one covered with the photographic emulsion (G) facing inwards. The chassis was kept together by metal clips P. Lippmann met the requirement of a near-perfect mirror that formed an almost completely adherent plane interface with the emulsion by filling the container with mercury, using a long, narrow funnel to prevent air bubbles from forming.

The rest of the apparatus is depicted in figure 4. Lippmann employed an electric light source L and a prism P to decompose white light into its constituent colours. The container was gripped by a clamp stand and inserted vertically into the open bottom of an ordinary photographic chamber C. Initially the container E was kept empty and its photographic plate replaced with a polished glass one, the matt side facing inwards, to allow it to be brought to the focus of the adjustable objective O. Once this had been done, the polished glass plate could be swapped for the sensitive one, and the container could be filled with mercury. The plate was then exposed and developed as usual.
Lippmann’s announcement of a solution to the apparently intractable fixation problem provoked widespread excitement. The French daily press and scientific periodicals such as the *Revue scientifique* swiftly proclaimed it ‘a true scientific event’.\(^{19}\) They regurgitated breathlessly the reasons he had given for the breakthrough. A contributor to the popular journal *Cosmos* declared that Lippmann had succeeded ‘almost without the use of a chemical compound’.\(^{20}\) This supposedly functioned merely in a passive role as a sort of simple reflector. The following year, 1892, Louis Alphonse Davanne, Vice-President of the French Photographic Society, declared that Lippmann had completely abandoned chemical processes in favour of experiments based on purely physical laws. In a burst of hyperbole, he drew an analogy with Le Verrier’s prediction of the position of a new planet based solely on calculation by proclaiming that the solution had been found by force of theory. No one questioned Lippmann’s failure to describe how he had succeeded in creating sufficiently fine-grained plates.\(^{21}\)

**Passive filtering**

Lippmann now began to work towards reproducing the ‘composite’ colours of real objects. These consisted of a superposition of light waves vibrating at multiple frequencies.\(^{22}\) The main obstacles to overcome were the insensitivity of the plates (indicated by a long
exposure time) and their lack of orthochromatism (equal colour sensitivity). The only means of increasing the sensitivity of silver salts to light was to ‘stain’ the light-sensitive layer with optical sensitizers, such as azaline and cyanine. This posed a real challenge because even ordinary orthochromatic photography was still in its infancy.
In fact, photographing the spectrum had presented the same problems. Photochemists typically divided it into three regions of distinct ‘chemical activity’. Lippmann associated blue and violet, green, and red with the maximum, intermediate and minimum activities, respectively. Depending on whether he employed albumin or collodion, he discovered that an appropriate duration of exposure for the red region was between 30 minutes and 2 hours, in comparison with a few minutes for the green and a few seconds for the blue and violet. He had initially overcome this lack of orthochromatism by selectively exposing the photographic emulsion to blue, green and red using a system of coloured screens to transmit each light ray for the requisite amount of time. The coloured screens were an unavoidable embarrassment for the interferometric method. They drew unwanted attention to physicochemical interactions through the variation in actinic values of light rays.

Lippmann dealt with this inconvenience simply by entirely neglecting to mention them. The only reference to them for which he was responsible was contained in a pamphlet written by his admiring assistant Alphonse Berget (1860–1934), who defended the use of the screens by idealizing them as passive light filters. He justified this conception by appealing to spectroscopic examination: the methyl orange solution employed, for example, ‘completely absorbs the green, blue and violet radiation and only transmits the red and yellow.’ The screens guaranteed the fidelity of the reproduced spectral colours because they transmitted the required wavelengths unaltered. This technique could only be a temporary stopgap, however: it was ineffective for compound colours and clearly impracticable.

So that he could maintain the generality of his physical theory credibly, Lippmann promoted an analogous conception of the optical sensitizers to the screens. On 20 July 1891 he described the research on ‘Absorption and colour photography’ of a professor named Labatut, of the École Préparatoire de Médecine et de Pharmacie in Grenoble, before the Académie des Sciences. Labatut had investigated the effects of light on sensitive layers treated with colouring materials with very precise absorption bands. He established that the recorded colour was concordant with the absorbed radiation by interposing a more strongly coloured but otherwise identical layer between the light source and the photographic plate, and by observing that the plate remained unexposed. In his opinion, whatever the physicochemical interactions that occurred between the optical ‘stained’ silver salts and light, the ultimate effect of adding sensitizers was therefore merely to change the relative rates of action of the various colours. In a rash conclusion, he then explained the implications of this observation for Lippmann’s research:

If you try to obtain an impression for a given colour, you just have to choose a sensitive plate coloured to absorb this colour, and you can do away with all coloured screens in front of the plate.

In other words, the coloured plates performed the inverse function of the screens. The latter excluded certain wavelength ranges, whereas the optical sensitizers determined which were included in the photographic impression:

If you illuminate a coloured photographic plate in contact with a mercury mirror with white light, there is interference; only the absorbed radiation acts upon the sensitive material, the others . . . have no effect.

Lippmann perceived that Labatut’s findings guaranteed the applicability of the original optical principles, and hence the fidelity of the photographic impressions. In his
mathematical theory of the reproduction of compound colours, published in 1894, he stated without justification that ‘the influence of absorption complicates the phenomenon and the formulae, but the conclusions remain qualitatively identical.’

Labatut’s simple conclusion was not widely shared by photochemists. They generally recognized that understanding of the physicochemical interactions of light with stained silver salts was as vague and inadequate as for unstained salts. It was likewise unclear whether the sensitizers acted physically or chemically. As a rule of thumb, a substance had to be capable of forming a silver compound to be an optical sensitizer. The German pioneer of orthochromatic photography, Hermann Vogel (1834–98), initially believed that silver salts became sensitive to the colour of the spectrum absorbed by the dyes. Abney maintained this opinion. He thought that light in the region of absorption of the sensitizer caused it to decompose, and the resultant decomposition products subsequently acted on the silver salt. Thus the silver salt became sensitive to light just in the region of absorption of the additive. Lea, however, had found that although optical sensitizers frequently imparted their own or a similar colour to the silver salt, the colour might nonetheless differ considerably from it.

Vogel and Abney’s views were probably compatible with Labatut’s, but Lea’s carried destructive consequences. If he were right, the absorption band of the colour sensitizer did not uniquely determine the response of the silver salt to incident wavelengths. There would therefore no longer be any guarantee that the sensitizers could replace the screens in the way that Labatut envisaged. It was consequently not quite so straightforward to guarantee the fidelity of the recorded compound colours. Equally seriously, photochemists were aware that each silver salt responded uniquely to light when treated with the same colour sensitizer (even though they disagreed about the physicochemical nature of these responses). As Lea put it, ‘the three silver salts [silver bromide, iodide and chloride] may be differently coloured by one and the same colouring matter.’ This meant that each one would require a unique combination of sensitizers to yield convincing images of real objects. Lippmann had used the free choice of light-sensitive substance as a powerful justification for emphasizing the generality of his physical method. The optical sensitizers rendered it incomplete in an important respect.

Fortunately for Lippmann, his physical conception remained largely unquestioned. Photochemists were used to manipulating colour sensitizers without worrying about how they acted, and the nature of the physicochemical interactions did not jeopardize the ‘direct’ status of interferometric colour photography. Moreover, they struggled to familiarize themselves with the wave theory of light, which Lippmann and Berget put across at every opportunity. Of the six chapters in Berget’s pamphlet, five were devoted to waves and interference. Photochemists were consequently unable and unwilling to dispute the pair’s claims that the same optical principles applied to composite colours.

Physicists simply subsumed optical sensitizers within the practical means of realizing the physical conditions specified by the method. For them, the possibility of reproducing composite colours naturally depended on extending the physical theory. Some members of the Académie des Sciences present at Lippmann’s initial announcement had expressed scepticism about this extension. Doubts were raised that a system of superposed independent reflecting surfaces could reproduce the original colour. Although he continued to insist on the applicability of the same physical principles, he did not publish a (Fourier-based) mathematical theory of the reproduction of composite colours until 1894. To demonstrate not only the fertility of interferometric photography to photochemists but also the validity of extending the physical theory, he therefore had to deliver images of composite colours.
A LUCKY ACCIDENT?

On 11 July 1891, Berget announced that by immersing ‘fine-grained’ photographic plates in cyanine, Lippmann had now rendered them equally sensitive to red and blue and could now photograph the spectrum with a single 6-minute exposure. By January 1892, Lippmann claimed to have reduced this time to less than 30 seconds. Unfortunately his plates were still insufficiently orthochromatic for photographing composite objects, which required a much longer exposure time. He had also exceeded his goals: they were now more sensitive to red than to any other colour.34

The previous year, Lippmann had admitted this limited progress to the Lumière brothers, who he heard had unsuccessfully attempted to replicate his results. They shared an expertise and industrial base that he lacked. In 1886 the brothers had founded the first French factory for the fabrication of photographic materials in Lyon-Montplaisir, where they mass-produced Louis’s patented industry-standard dry gelatine-bromide plates.35 Unfortunately, these were unsuitable for interferometric photography as a result of their opacity and grain size. On 2 August 1891 Lippmann wrote a letter to the brothers claiming favourable preliminary results with gelatine and encouraging them to persevere.36

By the beginning of February 1892, the month after Lippmann had announced his ‘half-minute’ spectrum, according to one of the Lumière’s correspondents, they had succeeded in reproducing one ‘so much more successful and more exemplary than Monsieur Lippmann’s’.37 The editor of Le Moniteur de la Photographie, Léon Vidal (1833–1906), declared that ‘you wouldn’t know how to achieve a more complete rendition.’38 Unfortunately, however, they also considered photographing composite colours to be impossible, reporting that the (composite) light rays transmitted through an objective during exposure always contained sufficient traces of white to blacken the entire thickness of the plate. This caused Vidal and a contributor to L’Amateur Photographe to write off interferometric photography as practically infeasible.39

Lippmann was now under serious pressure to produce results. In unfamiliar territory and without physical theory to act as a guide, he floundered. Success with gelatine-based plates was essential to commercializing interferometric colour photography. Yet producing decent ones for even normal photography was a notoriously difficult task.40 Despite requesting a supply of gelatine-bromide plates from the Lumière brothers to sensitize himself using silver baths,41 he failed to improve the quality of his own gelatine-based images and retreated to photographic processes that he had already mastered.

Lippmann had obtained his most successful spectra with transparent collodion-based and albumin-based plates.42 His first photographs of natural objects, presented to the Académie des Sciences on 25 April 1892, were produced with albumin-bromide.43 The images comprised a four-coloured stained-glass window (red, green, blue and yellow), a group of flags, a plate of oranges with a red poppy on top, and a multicoloured stuffed parrot. The flags and the bird required an exposure time of between 5 and 10 minutes to either sunlight or electric light; the others required several hours of exposure to diffuse light. He also claimed to have successfully reproduced the green tones of foliage and the greys of masonry. Blue sky, however, appeared indigo, and he conceded that that further improvements were required.44

Through a ‘fortunate coincidence’, the timing coincided with a combined meeting in Paris of French photographic societies and the opening of the associated photographic exhibition at the Champ de Mars. On 18 May 1892 Berget projected some of these new images in
natural colours and a Lumière-brothers spectrum before the meeting. Although almost the entire French community of photographers was present, the images drew remarkably little comment. Only the Lumières’ colours were praised for their fidelity.

At the exhibition, six photographs were on display—the stained-glass window, a holly branch, the stuffed parrot, and three spectral images. Vidal’s muted enthusiasm condemned the photographs with faint praise. He even suggested that further improvements in orthochromatism were required when, in his own words, imperfect orthochromatism was known to cause ‘a complete modification in the resultant colour’. The images gained little press coverage abroad, and foreign photographic societies barely discussed them. Grumbling that the original subjects were not shown for comparison, a British observer, Cameron Swan, offered a damning verdict. The stained-glass window (‘four pieces of coloured glass’) and the holly leaves and berries were the wrong colours, and the parrot had a ‘fuzzy appearance’. White photographed as black, and ‘where there should be black it is absent altogether.’ He concluded that ‘the problem of direct photography in natural colours is not solved.’ The American three-colour pioneer Frederick Ives (1856–1937) offered a similarly dismissive assessment.

The images may, however, have convinced the Lumières to reconsider their earlier pessimism. Lippmann had recognized that commercial success also depended on producing gelatine plates by industrial ready-mixing processes rather than with silver baths. Unfortunately, he admitted to the Lumières that he had ‘only managed to produce residual traces of colour in that manner’. The industrialists, while expressing respect for his achievements, wanted to avoid ‘the uncertainty and irregularity’ entailed by the baths, and they set about creating a viable process based on the industrial manufacture of gelatine-bromide plates. Progress towards establishing the necessary ingredients and their quantity was slow and largely by trial and error:

We’ve been forced, in the very large number of experiments we’ve carried out, to proceed methodically, only changing a single constituent element at once… hence the requisite number of trials and the considerable amount of time we’ve had to devote to them.

This was just to produce ‘absolute transparence’. To render the plates orthochromatic, a similarly laborious trial-and-error process took place.

They eventually settled on a gelatine-bromide plate recipe based on a mixture of two gelatinous solutions, one containing a soluble bromide salt (for example potassium bromide), the other silver nitrate, along with the optical sensitizers cyanine and erythrosin. The mercury mirror had been considered a practical impediment to commercialization, so the brothers adapted Lippmann’s design for the chassis (figure 5) to allow mercury to be pumped manually into the space V behind the plate (held in place by the rubber fixings B and H). A tap T allowed the mercury to flow to and from the reservoir pump P.

A year elapsed before the Lumières were producing composite images superior to Lippmann’s. On 17 April 1893 Lippmann presented several of their photographs on the new plates to the Académie des Sciences. These included a solar spectrum of large dimensions, an image of Newton’s rings, a picture of a landscape on Japanese crepe paper, and an artificial bouquet of flowers. A record of the meeting drew attention to the representation of whites, ‘faithfully rendered with their diverse nuances and their intensity’. Because white light was constituted by the reflection of every colour, this was regarded as proof of the images’ fidelity. Soon afterwards, at the Paris Photo-Club on
11 May 1893, Berget exhibited more of the brothers’ photographs, including the corner of a
park with sandy paths ‘perfectly distinguishable’ from the grass, a cottage illuminated by
sunlight, undergrowth ‘delightfully’ broken up by clearings, a reproduction of a
chromolithograph of a French admiral, and a bouquet described as possessing ‘true, real
colours, with their infinite subtlety of tones so numerous and varied. 57

The French response did not exaggerate the achievement. Lippmann’s detractor, Ives, was
forced to admit that ‘now... some really pleasing colour photographs have actually been
produced.’ 58 At the (later Royal) Photographic Society of Great Britain in London,
members agreed:

The pictures... show colours of unsurpassed beauty—beyond anything we are
accustomed to see in the way of the reproduction of colours—somewhat metallic in
appearance, but very bright and of very decided and definite colour... like real nature
on a bright summer’s day. Seeing these first photographs in natural colours we feel we
are in the presence of one of the greatest inventions of the nineteenth century. 59

Even the sceptical Abney considered the results very remarkable, and congratulated the
Lumières on reducing the exposure time to just 4 minutes. Further decreases followed
swiftly, which enabled them to photograph portraits. The brothers’ successes led a
contributor to Cosmos to declare on 23 September 1893 that only a single obstacle
remained—the short duration for which the photographic emulsion conserved its properties, which prevented the commercial preparation of the plates.\textsuperscript{60} The scientific press was unaware, however, of the extraordinary difficulty in reproducing the conditions for their successful fabrication. By 1895 the caution expressed by the Lumière in this regard before the Société d'Encouragement pour l'Industrie Nationale had turned into an admission of defeat:

\begin{quote}
Working with the most precise measuring instruments and weights of substances as equal as balances are capable of registering, separating successive operations by the same time intervals, [and] placing ourselves in as identical as possible conditions of temperature, hygrometricity, and environment, we can’t consistently produce the same results.\textsuperscript{61}
\end{quote}

The smallest change in any of these factors drastically influenced the orthochromatism of the plates, which had to be particularly precise to result in good photographs. The delicacy of the laminae meant that even minimal deviations from ideal processes of development and fixation could alter their spacing, the quantity of reduced silver, or its reflective power. According to Vogel, the conditions required to produce even a decent spectrum by the interferometric method were so particular that ‘any success has to be considered a lucky accident’.\textsuperscript{62} As long as the difficulties in plate manufacture (and conservation) persisted, commercialization remained impossible. Despite these problems, the brothers did not rule out a future for interferometric colour photography because of the potential quality of the results.

But as three-colour images improved, the special status of direct processes diminished, along with interest in interferometric ones. French photochemists began to realize that ‘colour photography’ was possible if the mind could be tricked into believing it was seeing ‘natural’ colours, and correspondingly based their assessments on image quality and practicality.\textsuperscript{63} Lippmann and other photographic researchers published new plate recipes throughout the 1890s and early 1900s, mostly variations on the cited Lumière recipe, and elaborated the conditions of their manufacture with varying degrees of specificity. Unfortunately the robustness of the emulsions never improved sufficiently. French review articles on colour photography published from 1895 onwards reveal a growing sense of pessimism about potential progress and treat interferometric processes in less and less depth.\textsuperscript{64} By 1907, when the Lumière brothers began to produce three-colour autochrome plates commercially, French photochemists had completely written off interferometric colour photography. Their eyes were not spectroscopes.

\textbf{UNQUESTIONABLY THE AUTHOR}

Lippmann’s invention of ‘colour photography’ turned him from one of France’s foremost scientists into a celebrity and a physicist of international standing. Throughout the 1890s and onwards he received numerous honours, including diplomas and medals from photographic societies and juries of international exhibitions, and was elected as an honorary, corresponding, or foreign member of academies of science and photographic societies all over the world, including the Royal Society in 1896.\textsuperscript{65}

From 1903 he began to be nominated frequently for the Nobel Prize in Physics by his French colleagues. These included Henri Becquerel, joint winner of the prize that year, and the two permanent secretaries of the Académie des Sciences, Marcellin Berthelot and
Gaston Darboux. They rushed to emphasize the scientific basis of interferometric colour photography: Lippmann had used optical theory to ensure its theoretical soundness and to specify the practical conditions of its realization in advance.

The Nobel Committee for Physics evaluated Lippmann’s achievement in terms of its significance for physical science. The best that his nominators had offered in this respect was that it ‘allowed the recording at a given moment of all the properties of a ray of light.’ In 1903–04 the committee regarded his ‘fixation’ of natural colours merely as an elegant demonstration of the wave theory of light. It did not consider this prizeworthy because his research had ‘failed to bring about any epoch-making progress in the physical sciences comparable with that resulting from other recent discoveries.’ In 1905 the situation remained much the same: the committee insisted that Lippmann’s work ‘cannot be placed in the first rank among inventions worthy of the Nobel prize.’ As the French nominations rolled in, however, the committee began to warm to him. In 1906 it recognized his status as ‘a leader in physics by his series of particularly meritorious contributions in different fields’ and offered a more favourable assessment of his candidacy.

In the following year, 1907, the situation changed even more dramatically. By now the French were lagging behind in terms of prize awards for physics—just one compared with three for Germany and two for Britain. So far, the committee had overwhelmingly favoured experimental research. Instead of proposing Lippmann alongside Henri Poincaré, as they had done previously, all the French nominators now rallied round Lippmann. They surely felt that their turn was coming and did not wish for their best chance of success to be overlooked. Darboux led the charge on behalf of the Académie des Sciences. His letter of nomination was signed by 14 other members and this time proposed Lippmann for the entirety of his contributions to physical science. The academicians were basically insisting that as an experimental physicist of international standing, Lippmann deserved an award.

The number and persistence of nominations began to bear fruit. The French push was sufficient to make Lippmann a finalist, even though the committee’s perception towards his ‘best work’ remained largely unchanged. Unfortunately for Lippmann and the Académie des Sciences, it ultimately preferred Albert Michelson for his optical precision instruments and spectroscopic and metrological investigations. The committee’s justification echoed its assessment of Lippmann’s work in 1903:

Lippmann has been nominated for the Nobel prize regularly every year and especially this year by a very large number of proposers, but his work, although meritorious, still has not had the importance for physical research that Michelson’s has.

In retrospect, he stood little chance of winning in 1907, because of the committee’s natural bias towards Michelson’s specific research areas.

When the French tried the same tactic in the following year, however, the situation was more favourable. Lippmann now occupied a prime position among the prizeworthy candidates. According to the committee’s general report, ‘already last year the committee made clear that Lippmann’s work was among those in first place for the consideration of the award of the physics prize.’ This time the other leading proposal was for a joint award between Wilhelm Wien and Max Planck, which eventually became a recommendation solely for Planck. The decision tied the committee in knots. It was uncomfortable about rewarding research that it considered insufficiently derived from
The minutes of the committee meeting on 18 September 1908 suggest a preference for Lippmann, but it was decided, ‘with grave doubt’, to recommend Planck. Lippmann fell at the last hurdle for the same reason as in the previous year: the alternative candidate’s work was more significant for physical science.

The 1908 prize decision is notorious among historians of science because the Swedish Academy of Science overturned the committee’s recommendation of Planck in Lippmann’s favour. In his special report on Lippmann’s candidacy, the chairman of the committee, the experimental physicist Knut Ångström (1857–1910), interpreted Lippmann’s discovery of a means of ‘fixing’ natural colours as colour photography for the first time. He now took it seriously as the basis for an award:

Since no-one can deny that this discovery like the entire art of photography concerns one of the most important advances in human culture, it seems to us that its honouring with a Nobel prize would agree to an unusually high degree with the founder’s intentions.

Ångström noted that the German firm Zeiss had recently begun to produce ‘not only all equipment necessary to produce Lippmann’s photographs but also the optical apparatus needed for ocular inspection or projection of the images.’ He probably intended the practical value of the discovery and concordance with Nobel’s intentions to compensate for the greater relevance to physical science of Planck’s research; he was only able to beef up Lippmann’s candidacy in this respect by benignly commenting that the French physicist’s work was responsible for ‘a large literature important scientifically as well as practically’.

Ångström’s assessment surely played a role in making Lippmann seem an attractive alternative candidate to the Swedish Academy of Sciences. In the final verdict, Ångström stuck with the basis of the committee’s assessment of Lippmann’s work from 1903: its importance to physical science. The Swedish Academy of Sciences, however, was not bound by this criterion and may thus have been more predisposed towards honouring an ‘advance in human culture’.

In doing so, however, it actually transformed the basis for the award. By 1907 Lippmann was considered a worthy candidate for ‘showing in a particularly elegant way the formation of stationary wave by reflection of light, thus confirming anew the theory of the interference of light.’ In 1908 he was awarded the Nobel Prize in Physics ‘for his method of reproducing colours photographically based on the phenomenon of interference.’ The real surprise is not that Lippmann received the award at Planck’s expense, but that he did so for colour photography.

Although autochromes dominated the photographic press, Lippmann’s nominators persisted in their belief that only a theoretically sound method would enable the faithful reproduction of natural colours and hence constitute true colour photography. In seeking to persuade the committee of the merits of his work, they indicated the deficiencies of three-colour processes and continued to rally round the scientific basis of interferometric colour photography. His fellow professors at the Sorbonne, Edmond Bouty and Henri Pellat, insisted on the superior image quality and doubted that the autochromes would ever achieve more than merely an approximate reproduction of natural tones.

In his special report, Ångström had followed suit by emphasizing the theoretical basis and image quality of interferometric photographs at the expense of autochromes. These were precisely the qualities that earlier had impressed physicists and other scientifically minded commentators who were unfamiliar with the overwhelming difficulties in preparing suitably sensitive and orthochromatic emulsions and the complexities of the physicochemical
interactions of light with ‘stained’ silver salts. He reasserted Lippmann’s authorship of the general method: ‘the initiator of [the interferometric] method is unquestionably Lippmann.’ The Swedish Academy of Sciences agreed. In his presentation speech, its president, K. B. Hasselberg, gave full credit to Lippmann and only associated the Lumière brothers with autochromes. The award of the 1908 Nobel Prize thus reaffirmed the physical characterization propounded by Lippmann and his French admirers.

CONCLUSION

Lippmann was not the sole developer of interferometric colour photography (as opposed to having ‘fixed’ the spectral colours). His successful but flawed emphasis on its comprehensibility in purely physical terms was responsible for the perceived primacy of his contributions. The Lumière’s superior attempts to develop a commercial process of manufacturing fine-grained, sensitive and orthochromatic plates suitable for his method were overshadowed first by his physical theory and subsequently by their own autochrome process. Lippmann ultimately had to endure a more unfortunate irony, however. The Nobel Committee had agreed that reproducing colours by interference was worthy of an award because this provided a renewed proof of the wave theory of light. Lippmann’s Nobel Prize consequently honoured a physical and photographic achievement soon swept aside—first by quantum mechanics (of which Planck was a leading architect) and second by the Lumière’s autochromes.

More broadly, the rise and decline of interferometric colour photography should focus historians’ attention on changes in how processes of ‘colour photography’ were evaluated during the late nineteenth and early twentieth centuries, the resultant disappearance of the labels ‘direct’ and ‘indirect’ from the photographic lexicon, and how physiology began to provide the scientific basis for three-colour methods. A direct method seemed desirable only as long as colour remained an objective property of nature. The revelation by the autochromes that visual perception could be ‘fooled’ convincingly undermined this belief (except perhaps among physicists) and hence influenced ideas about the nature of colour. This is how the history of colour photography is a history of colour itself.

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NOTES


5 The complementary colour was the colour that produced white when combined with the first.


14 See Lippmann, op. cit. (note 12), pp. 44–45.


24 Lippmann may have felt that the screens jeopardized the ‘direct’ nature of the interferometric photography, but there is no evidence to suggest that this was ever questioned.


31 See Berget, *op. cit.* (note 22), pp. 48–49.


37 A. and L. Lumière, *op. cit.* (note 36), p. 10. They donated one of their spectra to the Conservatoire Nationale des Arts et Métiers. It can be found in the reserves of the Musée des Arts et Métiers, Paris, inv. 12210. See *ibid.*, p. 6.


Some historians have incorrectly supposed that these plates were fabricated by the Lumières. See A. and L. Lumière, *op. cit.* (note 36), p. 5, and Nareid, *op. cit.* (note 7), p. 141. In his Nobel lecture, however, Lippmann magnanimously explained that he had ‘got good results from protein plates. Later, Valenta in Vienna and the Lumières at Lyons found means of coating the plates in grainless gelatine, sufficiently isochromatic and very much better than the protein plate.’ Gabriël Lippmann, ‘Colour photography: Nobel lecture, December 14, 1908’, in *Nobel lectures*, *op. cit.* (note 1), p. 187.


See Swan, *op. cit.* (note 47).


See Warnerke, *op. cit.* (note 2), p. 54. An image of a ‘Lippmann’ colour photograph of Lippmann’s niece Claire is reproduced as figure 6 in the electronic supplementary material. For additional images, see Daniel Jon Mitchell, *op. cit.* (note 7).

See Crépaux, *op. cit.* (note 55).


See in particular the cursory dismissal in C. Gravier, [untitled], *Bull. Soc. Fr. Photogr.* 20, 580–581 (1904).


General report 1905, p. 82.

General report 1906, p. 33.

Becquerel’s letter of nomination for 1905 explicitly recognized the need for the committee to rotate the nationality of award-winners. Letters 1905, p. 75.


General report 1907, p. 54.


General report 1908, p. 73.


Special committee report on Gabriel Lippmann [hereafter ‘Special report’] 1908, p. 93, Nobel Committee for Physics, Nobel Archives.

Special report 1908, p. 93.

Special report 1908, p. 92.

Special report 1908, p. 93. Robert Marc Freidman has emphasized the influence of the mathematician Gösta Mittag-Leffler over the decision. Mittag-Leffler spread the word among the Swedish Academicians that Planck’s work involved ‘hypothetical molecules of energy’. They subsequently voted overwhelmingly in favour of Lippmann by 46 votes to Planck’s 14. See Friedman, *op. cit.* (note 73), pp. 49 and 302–303.

General report 1907, p. 55.


Special report 1908, p. 93.