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THE MAGAZINE OF THE EUROPEAN PHYSICAL SOCIETY

The Stern-Gerlach experiment
Interview with Mike Kosterlitz
EPL in an eventful environment
Moiré with flat bands is different
Zeno's Paradox - Some thoughts

50/3
2019

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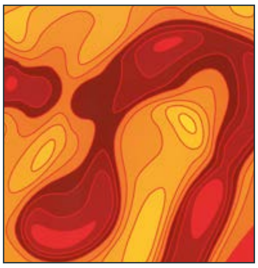
Cover picture: Painting by Juergen Jaumann. It shows Stern and Gerlach and is on display in the physics building of the University Frankfurt. See article "The Stern-Gerlach experiment re-examined by an experimenter" p. 15

▲ PAGE 12

Interview with Mike Kosterlitz



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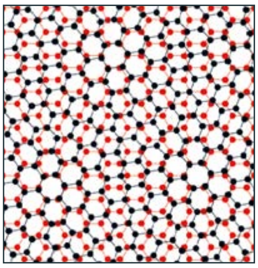
EPL in an eventful environment



▲ PAGE 24

Moiré with flat bands is different

[EDITORIAL]

Let's better support our postdoctoral researchers!

When trying to find out at which career stage women are most likely to quit academic physics I not only learnt that it was after the first postdoc, I also realized that the postdoc phase is the most vulnerable phase in every young researcher's career.

The reasons for this are varied: first and foremost the group leader who hires the postdoc is not so much interested in the career of this young scientist as s/he is in the success of his/her own project for which this postdoc was hired. In times when the work pressure is high due to increasingly lower success rates of grant proposals and rising student numbers, it is the career counseling of young collaborators which often gets lower priority.

Secondly, many postdocs do not realize that for their next career step in academia they do not need only good papers but develop a set of skills, which go well beyond what they learnt during the PhD. To be considered interesting as a tenure track candidate, the selection committee would like to see affinity for and budding experience in teaching; some indication that future fund raising attempts will be successful; confirmation that the candidate will be capable of supervising BSc, MSc and PhD students and signs of leadership such as organizing colleagues in a journal club, or, to stay within EPS, engagement in Young Minds. Obviously also postdocs aiming for a position outside academia, need to realize that they have to develop a variety of skills beyond research to become attractive for their potential employers.

Thirdly, the postdoc phase is also the time when many young researchers start a family with consequently completely new requests on their time and energy, which cannot be delegated or postponed.

I would therefore like to appeal to each and everyone, who employs a postdoc, to spend enough dedicated time with him/her to discuss these issues and to help her/him to organize their work in a way that they can also develop these skills as well as have a good work/life balance. I believe it is also important that postdocs, next to their research tasks, are given challenging assignments, in which they can learn about management, research planning, finances, in short all the things I would have liked to learn from a mentor instead of on my own later. As a boost of my self-confidence, I would have appreciated if my supervisors had told me more often when I did things well but also if every one of them had given me feedback when things went wrong.

We should all stimulate our universities to organize networking and training opportunities for postdocs, to provide them with grant writing skills, let them develop competences in teaching and maybe acquire a basic teaching certificate, or learn how to do outreach. Very often postdoc contracts are considered too short to invest a lot in their professional development but who should do it if not their employers? Many Graduate Schools throughout Europe now offer soft skills courses for PhD students where they acquire competences useful for future careers – this offer should be open to those postdocs who did not have such opportunities during their PhD and complemented with special modules just for postdocs. I am sure that also learning how to think about setting out several research projects in parallel, hearing more about interviewing and hiring, *etc.* could all be of great help to our future academics. Postdocs envisioning a career outside academia would enormously profit from learning about IP issues (theory & practice), following an entrepreneurship seminar or a Mini-MBA in the form of an intensive week where they absorb entrepreneurial and business basics. As an alternative to universities and research institutes, Physical Societies could offer such talent development initiatives as satellite events of their national conferences. EPS will support this by offering a "train the trainers" workshop in 2020, where a delegate of each member society will be trained in how to organize (and give) talent development and grant writing workshops.

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We should also ask our funding agencies to allow for prolonging a postdoctoral contract after a maternity/paternity leave for the same time as the leave: right now, postdocs starting a family are often disadvantaged because after the paid leave there is no possibility to compensate for the time dedicated to the family with extra research time afterwards and not all grant schemes take parenting time into account. ■

▲ Photo ©S. Germes

Petra Rudolf,
EPS President

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EPS Council 2019

The annual Council Meeting of the European Physical Society was held on 5-6 April 2019 at the Science Faculty of the University of Split, Croatia . The EPS Council is composed of representatives of the 42 EPS Member Societies and the chairpersons of the 12 Divisions, 6 Groups, and 6 Committees. Individual Members and Associate Members are each represented by 5 elected delegates.

The Council meets for a variety of reasons. There are extensive reports, covering the activities and finances of the previous year[1].

EPS Council delegates were warmly welcomed by the Vice-rector for Science, Leandra Vranješ Markić, and the Dean of the Science Faculty, Nikola Koceić-Bilan. Ante Bilušić also welcomed the EPS on behalf of the Croatian Physical Society.

Throughout 2018, the EPS organized many events celebrating its 50th anniversary. The real highlight of the year was the Festakt, which took place at the University of Geneva “Les Bastions”, in the same room as the inaugural meeting of the EPS in 1968. The programme included talks by Professor Luisa Cifarelli on "The European Physical Society: its story and impact", Professor Serge Haroche on "How blue sky science and technology nurture each other: the example of quantum physics", Professor Jean-Pierre Bourguignon on "The Pursuit of Knowledge as European Endeavour" and Professor Ernst-Ulrich von Weizsäcker on "Science and Long-term thinking". A round table discussion, led by Professor Martina Knoop on "The role of physics and science in our civil society" rounded out the session. The EPS Council thanked the immediate past President, C. Rossel for his hard work and dedication in making EPS 50 a success.

Conferences are an area where the EPS and its Divisions and Groups are traditionally strong. These conferences are often among the best conferences in their respective fields, where the latest developments in physics research are presented. They are also excellent for community building, networking and career development. Overall, the EPS organized 21 conferences in 2018.

EPS's flagship publication is EPL, a journal that publishes high quality letters in all fields of physics. In 2018, B. van Tiggelen became the Editor in Chief, assisted by 2 Deputy Editors, R. Citro and G. Muga. A main task in 2018 was the renewal of the Editorial Board, with over 20 new co-editors. While the journal has some strong points, it is facing major challenges. As a broad band journal, EPL has stiff competition from specialist journals. The community is slow to take up open access, and EPL will need to address this issue in the coming year. Nonetheless, EPL is enhancing its content with invited Perspectives and Focus Issues.

EPN is the EPS news magazine. It publishes highlights from other journals, editorials and opinions and news from the EPS. It also publishes

[1] the annual report can be downloaded here: https://www.eps.org/resource/collection/B56A47A3-6FCC-4E8F-A6EA-86F2532E8C2B/05_EPS_Council_2019_Activity_report_2018.pdf

scientific features on topics of interest to the physics community in general. The EPN Editor, V. Velasco, and the Science Editor, F. Iglói encourage all EPS Member Societies, Divisions and Groups to send in information on their activities to make the magazine more lively. In the course of 2019, E. de Wolf will take over as EPN Editor.

Distinctions and awards are another traditional activity of the EPS. Many of the Division and Group prizes anticipate the Nobel Prize. Awards serve to recognize the achievements of senior researchers, and are key elements in the career development of young researchers as well. The EPS and its Divisions and Groups awarded 14 prizes in 2018.

The Historic Sites programme remains popular. There are currently 46 sites in 22 countries. The EPS inaugurated 6 new Historic Sites in 2018, with another 2 already in 2019. K. Grandin, the chairperson of the EPS History of Physics Group has accepted to become the chairperson of the EPS Historic Sites Committee. Council warmly thanked the outgoing chairperson, L. Cifarelli who initiated the programme in 2012.

In 2018, the EPS published 3 statements:

- "Physics for Knowledge, the Economy and Society", with recommendations for the next Framework Programme of the European Commission;
- "EPS Response to Plan S", with comments on the transition to open access proposed by Coalition S;
- EPS Response to the "Future of Scholarly Publishing and Scholarly Communication".
- The EPS continues to work on documents demonstrating the role of physics in society. It has commissioned a study on the Importance of Physics to the Economies of Europe, which will be released in September 2019.

▲ EPS Past President Rüdiger Voss receives a gift from EPS President Petra Rudolph, on behalf of EPS.

The Young Minds Programme continues to be popular, with 57 sections in 30 countries. The Young Minds Action Committee is working with EPS Divisions and Groups to organize sessions for young researchers during D/G conferences.

EPS Distinctions 2019

The following individuals were elected as Fellows of the EPS:

- **Giulio Cerullo**, for his seminal contributions to the field of ultrashort pulse generation and applications to spectroscopy of molecules and solids, complemented by extensive service to the European photonics community within EPS.
- **Yves Sirois**, for his outstanding contributions to experimental high energy particle physics including a prominent role in the analyses leading to the discovery and characterization of the Higgs boson with the CMS experiment at the LHC, his leadership in the analysis of events at high Bjorken Q2 in deep-inelastic collisions with the H1 experiment at HERA, and wide range of developments in calorimetry detector techniques.
- **Kees van der Beek**, for his outstanding contributions in the field of superconducting vortex physics and his great engagement and leadership in the Condensed Matter Physics Division of EPS.

▼ EPS Council members following the activities.

The 2019 EPS Gero Thomas Medal was awarded to **Professor Sir John Enderby** for his lifelong commitment to European collaboration across all fields and ground breaking neutron research.

The European Physical Society would like to thank the University of Split for hosting the EPS Council meeting 2019 in particular Professor Ante Bilušić and his team for the excellent organization of the meeting.

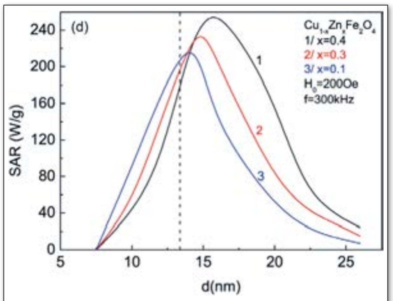
David Lee
EPS Secretary General

Highlights from European journals

CONDENSED MATTER

Magnetic nanoparticles can 'burn' cancer cells

Magnetic hyperthermia is still a highly experimental cancer treatment, but new research shows that the therapy is tunable



▲ The specific absorption rate

Unfortunately, cancer isn't simply a single disease, and some types, like pancreas, brain or liver tumours, are still difficult to treat with chemotherapy, radiation therapy or surgery, leading to low survival rates for patients. Thankfully, new therapies are emerging, like therapeutic hyperthermia, which heats tumours by firing nanoparticles into tumour cells. In a new study published recently, the authors show that tumour cells' specific absorption rate of destructive heat depends on the diameter of the nanoparticles and the composition of the magnetic material used to deliver the heat to the tumour. The authors show that the tumour absorption rate greatly depends on the diameter of the nanoparticles. Surprisingly, the absorption rate increases as particle diameter increases, as long as the level of doping of the material is sufficiently high and the diameter doesn't exceed a set maximum value (max. 14 nanometres for cobalt doping, 16 nm for copper). ■

■ **A. Apostolov**, **I. Apostolova** and **J. Wesselinowa**,
' Specific absorption rate in Zn-doped ferrites for self-controlled magnetic hyperthermia', *Eur. Phys. J. B* **92**, 58 (2019)

APPLIED PHYSICS

Optimising proton beam therapy **with mathematical models**

New model improves our understanding of energy transfer in radiotherapy treatment plans by replacing 50-year-old parameters with more complex ones

Particle beam therapy is increasingly being used to treat many types of cancer. It consists in subjecting tumours to beams of high-energy charged particles such as protons. Although more targeted than conventional radiotherapy using X-rays, this approach still damages surrounding normal tissue. To design the optimum treatment plan for each patient, it is essential to know the energy of the beam and its effect on tumour and normal tissue alike. In a recent study, a group of researchers put forward a new mathematical model outlining the effects of these beam therapies on patients' tissues, based on new, more complex, parameters. Using these new models, clinicians should be able to predict the effect of proton beams on normal and tumour tissue more precisely, allowing them to prepare more effective treatment plans. ■


▲ The MEVION S250™ with Verity Patient Positioning System™ installed at S. Lee Kling Proton Therapy Center at Siteman Cancer Center at Barnes-Jewish Hospital and Washington University School of Medicine in St. Louis. Credit: Romina Cialdella / CC BY-SA 4.0.

■ **R. Abolfath, Y. Helo, L. Bronk, A. Carabe, D. Grosshans** and **R. Mohan,**
'Renormalization of radiobiological response functions by energy loss fluctuations and complexities in chromosome aberration induction: deactivation theory for proton therapy from cells to tumor control', *Eur. Phys. J. D* **73**, 64 (2019)

QUANTUM PHYSICS

Infinite number of quantum particles gives clues to big-picture behaviour at large scale

Scientists gain a deeper understanding of phenomena at macroscopic scale by simulating the consequences of having an infinite number of physical phenomena at quantum scale

In quantum mechanics, the Heisenberg uncertainty principle prevents an external observer from measuring both the position and speed (referred to as momentum) of a particle at the same time. They can only know with a high degree of certainty either one or the other—unlike what happens at large scales where both are known. To identify a given particle's characteristics, physicists introduced the notion of quasi-distribution of position and momentum. This approach was an attempt to reconcile quantum-scale interpretation of what is happening in particles with the standard approach used to understand motion at normal scale, a field dubbed classical mechanics. In a new study published recently, the authors reverse this approach; starting with quantum mechanical rules, they explore how to derive an infinite number of quasi-distributions, to emulate the classical mechanics approach. This approach is also applicable to a number of other variables found in quantum-scale particles, including particle spin. ■

▲ Werner Heisenberg. Bundesarchiv_Bild 183-R57262 / Unknown / CC-BY-SA 3.0 [CC BY-SA 3.0 de (https://creativecommons.org/licenses/by-sa/3.0/de/deed.en)

■ **J. S. Ben-Benjamin, L. Cohen** and **M. O. Scully,**
'From von Neumann to Wigner and beyond',
Eur. Phys. J. Spec. Top. **227**, 2171 (2019)

SOFT MATTER

Liquid jets break up **more readily on a substrate**

Using computational models to investigate how liquid drops behave on surfaces

▲ Filaments

Whether we're aware of it or not, in day-to-day life we often witness an intriguing phenomenon: the breakup of jets of liquid into chains of droplets. It happens when it rains, for example, and it is important for inkjet printers. However, little is known about what happens when a liquid jet, also known as a liquid filament, breaks up on top of a substrate. According to a new study, the presence of a nearby surface changes the way the filament breaks up into smaller droplets. In a new paper published recently, computer simulations are used to show that a filament is more likely to break up near a surface. When a filament is broken into multiple droplets, the structure is unstable because surface tension means liquids tend to shrink to have the smallest-possible surface area. ■

■ **A. Dziedzic**, **M. Nakrani**, **B. Ezra**, **M. Syed**, **S. Popinet**, and **S. Afkhami**,
'Breakup of finite-size liquid filaments: Transition from no-breakup to breakup including substrate effects',
Eur. Phys. J. E **42**, 18 (2018)

NUCLEAR PHYSICS

Shape stability of pasta phases

Exotic non-spherical shapes of nuclear matter, so called pasta phases, are possible because of the competition between the short-ranged nuclear attraction and the long-ranged Coulomb repulsion, leading to the phenomenon of Coulomb frustration, well known in statistical mechanics. Such complex phases are expected in the inner crust of neutron stars, as well as in core-collapse supernova cores.

The authors of this work examine for the first time the stability of the « lasagna » phase, consisting of periodically placed slabs, by means of exact geometrical methods. Calculations are done in the framework of the compressible liquid drop model but obtained results are universal and do not depend on model parameters like surface tension and charge density. The stability analysis is done with respect to the different types of deformations corresponding to the eigenvalues of the deformation matrix.

Their compelling result is that this slab phase is locally stable in the whole density interval where pasta phases are present. Consequently, this specific phase could be present as a metastable structure in a larger density domain than previously expected, with potential important consequences on the resistivity of the crust and the cooling mechanism of neutron stars. ■

■ **S. Kubis** and **W. Wócjik**,
'Shape stability of pasta phases: Lasagna case',
Eur. Phys. J. A **54**, 215 (2018)

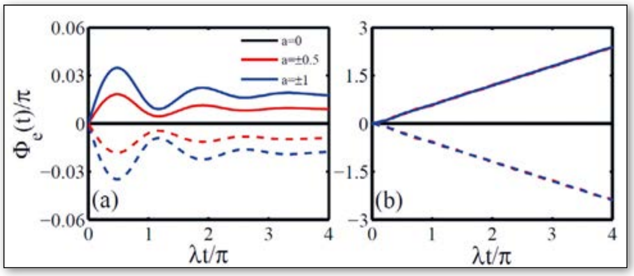
QUANTUM PHYSICS

Geometry of quantum evolution in a nonequilibrium environment

New ultra-fast laser method aims to improve control over the electron's degree of freedom, called spins, could enhance memory storage devices

The geometric effect of quantum dynamical evolution has potential applications in studying quantum phase transition and realizing geometric quantum computation. Due to the fact that a quantum system unavoidably interacts with its environments and undergoes decoherence, much extensive attention has been paid to theoretical investigations on the geometric dynamical evolution in open quantum systems under nonunitary dynamics. The investigation on the geometry in the dynamical evolution of an open quantum system is crucial for further understanding the origins of decoherence, quantum-classical transition and so on.

There are many significant situations where the nonequilibrium feature of the environment becomes dominant. In these



▲ Effective geometric phase Φe(t) as a function of evolution time t for different values of a with θ = π/2 in (a) the Markovian dynamics region with ν =0.5λ and κ = λ and (b) the non-Markovian dynamics region with ν =2λ and κ = λ (the solid and dashed lines are plotted for a>0 and a< 0, respectively)

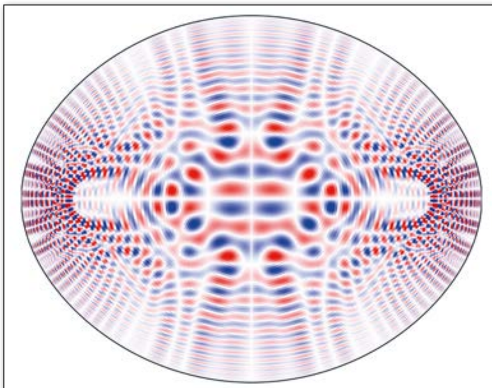
situations, the statistical properties of the environmental noise are nonstationary, corresponding physically to impulsively excited phonons of the environment in certain nonequilibrium states initially. We show that the renormalization of the intrinsic energy of the system, namely, the frequency shift induced by the nonequilibrium feature of the environment has a significant impact on the geometry of quantum dynamical evolution. ■

■ **X. Cai**, **R. Men**, **Y. Zhang** and **L. Wang**,
'Geometry of quantum evolution in a nonequilibrium environment', *EPL* **125**, 30007 (2019)

ASTROPHYSICS

Correlated chaotic pressure **modes in rapidly rotating stars**

Pressure oscillations in stars can be monitored through the Fourier analysis of luminosity curves, observed *e.g.* in recent and future space missions. Similarly to seismologists on Earth, astronomers use the oscillation modes of stars to access properties of their interiors. This method has been very successful for slowly rotating stars. For rapidly rotating stars, since the star is flattened by centrifugal acceleration, the acoustic ray dynamics is more complex, with both regular and chaotic zones in phase space. The authors study the properties of chaotic modes in the domain of high frequencies. The numerical simulations show that chaotic modes produce specific regularities in the oscillation spectra. This is at odds with the expected properties of chaotic modes, usually distributed like the eigenvalues of random matrices. Through a semiclassical theory, they link this peculiarity to the strong decrease of the sound speed near the star surface. Chaotic modes could contribute to the regularities observed in δ Scuti stars, attributed so far to regular modes. ■



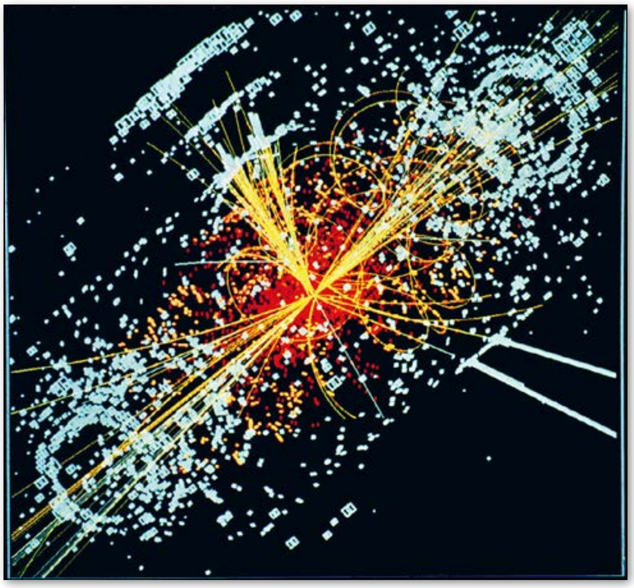
◀ Meridional section of a chaotic mode. The pressure *P* is represented, scaled by the distance to the rotation axis and the equilibrium density.

■ **B. Evano**, **B. Georgeo** and **F. Lignières**,
'Correlations in the chaotic spectrum of pressure modes in rapidly rotating stars', *EPL* **125**, 49002 (2019)

THEORETICAL PHYSICS

Turbulence theory closer to high-energy physics than previously thought

A new research paper finds the high-energy physics concept of 'un-naturalness' may be applicable to the study of turbulence or that of strongly correlated systems of elementary particles



▲ Higgs event at CERN Picture. Credit: Lucas Taylor / CERN CC BY-SA 3.0

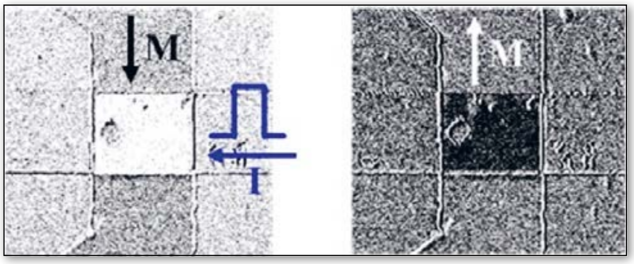
Many scientists have been disappointed that no new elementary particles have been discovered at CERN's Large Hadron Collider in the wake of the Higgs boson discovery in 2012. The no-show of elusive particles that had previously been predicted by theory is only one example of a 'hole' that has recently appeared in the concept of Naturalness in theoretical physics. In simple terms, the concept states that physical parameters should depend roughly equally on all the terms used to calculate them, in terms of proportion. Sauro Succi, a theoretical physicist at the *Fondazione Istituto*

Italiano di Tecnologia in Rome, Italy, has now published an intriguing essay in which he argues that several common natural phenomena do not operate under 'Naturalness' at all. Rather, they can only be explained using parameters with widely separated numerical values. ■

S. Succi,
'Of Naturalness and Complexity', *Eur. Phys. J. Plus* **134**, 97 (2019)

APPLIED PHYSICS

Efficiently manipulating magnetism with a sputtered **topological insulator**



▲ Magneto-optic Kerr microscopy imaging of the current induced SOT switching measurements.

The field of spintronics aims to efficiently control the magnetic state of magnetic material using electric currents for better magnetic memories. In this regard, the spin-orbit coupling (SOC) effect, which couples the orbital and spin degrees of the freedom of electrons, has received enormous research attention. The SOC provides a pathway to convert an electric current in a non-magnetic material to a spin current which can subsequently be utilized for fast and efficient control of a magnetic material.

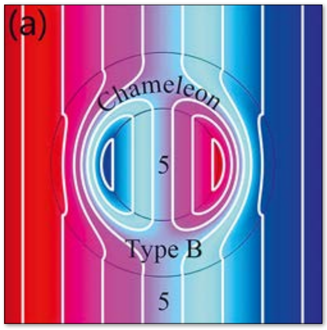
Recently, the material topological insulator (TI) has gained research interest due to its exotic properties including high SOC effect. Although earlier works have utilized the SOC effect of TI to efficiently control the magnetization, the TI material was mostly grown using molecular beam epitaxy technique which is not common in the memory industry. In this work, the authors utilize the more common growth technique of sputtering to grow the TI material (Bismuth Selenide), which allows both the TI and the magnet to be grown *in situ*. Subsequently, the authors demonstrate a highly efficient switching of the magnetic information storage layer using the high SOC from the sputtered Bismuth Selenide. ■

R. Ramaswamy, T. Dutta, S. Liang, G. Yang, M. S. M. Saifullah, and **H. Yang,**
J. Phys. D: Appl. Phys. **52**, 224001 (2019)

MATERIALS SCIENCE

Intelligent metamaterials behave **like electrostatic chameleons**

Metashells can adapt their wave-bending behaviour based on the characteristics of the material they contain



▲ Chameleon-like behaviour.

A chameleon can flexibly change its colour to match its surroundings. And a similar phenomenon can now be seen in a new class of smart materials called metamaterials. The trouble is that these metamaterials lack the ability to respond to nearby objects due to their physical characteristics. To remedy this shortcoming, the authors have developed so-called 'metashells': hollow shells made of metamaterials and capable of carrying materials in their core. The advantage is that their physical characteristics, such as permittivity–the extent to which a material can store charge within an electrical field–change with the electromagnetic properties of the material they contain. In a theoretical study published recently, they describe how they have developed an entire class of these chameleon-like metashells. These intelligent metashells could become an all-purpose material to satisfy different permittivity requirements under different conditions. The next stages will focus on experimental research, and on industrial applications. ■

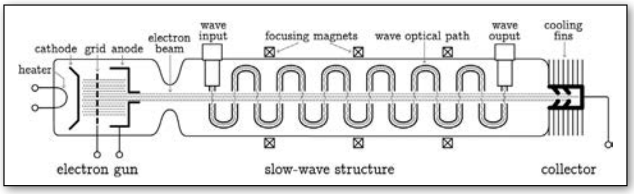
L. Xu and **J. Huang,**
'Electrostatic chameleons: Theory of intelligent metashells with adaptive response to inside objects', *Eur. Phys. J. B* **92**, 53 (2019)

PHYSICS HISTORY

Traveling-wave tubes: the unsung heroes of space exploration

An invention from the 1950s is still being used today

What do televisions and space exploration have in common? No, we're not talking about a cheesy physics joke; rather, this is the story of an often-overlooked piece of equipment that deserves a place in the annals of telecommunication history. Some would argue that the traveling-wave tube (TWT) has not received the recognition it deserves when it comes to the history of space travel and communications – until now. A group of researchers has published recently a work looking into the



▲ The traveling-wave tube.

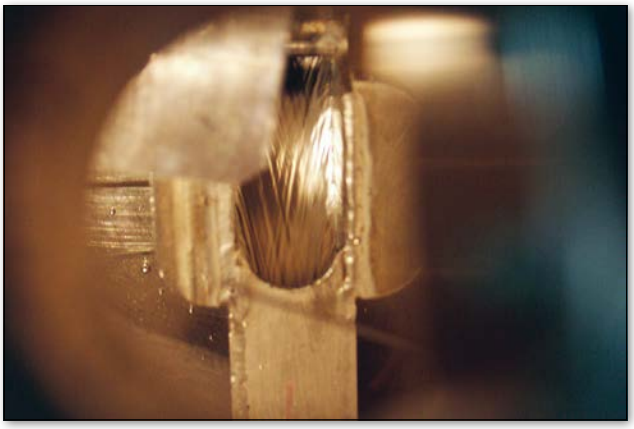
history of TWTs. This is the first time a paper aimed at the general public has described the vital role of this technology in various areas of development. The team collected and read hundreds of papers on the history and evolution of the traveling-wave tube. First introduced in the 1950s, a TWT is a relatively simple piece of equipment used for transmitting data across long distances, including the vast expanses of space. ■

▮ **D.F.G. Minenna, F. André, Y. Elskens, J.-F. Auboin, F. Doveil, J. Puech** and **E. Duverdier**,
'The traveling-wave tube in the history of telecommunication, *Eur. Phys. J. H* **44**, 1 (2019)

NUCLEAR PHYSICS

A Liquid-Lithium Target for Nuclear Physics

A liquid-lithium target (LiLiT) bombarded by a 1.5 mA, 1.92 MeV proton beam from the SARAF superconducting linac acts as a ~30 keV quasi-Maxwellian neutron source via the ^{7}Li(p,n) reaction with the highest intensity (5×10^{10} neutrons/s) available to date. We activate samples relevant to stellar nucleosynthesis by slow neutron capture (s-process). Activation products are detected by α, β or γ spectrometry or by direct atom counting (accelerator mass spectrometry, atom-trap trace analysis). The neutron capture cross sections, corrected for systematic effects using detailed simulations of neutron production and transport, lead to experimental astrophysical Maxwellian averaged cross sections



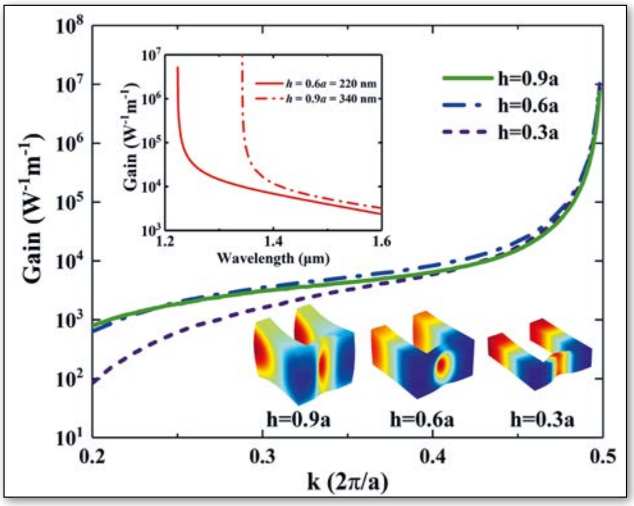
▲ The free-surface LiLiT flow, photographed while bombarded by a ~ 3 kW continuous-wave proton beam from the SARAF linac. The liquid lithium jet, ~1.5 mm thick, forced-flown at a velocity of 2.5 m/s at ~ 195 °C and supported by a 0.5 mm thick stainless steel backing wall, serves both as a neutron-producing target and the power beam dump. The target chamber pressure connected to the accelerator beam line is 1×10^{-6} mbar.

(MACS). A parallel effort to develop a LiLiT-based neutron source for cancer therapy is ongoing, taking advantage of the neutron spectrum suitability for Boron Neutron Capture Therapy (BNCT) and the high neutron yield available. ■

▮ **M. Paul** and **16 co-authors**,
'Reactions along the astrophysical s-process path and prospects for neutron radiotherapy with the Liquid-Lithium Target (LiLiT) at the Soreq Applied Research Accelerator Facility (SARAF)', *Eur. Phys. J. A* **55**, 44 (2019)

APPLIED PHYSICS

Exploiting Slow Light for Stimulated Brillouin Scattering



▲ Forward SBS gain with different waveguide heights as k varies from 0.2(2π/a) to 0.5(2π/a)

Stimulated Brillouin scattering (SBS) is an important third-order nonlinear process. The main challenge of utilizing SBS in silicon photonic waveguides is that the SBS gain coefficient is too weak to generate efficient power conversion between optical waves and acoustic waves.

In a recent study, the authors show how to improve the SBS process in a periodic suspended silicon waveguide by exploiting the slow light characteristic. They focus on tuning the structural parameters and working wavelength of the device to exploiting the resonance enhancement effect to amplify the weak SBS phenomenon. The calculated SBS gain coefficient is shown to be in the order of 10^{6} $W^{-1}m^{-1}$. They also prove the feasibility of the device design using standard silicon-on-insulator wafers. The slow-light waveguide provides a powerful platform for light-sound interaction through SBS process. ■

▮ **Y. Xu, L. Zhou, L. Lu, J. Chen,** and **B. M. A. Rahman,**
'Enhanced forward stimulated Brillouin scattering in silicon photonic slot waveguide Bragg grating',
J. Phys. D: Appl. Phys. **52**, 184001 (2019)

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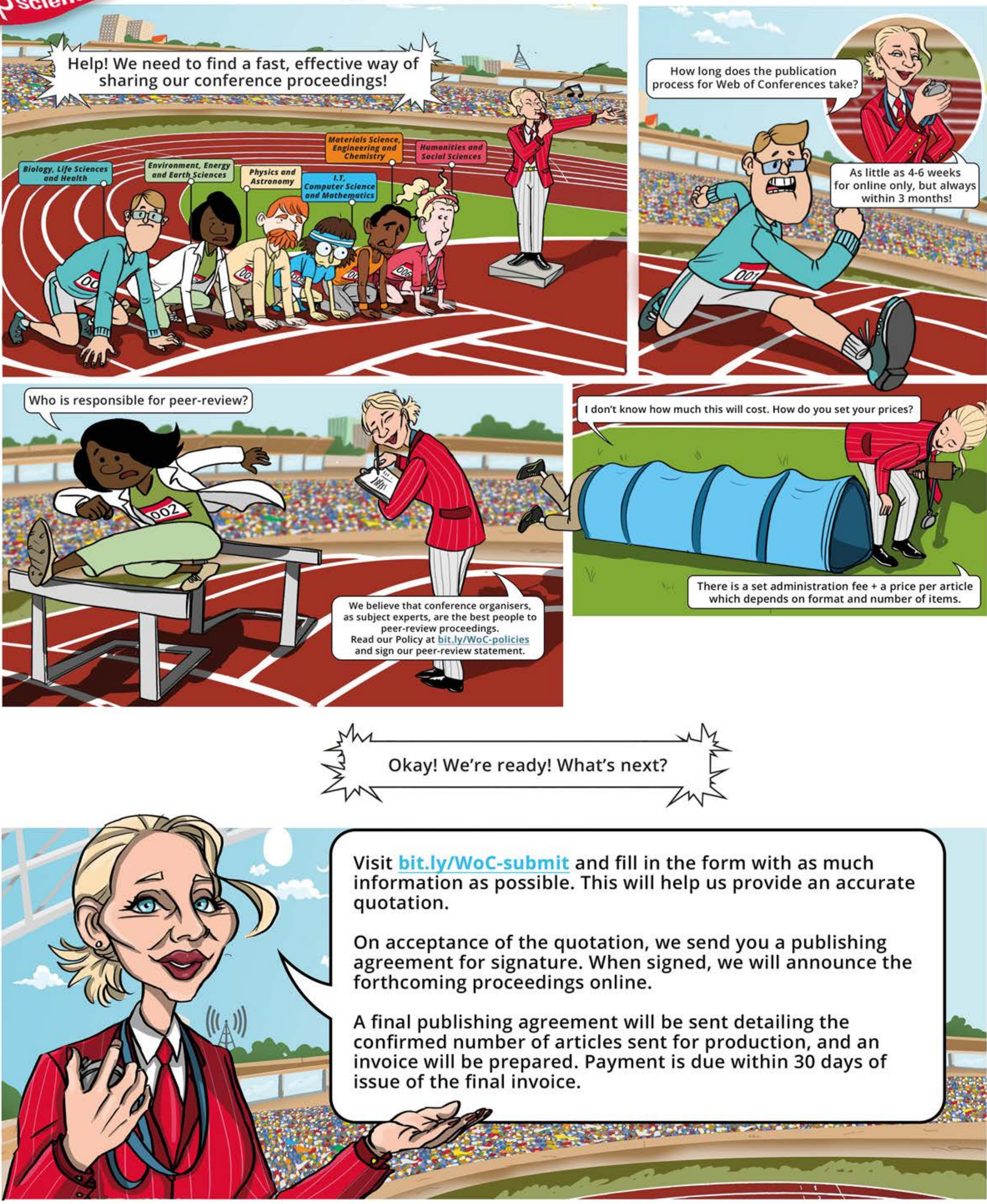

Interview with Mike Kosterlitz

Patrícia F.N. Faísca[1] and Rui D.M. Travasso[2] – DOI: https://doi.org/10.1051/epn/201931

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In the summer of 2018, Professor Michael Kosterlitz visited Portugal as a plenary speaker of the FÍSICA2018 conference organised by the Portuguese Physical Society (SPF) and by the University of Beira Interior. FÍSICA 2018 comprised two meetings: the 28th Iberian Meeting for Physics Teaching, and the 21st National Conference of Physics, a biannual event that brings together researchers from all areas of Physics working in Portugal.

FÍSICA 2018 was a fruitful encounter between researchers, high-school teachers and students interested in sharing experiences and in discussing the state-of-the-art of research in Physics. Professor Kosterlitz's talk entitled "Topological defects and phase transitions – Vortices and dislocations (A random walk through physics to a Nobel Prize)" was integrated in the 21st National Conference of Physics.

During his visit, Professor Kosterlitz was interviewed by Patrícia Faísca, from the Department of Physics and BioISI (University of Lisboa), and by Rui Travasso from the Department of Physics and CFisUC (University of Coimbra).

Vita

Professor Kosterlitz is currently the Harrison E. Farnsworth Professor of Physics at Brown University, where he has been teaching and doing research since 1982. He was born in Aberdeen (Scotland, UK) in 1943. He studied at the University of Cambridge (1961-1966), and did a DPhil in high-energy physics at the University of Oxford (1969). He then went to the University of Birmingham, and decided to move into the field of condensed matter physics, working as a post-doc with David Thouless (1970-1973). Together they published a paper [1] on phase transitions in two-dimensional systems (in the XY-model), where they introduced a novel type of long-range order based on the overall properties of the system (instead of the two-point correlation function), and to which they referred as topological order. The latter gives rise to an unusual phase transition, known as the Kosterlitz-Thouless (KT) transition, which underlies the superfluid transition in ^{4}He films. The importance of this work was recognized with the Nobel Prize in Physics in 2016, which Professor Kosterlitz (prize share: 1/4) and Duncan Haldane (prize share: 1/4) shared with David Thouless (prize share: 1/2). Prior to receiving the Nobel Prize his contributions to Physics were recognized with the Lars Onsager Prize (2000), and with the Maxwell Medal (1981). Professor Kosterlitz is a passionate mountaineer and in his youth he was considered one of the best climbers in Britain. In 2017 he was awarded the prestigious Climbing Ambassador prize at the Arco Rock Legends Awards. This prize recognizes "those who, through their passion, energy and vision have guided and influenced the development of this sport".

1. How did the environment in your household while you were a kid drive your curiosity towards science?

I guess you could say my parents didn't try to influence what I studied at all. I gravitated naturally towards maths and science because I have a lousy memory, and all the humanity subjects required too much memory. So I didn't handle them very well. But I found maths and science didn't require too much memory. And I could handle them with logic and deduction, which suited my way of functioning.

2. In line with what you have just said, in your Nobel biography [2] you mention that you could do best in Physics and Mathematics than in Chemistry because your "ability to make logical deductions compensated for your unreliable memory". Was this the main reason why you decided to become a physicist?

I think so. One of the other reasons was that although I really like Chemistry I decided it was too dangerous. One time I was just holding a test tube of a colourless liquid, wondering what to do with it… Then I noticed it was changing colour for no reason at all, so held it out away and then boom! It exploded. So I decided, Chemistry is not for me, it's too dangerous. Chemistry was fun because I could mostly control when something exploded, but then I realized there were some things I couldn't control. So I decided, no, this is too dangerous. Theoretical Physics is much safer.

3. What, in your opinion, are the main advantages of taking a degree in Physics? Do you take the view that a background in Physics is the best to develop problem-solving abilities?

Yes, I suppose that Physics is about the only subject in which you learn how to solve problems. In Mathematics the things you learn are about problems that are already solved, whereas in Physics any problem is given as a set of words disguising a problem, and one learns how to understand the problem and to solve it. So I think Physics is a good subject to learn for this reason.

4. In 2017, i.e., one year after being awarded the Nobel Prize in Physics, you received the Climbing Ambassador at the Arco Rock Legends Awards. How do you rate the importance of this prize?

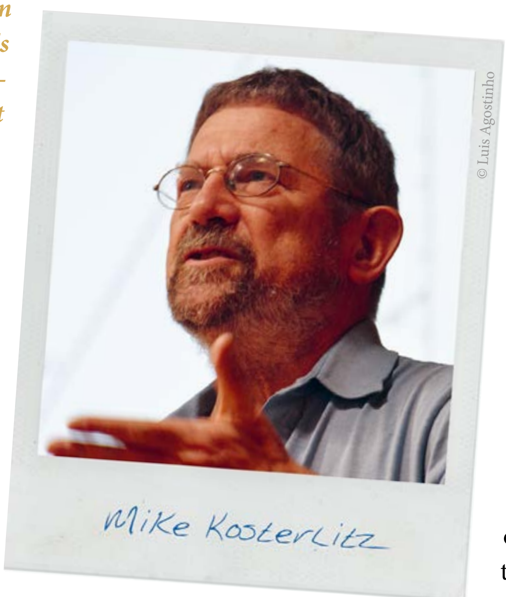
To me it is as important as the Nobel Prize.

5. We understand that it is not straightforward to explain the KT phase transition to the general public since it requires a substantial amount of Physics background. Do you teach it to your students? How would you summarise it?

I don't teach it to undergraduates, because I think it's probably too sophisticated for the undergraduate level. But I do teach it as an advanced graduate course. If you happen to be interested in phase transitions, and you want to understand why a thin helium film goes from a super fluid to a normal fluid, then I would say that the only way to understand how a super flow can dissipate is through the creation of vortices and so, the KT theory is all about the properties of a collection of vortices in two dimensions. The good thing about two dimensions is that vortices are points, which is why Thouless and I studied this problem in two dimensions. David said vortices are important and complicated in three-dimensions and so, look at the problem in two-dimensions.

6. Regarding the presence of KT transitions in many different 2D systems (from XY-models to superfluids, from Bose-Einstein condensates to melting) which recent systems that have KT transitions would you highlight?

I think one of the most interesting applications is recent stuff on cold gases: cold atoms, clouds of cold atoms. If you make a two-dimensional system of this it is possible to have a KT transition in this system too, and surprisingly, the theory fits fairly well with the experimental data, although not as well as it does in superfluid or in two-dimensional melting. These transitions are associated with exactly the same Physics as superfluid helium, but the cloud is too small to really get good data from it.



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7. At the time, during your work in the KT transition, did you have the feeling of discovery? Was it obvious to you that the new type of transition would have a large impact in the community?

You have to remember that this was the first problem in condensed matter that I was involved in. I was a high-energy physicist before that, and I was getting very, very fed up with it because I was not getting anywhere. I was doing long, elaborate calculations basically for nothing. I got really tired of it when I was in Birmingham and I decided that I had to find another problem. So I was walking around the department asking everybody 'Do you have a problem that I may look at? Because I need something new'. And the answer in general was 'no' until I got to David Thouless's office. I asked him the question, and then I spent the next couple of hours in his office listening to him talking about various phenomena, staring at the board, writing equations and things. I was understanding very little of it. Eventually I got to admit I was not understanding a word of what he was talking about, and I thought I was looking like a complete idiot. So, I said, 'David, I'm sorry I have to stop you there. Could you please explain where the first equation that you wrote down came from?' He turned and said 'Didn't I tell you that?' And I could honestly say 'No, you didn't'. And he said 'Oh!' and then he proceeded to give me a very clear explanation, and from that point on, we went on very well together, and the rest is history. I was quite surprised because I was very nervous about going to Thouless's office because he had a reputation for, how should I say... not suffering fools gladly. And by his standards almost everybody else was a fool. So I knew that when I went up to talk to him I was leaving myself open to appearing like a complete idiot. But fortunately he made this mistake, and I decided in the future that every time I didn't understand him, I would assume he had done the same thing. And this worked. So we actually got on very well together.

8. Since you did not come from condensed matter Physics, you didn't realise at that time, or, at least, did not realise properly, the extent of the contribution that you were making, right?

No, no idea. To Thouless and I it was just an interesting theoretical problem that needed a solution, and that was the only reason we did it. A fascinating theoretical problem.

9. At what point did the impact hit you?

As I said, it was my first foray into condensed matter Physics, and I thought this is what Physics should be. Something new, some new ideas, and the possibility to put everything together and come up with a result. Thouless said that what we had done was very good and should be important but that was all we thought about it. We just knew we'd done something good. We wrote it up, had some trouble getting it published, because it was just too new. Eventually, as I discovered later, one referee just said 'I don't understand this stuff' but he let it through and it was published. It was not cited for the first 5-6 years - not even a single citation - and then suddenly, the citations started to come. Then Halperin and Nelson basically re-did the theory in a much simpler way, and basically came up with the same results, and then it took off.

10. In a recent review on KT Physics [3] you say that at the time you moved from high energy Physics to condensed matter Physics you were most of all searching for an interesting (but tractable) problem. Nowadays, in an era where fundable research should have a clear societal impact, working on an interesting problem is not necessarily the route for a successful career in science. Do you think that the current funding policies have a negative impact on the development of science and scientific progress?

Yes and no. Scientific progress needs money so that people can actually do the research. Therefore, the funding agencies are actually important for providing support for scientists. However, the funding agencies are normally interested - as you said - in more directed research rather than letting the researchers do what they want to do. And directed research is unlikely to produce a major breakthrough. The major breakthroughs are going to come from curiosity driven research. But the chances of a major breakthrough coming from a piece of research are actually very small, and it is impossible to say, ok, let's fund this person because he or she is going to produce a breakthrough. It's more like playing the roulette, spinning the wheel, and saying ok, we'll bet several thousand dollars that this piece of research is going to be important. And the chances are that you're going to lose, but occasionally you'll be hitting the jackpot. But not very often. So, I don't know what should be done, because you have to pay a scientist to live, to be able to work and to produce original research, but just because you pay money doesn't mean that you are going to have that piece of original research coming out. So, I don't know how you can do it.

11. In your Nobel biography [2] you state that during your stay in Cornell with Wilson and Fisher you came to learn "the importance of testing one's theory against the ultimate authority in Physics: experiment". As you know, several theoretical physicists (especially string theorists, cosmologists, but also some high energy physicists) are strong advocates of the principle that "elegance will suffice" (i.e. if a theory is sufficiently elegant and explanatory, it need not be tested experimentally). Do you consider (e.g. as George Ellis and Joe Silk [4]) that the integrity of Physics is at risk and should be defended?

A theory like string theory has produced essentially no new Physics. It has produced some important advances in pure Mathematics, and so on. So it has not been a waste of time. But I wouldn't agree with the statement that a theory does not have to have experimental proof because a theory without an experimental verification is exactly what? It's cold. It's a theory. It's nothing more than that. The way I look at Physics is: we live in a Universe that does its own thing. It does not care about your Mathematics; it does not care about my Mathematics. It does what it does. And our job is to try to explain, or to understand why the Universe is doing what it does. The best tool we have is Mathematics. A piece of Mathematics is a self-contained consistent scheme. And, in principle, within that scheme all the answers are contained in this piece of self-consistent Mathematics. But this whole mathematical structure has to be compared to the real world. And maybe it will work. Maybe it will agree with the real world. But more likely it won't. And I think that this is the relation between Mathematics and Physics, and the real world. And maybe it's the right structure to describe the real world, or maybe it is.

12. Can you tell us a little bit about your current research interests?

The problem that I've been trying to understand is a problem in non-equilibrium Physics. Many driven out-of-equilibrium systems do seem to come to some sort of stationary state, a time-independent state. I'm looking at a system that does have a deterministic part, and does have a set of stationary states. Then you put some noise onto it. Just simple additive noise. And I'm asking the question: Does a unique stationary state get picked out on average? It's exactly what happens when a system evolves to equilibrium. We do know that this is true, that it does come to some equilibrium, some unique stationary distribution. And this unique stationary distribution is picked out by the thermal fluctuations or stochastic noise. And I was thinking, maybe the same thing happens for a driven out-of-equilibrium system, that some stochastic noise is essential to pick out a unique stationary state. Or at least, some narrow band of stationary states. Numerically this seems to be what happens, at least in some simple systems. But when you try to go through the Mathematics of this… For a system approaching equilibrium you write down a Langevin equation and asymptotically it comes to the Boltzmann distribution, and you can go through the Mathematics and demonstrate this - not rigorously - but demonstrate this. For the out-of-equilibrium system, which looks very similar, you can go through the same piece of Mathematics, but suddenly you discover that everything falls apart. And that's the problem I'm trying to understand.

13. Many Physics graduates will end up working as part of interdisciplinary teams researching topics that may be outside the traditional realms of Physics. How do you think we can best prepare our students for this new reality?

Well, I don't know how one can't teach such things, but I always thought that the connections between Physics and other fields are obvious, and shouldn't require much teaching. Basically, I knew this almost as a child - it's almost part of me that I know that Physics is connected with all sorts of other subjects, and has something to offer other fields. Some other fields, not all. And vice-versa. Maybe it has something to do with the way it was taught at school, when we were taught science. Sometimes it was Physics, sometimes Chemistry, or Biochemistry, and all these subjects were not really separated-out. They were all science. I still feel that way, that there shouldn't be any distinction between Physics, Chemistry and so on and so forth. They are all the same thing.

14. Let us imagine that you were about to enter the University right now. Would you still choose to study Physics?

Probably. Or may be not. I might choose to study something to do with computers, or a bit more mathematical. In fact at one point of my education, at Cambridge, I actually explored the possibility of dropping Physics and study Mathematics. But I was told, no, that is not a good idea, it is very difficult to change and, quite right because I probably would have managed Mathematics, but I think I would have got very irritated with that. As far as Physics is concerned, there are two ways of doing it. One is to have a very broad curriculum and learn essentially nothing about anything. The other way is to be more specialized and go more deeply into it. But that means you learn something about a very small subset of Physics and nothing about anything else. It is a choice that has to be made, and whichever choice you make, I don't think matters very much. Someone who is motivated enough will learn things not formally taught. And they are probably more successful people. ■

References

[1] J.M. Kosterlitz and D.J. Thouless, *J Phys C: Solid State Phys* **6**, 1181–203 (1973)

[2] J. Michael Kosterlitz – Biographical. NobelPrize.org. Nobel Media AB 2018 (www.nobelprize.org/prizes/physics/2016/kosterlitz/auto-biography)

[3] J.M. Kosterlitz, *Rep. Prog. Phys.* **79**, 026001 (2016)

[4] G. Ellis and J. Silk, *Nature* **516**, 321 (2014)

THE STERN-GERLACH EXPERIMENT RE-EXAMINED BY AN EXPERIMENTER

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The historic Stern-Gerlach experiment (SGE), which was performed in 1922 in Frankfurt, is reviewed from an experimental point of view. It is shown that the SGE apparatus is a purely classical momentum spectrometer, in which the trajectories of particles are measured. With modern detection devices the passage of each single atom can be identified and its trajectory in the magnetic field precisely determined. At the time of their experiment Stern and Gerlach achieved a hitherto unprecedented momentum resolution corresponding to an energy resolution of one μeV.

Otto Stern – a cross-thinker

Otto Stern was a lateral thinker, someone who favoured carrying out experiments in unexplored areas of physics. Two years working closely together with Albert Einstein (Charles University Prague 1912 and ETH Zürich 1912-1914) strongly influenced him to examine scientific questions very carefully [1]. Thus it was typical of him to oppose the hypothesis of Pieter Debye and Arnold Sommerfeld concerning the " Richtungsquantelung" (space quantization, but the German word Richtungsquantelung means "directional quantization") of internal atomic magnetic momenta in the presence of an external magnetic field [2]. For him this hypothesis seemed to completely contradict common sense, as he said in his 1961 Zürich interview [3]. Using the Molecular

Beam Method (MBM) that he invented in 1919 in Frankfurt, he was convinced that he could test this hypothesis experimentally [4]. When he conceived the now-famous Stern-Gerlach experiment (SGE) in 1919, he designed an ingenious apparatus which could measure the tiny momentum transfer between a single atomic particle and a classical detection device with very high resolution. This enabled him to investigate internal atomic properties of atoms in their ground state in an unprecedented manner.

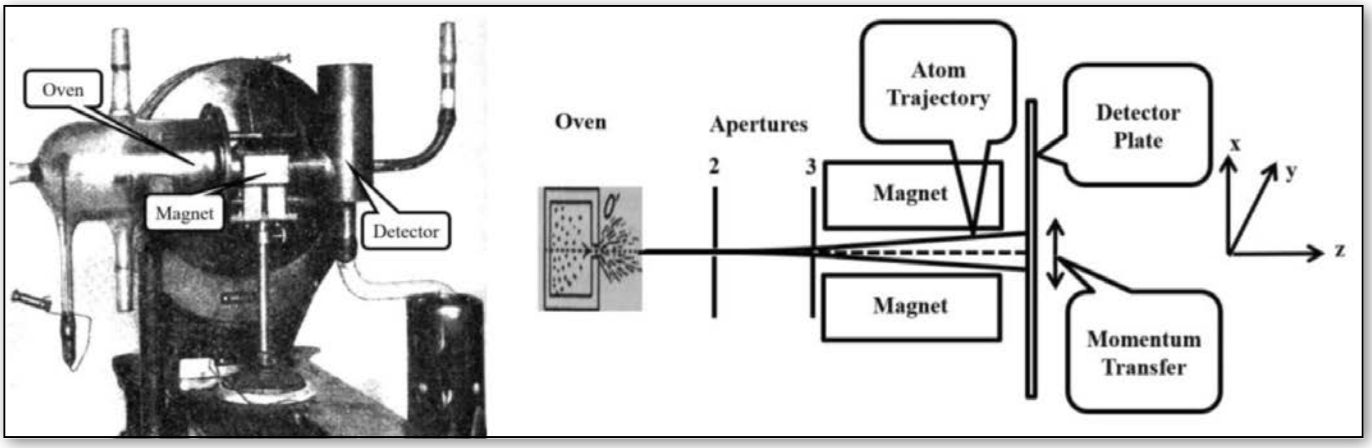
Invention of the Molecular Beam Method

In February 1919 after World War I, Stern returned to the Institute of Theoretical Physics at the University of Frankfurt, which was directed by Max von Laue. A few months later von Laue moved to the University of Berlin, alongside Max Planck, to work with Albert Einstein, and Max Born became von Laue's successor. With the help of Adolf Schmidt, a young mechanic, Stern invented the MBM at the theoretical institute. This enabled him to create in vacuum a beam of atoms (or molecules) all moving in the same direction with about the same velocity, that is all atoms in the beam were prepared in a well-defined momentum state. He used an effusive beam and thus the atoms had a Maxwell-Boltzmann velocity distribution. By deflecting these single atoms by an external force (*e.g.* a magnetic field), he was able to probe their internal magnetic properties and achieve a very high momentum resolution in the transverse direction. In order to deduce absolute values of these quantities by this kinematic method he had to know the absolute velocity of the atoms in the direction of the moving beam (z direction). In spite of the very difficult financial situation so soon after the war, he was successful in measuring the Maxwell-Boltzmann velocity distribution of silver atoms evaporated from a solid at the boiling point of silver. He invented a rotating streak camera and measured the beam trajectories when the system was rotating and non-rotating. From the two different strips he deduced the atomic velocities and obtained good agreement with the Maxwell theory [4].

Design of the Stern-Gerlach experiment

Knowing the beam velocity and using the molecular beam deflection method, he was aware that he could test the hypothesis of "Richtungsquantelung" (space quantization), and even measure the ground state magnetic moment of the silver atom, which was not possible by spectroscopic means. In 1921 he published, as sole author, the proposal for such an experiment [5]. As was typical of all experiments he performed, he carefully calculated the required conditions (the beam collimation parameters, the strength of the magnetic field, *etc.*) in order to be able to resolve, from the deflected beam, the tiny transverse momentum transfer due to the existence of an internal atomic magnetic moment (fig.1). For the silver beam used, which had a velocity of about 540 m/s, the average momentum in the z-direction was 49 a.u. (an electron with 13.6 eV kinetic energy has a momentum of 1 a.u.). To be able to test "Richtungsquantelung" he needed a momentum resolution in the transverse direction of about 0.1 a.u. which seemed hardly achievable at the time. This momentum resolution corresponds to a kinetic energy resolution in the transverse direction of about 2 μeV, about 25 times smaller than the internal atomic Zeeman splitting of the silver ground state in a magnetic field of 20 kGauss, the field strength required to perform the SGE. The prepared silver atom momentum vector $\boldsymbol{p}$ finally reached a quality of $\Delta\boldsymbol{p} = (\Delta p_x, \Delta p_y, \Delta p_z)$ = (± 0.1 a.u., ± 0.1 a.u., 49 ± 5 a.u.). Stern and Gerlach used mercury diffusion pumps, a glass Gäde pump for a rough vacuum and a one-stage glass Volmer pump for high vacuum (about 10-5 torr). Both pumps had a rather low pumping speed.

▾ FIG. 1: left: photograph of the Stern-Gerlach apparatus [6-8]; right: scheme of the apparatus designed by Stern, with four sections; 1: the oven, heated to a temperature of about 1050° C, from which the silver vapor effused through a tiny aperture; 2: the collimator, in which at a distance of about 2.5 cm from the oven a second aperture and, 3.3 cm beyond that, a third aperture, were carefully positioned; 3: the magnet, 3.5 cm long, providing an inhomogeneous magnetic field; 4: the detector, a cooled glass plate at the freezing point of carbonic acid, where the atoms were collected, the silver being made visible as silver sulphide (AgS).



The role of Walther Gerlach

The theoretically-trained physical chemist Otto Stern was fortunate in finding in Walther Gerlach a collaborator who was an excellent experimental physicist. Gerlach had left his job in industry and in 1919 had joined the group of Richard Wachsmuth, who was the director of the Institute for Experimental Physics at Frankfurt. Gerlach was willing to help Stern in this really difficult project. Following Stern's proposal and design, it was Gerlach, together with the mechanic Adolf Schmidt, who enabled the experiment to finally succeed.

In October 1921 Stern left Frankfurt for a professorship at the University of Rostock, but he continued to collaborate with Gerlach, though the latter had to carry out the SGE alone. On November 4th Gerlach succeeded in observing for the first time a broadening of the silver spot when the magnetic field was switched on. But the momentum resolution in the transverse direction was still too poor, so that only a rough estimate of the magnetic moment could be made, and no conclusion about "Richtungsquantelung" (space quantization) could be drawn. The main problem was avoiding slit-scattering due to the passage of the beam through the three very tiny apertures. At a meeting in Göttingen in early February 1922, Gerlach and Stern discussed this problem and decided to replace the final circular aperture by a longer rectangular slit. This modification achieved the breakthrough required and during the night of 7th-8th February, Gerlach succeeded in observing the splitting of the beam into two components (fig.3) [7].

The Interpretation of the SGE doublet splitting

The SGE results clearly showed a doublet splitting. Gerlach was convinced that the prediction of Niels Bohr was correct, proving the classical expectation that the electron can run clockwise or anti-clockwise with magnetic projections m = ± 1. Based on the analysis of the normal Zeeman effect , Arnold Sommerfeld had however predicted a triplet splitting (angular momentum components m = +1, 0, -1). In 1922 a third explanation also existed: according to Alfred Landé the doublet splitting was due to the magnetic moment of a single electron in a 1s state moving around a core [9]. Landé recognized from the analysis of Zeeman multiplet structures that k = ½ with a g-factor of 2. In 1923 he published this interpretation of the SGE, implying the existence of a half integral quantum number m = ± ½ with g-factor of 2 [10]. However, he did not then explicitly attribute this quantum number to the electron internal angular momentum, namely its spin of ½.

▲ **FIG. 2:** Members of the Frankfurt Physics faculty in 1920: seated, right to left (excluding ladies): Otto Stern, Max Born, Richard Wachsmuth; standing, 3rd from the right Alfred Landé, 4th Walther Gerlach [photograph: Nachlass Otto Stern, Bancroft Library, Berkeley].

The role of Albert Einstein in the SGE

Einstein followed the SGE with great interest and he even supported the experiment by providing money from the Kaiser Wilhelm Gesellschaft for the magnet. When the SGE finally provided evidence for the existence of "Richtungsquantelung" (space quantization), Einstein and Ehrenfest immediately tried to find a theoretical explanation of how this process of rotating magnetic momenta in well-defined directions could occur [11]. They expected,

THE IMPACT OF THE SGE

1. The SGE was the first application of the MBM as a dynamic measuring approach yielding excellent subatomic momentum resolution, *i.e.* micro eV energy resolution. It provided a new breakthrough for the momentum measurement of atomic particles.
2. The SGE in 1922 was the first measurement where a ground-state quantum property of an atom could directly be determined.
3. The SGE measured for the first time in a direct way the magnetic moment of an atom, *i.e.* Ag atoms.
4. The SGE verified Debye's and Sommerfeld's hypothesis of RQ (directional quantization) of inner magnetic moments in outer magnetic fields (Zeeman effect).
5. The SGE presented the first direct experimental evidence that the inner-atomic angular momenta are quantized in units of $\hbar = h/2\pi$.
6. The SGE showed for Silver atoms the doublet splitting, *i.e.* it provided the first direct observation of the electron spin. As we know today this splitting is due to the inner magnetic moment of the electron of about one Bohr magneton resulting from the electron spin = $1/2\hbar$ with a g-factor of about two.
7. The SGE delivered an atomic beam in a well-defined quantum state yielding the basis for population inversion and the maser development.
8. The SGE produced the first fully spin-polarized atomic beam.

instead of discrete space quantization, a continuous classical Larmor precession and no change of angle between internal momenta and the external magnetic field. According to them an adiabatic rotation process could only be induced by another (unknown) force. Without such a force in the SGE, the rotation would take thousands of years. From the Schrödinger equation it also follows that the Larmor rotations must be quantized (for integer quantum numbers one obtains m = 0, ± 1, ± 2, … and for half-integer quantum numbers m = ± 1/2, ± 3/2, ...). The only allowed lowest Larmor quantum states are those two states which were observed in the SGE. Space quantization is a purely quantum mechanical process and is thus not to be understood within classical physics. On entering the magnetic field in the SGE, each atom is immediately directionally quantized with 100% probability, independent of its velocity and its time duration in the field. Much later, Frisch and Segrè performed a three-stage SGE in Stern's institute in Hamburg, and showed that, if in stage one a pure spin state is selected and injected into the second stage with a parallel magnetic field, all atomic momenta remain in the same orientation and no flipping of the magnetic moment occurs [12].

LAUDATION BY ERIK HULTHÉN

I shall start, then, with a reference to an experiment which for the first time revealed this remarkable so-called directional or space-quantization effect. The experiment was carried out in Frankfurt in 1920 by Otto Stern and Walter Gerlach, and was arranged as follows: In a small electrically heated furnace, was bored a tiny hole, through which the vapor flowed into a high vacuum so as to form thereby an extremely thin beam of vapor. The molecules in this so-called atomic or molecular beam all fly forwards in the same direction without any appreciable collisions with one another, and they were registered by means of a detector, the design of which there is unfortunately no time to describe here. On its way between the furnace and the detector the beam is affected by a non-homogeneous magnetic field, so that the atoms - if they really are magnetic - become unlinked in one direction or another, according to the position which their magnetic axes may assume in relation to the field. The classical conception was that the thin and clear-cut beam would consequently expand into a diffuse beam, but in actual fact the opposite proved to be the case. The two experimenters found that the beam divided up into a number of relatively still sharply defined beams, each corresponding to one of the just mentioned discrete positional directions of the atoms in relation to the field. This confirmed the space-quantization hypothesis. Moreover, the experiment rendered it possible to estimate the magnetic factors of the electron, which proved to be in close accord with the universal magnetic unit, the so-called "Bohr's magneton".

Particle or Wave?

Another fundamental question often raised in the theoretical interpretation of the SGE is: when an atom passes through the apparatus, is it to be treated as a quantum mechanical wave or as a classical particle [13]. In many theoretical articles the atomic beam motion is treated as a wave so that the partial waves of the two spin directions can interfere, since the experimenter does not know in which spin orientation the atom passes the magnet.

To refute this argument one can show that the experimenter does in fact know the orientation of the magnetic moment from the measured deflection, that is, from the curvature of the trajectory. One must consider what the possible origins of the deflection could be. The atoms can either be transversely deflected due to slit-scattering (diffraction), or due to transverse momentum exchange with the magnet via the magnetic force. To answer this question one must consider what is the possible origin of the measured deflection of a few millirad? Since the aperture widths in the SGE are about 100 μm and the de Broglie wave length of silver atoms is only about 0.1 Ångström, diffraction structures will be observed only for deflection angles below a few μrad. In the SGE therefore, the observed deflection results only from the magnetic force between the atom and the magnet. From the impact position on the detector one knows the direction of the magnetic force and thus the orientation of the magnetic moment. If the magnetic moment would have oscillated between both directions and then, at impact, would have been fixed where the wave collapses on the detector, the atom would never impact with the observed maximal deflection. Furthermore the asymmetric silver density distribution for both magnetic components in the historic SGE (fig.3, red circle) provides further evidence that the trajectories of the atoms are influenced by the inhomogeneity of the magnetic field (fig.3, blue circle) and by the tiny misalignment of the beam trajectory with respect to the edge of the magnet. Classical trajectory effects are thus clearly visible in the detection pattern. As Gerlach and Stern pointed out, these effects clearly tell the experimenter on which trajectory each atom passed the magnet.

The paradigm experiment of electron scattering on a double slit is often used to justify the necessity of describing the SGE in the wave approach. One should however note, that the deflection of the atom in the SGE and in electron scattering on a double slit have nothing in common. In the double-slit experiment the de Broglie wave length of the electron and the slit width are of similar magnitude; thus one cannot decide with which slit the electron interacted. Beyond the slits the scattered electron wave moves in a straight line; so that one can never decide from the shape of the trajectories at which slit the electron was scattered. However the atoms in the SGE move on clearly distinguishable curved trajectories.

Nobel Prize history concerning Stern and Gerlach

For their contributions to modern quantum physics, Stern and Gerlach were jointly nominated for the Nobel Prize in Physics on 31 occasions, the first being in 1924 by Albert Einstein and the last in 1944 by Manne Siegbahn [14]. For his invention of the MBM (in Frankfurt) and his measurements of the magnetic moments of the proton and deuton (now deuteron), as well as for his helium beam interference experiments with the direct measurement of the de Broglie wave length of helium atoms (in Hamburg), Stern received 52 additional individual nominations. Finally, Stern was awarded the Nobel Prize in Physics for 1943 alone (the official appreciation on the Nobel certificate was for the 'Invention of the MBM and measuring the proton magnetic moment'). Gerlach was not considered for the Prize since at the time when this award was made he was head of the German 'Uran Verein' ('Uranium Club'). Nevertheless, the laudation speech for Stern given by Erik Hulthén on December 10th 1944 did actually mostly celebrate the SGE. ■

About the Author

Horst Schmidt-Böcking was from 1982 till 2004 Professor for experimental atomic and molecular physics at the University Frankfurt. He retired in 2004. Together with his group and collaborators he has developed the COLTRIMS reaction microscope a multi-coincidence momentum imaging device which can visualize inner atomic and molecular dynamics on the one atto-second scale. For his contributions to experimental quantum physics he has received in 1991 the "Max Planck Forschungspreis, in 2008 the Davisson-Germer award of the American Physical Society and in 2010 the Stern-Gerlach medal of the German Physical Society. In recent years he has published several books on the life and work of Otto Stern.

Acknowledgement

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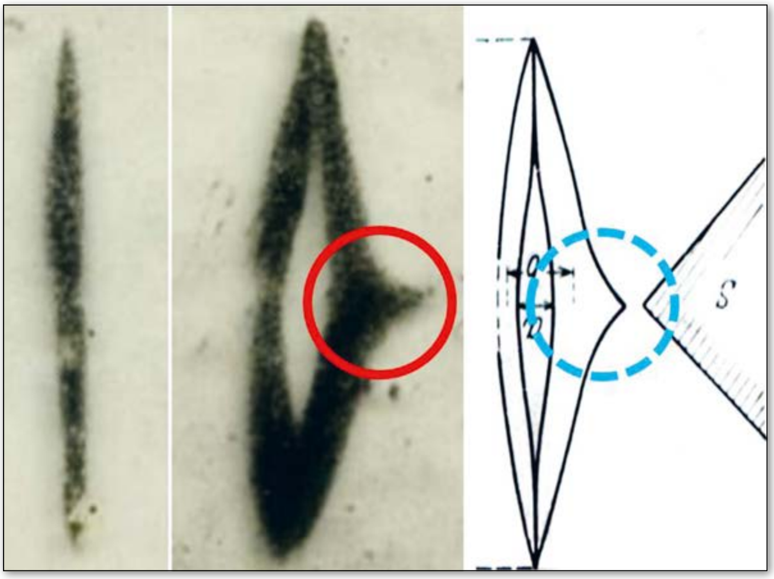

▲ FIG. 3: The AgS distribution obtained in the SGE, the photographs are from the private slide collection of Otto Stern. Left: the Ag beam spot without magnetic field (spot length about 1.1 mm, spot width about 0.06 to 0.1 mm). Centre: the beam spot with magnetic field, showing a splitting into two components with broadening of the silver condensate due to the breadth of the velocity distribution. The asymmetry of the magnetic field strength between the two magnetic poles is clearly visible in the shape of the condensate. Atoms passing near the tip S of the pole are more strongly deflected.

References

[1] B. Friedrich & D. Herschbach, *Phys. Today* **56**, 53 (2003) ; H. Schmidt-Böcking & K. Reich, *Biographie über Otto Stern, herausgegeben von der Goethe Universität Frankfurt*, Societäts Verlag, 2011; J. P. Toennies, H. Schmidt-Böcking, *B. Friedrich & J. C. A. Lower; Ann. Phys. (Weinheim)* **523**, 1045 (2011) ; H. Schmidt-Böcking *et al.*, *Eur. Phys. J. H* **327**, 41 (2016).

[2] P. Debye, *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen*, Mathematisch-Physikalische Klasse, (1916) 142; A. Sommerfeld, *Phys. Z.* **17**, 491 (1916).

[3] O. Stern, *tape-recording at ETH Zürich in 1961*, folder 'ST-Misc', R. Jost, archive, ETH-Bibliothek Zürich, www.sr.ethbib.ethz.ch/; A. Templeton 'O. Stern Nachlass'.

[4] O. Stern, *Phys. Z.* **21**, *582 (1920); Z. Phys.* **2**, *49 (1920) ; Z. Phys.* **3**, 417 (1920).

[5] O. Stern, *Z. Phys.* **7**, 249 (1921).

[6] W. Gerlach, *Ann. Phys. (Leipzig)* **76**, 163 (1925).

[7] W. Gerlach & O. Stern,. *Z. Phys.* **8**, *110 (1922) ; Ann. Phys. (Leipzig)* **74**, 673 (1924).

[8] J. G. Huber, *PhD dissertation*, LMU München, 6 August 2014.

[9] A. Landé, *Z. Phys.* **5**, *231 (1921); Z. Phys.* **7**, 398 (1921).

[10] A. Landé, *Phys. Z.* **24**, 441 (1923).

[11] A. Einstein & P. Ehrenfest, *Z. Phys.* **11**, 31 (1922) ; N.Hermansphan, N. H. Haffner, H.-J. Kluge, W. Quint, S. Stahl, J. Verdú & G. Werth, *Phys. Rev. Lett.* **84**, 427 (2000) ; I.Unna & T.Sauer, *Ann. Phys. (Weinheim)* **525**, A15 (2013).

[12] O. R. Frisch & E. Segrè, *Z. Phys.* **80**, 610 (1933) ; T. E. Phipps & O. Stern, *Z. Phys.* **73**, 185 (1932).

[13] F. Aaserud & J. L. Heilbronn, Oxford, Oxford University Press (2013); M. Devereux, *Can. J. Phys.* **93**, 1382 (2015); J. E. A. Ribeiro, *Found. Phys.* **40**, 1779 (2010) ; T. Sauer in: T. Sauer & R. Scholl, editors, *The Philosophy of Historical Case Studies*, 251 (2016) , Springer ; M. O. Scully, W. E. Lamb, Jr. & A. Barut, *Found. Phys.* **17**, 575 (1987) ; H. Wennerström & P. Westlund, *Phys. Chem. Chem. Phys.* **14**, 1677 (2012); M. Utz, M. H. Levitt, N. Cooper & H. Ulbricht, *Phys. Chem. Chem. Phys.* **17**, 3867 (2015) ; Y. Margalit, Z. Zhou, O. Dobkowski, Y. Japha, D. Rohrlich, S. Moukouri & R. Folman arXiv.org > quant-ph > arXiv:1801.02708.

[14] Center for History of Science, The Royal Swedish Academy of Sciences, Stockholm, Sweden, https://centrum.kva.se/en/startsida.

EPL
IN AN EVENTFUL ENVIRONMENT

▮ Bart van Tiggelen – DOI: https://doi.org/10.1051/epn/2019303
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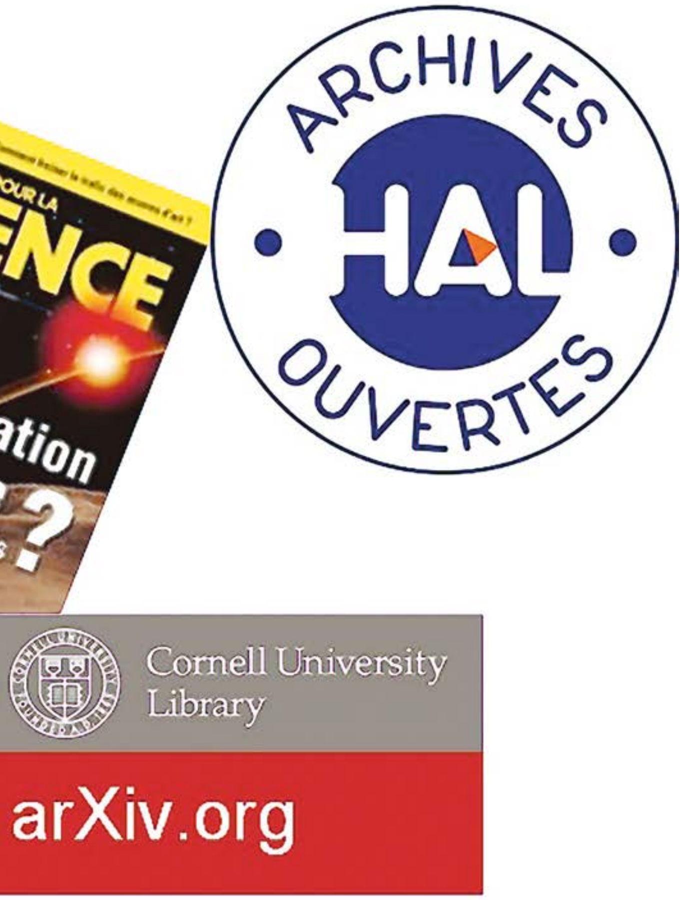
Europhysics Letters was cofounded in 1986 by 17 European learned societies, and merged the two existing Letter journals Lettere al Nuovo Cimento – published by the Società Italiana di Fisica (SIF) – and the Journal de Physique Lettres, from the Société Française de Physique (SFP). The original idea was to create a real European Letter journal competitive with Physical Review Letters of the American Physical Society. The major scientific force behind EPL is the European Physical Society (EPS) that celebrated its 50th anniversary only last year in Geneva. The publication of Europhysics Letters, re-baptized EPL in 2007 to emphasize its global impact, is a joint venture of the publishing houses of three physical societies: the Institute of Physics (IOP), the SIF, and the SFP.

The launch of scientific journals by physical societies started more than one century ago *"to give a new impulse to physics, to stimulate training, to excite the spirit of research, and to initiate discoveries"*. This is a quote attributed to Jean Perrin when the scientific publisher EDP Sciences was founded exactly one century ago by the SFP, supported by several distinguished scientists, such as Marie Curie and Louis de Broglie. The creation of physics journals started much earlier. The oldest two, *Le Journal des Savants* and the *Philosophical Transaction*, date back to 1665, a time where physics was still part of more general science, including medicine, biology, chemistry and even literature, published under the auspices of the national Scientific Academies, the *Institut de France* and the *Royal Society* respectively. The first commercial journals followed, such as the *Philosophical Magazine* in 1798 by Taylor & Francis and *Annalen der Physik* in 1790, still published today by Wiley. Il *Nuovo Cimento* was probably one of the first journals founded by a pure physical society, created in 1855 to become the flagship journal of the SIF. Others followed rapidly, in 1873 the Russian Academy of Science founded the *Journal of the Russian Society for Physics and Chemistry*, later re-baptized *JETP*. In 1874 the Journal of Physics was created by the IOP in the UK, the *Physical Review* by the American Physical Society in 1893.



The statement by Jean Perrin is still the reason why scholarly journals exist, but the landscape has changed dramatically after one century. The most significant change has been the arrival of Internet. Print versions have almost disappeared and articles can now be accessed in two clicks. Such easy access to all research sounds wonderful; it makes science move forward faster, and innovation is undoubtedly boosted when industry utilises scholarly articles. However, the commercial value of science has not gone unnoticed. Commercial publishers exist today that make profits in excess of 30 %, to disseminate research articles. A large scale study conducted in 2011 showed that the scientific publishing industry that year generated roughly 10 billion USD in revenue. With 2 million English language articles published in 2011 this is equivalent to roughly 3000 today's Euros for each article published worldwide. Journal prestige seems to have become a major tool for commercial exploitation. The economic model is simple but efficient: Accept only potentially high-impact articles that will raise the Impact Factor of the journal. This indicator, originally introduced by libraries as a tool to identify the journals to be purchased, counts the number of citations to all articles published in one year during the two years that follow. The higher the Impact Factor, the more attractive the journal becomes. Since rejecting papers costs money, the subscription fee for libraries also increases.

No need to insist that this model is highly unfair to the scientific community. Articles are rejected on their lack of direct impact, rather than on their "real" quality and originality, which we all know in physics often takes many years to reveal. Prestige is valuable to the community and clearly privileges researchers with prestigious grants. The threat of this vicious circle is that prestige gradually infiltrates the assessment and funding of research. In several European countries, such as Finland, the research budget of a laboratory or university depends explicitly on the number of articles published in journals with high Impact Factor. This unfortunate drift of science, is hardly a new impulse to physics. It is hardly exciting, and it hardly stimulates our students to "go where no one has gone before". Finally, it is by far the most inefficient way to favour blue-sky research, which for several centuries long has been the one and only trigger for important discoveries. Jean Perrin would have been disappointed.

Physics journals run by physical societies still exist and survive. For historic reasons, the landscape in Europe is more biodiverse than in the US, where the *Physical Review* journals have an almost monopoly position and attract many European scientists. In physics the most important learned society journals are the *Journal of Physics* series (IOPP), the *New Journal of Physics*, the full open-access journal in Europe founded by IOPP and DPG in 1998, and of course EPL, published by SIF, EDP Sciences, EPS, and IOPP. A few good journals are still published by national physical societies such as *Acta Physica Polonica* and *Il Nuovo Cimento*. Several others merged into the *European Physical Journal platform EPJ*

“It is crucial that physical societies keep taking the lead on scientific publishing; after all, they represent the physics community. It is important that they work together, without internal competition, and keep insisting on scientific quality and readability of research papers as the only criteria that count.”

created in 1992, such as *Portugaliae Physica*, *Zeitschrift für Physik*, *Acta Physica Hungarica* and *Journal de Physique*, federating no less than 25 European physical societies and published by SIF, EDP Sciences and the commercial publisher Springer-Verlag. On the commercial side, we find the large *Freedom collection* by Elsevier, that includes the *Physics Letters* Series, as well as *Physics Reports*, and the many journals published by the joint company Springer Nature created in 2015. The Springer journals focus on specialized communities such as fluid mechanics, statistical or mathematical physics. On the Nature side we find the prestigious, broad scope journals *Nature*, *Nature Physics*, and *Scientific Reports*, managed using the clever cascade model to keep rejected manuscripts in-house.

This huge European biodiversity makes the piece of the cake for each journal very small. It is crucial that physical societies keep taking the lead on scientific publishing; after all, they represent the physics community. It is important that they work together, without internal competition, and keep insisting on scientific quality and readability of research papers as the only criteria that count. This gentle reminder was issued in 2012 in the form of the San Francisco Declaration on Research Assessment (DORA). An important role exists for the European Physical Society to coordinate these efforts in Europe. EPL is intended to be at the service of the whole community, with a broad scope and transparent rules, providing the professional support of the four editorial offices in Bologna, Bristol, Mulhouse and Paris, all run by physical societies. As is the case for most such journals, the benefits of the EPL Association flow back to their 17 European partner societies who benefit each year from a vital contribution to their tight annual budget. EPL also supports many poster prizes at international conferences, especially for young students. This also implies that physical societies should encourage their members to publish in “their” journals, like in the old days.

EPL and EPJ are two examples that demonstrate that by joining forces visibility and quality increase. My ultimate dream would be to create a European Platform comprising all learned society journals. Journals and publishers face a few major challenges in the near future, and the physical societies have to stand together if they do not want “others” to decide. The first is undoubtedly the reinvention of peer-review. All articles submitted to EPL get on average 1.8 reviews by expert peers, who evaluate the reported research on validity, broad interest, originality and readability. Getting independent reports within a reasonable time is hard work, since only 50 % of the requests for review results in a report. Yet, more than 80 % of all physicists recognize the importance of and need for an *a posteriori* quality check, and confirm that their paper improved after review. This was reported as the outcome of a survey conducted by Elsevier in 2009, and was confirmed by a similar survey conducted last year among members of the SFP.

▸ **FIG 1:** (a) The first cover of Europhysics Letters, (b) a new cover of Europhysics Letters, (c) EPL last printed cover Volume 124

Nevertheless, the basic "peer review" principle, that all authors be reviewers and vice versa, suffers from broken symmetry. What can we do to make review attractive again? How do we get more recognition and visibility for the referees? Should we publish the report together with the article if the reviewer agrees? Should we create a worldwide database containing all active reviewers, updated by all journals?

The second challenge is Open Access. The arrival of Internet has made the subscription-based model obsolete and maybe perverse. The paper is online but impossible to access if you are connected outside the perimeter of your institution. The online access, that has replaced the shipping of print versions, has made libraries confronted with the obligation to accept "Big Deals", a popular term that refers to huge packages of journals, rather than to choose their own catalogue *à la carte*. Subscription fees grow faster than inflation rates, and become impossible to support for less-developed countries. Finally, the transfer of copyright to publishers has been bothering both authors and their employers for a while but is necessary because the publisher cannot sell what it does not own. The Internet facilitates easy access and rapid text mining but the current economic model prevents it. I am convinced that scientific publishing has a price and that scholarly journals should continue to exist if we want the scientists to do science, and not to spend their precious time looking out for referees, for proofreading, for indexing, and for publishing the articles on the net. It is the economic model that needs to be updated, and not the scientist. In the current subscription model, the reader or library pays the access. In an "author-pay" model the authors pay upfront for the publishing service and remain owner of their article. All readers would then be able to have Open Access "for free", and this will solve many issues raised earlier, including the (in most countries) ill-defined, so-called "Green" coexistence of preliminary versions on preprint servers and published versions in peer-reviewed journals under embargo. Physicists have a long tradition to distribute, deposit or self-archive preprints prior to publication. In an "author-pay" model, all versions can converge to one final version if the author wants this to happen.

Of course, the "author-pay" model is not the only route towards Open Access. A rich "biblio-diverse" landscape starts developing, where also institutional archives such as ORBi at Luik University in Belgium and HAL at CNRS and CEA in France start developing green policies on open access. The Green model is arguably not a model from the economic point of view, since the role of the publisher does not necessarily change. It is much more a highly justified cry for having no embargo on research articles produced by the employees of these institutions. The Gold "author-pay" breaks with the subscription model, but many colleagues protest against it, saying that "publishing should be for free", that "they do not want to be bothered by paying fees to journals", and that "they have no money to spend anyway". What they seem to ignore is that in the "reader-pay" model, our employers, or at the end of the day all tax-payers in the country, always have paid thousands of invisible Euros for the publication of their papers. In a successful implementation of any Open Access model tax-payers are again supposed to pay. Research organizations and universities in Europe have to stand together to negotiate agreements with the Publishing houses. Governments have to redirect the existing subscription fees to a unique national open-access platform. Quite recently, the cOAlitionS, a group of 15 European funding agencies endorsed by the European Commission, published their "Plan S" to force an Open Access transition. This initiative, that comes with a handful of recommendations and an ambitious timeline, will undoubtedly evolve in time. Most learned societies tend to support the open access initiative, but also realize that their journals, including EPL, cannot change the one-century-old economic model from one day to the other.

The publication of scientific articles must be carried out by professionals and thus comes with a price. However, the present economic model has become obsolete and perverse. Finding an international state-of-the-art ecosystem that responds to the needs of society and science requires an international force. National physical societies, with their century-old experience in publishing, have common interest and common knowledge. They should collaborate, control, and be proactive. ■

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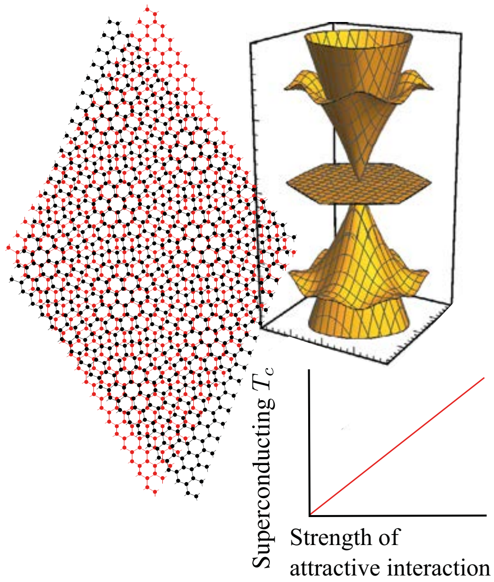
MOIRÉ WITH FLAT BANDS IS DIFFERENT



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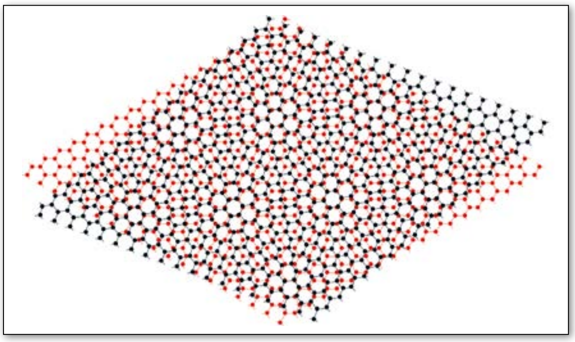
Recent experimental discoveries of superconductivity and other exotic electronic states in twisted bilayer graphene (TBG) call for a reconsideration of our traditional theories of these states, usually based on the assumption of the presence of a Fermi surface. Here we show how such developments may even help us finding mechanisms of increasing the critical temperature of superconductivity towards the room temperature.

Last year's **Physics World** *Breakthrough of the Year* award went to the experimental discovery [1] of an exotic superconducting state in a system where two layers of graphene were twisted close to a "magic" angle of around 1 degree. This angle was believed to be important because of an earlier prediction of a "flat" electronic band taking place at this angle [2]. In flat bands the density of electronic states is high, paving the way for strong interaction effects. Soon after the first discovery, another group reported similar type of behaviour in their samples [3] and showed that the superconductivity can be strongly affected by applying hydrostatic pressure. Both groups also managed to switch superconductivity on and off by an *in situ* tuning of the electronic density via a nearby gate voltage.

However, superconductivity was not the only type of exotic effect discovered in such systems: during the past year different groups have reported measurements of a correlated insulator state [4] tunable by a gate voltage, and a ferromagnetic state at a certain value of the electronic density [5]. Because of the closeness to the insulating state, the superconducting state was compared to that found in high-temperature superconductors, although TBG became superconducting only at a temperature around one Kelvin.

Needless to say, these observations lead to a flurry of theoretical activity, with dozens of papers trying to explain the observations from different points of view, including our own [6]. This quest is still on-going, and here we try to illustrate two fundamental aspects of these systems. First, *we cannot extend what is known in regular Fermi surface systems to those with flat bands by simply increasing the density of states or considering some generic low-energy Hamiltonian. Rather, in many cases we need to know the structure of the entire flat band. Secondly, we discuss how it might be possible to control the critical temperature of superconductivity in these systems.*

Let us start by sketching why the flat band physics becomes essential in TBG. Placing two honeycomb lattices on top of each other and twisting them relative to each other (Fig. 1) leads to the formation of a moiré pattern that looks periodic, such that the period increases as the twist angle becomes smaller. The strict periodicity holds only for certain commensurate angles, otherwise the moiré lattice is quasiperiodic. However, as a first approximation we may assume that the electronic response is a smooth function of the angle, and concentrate on studying the commensurate angles. Periodicity enforced by the interlayer coupling means that we are allowed to use Bloch's theorem, and describe the electronic spectrum within the Brillouin zones of the superlattice. This is obviously not yet enough for the flat band formation, but we need two more concepts for it. First, graphene is a semimetal with a Dirac-point spectrum around two valleys in momentum space. Second, because of the twisting the valleys are shifted in momentum space with respect to each other (see Fig. 2a). For uncoupled layers, the energy bands cross between the two Dirac points (Fig. 2b).



◂ **FIG. 1:** Moiré pattern formed by two twisted honeycomb lattices. © Teemu Peltonen

Coupling turns the crossing into an avoided crossing, hybridizing the modes from the two layers. Increasing the coupling moves one of the hybridized levels closer to zero energy (Fig. 2c-d), and at a critical value of the coupling the energy of this level ceases to depend on momentum, and the band becomes flat. This critical value of the coupling depends on the distance between the valleys, which is a function of the twist angle. This is how we can understand not only the formation of the (approximate) flat band, but also the fact that the magic angle can be tuned with pressure: applying pressure moves the layers towards each other, and therefore affects the interlayer coupling.

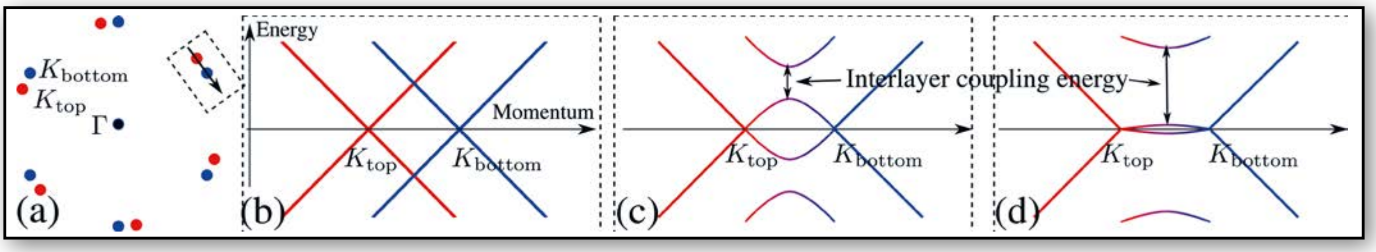
The picture given here is a schematic one, but can be reproduced by more microscopic calculations. For example, Fig. 3 shows the spectrum calculated with the methods of Ref. 6 around the magic angle. It shows the formation of a pair of (spin degenerate) flat bands spanning the first Brillouin zone of the superlattice around each graphene valley. In the experiment the relevant energy scale for superconductivity is determined by the critical temperature, which means that one should zoom in to the range of the order of a few meV (Fig. 3c), where even the band at the "magic angle" (here 1.08°, precise value depends on the employed model) ceases to be entirely flat.

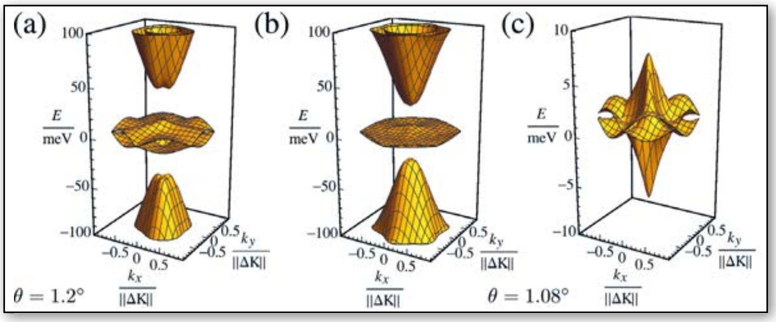
Now, how is this different compared to the ordinary systems with near-quadratic dispersions, where majority of our knowledge of the superconducting state derives from? If the Fermi energy is far from the region with the flat bands, the difference is minor. But close to half-filling (Fermi energy close to zero), the picture is different and schematized in Fig. 4 for three different types of spectra: ordinary quadratic spectrum with a Fermi surface at some finite energy, Dirac (or Weyl) spectrum, and the flat band. The same figure also shows how the critical temperature for superconductivity scales with the superconducting coupling constant in the three cases. The "ordinary" case is the regular Bardeen-Cooper-Schrieffer (BCS) theory [7] whose microscopic coupling mechanism based on electron-phonon coupling was explored by Eliashberg [8]. It showed how the critical temperature is given by the Debye temperature times an exponentially small factor containing the electron-phonon coupling constant and the density of states at the Fermi level. Later it was also shown how the direct electron-electron interactions can be included via a pseudopotential that is often treated semi-phenomenologically [9]. This approach works well for electron-phonon mediated superconductivity in systems with Fermi surfaces.

One can also generalize the BCS theory for other types of electronic spectra. For Dirac or Weyl semimetals the density of states becomes very small close to the Dirac or Weyl points. On the mean-field level, this means that interaction effects are suppressed. For example, the Cooper instability according to which any Fermi surface is unstable to an infinitesimally small attractive interaction is turned into a more stringent condition for superconductivity: at the Dirac or Weyl points, superconducting state is obtained only above a critical coupling strength [10].

If ordinary Dirac or Weyl fermions do not easily become superconducting, the opposite is true for flat bands: unlike in the usual Eliashberg theory, the (mean-field) interaction driven broken-symmetry phase has a critical temperature that is a linear function of the interaction strength [11]. It can thus be much larger than in conventional superconductors – perhaps up to room temperature? In TBG, the superconducting energy scales tend to be comparable to the bandwidth of the approximate flat band and thus approach this flat-band limit [6]. This means that almost all theoretical results we know based on Fermi surfaces cease to work in such systems. In particular, whereas typically many physical quantities especially related to electron transport can be obtained by concentrating on the Fermi surface or the vicinity of Dirac or Weyl points, in this case we have to take into account the contribution from the whole band, including for example effects originating from the quantum metric of the Bloch functions [12]. Another interesting feature of the flat-band systems is that they are not only unstable against the formation of the superconducting state in the case of an infinitesimally small attractive

▾ **FIG. 2:** Sketch of the flat band formation. **(a,b)** Dirac points of the two uncoupled but rotated layers form at slightly different points in the momentum space. **(c)** coupling the layers hybridizes the levels. **(d)** at a critical value of the coupling or of the distance between the two valleys (K_{top} and K_{bottom}), the hybridized band becomes flat.





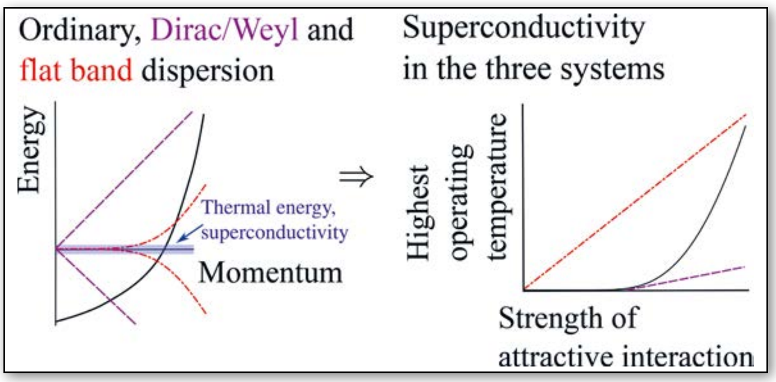
▲ **FIG. 3:** TBG spectra from a tight-binding calculation along with a Dirac point approximation, see Ref. 6. (a) Above and (b,c) at the magic angle. © Teemu Peltonen

interaction but they are also susceptible for the formation of other types of correlated states (*e.g.* spin, charge or orbital order) in the case of an infinitesimally small repulsive interaction [11]. This gives an intuitive explanation why so many different correlated states have been observed in moiré superlattices.

The experimentally obtained critical temperatures for the twisted bilayer graphene (TBG) are of the order of one or two kelvin at maximum. Based on the electron-phonon model (assuming it is the valid approach, which is still under debate), how can we understand this low value? It is not due to the weakness of the electron-phonon interaction, but rather results from the small size of the flat band: in twisted bilayer graphene, the flat band takes place in the first Brillouin zone of the moiré superlattice. In momentum space the area of the flat band is inversely proportional to the square of the superlattice lattice constant, and the latter is quite large around the magic twist angles. To increase the critical temperature, we would hence need a way to create more extended flat bands.

From the viewpoint of the theory more extended flat bands can be obtained in multilayer systems. The extreme case would be bulk graphite where it is known that extended flat bands appear in systems containing interfaces between differently twisted or stacked graphite regions [13]. Experimental signatures of high-temperature superconductivity have been reported in such systems [14], but the community has not widely accepted these results because of the strong sample dependence of the results and the fact that they have not been reproduced by other experimental groups. The recent experimental advances have already allowed creating multilayer systems with tunable twist angles and it would be interesting to see a systematic study how the extension of the flat band in the momentum space affects the critical temperature. Well-controlled repeatable experiments in multilayer systems could also shed new light on the earlier experiments and lead to a better understanding of the limits of the critical temperature in these systems. In any case, understanding the characteristics of this type of exotic electron systems also requires a fresh look on the "well-known" theories.

▼ **FIG. 4:** Sketches of energy spectra in three different generic types of electron systems, along with the behaviour of the mean-field superconducting critical temperature in the three systems. The shaded region shows the typical energy ranges around the Fermi level.



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References

[1] Y. Cao, *et al.*, *Nature* **556**, 43 (2018).

[2] E. Suárez Morell, *et al.*, *Phys. Rev. B* **82**, 121407(R) (2010).

[3] M. Yankowitz, *et al.*, *Science* **363**, 1059 (2019).

[4] Y. Cao, *et al.*, *Nature* **556**, 80 (2018).

[5] A. Sharpe, *et al.*, arXiv:1901.03520

[6] T. J. Peltonen, R. Ojajärvi, and T.T. Heikkilä, *Phys. Rev. B* **98**, 220504(R) (2018). See also Fengcheng Wu, A.H. MacDonald, and Ivar Martin, *Phys. Rev. Lett.* **121**, 257001 (2018).

[7] J. Bardeen, L. N. Cooper, and J. R. Schrieffer, "Microscopic Theory of Superconductivity", *Phys. Rev.* 106, 162 - 164 (1957).

[8] G. M. Eliashberg, *Sov. Phys. JETP* **11**, 696 (1960).

[9] P. Morel, and P. Anderson, *Phys. Rev.* **125**, 1263 (1962).

[10] N.B. Kopnin and E.B. Sonin, *Phys. Rev. Lett.* **100**, 246808 (2008).

[11] N. B. Kopnin, T. T. Heikkilä, and G. E. Volovik, *Phys. Rev. B* **83**, 220503 (2011). See also R. Ojajärvi, T. Hyart, M.A. Silaev, and T.T. Heikkilä, *Phys. Rev. B* **98**, 054515 (2018) that generalizes the Eliashberg theory, along with the pseudopotential corrections, to the case of flat bands.

[12] For example, S. Peotta and P. Törmä, *Nature Commun.* **6**, 8944 (2015).

[13] T.T. Heikkilä and G.E. Volovik, Chapter 6 in the book "Basic Physics of functionalized Graphite" (Edited by Pablo Esquinazi, Springer 2016) [arXiv:1504.05824]; T. Hyart and T. T. Heikkilä, *Phys. Rev. B* **93**, 235147 (2016).

[14] P. Esquinazi, *Pap. Phys.* **5**, 050007 (2013).

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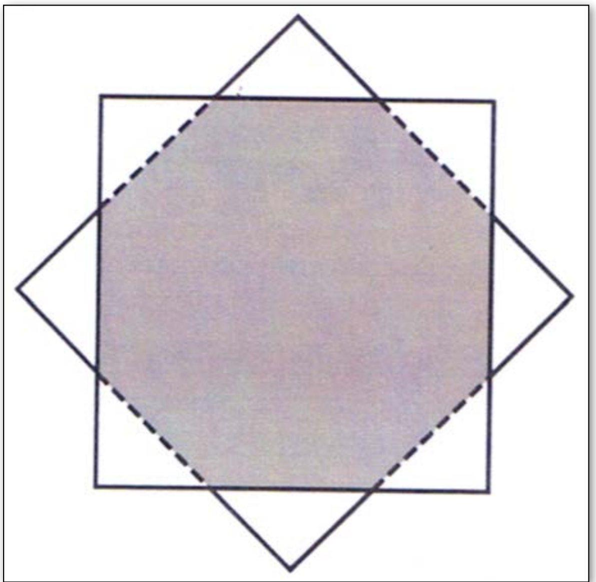
Zeno's Paradox - Some thoughts

Ancient Greek Philosopher Zeno of Elea (c.490 – c. 430 BC) is famous for his paradoxes, one of which, *Zeno's arrow paradox*, states that because an arrow in flight is not seen to move during any single instant, it cannot possibly be moving at all. (Not unless one understands the concepts of calculus, which came two millennia later!).

A related phenomenon, often called the Quantum Zeno Effect, was first discussed in John von Neumann's early work on the mathematical foundations of quantum mechanics [1]. In particular, in the rule sometimes called the "reduction postulate" he showed that, indeed, one can "freeze" the evolution of a system by measuring it frequently enough in its known initial state. Sometimes this is interpreted as saying that "a system can't change while you are observing it" or, more facetiously, "a watched kettle never boils".

The way this works is as follows (see the box for detailed derivation): the probability of a system, which is being measured with an apparatus described by a Hamiltonian H remaining unchanged (*i.e.* "surviving") while evolving by a short time Δt, is given by: $|\exp((-i/\hbar)H\Delta t)|^2 \approx [1 - [(1/\hbar)\ \Delta H\Delta t]^2$ provided that $[(i/\hbar)\ \Delta H\Delta t]$ is small enough.



▲ **FIG. 1:** Two sheets of Polaroid, the one behind turned by an angle θ (here shown at 45 degrees) allows the plane of polarisation of the transmitted light to be turned by the angle θ and the transmitted intensity be multiplied by $\cos^2\theta$, shown shaded.

Being quadratic in $[(1/\hbar)\ \Delta H\Delta t]$, this is simply equal to unity, meaning that if "observed" after a very short time, the system remains unchanged. Furthermore, if the observation is repeated at sufficiently small time intervals Δt, the system can be prevented from evolving at all. This Quantum Zeno Effect, or Quantum Zeno Paradox [2,3] is far from obvious but actually it has been verified experimentally [4] and is the subject of discussion in hundreds of articles [5].

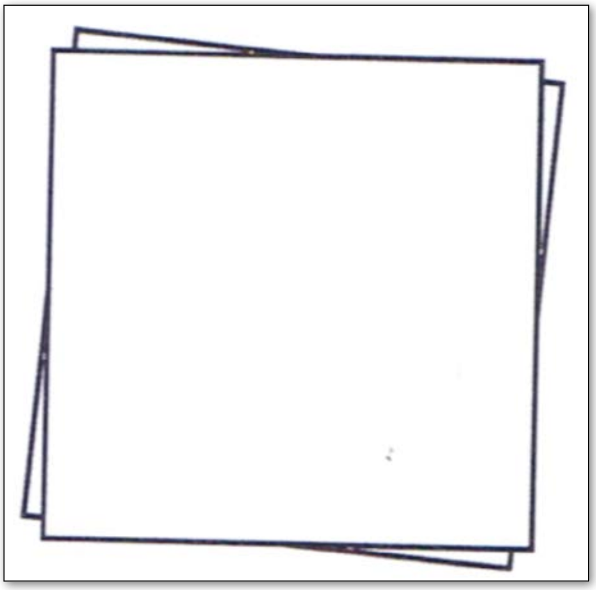
Quite a similar effect occurs in optics and may be demonstrated quite vividly, is a phenomenon that may also be termed a Zeno Effect. Here is how it works:

Consider a piece of polaroid in the shape of a square. Now imagine behind it an identical piece, rotated by an angle θ. (Fig.1, where θ = 45 degrees). The transmission of light going through both is proportional to $\cos^2\theta$ which, for small angles $\Delta\theta$, is approximately equal to $(1 - \Delta\theta^2/2)^2$ *i.e.* negligibly different from unity, for sufficiently small $\Delta\theta$, (*e.g.* 5 degrees, as in figure 2).

Now do it again with another sheet of polaroid, behind the first two, rotated by a further 5 degrees. Keep doing this 9 times for a total of 45 degrees. (Fig. 3). As you can see, the transmitted fraction of light through this stack remains near enough to one, *i.e.* zero absorption or zero change from the incident intensity - hence Zeno Effect.

However while absorption is to first order negligible, the angle of polarisation ends up being rotated by 5 degrees through every sheet, to a cumulative total of 45 degrees, in this example. So by being "measured" at sufficiently small intervals, the transmitted intensity is thereby being kept near enough equal to unity. However, the angle of polarisation can be rotated to any desired angle by a stack of a sufficiently large number of polarising sheets, gently rotated about the incident axis. A way of visualising this is by imagining a stack of Polaroids contained in a rectangular rubber tube, the back of which can be gently twisted with respect to the front so that the total angle is subdivided by N where N is the number of Polaroid sheets. (Circular Polaroids in a circular rubber tube would be easier to organise, of course, but would be harder to draw!).

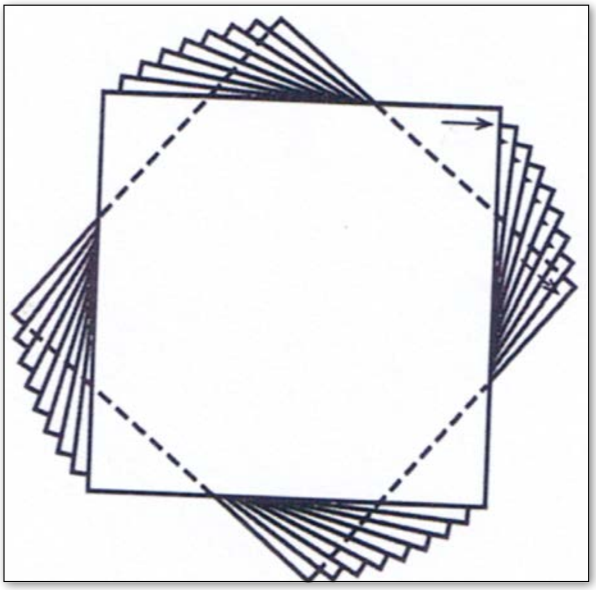
While this cumulative polarisation shift is essentially a classical effect, a quantum mechanical analogue has been shown [6] to lead to a geometrical phase shift *i.e.* a Berry



▲ **FIG. 2:** A piece of polaroid with a second piece placed behind at angle $\Delta\theta$ (5 degrees).

phase since that is a result of a first order variation of the parameter Δt. It is the second order variation $(\Delta t)^2$ that gives rise to the quantum mechanical Zeno Effect.

So, what about the original "arrow paradox" invented by Zeno? If we can think of the position of the arrow as due to first order changes of the time parameter, (the "instant") then the effect is clearly cumulative and results in the motion of the arrow, and hence there is no paradox. However, if we consider second-order changes of the "instant", interpreted as the velocity of the arrow, then of course, the velocity will stay constant! Is that what Zeno had in mind? But, of course, he didn't have calculus at his disposal!



▲ **FIG. 3:** Sheets of polaroid separated by 5 degrees. 9 sheets leads to a change of polarisation angle of 45 degrees, whilst the transmitted intensity is unchanged.

This article is reprinted, with permission, from the "Australian Optical Society News" as "The Zeno Paradox In Optics"; the author is grateful to Dr Jessica Kvansakul who helped with the graphics, and to the Science Editor of EPN, Professor Ferenc Iglói, for helpful comments.

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References

[1] J. Von Neumann (English Translation) *"Mathematical Foundations of Quantum Mechanics"*, Princeton University Press, Princeton, (1955) p.366

[2] E. C. G. Sudarshan, B. Misra, *J. Math Physics.* **18 (4)**, 756 (1977).

[3] A. Venugopalan, *"The Quantum Zeno Effect – Watched Pots in the Quantum World"*, arXiv: 1211.3498v1 [Physics.hist-ph] (2012)

[4] https://phys.org/news/2015-10-zeno-effect-verifiedatoms-wont.html

[5] W.M. Itano, *"Perspectives on the quantum Zeno paradox"* J.Phys.:Conf.Series 196, (2009) 012018

[6] P. Facchi, A.G. Klein, S. Pascazio, S. and L.S. Schulman, *Phys. Lett. A* **257**, 232 (1999)

Let us consider the state of the quantum system as $|\Psi_0\rangle$ at time $t = 0$ and the measurement is performed with an apparatus described by the Hamiltonian $\mathcal{H}$. The unitary time-evolution of the system due to the measurement is described by the operator $U(t) = \exp(-\frac{i}{\hbar}\mathcal{H}t)$, so that the state of the system at time t is given by $|\Psi(t)\rangle = U(t)\,|\Psi_0\rangle$. The probability that the system after the measurement will be in the initial state is: $P(t) = |\langle\Psi_0|\Psi(t)\rangle|^2 = |\langle\Psi_0|U(t)|\Psi_0\rangle|^2$. Expanding this for a small time-interval Δt gives:

$$P(\Delta t) = 1 - \left(\frac{\Delta t}{\hbar}\right)^2 (\Delta\mathcal{H})^2 + \ldots$$

with $(\Delta\mathcal{H})^2 = (\langle\Psi_0|\mathcal{H}^2|\Psi_0\rangle)^2$. Now performing N consecutive measurements in total time $t = N\Delta t$ this surviving probability is given by:

$$P^{(N)}(t) = [P(\Delta t)]^N = \left[1 - \left(\frac{t}{N\hbar}\right)^2 (\Delta\mathcal{H})^2\right]^N + \ldots$$

which goes to 1 for large N.

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Opinion: Climate Change, a point of agreement!

Gianluca Alimonti, INFN (National Institute for Nuclear Physics) and Universita' degli Studi, Milano Italy. Teaches Fundamentals of Energy at the University of Milan and is a member of the EPS Energy Group

At the EPS Energy Group meeting held in Barcelona at the beginning of October, I was honored to be the chairman of the session where Prof. R.Lindzen, emeritus Alfred P. Sloan Professor of Atmospheric Sciences at MIT, and Prof. P.Williams, Professor of Atmospheric Science in the Department of Meteorology at the University of Reading, had a very interesting discussion.

Prof. Lindzen's research in atmospheric dynamics has led to his conclusion that the sensitivity of surface temperature to increases in atmospheric carbon dioxide is considerably lower than that necessary to generate disastrous climate change, while Prof. Williams http://www.met.reading.ac.uk/~williams/ had rather opposite views.

After the presentations from both speakers, a long question and discussion time had been foreseen to allow for a better scientific understanding of the several issues presented.

Throughout the whole session the two speakers have shown a great mutual respect and professional esteem, an attitude that should be taken for granted in a scientific debate but which lately has not been too fashionable, especially when it comes to climate change discussions; such a proper situation bore out many more points of agreement than what could have been supposed à priori.

Among these, a "detail" of the IPCC (Intergovernmental Panel on Climate Change: the international body for assessing the science related to climate change) fifth report caught my attention, and deserves to be underlined in my opinion: the IPCC, in presenting its best estimates for the Equilibrium Climate Sensitivity (ECS is defined as the equilibrium change in annual mean global mean surface temperature following a doubling of the atmospheric carbon dioxide), shows a likely interval between 1.5°C to 4.5°C (*medium confidence*) and underlines, in a very marked and original way, that a best estimate is not indicated. The following is taken from the AR5 (Fifth Assessment Report, the most recent assessment report by IPCC) Technical Summary: "In contrast to AR4 (Fourth Assessment Report, the previous assessment report by IPCC, 2007), no best estimate for ECS is given because of a lack of agreement on the best estimate across lines of evidence and studies and an improved understanding of the uncertainties in estimates based on the observed warming. Climate models with ECS values in the upper part of the *likely* range show very good agreement with observed climatology, whereas estimates derived from observed climate change tend to best fit the observed surface and ocean warming for ECS values in the lower part of the *likely* range."

I personally find this message very clear and in contrast to what is reported by most of the media: any ECS value may be chosen within the given interval and Climate Models working with high ECS values foresee temperatures higher than the observed ones.

> **Any ECS value may be chosen within the given interval and Climate Models working with high ECS values foresee temperatures higher than the observed ones.**

Moreover, in an October 8th news on Nature https://www.nature.com/articles/d41586-018-06876-2 it can be read "The previous IPCC assessment, released in 2014, estimated that the world would breach 1.5 °C by the early 2020s at the current rate of emissions. The latest report (Special Report on Global Warming of 1.5 °C, author's note) extends that timeline to 2030 or 2040." Actually in the SR15 (Special Report on Global Warming of 1.5 °C) headline statements of 2018 one can find: "Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate (high confidence)".

I'm certainly not downplaying the severity of global warming if a 1.5 °C global temperature increase over the preindustrial times should be reached by 2052 instead of the early 2020s; what I intend to underline is the caution taken by IPCC in presenting these estimates and I think this is an important point that should always be considered in climate change scientific debates.

It should also be emphasized that taking any value for ECS in the reference range, no mistake is made as all are equally scientifically acceptable: the difference is that considering values close to 1.5 ° C, all catastrophic claims regarding climate change are heavily exaggerated, while if we assume ECS close to 4.5 ° C, the measures foreseen by international agreements like that of Paris, are insufficient.

Yet global policies are based on this uncertainty. ■

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