Qian Niu

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Education

Ph. D. Physics, University of Washington (1985)
M. S. Physics, University of Washington (1983)
B. S. Physics, Peking University (1981)

Professional Employment

Trull Centennial Professor, University of Texas (2001-).
Assistant and Associate Professor, University of Texas (1990-2001).
Visiting Scientist, UC Santa Barbara (1988-1990).
Research Associate, University of Illinois (1985--1987).

Visiting Positions

ICQM at Peking University (2010-2018), as director during (2012-2014)
ICQS at Institute of Physics, Beijing (2000-2010),
Institute of Theoretical Physics and QUEST at UCSB (1990)
Oak Ridge National Lab
University of Tennessee at Knoxville
Hong Kong University of Science and Technology
University of Michigan
University of Washington
Tsinghua University, Taiwan
University of Houston

Honors and Awards

Fellow of the American Physical Society (1999-). Citation: `for contributions to the theories of quantum transport'
Trull Centennial Professorship (2001-).
Blumberg Fellowship (1992-1993).
Trull Centennial Fellowship (1990-1992).
Thousand Talent Program of China (2011-2018).
Wang Kuan Cheng Research Award (1997).
Outstanding Overseas Young Scientist (1999, Natural Science Foundation of China).
Honorary Adjunct Professors at the Institute of Physics, Institute of Theoretical Physics, and Shanxi University in China.

Professional Service

Has mentored 18 Ph.D. students and 16 postdocs, 26 of whom are now at various levels of teaching and research positions in physics.
Director of the International Center of Quantum Materials, Peking University (2012-14).
Director of the International Center of Quantum Structures, Beijing (2007-08).
Editorial Board Member of the International Journal of Modern Physics B and Modern Physics Letters B (1995-2011).
Editorial Board Member for Chinese Physics.
Panel review member for US Civilian Research and Development Foundation (2004).

Meetings Organized

APS Invited Session on Valley Polarization Physics (2013, Baltimore)
APS Invited Session on Topological States and Plasmonics in Graphene (2013)
APS Symposium on Orbital Magnetization (2008, New Orleans)
APS Symposium on Anomalous Hall and Nernst effects (2007, Denver)
ICQ International workshop on The World of Hall Physics (2011, Beijing)
CECAM workshop on The Anomalous Hall Effects (2005, Lyon).
International workshop on Nanostructures and Quantum Phenomena (2001, Beijing)
International Workshop on Formation Mechanisms and Physical Properties of Natostructures (1998-1999, Taiwan).
Summer school on `Mesoscopic and Strongly Correlated Systems' at CCAST, Beijing (1993).
Minischool on `Quantum Hall effects and Quantized Charge Transport' at CCAST, Beijing (1990).

Publication Record

250+ publications in refereed journals, including 75 in Physical Review Letters, 3 in Science, 5 in Nature and its subsidiaries, 1 each in Review of Modern Physics, Physics Today, and Physics World. These papers have generated 20k+ citations (2291 in the last year), 55 of which have been cited more than 100 times each.

Book: The Geometric Phase in Quantum Systems, A. Bohm, A. Mostafazadeh, H. Koizumi, Q. Niu, and J. Zwanziger, (Springer, 2003).

Book： Physical Effects of Geometric Phases, Q. Niu, M. C. Chang, B. Wu, D. Xiao, R. Cheng, (World Scientific, 2017)

380+ invited talks at professional meetings and research institutions.

Ten Representative Publications

[1] Berry phase effects on electronic properties
Xiao, D; Chang, MC; Niu, Q
REVIEWS OF MODERN PHYSICS 82**:** 1959-2007 **(**2010).
Times cited: 1435

[2] Quantized Hall conductance as a topological invariant
NIU, Q; THOULESS, DJ; WU, YS
PHYSICAL REVIEW B 31**:** 3372-3377 **(**1985)
Times cited: 574

[3] Ground-state degeneracy of the fractional quantum Hall states in the presence of a random potential and on high-genus Riemann surfaces
WEN, XG; NIU, Q
PHYSICAL REVIEW B 41**:** 9377-9396 **(**1990)
Times cited: 593

[4] Wave-packet dynamics in slowly perturbed crystals: Gradient corrections and Berry-phase effects
Sundaram, G; Niu, Q
PHYSICAL REVIEW B 59**:** 14915-14925 **(**1999)
Times cited: 486

[5] Berry phase, hyperorbits, and the Hofstadter spectrum: Semiclassical dynamics in magnetic Bloch bands
Chang, MC; Niu, Q
PHYSICAL REVIEW B 53: 7010-7023 (1996)
Times cited: 269

[6] Anomalous Hall effect in ferromagnetic semiconductors
Jungwirth, T; Niu, Q; MacDonald, AH
PHYSICAL REVIEW LETTERS 88**:** 207208 **(**2002)
Times cited: 494

[7] First principles calculation of anomalous Hall conductivity in ferromagnetic bcc Fe
Yao, YG; Kleinman, L; MacDonald, AH; Sinova, J; Jungwirth, T; Wang, DS; Wang, EG; Niu, Q
PHYSICAL REVIEW LETTERS 92**:** 037204 **(**2004)
Times cited: 388

[8] Berry phase correction to electron density of states in solids
Xiao, D; Shi, JR; Niu, Q
PHYSICAL REVIEW LETTERS 95: 137204 (2005)
Times cited: 222

[9] Valley-contrasting physics in graphene: Magnetic moment and topological transport
Xiao, D; Yao, W; Niu, Q
PHYSICAL REVIEW LETTERS 99**:** 236809 **(**2007)
Times cited: 826

[10] Valley-dependent optoelectronics from inversion symmetry breaking
Yao, Wang; Xiao, Di; Niu, Qian
PHYSICAL REVIEW B 77: 235406 (2008)
Times cited: 412

Research Accomplishments

My work has been concentrated on the fundamental theory of condensed matter, and made contribution to its major overhaul by systematic applications of topological and geometric phase ideas [1]. These applications have made lasting impact on the field of quantum Hall effect, paved the ground for adiabatic pumping and theory of polarization, revived the field of anomalous Hall effect, broke new ground for the theory of orbital magnetization, and played a key role in the development of spin Hall effect, among other things to be pointed out below. In today's very diverse and ever specializing subject of condensed matter physics, these new ideas provide a valuable tiding thread and unifying view, and have essentially transformed its basic theory at the textbook level. As a result, we now have a much richer notion of insulators, a much deeper understanding of electron dynamics in metals and semiconductors, and more effective means of calculation of transport as well as thermodynamic properties of materials.

The quantum Hall system is the first example of a new kind of insulator, which does not conduct current in the direction along the electric field as in an ordinary insulator, but has a nonzero transverse conductance which is quantized. Thouless and collaborators related such conductance to topological Chern numbers in the band structure, and my thesis work [2] in 1985 generalized this notion to the realistic situation where disorder and many-body interactions are inevitably present. This robustness endows the topological notion its full meaning.

This work also pointed out the necessity of ground state degeneracy for the fractional quantum Hall phase on a torus. The general dependence of ground state degeneracy on the genus of Riemann surface was worked out in a collaboration with Wen [3] in 1990, laying out an early ground for the important notion of topological order.

In an earlier paper in 1984, which also provided the technical basis for [2], I generalized the quantum pumping idea of Thouless by allowing disorder and many body interactions. Later, I proposed in 1990 a quantum charge pump for a current standard, which inspired a line of experiments by Pepper's group on high precision pump (20 parts per million) of quantized currents. On the other hand, our theory has provided the basis for the Berry phase formulation of electric polarization by Vanderbilt and King-Smith and by Ortiz and Martin.

The physical significance of Berry curvatures of Bloch states in the crystal momentum space was recognized by Sundaram and Niu [4] in 1999, following an earlier exposition on magnetic Bloch bands by Chang and Niu in 1995 and1996 [5]. We realized that the Berry curvatures can have important effects on electron dynamics and transport in metals and semiconductors where the Bloch bands are partially occupied. The intrinsic contribution to the anomalous Hall conductivity in the Karplus-Luttinger theory in 1954 is precisely of this nature.

Inspired by this new understanding, Jungwirth, MacDonald, and myself decided to evaluate it in 2002 [6] for a magnetic semiconductor, finding almost perfect agreement with experiment. We have thus found the key to solve a half-century mystery surrounding the anomalous Hall effect. My then postdoc, Yao, followed up with first principles calculation for ferromagnetic Iron [7] and GeMn, and also got quantitative agreement with experiments. In the mean time, a large number of theoretical and experimental groups around the world became interested and gave a thorough reexamination of the anomalous Hall effect, clearly establishing the importance of the intrinsic contribution.

Our success on the Berry phase induced anomalous Hall effect also spurred the investigation of the intrinsic spin Hall effect. After a huge wave of theoretical studies led by the Texas group of MacDonald and myself and the Tokyo-Stanford group of Nagaosa and Zhang, experiments have indeed confirmed the existence and sometimes dominance of the intrinsic effect. At the same time, our semiclassical theory with Berry curvature effects have become widely appreciated, driving a diverse set of researches on anomalous Nernst effect of electrons, thermal Hall effects of phonons and magnons, and anomalous Hall effect of light (Bliokh and Bliokh 2004; Onoda, Murakami, and Nagaosa, 2004).

Working with Xiao and Shi (then my student and postdoc, respectively), we discovered that the Berry-phase modified electron dynamics in solids has an invariant measure different from the canonical one for the phase space [8]. We interpreted this as a fundamental modification of the density of quantum states, and pointed out its wide implications in solid state physics. This investigation also led us to the discovery of a Berry phase contribution to the orbital magnetization, which is confirmed by Resta and Vanderbilt groups using numerical and other methods, and also by ourselves using perturbation theory. Finding the correct formula for orbital magnetization is another breakthrough in solid state physics after the work on electric polarization.

It turned out that this Berry phase contribution to orbital magnetization provides a key to understand some issues surrounding thermoelectric and thermal Hall effects. Driven by the statistical force of a temperature gradient, an anomalous current can be produced through the inhomogeneous orbital magnetization, exactly like a mechanical force producing an anomalous current from the Berry curvature induced anomalous velocity. Without this understanding, it had seemed that the transverse thermoelectric effects would violate the Onsager relation, and that thermal Hall effect would diverge rather than vanish at zero temperature.

Our semiclassical theory also laid the original ground for valley contrasting physics that is being hotly studied on two-dimensional semiconductor materials. Working with Xiao and Yao then in my group, we found that the orbital magnetic moment and Berry curvature endow the carrier valleys the same properties as an electron spin [9]. In addition, the three fold rotational symmetry should dictate a valley dependent chiral selection rule for optical transitions [10]. By now a large number of experiments have been conducted, confirming our predictions on the valley dependent optical, transport and magnetic properties.

The Berry curvature in momentum space has been generalized in various directions to cover the very diverse situations of solid state physics. From my own group, with my then student, Dimi Culcer, we formulated a general theory of coherent wavepacket dynamics in degenerate multi-bands, where the Berry curvature and magnetic moment become non-abealian matrices, and the phase space dynamics include internal degrees of freedom. Working with my former student, M.C. Chang, we also succeeded in quantizing our semiclassical theory by generalizing the venerable Peierles substitution rule, elucidating the geometric origin of spin-orbit coupling and an obscure Yafet term in Zeeman coupling. More recently, working with my student, Yang Gao, we are able to show that our semiclassical equations of motion keep its form to second order accuracy in electromagnetic fields, provided additional field corrections are included in the band energy and in the Berry curvature, which has opened the door for systematic study of geometric phase effects in quadratic response thermodynamic and transport properties.

The concept of momentum space Berry curvature can also be generalized to quasi-particle physics in interaction systems. Haldane (2004) pointed out the necessity of updating the Landau Fermi-liquid theory by including the Berry curvature on the Fermi surface. Shindo and Balents (2006) discovered an artificial electric field in addition to the artificial magnetic field in momentum space. Recently, there has been considerable study of chiral anomaly in Wyle semimetals, and our semiclassical dynamics provides natural language for the formulation of chiral kinetics (Stephaov and Yin 2012) and calculation of transport properties (Son and Spivak 2013).

The work of Sundaram and Niu [4] also discussed Berry curvatures defined for the cross planes between momentum and position. One natural place for their existence is an electron system where the carrier spin couples to position and momentum dependent Zeeman fields. The former is realized by a textured background magnetization, and the latter comes from spin-orbit coupling. Therefore, such cross-plane Berry curvatures play a natural roll in the study of spin-orbit torques (Sinova) and other current induced forces on domain walls and skyrmions.

I have also worked on other aspects of Berry phase effects in condensed matter, as partially summarized in a book that I coauthored, `The geometric phase in quantum systems' (Springer, 2003). This includes work on Magnus force on superfluid vortices, a first principles formulation of spin wave dynamics, and more recently on a universal emf induced by domain wall motion known as the ferro-Josephson effect. In the spin wave work, I showed with Kleinman and others how to unify the local moment picture with the itinerant view of the density functional theory, and we were able to predict the spin wave spectrum in Iron in quantitative agreement with experiment. The ferro-Josephson effect had been predicted long ago for a special setting by Berger. Yang (then student), Xiao and myself showed its existence in more realistic situations, and with our help, it is now observed by our experimental colleagues. This work is featured in the APS online journal Physics, and is regarded as a breakthrough in spintronics research.

Over the years, I have also worked on other aspect of solid state physics. I was an original contributor to the development of a quantum electronic growth concept for metallic over-layer formation on semiconductor substrates, which successfully explained the observation of a critical thickness in the growth of ultra-thin and flat silver films, and predicted the existence of magic thicknesses for the growth of other metal films. Our work stimulated an active line of experimental and theoretical research on quantum size effects in film growth as well as in physical properties such as superconductivity.

Apart from solid state physics, I have also made important contributions to the study of ultra-cold atoms and their condensates in optical lattices. I helped my experimental colleague, Raizen, with calculations and design, to observe Wannier-Stark ladders in the atomic system (review article in Physics Today, July 1997). These ladders had been predicted in the 60's, subjected heavy theoretical debates over the years, and had never been observed in the solid state setting. This work not only solved a long standing puzzle in solid state physics, but also laid the ground for later studies of atomic Bose-Einstein condensates (BEC) using optical lattices. I have also written a series of influential papers, with students and postdocs, on various nonlinear effects in atomic BEC. We predicted Landau and dynamic instabilities, nonlinear Landau Zener tunneling, and pointed out a nonlinear effect in the interference fringes of two BEC clouds. We also formulated a general theory of adiabatic evolution of nonlinear quantum systems, and proposed geometric phase effects in them.