



# Maxwell's Electromagnetism and the French Savants. What's travelling?

Michel Atten

## ► To cite this version:

Michel Atten. Maxwell's Electromagnetism and the French Savants. What's travelling?. La Lettre de la Maison Française d'Oxford, 1997, 7, pp.110-122. hal-02560353

**HAL Id: hal-02560353**

**<https://hal.science/hal-02560353>**

Submitted on 1 May 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## *Maxwell's Electromagnetism and the French Savants. What's travelling ?*

---

"Knowledge transfer" is often, particularly in the theoretical field, seen as being akin to dissemination or diffusion. A theory or concept which is local in origin is conceived of as propagating into other locations with greater or lesser difficulty. To explain in epistemological terms resistance to the broadcasting of knowledge, obstacles - in the form of scholarly tradition, of the dominance of alternative theories, and of entrenched thought patterns - are said to come into play. One of the major criticisms to be levelled against this approach is that it assumes that the initial "theory" or concept is clearly and firmly established, and can therefore be propagated in abstract form because it is on destination perceived as identical to the concept on departure. But this is, in general, not the case. Taking Maxwell's theory of electromagnetism as a case in point, we will give an account of how the theory was transferred into France, and show that this was rather a process of development, and the result of two-way interaction. In fact, the theory was carried into France embodied in a book, but was also conveyed into the mind of the French reading public by a number of interpretations or translations.

### **1 - Maxwell, a little-known scientist in 1870**

It is generally considered that by the beginning of the 1870s, Maxwell had completed his major theoretical advances, both regarding the statistical theory of gases, and electromagnetism. His work in the latter field is contained in four seminal articles published between 1855 and 1868 [see Maxwell in bibliography]. However, the fact that he was dismissed from his teaching post in Aberdeen and replaced by a local teacher<sup>1</sup>, indicates that he was relatively little known in Great Britain, and that his reputation was confined to a small number of scientists. They, however, supported his appointment to the head of the Cavendish Laboratory, after W. Thomson and H. von Helmholtz turned down the opportunity.

It comes therefore as no real surprise that, in France at this time, we find only three references to his name. The first is by an experimental physicist, E. Verdet, a teacher at the *Ecole Polytechnique* and at the *Sorbonne*. Verdet systematically and in depth studied the phenomenon evidenced by Faraday

---

<sup>1</sup>[Tolstoy, 1981], 94 - 95.

of the rotation of polarised light under the effects of magnetism. Once he believed he had established the laws - which were subsequently in France known as Verdet's Laws - applicable to the phenomenon, he sought to bring his measurements into consistency with a theory that encompassed them<sup>2</sup>. This was the cause of his interest in the 1861-62 article [Maxwell 1961 - 62].

The second reference was by two telegraph engineers, E. Gounelle, and E. E. Blavier. Both were graduates from the *Ecole Polytechnique*, and had directed the initial work on electric telegraphy in France, in the 1840s. They had set up teaching within the telegraph department of the French civil service, and were retraining optical telegraphists in the new technique. They also had responsibility for improving the equipment in use, and were the leading lights in the study of electricity and telegraph technology, being the producers of a journal known as *Annales Télégraphiques*. A major feature of this journal was the attention it devoted to theoretical and practical innovations. Blavier and Gounelle popularised the works of the British Association for the Advancement of Science on electrical units, and gave an account of the experimental work of Maxwell and Fleeming-Jenkin in the determination of electrical standards.<sup>3</sup>

The third and last reference is more expected. J. Bertrand, professor of mathematical physics at the *Collège de France*, gave an account of recent theoretical work [Bertrand, 1869]. His article reviewed nine books and articles which had appeared between 1867 and 1869. Three were German (by Mayer, Clausius, and Helmholtz), two were from Great Britain (W. Thomson, and Tait), and four from France (Verdet, Combes, Briot, and Reech). He denounced the lack of rigour in this modern physics, which he saw as similar to Descartes' and opposed to Newton's, which he took as his model. Carried away at the end of his article, Bertrand went on to deal with other works. Although reputed masters in their field, their authors are said to provide examples of reasoning unacceptable to "*any mind habituated to the proof offered by rational mechanics*". Bertrand indignantly proclaims that we are brought into regions at many removes from science, by "*such logical deficiencies, such laisser aller*" in the way ideas are strung together<sup>4</sup>. There follows a list of culprits, including Maxwell, Helmholtz, Verdet, Kirchhoff, Clausius, and W. Thomson. The Maxwell in question is the investigator of electromagnetism<sup>5</sup> and the target of criticism as a protagonist of the "*Renaissance of Cartesian* [or purely speculative] *physics*".

---

<sup>2</sup>[Verdet, 1854 - 63].

<sup>3</sup>[Blavier, 1865].

<sup>4</sup>[Bertrand, 1870], here pp. 452-454.

<sup>5</sup>[Maxwell, 1964-65].

## **2 - An organisation of French physics which explains the relative lack of interest in more advanced work on electricity**

The fact that only three references were made to Maxwell, and that his reputation was relatively small, might well be the result of a "normalised" scientific method, dominated by a specifically French approach to these questions. Indeed, on the publication of Maxwell's electromagnetic theory of light in 1868, there were quite different reactions in other countries (Helmholtz in Germany, or Lorentz in the Netherlands...).

The absence of theoretical interest from French scientists has given rise to intense discussion among historians, which in simplified form can be summarised as the debate over the "decline of French science." According to the proponents of this thesis, after great brilliance in the first half of the century, from men such as Laplace, Ampère, or Fresnel, the years 1850 to 1880 saw few French scientists present in the fast-evolving major fields of theoretical physics (electrodynamics, electromagnetism, thermodynamics, statistical mechanics...).

Although this thesis is not without foundation, there are a number of implicit and possibly unacknowledged assumptions as to the analytical approach prevalent in France, which is seen to be pre-eminently theoretical and dominated by an anachronistic concept of the relationship between theory and experiment. However, if the way in which French scientists apprehended Maxwell's theories is to be properly accounted for, an explication of French value systems and practice in the field of physics is required.

In the main institutions of France in the 1850s and 1860s (*Ecole Polytechnique*, *Sorbonne*, and *Collège de France*), a model of scientific thinking can be seen at work which assigns a very precise status to experiment and to the elaboration of theories. Since the end of the eighteenth century, exactness and precision had become the dominant values in experimental practice, both in France and elsewhere<sup>6</sup>. All the world agreed on the need to base one's knowledge of nature on experiments carried out by means of artificial and increasingly complex devices. It was also widely accepted that the application of mathematics to a Baconian approach to science continued to give pride of place to mathematical logic in the hierarchy of scientific thinking. Yet French scientists went a step further.

Their model of experimental science was constructed by the professors of physics at the *Ecole Polytechnique*, the torch-bearer of the French scientific approach. According to these practitioners, the role of the physicist was to extract regularity or laws from the chaos of nature. Their field of action was

---

<sup>6</sup>[Licoppe, 1996].

therefore systematic observation, the carrying out of artificial experiments which would identify the parameters necessary to achieve the control over natural phenomena requisite to the construction of stable relationships between particular magnitudes. These scientists had responsibility - by multiplying their observations and varying their measurements - for the construction of the laws of nature. Such a task, self-evidently, in their minds, required an approach devoid of aprioristic thinking, and the elimination of any hypotheses. At this point only, there began the work of the geometers and mathematicians, who, with their mastery of mathematical techniques, were able to co-ordinate the new "*lois*" or laws to other theories, and complete "the mechanical and mathematical synthesis" required of them. In a given field such as physics, "experimentation permits the establishment of physical laws [...] and when they are known, all that remains is to ask mathematicians to rationally develop their consequences." Once a field of knowledge has reached the stage of "mathematisation", it becomes a science. For example, mechanics became rational mechanics and celestial mechanics. This concept, which is clearly explicated by J. Jamin, professor at Ecole Polytechnique and at the Sorbonne, in his introduction to *Cours de l'Ecole Polytechnique*, is also the one which, with only minor differences, is elaborated by France's major experimental physicists like Verdet, Regnault, Desains, and Cornu<sup>7</sup>. This theory became the more dominant during the 1860s as it was supported by the geometers who were the incumbents of the chairs of mathematical physics<sup>8</sup>. A typology of this historically characterisable school of inductive thinking can be briefly sketched. Its main features were:

- a theory of physics is a mathematical discourse which belongs to the field of geometry, but which has its basis in experimental results considered to be definitively established.
- mathematics lay down laws: a field of knowledge becomes a science if it can be subsumed by mathematics (systematic hierarchisation of science),
- scientific advance is a cumulative process, akin to territorial conquest (rational and celestial mechanics in the past, extending in the future to optics and acoustics),
- the process of development is temporally linear: first laws are established, followed, sometimes with a time lag, by mathematical constructs,
- the division of labour between experimental physicists and mathematical physicists, which in sociological terms was to become increasingly apparent, crystallised into teaching and research practice, the allocation of

---

<sup>7</sup>[Jamin, 1859].

<sup>8</sup>[Atten, 1992].

professorial responsibilities, scientific reviews, teaching manuals, and learned societies...

This model is consistent with the approaches to Maxwell by Verdet and Bertrand that we have alluded to above. Verdet is seeking a theory which may possibly corroborate his results, but only after experimentation has taken place. It is because there is no sure empirical base, and because of a failure to adopt the French practice in mathematical physics, that Bertrand condemns the recent theoretical work of Kirchoff, Clausius, Helmholtz, W. Thomson, and, naturally, Maxwell. The same approach was to be adopted when Maxwell's own treatise was published. However, before turning to this, the treatise itself should be presented.

### **3 - A book of another kind: *Treatise of Electricity and Magnetism* (1873)**

Maxwell had devoted several years of retirement on his family estate to the writing of a book which systematically presented his previous theoretical constructs. However, the book goes considerably beyond this, in that the *Treatise* is quite clearly the fruit of Maxwell's own position within the British scientific community. It is the result of a conceptualisation, and of the constitution of a domain of enquiry into physics and electricity, within that community. His *Treatise* propounds Maxwell's own conception of theoretical, experimental, and engineering practice, presented as different from those of the major treatises he cites, those of A. de la Rive, Wiedemann, Riess, or Beer.

His approach, presented below in simplified form, was as follows:

- this is a "summmum," in that it deals with all known electrical and mechanical phenomena, with some of their "utilities," and with all of the theories dealing with electricity and magnetism, including the most recent work,
- he combines presentation of experimental work, descriptions of the construction of scientific instruments and highly advanced mathematics in a typically British form (quaternions),
- he opted for a systematic presentation of his radical re-elaboration of the concepts of electricity and magnetism and of their relationship with other fields (dynamics, optics, heat, chemical action, constitution of bodies),
- behind the declarations of humility (a mere translator of Faraday, under the tutelage of W. Thomson and Tait), he actually proposes another means of conceiving and handling electricity, which he presents with his own special rhetoric, in opposition to the "German mathematicians."

This is therefore a strategic undertaking on Maxwell's part, whose aim is to show the heuristic interest of his method. "There is another way of treating

the subject, which is not fitted to explain the phenomena, and which, though in some parts it may appear less definite, corresponds, as I think, more faithfully with our actual knowledge, both in what it affirms and in what it leaves undecided."<sup>9</sup>

A brief comparison with the French treatises of mathematical physics (Briot, Résal, Bertrand...), which are purely mathematical texts supported by a number of experimental "axioms," or with the treatises of physics (Jamin and Cornu), which exclude all theorisation which cannot be directly deduced from experimental work, is sufficient to demonstrate how strange the lateral or multidisciplinary approach adopted by Maxwell must have appeared to the French mind.

#### 4 - The immediate reactions to the publication were contradictory

The reactions of the French academics to the theory were therefore much as might have been expected. Bertrand was extremely critical of the book, as it did not in any way correspond to his own canons for appropriate scientific practice. Devoting great attention to the foundations of the approach, his commentary was restricted to the electrostatics (a quarter of the Treatise only), which he unrelievedly condemns, for its lack of rigour.

The experimental physicists passed the book over in silence, as it was not, in their minds, a treaty of physics. There was one exception: A. Potier, a physics *répétiteur*, who welcomed one of the chapters of the Treatise, as containing the electromagnetic theory of light, which he presented in a form bearing the marks of inductivist thinking, as being "the equality of two fundamental constants."<sup>10</sup>

The appraisal of Potier, who was also a professor at *Ecole des Mines*, and much involved in the geological map of France, was overlaid by the criticism of Bertrand, who was the then acknowledged master of French mathematical physics, perpetual secretary of the Académie des Sciences, a man of power, to whose salon - a place where careers were made or broken - thronged the influential. Maxwell's treatise disappeared from the French academic stage for a dozen or more years.

However, the world of French physics did not always divide neatly into experimental physicists and abstract mathematicians. There were exceptions, the most notable being the telegraphic engineers. Trained under the *Ecole Polytechnique* prior to Jamin, devoted to issues of practice, and much attached to the British contribution to science - and to a telegraphy system second to none - these engineers adopted a different approach and took the combination of theory and practise as the guiding line of their

---

<sup>9</sup>[Maxwell, 1873] p. xii.

<sup>10</sup>[Potier, 1873].



conduct. Blavier, who survived professional problems in the last years of the second empire, returned to his vulgarisation of the unit system of the British Association in a series of articles. The British literature - treatises by Gordon, Everett and Maxwell in book form - was their tool. Maxwell's Treatise was introduced into the *Ecole Supérieure de Télégraphie*, a small teaching establishment set up in 1878, and formed the basis of teaching by J. Raynaud, followed by A. Vaschy in the electrical measurements field. It was finally translated into French in the 1880s by one of the school's first pupils, Seligmann-Lui.

In 1881, Blavier published all of his articles in the form of a much noticed book. This was also the year of the International Electricity Exhibition in Paris, which coincided with an international congress on electrical units. While the initiative for the exhibition was taken by a number of engineers working in private companies, the newly appointed Minister of Postal Services and Telegraphy grasped the opportunity to reaffirm France's position in one of its traditional fields: systems of units. The Minister therefore relied on the *Ecole Supérieure de Télégraphie*. There then occurred a fruitful meeting between its engineers and E. Mascart, professor at the *Collège de France*, who rose to the requirements of the new situation. Mascart organised the French work on the determination of international standards in the first half of the 1880s. The impact of this event was substantial in France - there was a flowering of technical journals devoted to electricity applications, and the International Society of Electricians was founded. Mascart's own teaching at the Collège de France was published as a collaborative venture with J. Joubert, and presented the major results recently obtained by W. Thomson and Maxwell.<sup>11</sup>

The two professors were innovative, in that they devoted a volume to electrical theories, although these were presented in juxtaposed chapters rather than within the framework of a critical discussion. Similarly, in the manner in which they updated current knowledge, they were more or less fettered by the structural approach to physics described above, in that, for example, they rejected Maxwell's electromagnetic theory of light, which was deemed to be speculative, in a last chapter at the end of the book.

## **5 - 1885-1890: more widespread reading and interpretation of the Treatise.**

Maxwell's book, in the first half of the 1880s, was now a success in the eyes of a few initiates. It was translated into French with critical commentary by Cornu and Potier. Items from it were presented by Mascart and Joubert, and a physics thesis was explicitly based on it by M. Brillouin (1882), using the

---

<sup>11</sup> [Mascart & Joubert, 1882-1885]



measurement methodology expounded by Maxwell. Other references to the measurement methods of the Treatise, now used by experimental workers, are to be found, particularly in the units of measurement programme. Certain facets of the Treatise were popularised in the *Annales Télégraphiques*. Maxwell's treatise found supporters, particularly among experimental scientists, for whom it supplied investigative tools.

However, it was not until the second half of the 1880s, that there occurred theoretical explanations, and "translations" by mathematical physicists, some of them critical. These were the supporters of Helmholtz. Duhem laid the initial basis for an outright opposition to Maxwell, while Mathieu, on the other hand, in the middle of a book entirely constructed on Helmholtz's work of 1870, jumps straight to a Maxwellian exploitation of Lagrange equations,<sup>12</sup> without acknowledgement.

Three works merit attention. A. Vaschy, who worked in telegraphy, and taught at the Ecole Supérieure de Télégraphie and at the Ecole Polytechnique, published a number of notes exploring certain points of the Treatise, and from his familiarity with it, drew aspects of his criticism of W. Thomson's 1854-55 theory of propagation of electricity along electric wires. In accounting for the role of self-induction he was led, in 1888, in parallel with Heaviside, to the development of the generalised telegraphy equation and its solution, so opening the way to long-distance telephone connections.

M. Brillouin, who was much attracted to the electromagnetic theory of light, was a fervent supporter of W. Thomson and of the mechanical view of electricity. Hence, he was sceptical with regard to many of the developments of the Treatise, but undertook an original approach to it in 1887. He attempted to find a way back to Maxwell's equation and to his theory of light by basing himself on a mathematical formalism considered by the French school to be a matter of certainty, Lamé's mechanical theory of elasticity. While he was unsuccessful - the result he came up with he himself thought to be logically incoherent - he did not despair of subsequent success.

Poincaré, in 1887-1888, at the Sorbonne, to whose chair of mathematical physics and calculation of probabilities he had just been appointed, presented some of the chapters of the Treatise. However, in the introduction to his lectures, he gave a synthesis of a number of ether-elastic theories of light, from which he extracted a core of equations which he judged to be mathematically equivalent to the equation he extracted from Maxwell's book. He also confronted the Maxwellian theory of dielectrics with his own mathematical construction based on the calculations of Poisson-Mossotti.<sup>13</sup>

---

<sup>12</sup>[Mathieu, 1888]

<sup>13</sup>[Atten, 1996]

Hence, in the years 1887 to 1888, we note several readings and explorations of the Treatise by French theoreticians who sought to bring into concordance the results obtained by Maxwell with the formal approaches derived from theories known and accepted in France (those of W. Thomson, Lamé, and Poisson). While this theoretically new approach was supported by a rising generation of scientists (Poincaré and Brillouin were born in 1854, and Vaschy in 1857), their approach was essentially consistent with the canons of mathematical physics as defined above. Their exploratory work was centred on mathematical formalism and precluded any discussion of physical representation and concepts. Furthermore, their work related only to the Treatise, and did not take into consideration recent work by Poynting, Fitzgerald and Heaviside, in particular.

## **6 - Maxwell, Hertz and the French theoreticians**

One of the last stages in the process of appropriation of the new theory through reading and translation is clearly tied up with the explosive effects of Hertz's research. After announcing that he had completed a new device to create and detect oscillating electrical effects in 1887, Hertz in May 1888 explained his experimental work in terms of electrical oscillations travelling at the speed of light in air and at a lesser speed along wires. Hertz rounded off his experimental results with a Maxwellian calculation which was interpreted as his "conversion"--the expression is Lodge's--in December 1888. This was followed by further experiments on our shorter wavelengths in 1889, and a complete theoretical rewriting leading to "Maxwell's equations," which were adopted from 1890 onward.

The French reactions to these discoveries followed exactly the same lines as before. The experimental physicists were, with a single exception, initially extremely sceptical.<sup>14</sup> Hertz's experimental work did not comply with the canons of the appropriate experimental approach. The results were a mixture of measurements and calculations. Mention was made of error by Hertz in both calculation and measurement. The phenomenon itself was poorly circumscribed, in terms of the multiple resonance effects of Sarasin and De la Rive. The determination itself of the speed of electricity along wires was in their eyes the object of suspicion. One scientist, Cornu, instigated a polemic as to whether Hertz's Maxwellian conversion was justified, as it was in his view *par principe* unsupported by the existing state of experimental knowledge.

However, in the camp of the mathematical physicists, after an initial attempt at comparing the formalisms of Helmholtz and Maxwell, Poincaré lost little time in taking up the Hertzian reformulation of "Maxwell's equations",

---

<sup>14</sup>[Atten, 1995]

which was very close to his own earlier "mathematical core". Poincaré's commitment to the new theory, which contributed to and interacted with the reinterpretation, by V. Bjerknes and Hertz, among others, of all the previous experimental work as a function of the dampening effect, marked a turning point in France. The new master of French mathematical physics innovated with respect to his predecessor, Bertrand, by intervening immediately on the work of experimental scientists. He was, nevertheless, a mathematician, had no background whatsoever in experimental science, set store on mathematics alone, and even gave a theoretical form to his own position by stating his mistrust of physical assumptions on principle. At the outset of his *Mathematical Theory of Light* [Poincaré, 1889], he states that "these [molecular] hypotheses play a secondary role only. They might be sacrificed."

Henceforth, it was through Poincaré's own "translations" of Maxwell (*Electricity and Optics* volumes 1 and 2, and *Electrical Oscillations*), that subsequent generations were, in France, to learn about what was still known as Maxwell's "theory"; mistrust about its supposed speculative nature did not vanish overnight.

### **Conclusion: transfer of knowledge or cultural acceptance**

We may now rapidly summarise our conclusions:

- i. The major reconstructions, which took centre stage, and which over time became known as "Maxwell's theory," were in France the product of the translation and reelaboration of the original theory. In Maxwell's own treatise, there is no mention of what were known as "Maxwell's equations." It is therefore inappropriate to talk about a dissemination or even transfer of the theory.
- ii. This case study shows how important the medium itself can be. The book form is suited to long distance travel and in many instances its influence is more sustained than a scientific review article (Helmholtz's was forgotten, and reappeared in connection with Hertz's results).
- iii. A book is written with a readership in mind. Maxwell's book was written for an audience, for no-one knew about quaternions outside the British mathematical community. When the Treatise was translated into French, Sarrau was to include instructions on how to use it. The combination of learned mathematics, of in-depth discussion of physical representation, and of descriptions of measurement devices, showed that the way in which British physicists were organised had very little in common with the French approach. Even the word "inductivism" appears to have had a different

meaning in both communities. The founding experiments on electrical phenomena, described at the beginning of the Treatise, were considered by Cornu as "scarcely feasible," "purely theoretical," or leading to "petitions of principle".<sup>15</sup>

iv. French readers used Maxwell's theories to support their own values and for their own requirements. For cultural and professional reasons, the first Frenchmen to use the theories were telegraphic engineers. Like the experimental workers who were to succeed them some years later, they found in Maxwell tools and methods. This, and not pure propagated knowledge, was what ensured the successful reception of the Treatise.

v. Mathematical physicists carried out a series of translations and explorations, whose main characteristics, as required by the French canon, centred on set mathematical procedures and the use of other known and mastered formalisms. Thus the greatest emphasis was laid on the "core of equations". Different readings and interpretations of Maxwell's work were made in Great Britain and in Germany.

vi. The rapid convergence of readings and translations at the time of the controversy surrounding the interpretation of Hertz's experimental work was in large part due to the long-standing work of cultural familiarisation that had already taken place. This is the process that we have illustrated within the French scientific community. Such familiarisation may take different forms in other scientific groups or communities.

We warmly thank D. Pestre for his valuable critical discussion of this text.

Michel ATTEN

Centre National d'Etudes des Télécommunications (France Télécom) /  
Centre de Recherche en Histoire des Sciences et des Techniques (La  
Villette), Paris.

## **Bibliographie**

Atten M.

(1992) *Les théories électriques en France. 1870-1900. La construction des mathématiciens, des physiciens et des ingénieurs à la*

---

<sup>15</sup> [Maxwell, 1882], 36, 39, 40, 41...

*construction de la théorie de Maxwell*, thèse de doctorat EHESS, Paris.

(1995) "De la réplique des expériences de Hertz", *Les Cahiers de Science&Vie*, n° 30, Paris.

(1996) "Poincaré et la tradition de la physique mathématique française" in *Henri Poincaré. Science and Philosophy*. Akademie Verlag-Albert Blanchard. Berlin-Paris.

Bertrand J.

(1869) "Renaissance de la physique cartésienne", *Journal des savants*, pp.581-596, 662-679, (1870) pp.225-242, 445-464.

(1873) "A Treatise on electricity and magnetism, by J. C. Maxwell, professor of experimental physics in the university of Cambridge. Papers on Electrostatics and Magnetisms, by sir W. Thomson", *Journal des savants*, pp.451-468.

Blavier E.-E.

(1865) "Détermination d'un nouvel étalon de résistance électrique", *Annales télégraphiques* 2eS. t.8 p.273.

(1881) *Des grandeurs électriques et de leur mesure en unités absolues*, Paris.

Brillouin M.

(1882) "Comparaison des coefficients d'induction", *Annales scientifiques de l'Ecole normale supérieure*, 2eS t.11 pp.339-424.

(1887) "Essai sur les lois d'élasticité d'un milieu capable de transmettre des actions en raison inverse du carré de la distance", *Annales scientifiques de l'Ecole normale supérieure*, 3eS t.4 pp.201-240.

Cornu A.

(1881-83) *Cours de physique*, rédigé par les élèves de l'Ecole polytechnique, autographié.

Helmholtz H. von

(1870) "Ueber die Bewegungsgleichungen der Electricität", *Journal für die reine und angewandte Mathematik*, t.72 pp.56-129.

Jamin J.

(1858-59) *Cours de physique de l'Ecole polytechnique*, Gauthier-Villars : 1ere éd. (2 vol.); 2ème éd. 1863-1869 (2 vol.); 3ème éd. (en collaboration avec E. Bouty) 1878-1881 (3 vol.); 4ème éd. 1885-1891 (4 vol.).

Licoppe C.

(1996) *La formation de la pratique scientifique*, La Découverte, Paris.

Mascart E., Joubert J.,

(1882) *Leçons sur l'électricité et le magnétisme*, avec 2 vol. Paris Masson.

Mathieu E.

(1888) *Théorie de l'Electrodynamique*, Paris Gauthier-Villars

Maxwell J. C.

(1855-56) "On Faraday's lines of forces", in *The scientific papers of James Clerk Maxwell*, édités par Niven (1890), t.1. pp.155-229.

(1861-62) "On physical lines of force", in *Papers*, t.1 pp.451-513.

(1864) "A dynamical Theory of the electromagnetic field", in *Papers*, t.1 pp.526-597.

(1868) "A note on the electromagnetic theory", in *Papers*, t.2 pp.137-143.

(1873) *Treatise on electricity and magnetism* 1ère éd., 2è (1881); *Traité d'électricité et de magnétisme*, Trad. franç. Seligmann-Lui, annotée par Cornu, Potier et Sarrau. 2 tomes. Paris (1885-1889)

Poincaré H.

(1889) *Théorie mathématique de la lumière*. Paris. G.Carré.

(1890) *Electricité et Optique*. Tome 1. Paris. G.Carré. Le sous titre est : "Les Théories de Maxwell et la Théorie électromagnétique de la lumière".

(1891) *Electricité et Optique*. Tome 2. Paris. G.Carré. Le sous titre est : "Les Théories de Helmholtz et les expériences de Hertz".

(1894) *Les oscillations électriques*. Paris. G. Carré.

Potier A.

(1873) "Egalité des constantes numériques fondamentales de l'optique et de l'électricité", *Journal de physique*, 1eS. t.2 pp.377-388.

Vaschy A.

(1886-87) *Cours de mesures électriques*, professées à l'Ecole supérieure de télégraphie, Imprimé par Régnier.

(1888-89) "Théorie de la propagation du courant sur une ligne électrique", *Annales Télégraphiques* 3eS. t.15 p.481-521, t.16 pp.148-155.

Verdet E.

(1854-63) "Recherches sur les propriétés optiques développées dans les corps transparents par l'action du magnétisme", *Annales de Chimie et de Physique*, 3e S, t.41, 370-412 (1854), t.51, 37-44 (1858), t.52, 129-153 (1858), t.69, 415-491 (1863).