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50 YEARS OF CMD

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Condensed Matter Physics touches some of the deepest phenomena in nature. Fascinating physics occurs throughout this very broad area of physics, largely enabling the technologies that underpin modern society. Since 50 years, the EPS Condensed Matter Division is the voice and the tool of the strong European Condensed Matter community.

The founding of the European Physical Society (EPS) came relatively soon after the invention of the transistor in 1947[1], at a time when the latter steadily gained importance in applications such as radios. It was a time when "Solid State" was *en vogue*. Research units chose names like "Solid State Physics Department" and "Division of Solid State Science". Still, when divisions were created in 1969 as working units within the brand-new EPS, it was a "Condensed Matter Division" (CMD) that resulted. Presumably the fact that Sam Edwards, founder and chairman of the division from 1969 till 1972 was a pioneer in the field of polymers played a role in baptising our division. The corresponding division of the APS was given the name CMD only in 1978; initially it was called "Division of Solid State Physics".

▼ FIG. 1: Gero Thomas and Jozef Devreese at CMD1 in Antwerp, 1980

It is not easy to pinpoint a single "parent" of the condensed matter concept. Experimental studies on the vapour – liquid transition were referred to by Hooke as Boyle's "condensation" experiments[2] in *the Royal Society's Journal Book* in 1662. The term "*Condensed phase*" was commonly used in the 19th century and work by *e.g.* Gibbs and Van der Waals is devoted to it. In the nineteen-sixties there was a growing interaction and overlap between solid state physics and the study of liquids at the atomic level and – as stated by Conyers Herring - the enlarged concept of *physics of condensed matter* was increasingly used in universities and in industry. Today the concept "condensed matter" has come to include, beyond the solid and the liquid state per se, superconducting and superfluid phases, quantum Hall and topological phases, large parts of quantum physics, with, in particular, condensed matter quantum simulators consisting of cold atoms, but, also, the vast domain of surface science, polymers, soft matter, biological matter, and a wide spectrum of materials science, including nanomaterials.

Manuel Cardona has argued that Einstein comes closest to being at the origin of "condensed matter physics": " *... I shall demonstrate that (Einstein) is also the father of Solid State Physics, or even (its) broader version … known as Condensed Matter Physics (including liquids)*"[3] and "His first publication (1901)[4] could already be considered to

[1] https://www.aps.org/programs/outreach/history/historicsites/transistor.cfm
[2] Royal Society's Journal Book, See "The Hooke Folio online": *e.g.* October 1 (1662)
[3] M. Cardona, arXiv:physics/0508237v1 [physics.hist-ph] (2005)
[4] "Folgerungen aus den Capillaritätserscheinungen", *Annalen der Physik* **4**, 513 (1901).

be in the realm of Condensed Matter Physics (liquids)". Certain is that the journal "Physics of Condensed Matter" (Springer) started publishing in English, French, and German as of 1963.

The early years, Condensed Matter Physics in Europe (1969-1979)

The founders of EPS (1968) were inspired by the creation of CERN (1958), itself part of peaceful international collaborative efforts in the wake of the recovery of Europe from World War II. Around that time, scientists, including physicists, in Europe were taking more and more initiatives, stimulated, amongst other things, by the successful (and totally surprising) launch of Sputnik (October 1957). By 1969 physics was flourishing in Europe once again and collaboration with the USA and Japan was on the rise. In the first decade of CMD - EPS, condensed matter physics was much influenced by discoveries and inventions of the previous decades such as the transistor effect (Lilienfeld, 1925; Bardeen, Brattain, Shockley, 1947), neutron scattering and diffraction (1945), the BCS-theory of superconductivity (1957), and the Esaki and Giaever tunnelling phenomena and -diode (1958-1960). The first decade after 1969 saw spectacular miniaturisation in electronics leading to the increasing impact of computers and computational physics, a trend that continues to this day. Nobel Prizes for Néel (1970), Mott (1977), and Kapitsa (1978) honoured profoundly fundamental European condensed matter research, while the Nobel Prize of Josephson (1973) for work in 1962 rewarded an exceptional theoretical prediction with pronounced technological impact: the Josephson junction. Nevertheless, as reflected by the founding years of its sections (Table I), CMD has, from the outset, paid attention to the whole span of condensed matter physics.

Attempts towards "*topical* divisional conferences"

Sam Edwards contributed to the organisation of the Inaugural Conference of EPS (Florence, Italy, in 1969) and especially to its condensed matter aspects with talks by Casimir, Mott and Friedel, among others. Next, Edwards started, for CMD, what were called "Divisional Conferences". The initial concept was to concentrate the programme on two themes: 1) *"a particular region of condensed matter"* and 2) *"a general phenomenon"*. The first such "topical" Divisional Conference took place in Florence in September 1971, with *"metals"* as material and *"phase transformation"* as general phenomenon. This conference - helped by the enthusiasm for the new EPS – was a success and held much promise for the future. The second "Divisional conference" (Budapest, 1974) was planned as an occasion for nurturing contacts between physicists from Eastern and Western Europe. However the level of participation had declined considerably, with a further decline (a "euphemism") at the third meeting in Leeds in 1977. Clearly, the "topical" scheme could not lead to a successful, recurrent, condensed matter (CM) meeting in Europe, and was therefore inappropriate as the seat of regular interaction between European CM physicists. In 1978, one of us (JTD) was approached by CMD with the request to take an initiative that could lead to a successful series of CMD conferences, and, thereby, successful CMD integration.

CMD SECTION	YEARS IN OPERATION
Liquid physics	1982 -
Low temperature physics	1974 -
Macromolecular physics	1974 – 2017 (succ. by Soft Matter and Bio)
Magnetism	1969 – 2017 (succeeded by EMA)
Metal physics	1969 - 1999
Soft Condensed Matter and Biophysics	2017 -
Semiconductors and Insulators	1969 -
Structure and Dynamics of Condensed Matter	1998 -
Surfaces and Interfaces	1974 -

▲ **Table I:** Sections of the Condensed Matter Division of the EPS

Antwerp 1980 and the General Conferences of CMD

It was no obvious decision to start a new series of CMD-conferences in Antwerp. Nevertheless, the challenge was accepted (by JTD) because of the conviction that there was a genuine need in the European CM physics community for an international forum, similar to the successful "*March Meeting*" of the APS. Already then, many European CM physicists attended the March meeting. The strategy for Antwerp – CMD1 was, among others,

- to conceive the conference as "general", *i.e.* encourage all CM-physicists to contribute;
- to cover a wide range of topics, in principle, all subjects of interest to CM physicists;
- to promote the "General Conference of CMD" as an international forum for discussion and exchange on the latest scientific developments;
- to form the International Advisory- and Programme Committees with great care and with relatively many and *active* members. The two committees had about 30 members each, including leading European physicists such as A. Abrikosov, H. Casimir, H. Haken, N. Mott, N. Bogoliubov, M. Cardona, S. Edwards, J. Friedel, G. Benedek, H. Fröhlich, R. Peierls, …

The team in Antwerp collected addresses (internet did not exist yet) of around 8000 physicists in Europe working in the broad field of condensed mater physics. The deadline for registration for the conference was February

▸ FIG. 2: Opening session of CMD1 in Antwerp, 1980

1, 1980. In the last three days of January- to the surprise of the organizers - around 180 letters were received per day (with abstracts or/and subscription for participation). In the end more than 600 CM physicists participated in the 1980 First General Conference of CMD-EPS. The distribution of participants over Western European countries was quite homogeneous, with relatively few participants from Eastern Europe at that time, but several from the USA, Japan and China. During the conference there was a strong interaction between the participants and there was enthusiasm about the forum provided by the new "General Conference" format.

Within two weeks after Antwerp-CMD1, two formal offers were received to organise the second conference: one for Manchester, one for Lausanne. Since then, the meeting has become "self-propelling", with spontaneous proposals coming to organise the next conference. A list of the 27 CMD Conferences to date can be found on the CMD web pages[5].

The original Antwerp "general forum"-format has evolved over the years. Typically the CMD General Conference has attracted 400 to 600 participants from outside the organising country. Attendance has ebbed and flowed, with the meeting evolving and re-inventing itself over the years. The overall attendance exceeded 1000 participants in Grenoble, Montreux, Brighton, and Paris, with a good balance in each case of "local" and international participants. The number of attendees peaked at 6735, when CMD 27 was co-organised with the German spring meeting in Berlin in 2018. Even if the attendance was predominantly from German institutions, the EPS-CMD character of the conference was distinct, due to the careful selection of a representative panel of European invited speakers. Recurring problems are the fluctuating number of delegates as function of the host country, the relative strength of its national physical society, and of the meetings CMD is combined with, and CMD's two-yearly frequency. Establishing CMD as a yearly rendezvous, thereby securing the repeated presence of graduate students and young researchers from across Europe – *i.e.*, more than once during their PhD or post-doc contract – and establishing CMD attendance as a habit is a major challenge for the years to come.

One should realise that back around 1980 not all physicists in Europe were convinced of the utility of a CMD conference at the European level – and that this sentiment remains today! Some expressed the opinion (sometimes strongly) that national physics society meetings were to be preferred in Europe. It is then no surprise that, over the years, much attention and energy of the CMD Board has been devoted to promote the conference and to convince colleagues to attend. It is truly encouraging that, for the last issues, a growing number of communities have elected CMD as its biyearly rendezvous.

▾ Table II: CMD Board chairs

YEAR	FIRST NAME	SURNAME	INSTITUTION
2014 -	Kees	VAN DER BEEK	CNRS, Palaiseau, France
2004 - 2014	Eoin	O'REILLY	Tyndall, Cork, Ireland
1998 - 2004	Hans Rudolf	OTT	ETH Zürich, Switzerland
1992 - 1998	Peter	WYDER	Max Planck Institute, Grenoble, France
1986 - 1992	Franco	BASSANI	Scuola Superiore Normale, Pisa, Italy
1980 - 1986	Jozef T	DEVREESE	Universiteit Antwerpen, Belgium
1978 - 1980	Minko	BALKANSKI	Université Pierre et Marie Curie, Paris, France
1976 - 1978	Walter	MERZ	RCA Labs, Zurich, Switzerland
1973 - 1976	André	GUINIER	Université Paris-Sud, Orsay, France
1968 - 1973	Samuel F.	EDWARDS	Cambridge University, United Kingdom

CMD Sections

Because condensed matter covers such a broad range of fields, a series of sections specializing in different areas of CM physics have been established (see Table I). Several of these have established highly successful, large specialist

[5] http://cmd.epsdivisions.org/

conferences, including the European Conference on Surface Science (ECOSS), which has been running on an annual basis since 1978, the annual Joint European Magnetism Symposia (JEMS), and the EPS Liquid Matter Conference, which takes place every three years. Other sections run and are involved with successful smaller meetings (*e.g.* the Low Temperatures, the Semiconductors and Insulators, and the Structure and Dynamics of Condensed Matter sections), or highly successful Schools (*e.g.*, the bi-yearly Cryocourse of the Low Temperature Section or the European School on Magnetism of EMA[6]).

The recognition of European Condensed Matter Physics

The greatest impact of the EPS Condensed Matter Division has probably been through the establishment and award of what is now called the "EPS Europhysics Prize for Outstanding Achievement in Condensed Matter Physics". The object is stated as: "*The award will be given in recognition of recent work by one or more individuals in the area of condensed matter physics, which, in the opinion of the selection committee, represents scientific excellence… The award will recognize research for which a significant portion of the work was carried out in Europe, and may be given for either pure or Applied research at the discretion of the Society*". Originally sponsored by Hewlett Packard, the Prize was strongly supported by Agilent Technologies until the re-alignment of their outreach activities in 2006. Most key research areas of condensed matter physics are represented and honoured through the work of the Europhysics Prize laureates. Several laureates went on to become Nobel-laureates, both in physics and in chemistry: one has, *e.g.*, Z.I Alferov (EPS-Prize: 1978/Nobel Prize 2000), K. von Klitzing (1982/1985), G. Binnig and H. Rohrer (1984, 1986), J. Bednorz and K.A. Müller (1988/1987), G. Ertl (1992/2007), H. Kroto (1994/1996), A. Fert and P. Grünberg (1997/2007), and A. Geim and K. Novoselov (2008/2010). The EPS Europhysics Prize of a laureate always preceded the Nobel Prize. This includes Bednorz and Müller, for whom the EPS Prize was announced in EPN in October 1987, although –formally- the prize was for 1988. In 1985, Hewlett, the founder of HP expressed his great satisfaction when the 1982 laureate of the HP-Europhysics prize (von Klitzing) was awarded the Nobel Prize.

In the wake of the Nobel Prizes for P.G. de Gennes in 1991 and A. Leggett in 2003, the EPS Liquid Matter Prize "*for outstanding achievements in physics of liquids*" was instated alongside the Europhysics Prize in 2005, so as to ensure that all areas of Condensed Matter physics are duly recognized. Liquid prize laureates include D. Chandler who, with H. Andersen and J. Weeks, is at the origin of our understanding of the molecular nature of liquid matter and glass formation, and R. Evans, who made fundamental and lasting contributions to the physics of interfaces, capillarity, wetting, and phase transitions in fluids.

The fields covered by laureates of the two prizes attest to the vitality and pioneering character of CM research in Europe, as well as to its major impact on our daily lives. The Quantum Hall effect (QHE) constitutes a striking advance in metrology – it came as a total surprise that QED-precision experiments can be realized in a MOSFET, with the later discovery of fractional charge and a new kind of quantum fluid in GaAs/AlGaAs heterojunctions. That atomic scale resolution can be reached in scanning tunnelling microscopy (STM) by recording the vertical movement of a sharp tip across a solid surface is actually astonishing. The discovery of superconductivity in ceramic materials, with a Tc 12 K above the record of 23 K realized in Nb_3Ge in 1973, soon followed by materials with Tc's up to 150 K (discovered in Europe), came as a third explosive development in condensed matter physics. This has now been followed by the remarkable discovery of electron-phonon mediated high Tc superconductivity in H_2S under high pressure, again, a European achievement.

The QHE (1981), the STM (early 1980's), and high-Tc superconductivity (1986) have brought three breakthroughs in condensed matter physics that had an immense impact, within just a five-year span. The Nobel Prize for developing semiconductor hetero-structures used in high speed- and opto-electronics (2000) has laid the foundation of modern IT, while the 2007 Nobel Prize honouring the technology to read data on hard disks is of tremendous significance for further miniaturization. The work on graphene (2008), topological insulators and the quantum spin hall effect (2010), two-dimensional electron liquids (2014), skyrmions (2016), are likely to have a similar influence on the nano-electronics, sensors, and computational devices of the future.

▼ **FIG. 3:** Opening Session of CMD25 in Paris, 2014

[6] The European Magnetism Association, see http://magnetism.eu/

YEAR	WINNERS	TOPIC
1975	V.S. Bagaev, L.V. Keldysh, J.E. Pokrovsky, M. Voos	The condensation of excitons
1976	W. Helfrich	Contributions to the physics of liquid crystals
1977	W.E. Spear	Amorphous silicon devices
1978	Z. I. Alferov	Heterojunctions
1979	E.A. Ash, J.H. Collins, Y.V. Gulaev, K.A. Ingebrigtsen, E.G.S. Paige	The physical principles of surface acoustic wave devices
1980	O.K. Andersen, A.R. Miedema	Original methods for the calculation of the electronic properties of materials
1982	K. von Klitzing	Experimental demonstration of the quantized Hall resistance
1983	A.F. Silvera	Atomic and solid hydrogen
1984	G.K. Binnig, H. Rohrer	Scanning tunnelling microscope
1985	J. Als-Nielsen, M. Pepper	The experimental study of low dimensional physics
1986	F. Mezei	Neutron spin echo spectroscopy
1987	I.K. Yanson	Point-contact spectroscopy in metals
1988	J.G. Bednorz, K.A. Müller	Discovery of high-temperature superconductivity
1989	F. Steglich, H.-R. Ott, G.G. Lonzarich	Pioneering investigations of heavy-fermion metals
1990	R. Car, M. Parrinello	A novel and powerful method for the ab-initio calculation of molecular dynamics
1991	K. Bechgaard, D. Jérome	Synthesis of a new class of organic metals and the discovery of their superconductivity and novel magnetic properties
1992	G. Ertl, H. Ibach, J. Peter Toennies	Pioneering studies of surface structures, dynamics and reactions through the development of novel experimental methods
1993	B. L. Altshuler, A. G. Aronov, D. E. Khmelnitskii, A. I. Larkin, B. Spivak	Theoretical work on coherent phenomena in disordered conductors
1994	D. R. Huffman, W. Krätschmer, H. W. Kroto, R. E. Smalley	New molecular forms of carbon and their production in the solid state
1995	Y. Aharonov, M. V. Berry	Introduction of fundamental concepts in physics that have profound impact on condensed matter science
1996	R.H. Friend	Pioneering work on semiconducting organic polymer materials and demonstration of an organic light emitting diode
1997	A. Fert, P. Gruenberg, S.S.P. Parkin	Discovery and contribution to the understanding of the giant magneto-resistance effect in transition-metal multilayers and demonstrations of its potential for technological applications
1998	M.T. Rice	Original contributions to the theory of strongly correlated electron systems
1999	C. Glattli, M. Reznikov	For developing novel techniques for noise measurements in solids leading to experimental observation of carriers with a fractional charge.
2000	P. Carra, G. van der Laan, G. Schütz	Pioneering work in establishing the field of magnetic x-ray dichroism
2001	S. Iijima, C. Dekker, T. W. Ebbesen, P.L. McEuen	Discovery of multi- and single-walled carbon nanotubes and pioneering studies of their fundamental mechanical and electronic properties.
2002	B. Barbara, J. Friedman, D. Gatteschi, R. Sessoli, W. Wernsdorfer	Development of the field of quantum dynamics of nanomagnets, including the discovery of quantum tunnelling and interference in dynamics of magnetization.
2003	H. Finkelmann, M. Warner	Discovery of a new class of materials called liquid crystal elastomers.
2004	M. Devoret, D. Esteve, J. Mooij, Y. Nakamura	Realisation and demonstration of the quantum bit concept based on superconducting circuits.
2005	D. Awschalom, T. Dietl, H. Ohno	Work on ferromagnetic semiconductors and spintronics
2006	A. Georges, G. Kotliar, W. Metzner, D. Vollhardt	Development and application of the dynamical mean field theory
2008	A. Geim and K. Novoselov	Work on graphene
2010	H. Buhmann, C. Kane, E. Mele, L. W. Molenkamp and S. Zhang	Quantum spin Hall effect and topological insulators.
2012	S. Bramwell, C. Castelnovo, S. Grigera, R. Moessner, S. Sondhi, A. Tennant	Magnetic monopoles in spin ice.
2014	H. Y. Hwang, J. Mannhart, J.-M. Triscone	Electron liquids at oxide interfaces.
2016	A. Bogdanov, P. Böni, C. Pfleiderer, A. Rosch, A. Vishwanath	Magnetic skyrmion phase in MnSi
2018	L. Braicovich and G. Ghiringhelli	High-resolution Resonant Inelastic X-ray Scattering (RIXS)

▲ **Table III:** Europhysics Prize of CMD, list of laureates.

Perspectives

The award-winning work discussed above is inconceivable without the existing fertile ground for research in Europe. Many European physics institutes host internationally leading condensed matter groups with great impact, along with highly talented and successful young researchers, often working in worldwide collaborations: they form the basis for future innovative work. In spite of insufficient funding as a whole, European science can count on a coordinated public policy on the EU level, with, notably, the highly successful ERC and Marie Curie-Sklodovska schemes, that promote flourishing individual research as well as exchange. It is our task at EPS – and at CMD - to reflect on European research strategies, help define them, and to propel physics as a discipline essential both for gathering fundamental knowledge and for fostering innovative solutions to solve modern-day problems.

Condensed Matter Physics is a very broad field that touches some of the deepest phenomena in nature: symmetry breaking, quantum mechanics, superconductivity, superfluid matter, fractional charges, topological properties, complex systems, to name but a few. It has undergone many great changes in the last decade or two, with the advent of new experimental techniques with stunning resolution and precision, of new *in situ* and *operando* techniques, the treatment of data sets the magnitude of which was inconceivable until recently, and the use of phenomenal computational power. Developments in material physics, notably nanomaterials, functional materials, and hybrid materials set the stage for new revolutions. The impact of condensed matter physics and its methods on disciplines such as chemistry and the life sciences is greater than ever. Thus, the developments in condensed matter research enable the technologies of our modern, technological society, and allow physicists to work at the frontiers of both science and technology. EPS - CMD and its sections have represented and accompanied the strong European Condensed Matter community over the last 50 years. and are committed to not only continue doing so, but to play a central role as a forum for discussion, reflection, organization, and proposition - for at least the next 5 decades! ■

About the Authors

Jozef T. Devreese is emeritus professor at Universiteit Antwerpen (Belgium), where he founded the research group TFVS (Theoretische Fysica van de Vaste Stoffen). He is also 'professor extraordinarius' at the Technische Universiteit Eindhoven (the Netherlands). He notably contributed to the theory of polarons, to quantum theory of solid matter, to superconductivity, and superfluidity, and to nanophysics). Jozef was chair of the first CMD General conference, CMD1 Antwerp, in 1980, chair of the EPS Condensed Matter Board from 1980 to 1986, and member of the Board from 1989 until 1995.

Eoin O'Reilly is Professor of Physics at University College Cork, Ireland, and Chief Scientist at Tyndall National Institute. His research interests mainly concern the physics and applications of semiconductor devices and materials and optoelectronics. Eoin O'Reilly chaired CMD19 in Brighton in 2002. He was Chairman of the EPS Condensed Matter Division Board from 2006 to 2014.

C.J. (Kees) van der Beek is a senior researcher at the French Centre National de Recherche scientifique, and head of the Physics of Light and Matter Department of the newly founded Université Paris-Saclay. His research interests concern superconductivity, magnetism, and the physics of disordered materials. Kees chaired CMD25 in Paris in 2014, and has been EPS-CMD Board chair since 2015.

▾ **FIG. 4:** Anna Minguzzi, Eoin O'Reilly, and Jean-Marc Triscone at CMD25, Paris, 2014.

2017	Jacob Klein	Soft and liquid matter under confinement
2014	Robert Evans	Application of density functional theory to the statistical mechanics of liquid matter,
2011	David Chandler	The molecular nature of liquid matter
2008	Henk Lekkerkerker and Peter Pusey	The phase behaviour of, in particular, rodlike and plate-like colloids
2005	Jean-Pierre Hansen	The statistical mechanics of complex fluids and biomolecular assemblies

◂ **Table IV:** Liquid Physics Prize of CMD, list of laureates.