

Applied and Computational Electromagnetics in Poland on the 200 Anniversary of the Oersted Discovery

Abstract. The paper is to remind of the 200 anniversary of the discovery by Hans Christian Oersted, which can be recognized as the beginning of electromagnetism as the phenomenon which physically joins electricity and magnetism. In the frame of the 200-year history, the development of Polish research activity in this area is presented.

Streszczenie. W artykule przypomniana została twórczość Hansa Christiana Oersteda w kontekście 200-lecia odkrycia związku pomiędzy elektrycznością i magnetyzmem, inicjującego nowy obszar wiedzy – elektromagnetyzm. W ramach dwustulecia elektromagnetyzmu zaprezentowany został dorobek polskich badaczy w tej dziedzinie (*Elektromagnetyzm stosowany i obliczeniowy w Polsce w dwustulecie odkrycia Oersteda*).

Keywords: Oersted's experiment, electromagnetism, electromagnetic achievements in Poland
Słowa kluczowe: eksperyment Oersteda, elektromagnetyzm, badania elektromagnetyzmu w Polsce

Life and Legacy of Hans Christian Oersted

The two independent phenomena, i.e. electricity and magnetism were described separately since antiquity through middle ages as well as William Gilbert's *opus vitae* De Magnete, Magneticisque Corporibus et de Magnete Tellure (On the Magnets and Magnetic Bodies and on the Great Magnet the Earth). This paradigm was in force until Hans Christian Oersted, the Danish physicist, made his great discovery in 1820.

Hans Christian Oersted was born in August 1777, in Rudkøbing, Denmark (Fig. 1).



Fig.1 The monument of Hans Christian Oersted in his mothertown Rudkøbing [1]

His education was mainly based on home teaching and the tutor was his father, a pharmacist. He began his formal studies in 1794 at the University of Copenhagen where he studied physics, philosophy and pharmacy.

After having finished his studies in 1801 with the PhD, within the years 1801-1823 he made three big trips around Europe, especially through Germany and France. During the first trip (1801- 1803) he met a few important scientists, Johann Ritter among others, a man who probably inspired his considerations on thinking on electricity and magnetism as bonded phenomena. Oersted and Ritter became friends and exchanged their scientific reports until Ritter passed away in 1810, at the age of 32.

The experiment which led to quite a new paradigm of electromagnetism (the term which Oersted introduced to scientific vocabulary) took place on 21 April, 1820 while

Oersted lectured for students. He revolutionized natural science by observation that there is a deflection of a magnetic needle caused by electric current in a wire. It completely changed the conviction that the two phenomena, electricity and magnetism are independent. The discovery opened the door to an entirely new area of scientific research, being an inspiration for Faraday and Maxwell who ten years later made the understanding of electromagnetism completed [2].

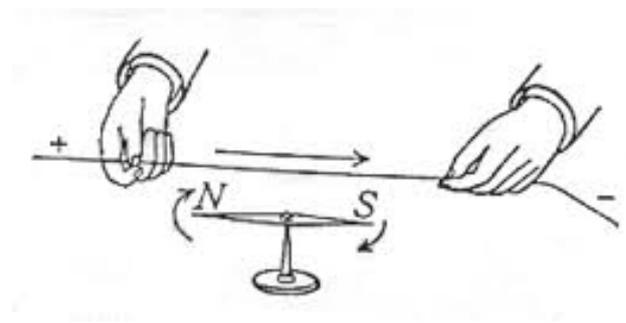


Fig. 2 The scheme of Oersted's experiment

On July 21, 1820, the four pages publication written in Latin *Experimenta circa effectum conflictus electrici in acum magneticam* was released and sent to forty-eight European academicians, e.g. Ampere, Arago, Laplace, Biot, Savart, Seebeck and the like (Fig.3)

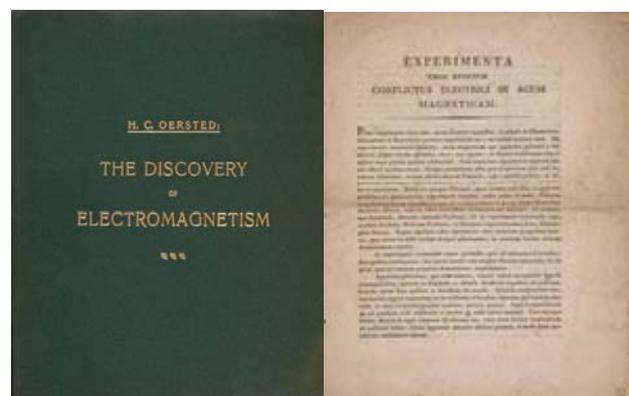


Fig.3 The cover and first page of Oersted's report. [1]

After the report had been read some objections were raised from some scholars, especially from Andre Maria Ampere. He repeated Oersted's experiment very soon, namely on September 11, 1820 and found that Oersted had not taken into account the influence of Earth magnetism. Anyway, after some discussions there was commonly accepted opinion that it was Hans Christian Oersted who made the crucial experiment in which he showed the relation between electricity (electric field) and magnetism (magnetic field). It should be stressed again that the commonly used term "electromagnetism" was established by him. In 1820, just for his electromagnetic discovery the Royal Society, the eminent organization in London, awarded him the Copley Medal. Also the French Academy highly appreciated Oersted's discovery and granted him 3000 francs.

The discovery for which Oersted found the eminent place in the history of science was not the last in his life. In 1825 he produced aluminum in the form which was almost purely metallic. The aluminum alloy he obtained by his method contained a little impurities but, in spite of it, he is univocally considered the father of aluminum.

The Danish people honoured their great citizen naming by his name some places in Copenhagen and other Danish towns as well as some scientific buildings. To spread his name in the Universe the first Danish satellite received his name. In the Copenhagen park of his name the statue of Oersted was erected in 1880 (Fig. 4)



Fig. 4 The statue of H.C. Oersted in Copenhagen [1]

In 1930 the International Electrotechnical Commission decided to honour Hans Christian Oersted by naming the unit of magnetic field strength after him (oersted Oe in CGS, $1 \text{ Oe} \approx 79.5775 \text{ A/m}$).

Beside his activity as a physicist he was also occupied with philosophy, which those who opened his legacy had the chance to find out. There he left in his legacy the book containing his philosophical writings. It was published in Danish, shortly before his death, in 1849, and in English under the title "The Soul of Nature" in 1851. The book evoked a great discussion among philosophers and scientists as it deals with some reflections on Oersted's works relevance to aesthetics, politics, pedagogy and religion.

Hans Cristian Oersted died in Copenhagen in 1851, His grave is in the Assisten Cemetery, where many Danish important people are buried (Fig. 5).



Fig. 5. The grave of H.C. Oersted [1]

The germination of applied and computational electromagnetics in Poland

Because of political situation in Poland in 19th century the Polish activity in science and technology was not strong. The turn of 19th and 20th centuries brought some activities in electrical engineering, for example the inventions made by Michal Doliwo - Dobrowolski, who co-invented the three-phase electric current and invented three-phase induction motor and electric power transmission [3]. The real scientific activity in the area of applied electromagnetism can be dated for the 60-ties and 70-ties of the last century. The first book by prof. Turowski [4] opened the new area of study. After years prof. Turowski aided by his son released the English edition of the book (Fig.6) [5].



Fig. 6. The covers of the books [3,4]

There were also other researchers worth noticing as the precursors of the applied and computational electromagnetics, e.g. [6-8]. Till now, two papers describing the so called, Polish research activity in electromagnetism, have been already described - the first publication appeared in 1998 [8] and the second in 2001 [10]. As the second article was published almost 20 years ago, the authors decided to present what happened in the last 20 years.

Ending the presentation [9] few subjects of research, which were representatives for that time, have been pointed out:

- bioelectromagnetic interactions,
- new optimization techniques
- mathematical modelling of special electrical devices
- computational electromagnetics in new materials

Contemporary applied and computational electromagnetism in Poland

Looking at the list after those 20 years, one can find that the main ideas of the electromagnetic research are similar, although the stress is a little bit changed. Namely, the computer modelling techniques are already well understood and the activity of researchers has rather been focused on the applications. Indeed, the majority of the papers presented at the conferences and symposia are devoted to the analysis of electromagnetic phenomena in devices, systems and nature. For example, taking into account the bioelectromagnetic problems, the attention of the scientists is mainly directed to studying the mechanism which rule and control the processes being within the scope of the interaction between electromagnetism and biology.

Looking at the activity of Polish researchers one can group the subjects of the present research in the categories as follows:

1. Electromagnetism in electrical engineering applications (mechatronics, automation, e-textiles, modern drive systems, electric sensors)
2. Bioelectromagnetics, electromagnetic field impact on the environment,
3. Electromagnetic medicine (diagnosis, therapy, telemedicine)
4. Telecommunication and wireless technologies (new generations of mobile phones 5G, 6G)
5. Agriculture technologies which use electromagnetism
6. Electromagnetic tomography (magnetic induction, electric resistance, eddy currents, microwave).

The above items more or less cover the area of contemporary electromagnetic research in Poland. Below all the thematic groups are presented in a more detailed way.

Ad. 1

The research activity in this group can be seen as classical research developed from the very beginning of applied electromagnetics in Poland. One can say that the research was initiated by Prof. Turowski in the 60-ies of the previous century [4,5].

Now the topics of research have been highly modernized and besides electrical machines and transformers quite new areas of research are developed. The results of research in such topics as smart textiles, electric sensors, automation, mechatronics, modern drive systems are presented in books and papers [11-20]. The leading institution in this field is Łódź University of Technology but some other institutions are also involved in the above subject, e.g. the Technical University of Częstochowa, the Technical University of Opole, the Technical University of Wrocław and some other.

Ad. 2.

The subject of bioelectromagnetics combines electrical engineering, biology, physiology and the researchers coming from the above areas of interest try to find the mechanism which show EMF and human cell/organ/body interaction. It is especially important because of people's concern connected with greater and greater saturation of electromagnetic field sources. Therefore, one of the main directions of research in this area is searching for the answer: is electromagnetic field hazardous for human health or not? [21,22]. The research in Poland has been initiated by prof. Stefan Manczarski [23] many years ago but the real research started at the germination of mobile phone technology, i.e. in early 80-ties. The institutions involved in such research were Central Institute of Labour Protection, Institute of Labour Medicine, Institute of Electrical Engineering, Wrocław University of Science and

Technology, Military Institute of Hygiene and Epidemiology and some other.

Ad.3.

The results achieved in Ad.2 are very useful in the section devoted to electromagnetic medicine. The essence of the research is very similar (human body and electromagnetic field) but the purpose is quite contradictory. Here the researchers are concentrated on the positive aspects of electromagnetic field, i.e. they attempt at finding how to cure people by means of electromagnetic field. The problem has been under investigation since ancient ages [24] but in Poland started in the 80-ties of the last century, mainly by the scientists working in medicine [25,26] supported by electromagnetic community [27,28]. The Polish Society of Applied Electromagnetics' role in this activity cannot be overestimated. The efforts of both medical and engineering communities should be highly praised. who joined the efforts of medical and engineering communities. This engagement fruited in establishing within the Association of Polish Electrical Engineers the Polish Committee of the Applications of Electromagnetic Field in Medicine.

Ad.4

Because of the stormy progress of technologies using wireless transmission of data (mobile telephony, WiFi, etc.), the electromagnetic field plays more and more important role in the telecommunications engineering. In Poland it is Wrocław University of Technology, National Institute of Telecommunication, Military Technical Academy that play a very active role in the field. They published a pretty big number of papers and books [29,30]. Recently, there is an explosion of engineering projects devoted to 5G technology. The side effect of it is rapid increase of the people's concern connected with electromagnetic field emitted by the 5G installation. This situation needs the mutual efforts of telecommunication researchers and those involved in bioelectromagnetic problems (see Ad. 2).

Ad. 5.

The last few years brought bigger and bigger interest in the use of electromagnetic field in agriculture technology. The research in this area is carried out in the Agriculture University in Cracow, the University of Life Sciences in Lublin, the Wrocław University of Life Sciences. The researchers from the above mentioned universities cooperate with those involved in the electromagnetic area of interest. This leads to many important projects for agriculture industry [31,32].

Ad.6

Quite a new idea in the applied electromagnetics is electromagnetic tomography. The activity in this subject is nowadays concentrated in two institutions: Research and Development Center, Netrix Inc. and the University of Economics and Innovation in Lublin. The results of the research projects made there are published in Polish and international journals [33] and the exhaustive survey can be found in the book [34].

The important contribution to applied and computational electromagnetism is the International Symposium on Electromagnetic Field, known in the scientific world by its acronym ISEF (the present name is International Symposium on Electromagnetic Fields in Electrical Engineering, Electronics and Mechatronics). The conference is being organized biannually since almost 40 years and is recognized all over the world as the one of a few important world conferences devoted to applied and computational electromagnetism.

There are also the Polish journals which publish the papers of Polish (not only) authors who are involved in the

subject in question. The covers of the most important journals are shown in Fig. 7



Fig. 7 The covers of journals

Conclusions

The life and legacy of Hans Christian Oersted seems to be worth outlining in the paper as it is not widely known. It should be underlined, however, that his contribution to the foundation of electromagnetism is enormously essential and important. The deeper knowledge of Oersted's life and achievements can be found in [2].

The presentation of Polish activity in the field of applied electromagnetics is not complete but the authors of this paper hope that they are just showing the outline of the state of the matters as it is. A reader can find here a subject he or she is particularly interested in.

Authors: *prof. dr hab. inż. Andrzej Krawczyk, Polish Society of Applied Electromagnetism e-mail: ankra.new@gmail.com, dr hab. inż. Ewa Korzeniewska, prof. uczelni, Politechnika Łódzka, Instytut Systemów Inżynierii Elektrycznej, ul. Stefanowskiego 18, 90-537 Łódź, e-mail: ewakorz@matel.p.lodz.pl*

REFERENCES

- [1] www.wikiwand.com
- [2] D.C. Christensen, Hans Christian Oersted Reading Nature's Mind, Oxford University Press, 2013
- [3] <https://web.archive.org/web/20151222110240/http://www.bez-el.com.pl/index.php/elektroczny/michal-doliwo-dobrowolski-cz-i>
- [4] J. Turowski, Elektrodynamika Techniczna, WNT, 1968
- [5] J. Turowski, M. Turowski, Engineering Elektrodynamics. CRC Press 2014
- [6] R. Sikora, Teoria pola elektromagnetycznego, WNT, 1977
- [7] A. Krawczyk, J.A. Tegopoulos Numerical Modelling of Eddy Currents, Clarendon Press, Oxford, 1993
- [8] P. Di Barba, A. Savini S. Wiak, Field Models in Electricity and Magnetism, Springer Verlag, 2008
- [9] J. Sykulski, A. Krawczyk, S. Wiak, "Computational Electromagnetics in Poland: a review", *Compel – The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, Vol. 17 No. 4, 1998, pp. 427-438
- [10] A. Krawczyk, S. Wiak, Computational Electromagnetics in Poland: some remarks on the 400th anniversary of William Gilbert's book, in *Electromagnetic Fields in Electrical Engineering* (ed. A. Krawczyk, S. Wiak). IOS Press, 2002
- [11] A. Krawczyk, J. Turowski, Recent Development in Eddy Current Analysis, *IEEE Transaction on Magnetics*, 5, 1987
- [12] X.M. Lopez-Fernandes, H. Bulent Ertan, J. Turowski, *Transformers: Analysis, Design, and Measurements*, CRC 2013
- [13] S. Wiak, *Fundamentals of Mechatronics* (in Polish), Akademicka Oficyna Wydawnicza EXIT, 2009
- [14] S Wiak, A Firyeh-Nowacka, K Smółka, Computer models of 3D magnetic microfibers used in textile actuators, *Compel* No.5, 2010
- [15] E. Korzeniewska, A.Krawczyk, Applications of Smart Textiles in Electromedicine, *IEEEExplore*, 2019 19th International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering (ISEF)
- [16] A. Czaban, M. Lis, K. Szewczyk, Mathematical modeling of transient processes in a crane drive system (in Polish), *Przegląd Elektrotechniczny*, 2017, 93 (12), 97 - 82
- [17] R. Sikora, P. Markiewicz, W. Pabjanczyk, Computing active power losses using a mathematical model of a regulated street luminaire, *Energies*, 2018, 11(6), 1386
- [18] S. Wiak, A. Firyeh-Nowacka, K. Smółka, Z. Kotaciński, Ł. Szymański, Induction heating process of ferromagnetic filled carbon nanotubes based on 3-D model, *Open Physics*, 2017, 15(1), pp. 1061–1066
- [19] S. Wiak, P. Drzymala, H. Welfle, The field and power losses computation in structural components of HV power transformer, *IET Conference Publications*, 2011, 2011(577 CP), pp. 78–79
- [20] M. Lebioda, M. Tomczyk, Analysis of thermal and electrical properties of heating microsystems based on TCO layers, *Proceedings of the 24th International Conference on Mixed Design of Integrated Circuits and Systems, MIXDES 2017*, 2017, pp. 443–446, 8005249
- [21] W. Stankiewicz, A. Krawczyk. J. Kieliszek, The Cellular Phone-Induced Electromagnetic Radiation as the Risk Factor in Brain Cancer – a Survey of Recent Research, *Przegląd Elektrotechniczny*, 2013, 89 (2b), 25-27
- [22] A. Borkiewicz, E. Gadzicka, W. Szymczak., Mobile Phone Use and Risk for Intracranial Tumors and Salivary Gland Tumors - a meta-analysis, *Int.J.Occup.Med Environ. Health* 2017, 30 (1), 27-43
- [23] S. Manczarski, H. Kucia, Ochrona pracowników przed szkodliwymi polami elektromagnetycznymi wielkiej częstotliwości. *Ochrona Pracy*, nr 7 - 8, 1969
- [24] A. Krawczyk et al., Electrostimulation in medicine – history and contemporary usage (in Polish), *Przegląd Elektrotechniczny*, 2018, 94 (12), 230-233
- [25] A. Sieroń, G. Cieślak, Magnetic field and light in medicine and physiotherapy (in Polish), Alpha Medica Press, 2013
- [26] T. Zyss, *Electroshocks: Introduction to Bioelectric Nature of Deep Depression* (in Polish), Wydawnictwo Medyczne. Kraków, 2009
- [27] A. Krawczyk, R. Kubacki, S. Wiak, C.L. Antunes, *Electromagnetic field, health and environment*, IOS Press, 2008
- [28] B. Sawicki, J. Starzyński, S. Wincenciak, A. Krawczyk, and M. Trlep (2004), "Magnetic stimulation of knee – mathematical model", *COMPEL - The international journal for computation and mathematics in electrical and electronic engineering*, Vol. 23 No. 3, pp. 767-773. <https://doi.org/10.1108/03321640410540700>
- [29] R. Kubacki, *Microwave antennas. Technology and Environment* (in Polish), Wydawnictwo Komunikacji i Łączności, 2009
- [30] P. Bieńkowski, B. Zubrzak, *Electromagnetic fields from mobile phone base station - variability analysis. Electromagnetic Biology and Medicine*. 2015, 34 (3), 257-261.
- [31] T. Drózdź, P. Bieńkowski, P. Kiełbasa, P. Nawara, E. Popardowski, The research stand to stimulation of biological materials by the various electromagnetic field, *Przegląd Elektrotechniczny*, 2019, 95 (3), 66-69
- [32] M. Oziębłowski, T. Drózdź, P. Nawara, K. Nęcka, S. Lis, P. Kiełbasa, M. Tomasiak, The synergistic interaction of pulsed electric fields (PEF) and other methods on liquid food (in Polish), *Przegląd Elektrotechniczny*, 2016, 92(12), 121-124
- [33] T. Rymarczyk, E. Kozłowski, G. Kłosowski, K. Niderla, *Logistic Regression for Machine Learning in Process Tomography, Sensors*, 19 (2019), 3400
- [34] T. Rymarczyk, *Tomographic Imaging in Environmental, Industrial and Medical Applications*, Innovati Pres Publishing House, Lublin, 2019