News Releases

臺大張慶瑞團隊的《自旋電子學中的 Yang-Mills 理論》發表國際頂尖期刊《物理學報》

國立台灣大學張慶瑞教授及訪問學者陳繩義(已加入中國文化大學)，與其博士生陳松賢(已加入台北大學)，黃則鈞暨新加坡國立大學，皇家墨爾本理工學院和東京理工學院合作撰寫了一篇有關自旋電子學中 Yang-Mills 理論的物理學。這篇文章最近發表於國際頂尖期刊《物理學報》(Physics Reports) （2020 年 10 月）。

此期刊一直是物理界影響因子最高的雜誌之一，過去 5 年的影響係數平均值為 24.659，遠比《Nature Physics》的 5 年影響係數平均值 (21.797) 還高出不少。尤值一提的是，在《物理學報》發表文章，以台灣作者群為主體，甚至為通訊作者本已是鳳毛麟角，若是以凝聚態相關主題，本文更可說是該刊自 1971 創刊迄今，台灣的第一篇文章發表。本論文已可在期刊網頁下載。(https://www.sciencedirect.com/science/article/pii/S037015732030257X)。

Yang-Mills 理論是標準模型的基礎，傳統上是高能和數學物理學家非常感興趣的領域。在 1990 年代後，Yang-Mills 所啟發的物理學領域已擴展到自旋電子學（spintronics），現在半導體或拓撲材料等具有強自旋軌道耦合的材料中的結構中更容易觀測到，對現代工業產生極大影響。

本文由規範理論出發，來探討 Yang-Mills 理論在自旋電子學的應用。例如自旋霍爾和自旋力矩的現象，可以利用 Yang-Mills 的理論更清楚理解自旋軌道相關現象的問題。但是在大多數以前的工作中缺少了對 Yang-Mills 理論和個體現象之間的明確解釋。本文中提出的嶄新的觀點是從力和相位物理學的角度進行的討論。同時結合自旋霍爾，自旋抖動運動，量子自旋霍爾和自旋力矩來研究自旋電子學的規範物理。同時在自旋干涉和自旋螺旋的背景下討論了自旋相位物理學。奇妙的是，這些複雜的自旋電子學現象竟然可以透過簡單的力和相物理學在 Yang-Mills 的理論背景下來清楚解釋。

本文將規範理論方法與自旋和磁現象作出良好而直接聯繫，對凝聚態學家特別是納米科學領域的科學家來說非常有用，無論自旋電子學，拓撲系統，二維石墨烯和矽烯的研究都可以利用本理論而有更清楚物理與應用圖象。另一方面，本文也對試圖進入凝聚態科學和納米科學世界，而往往不知如何著手的高能理論家提供了一個友善的切入方向。

News Announcement

Professor Ching-Ray Chang and his collaborators Published “Yang－Mills physics in spintronics” in ＜Physics Reports＞

The National Taiwan University has, in an international team effort, collaborated with the Chinese Culture University, the University of Taipei, the National University of Singapore, the Royal Melbourne Institute of Technology, and the Tokyo Institute of Technology, to write a review article on the physics of Yang-Mills in spintronics. This article was recently published in the Physics Reports (Oct 2020).

Physics Reports has always been one of the academic journals with the highest impact factor in physics community. The 5-Year Impact Factor is 24.659, which is much higher than the 5-Year Impact Factor of Nature Physics (21.797). It is worth mentioning that the publication in Physics Reports, with Taiwanese authors, or even corresponding authors, is already rare. If it is related to condensed matter, this article can be said to be the first and only publication of Physics Reports since 1971. This paper is now available for download on the journal webpage.
(https://www.sciencedirect.com/science/article/pii/S037015732030257X).

Yang-Mills theory is the cornerstone of the standard model and is traditionally an area of great interest to high energy and mathematical physicists. Originally designed to explain the physics that permanently glue fundamental particles together, Yang-Mills has today expanded far beyond the realm of its original proposition. Concepts introduced in the high-energy model have now found useful applications in condensed matter as well as atomic and optical systems. In the 1990s, Yang-Mills-inspired physics expanded to spintronics - a modern field that straddles condensed matter and electron spin transport in very small devices. These devices are normally constructed out of materials with strong spin-orbit coupling, e.g. semiconductor, or the topological.

While review articles had been written on Yang-Mills in atomic and condensed matter physics, a consolidated summary of Yang-Mills-inspired spintronics – a role to be filled by this article, is clearly missing. This article started with an introduction of the history of the gauge physics as well as their modern manifestations in the Yang-Mills, the Aharonov-Bohm, the Aharonov-Casher, and the Berry-Pancharatnam effects. Yang-Mills-like physics is treated as a unifying context for numerous spin-orbit related phenomena, e.g. the spin Hall and the spin torque – this is in fact a consolidation of past efforts. However, what the authors think lacking in most previous work is an explicit elucidation of the links between Yang-Mills and the individual phenomena. Therefore, what we consider a fresh perspective in this review is a discussion carried out from the point of view of the force and the phase physics. For example, the spin force physics of the spintronic gauge is discussed in connection with the spin Hall, the spin jitter motion, the quantum spin Hall, and the spin torque. The spin phase physics is on the other hand discussed in the context of the spin interference and the persistent spin helix. It is simply remarkable that Yang-Mills is a unifying context, and the links could be plausibly explained by the simple physics of force and phase. To put things into perspective, gauge fields like the Berry-Pancharatnam, the Aharonov Bohm and the Aharonov Casher are also discussed alongside the Yang-Mills in terms of their forceful and forceless physics.

This article would be useful to condensed matter physicists, particularly those in the fields of nanosciences e.g. spintronics, topological systems, 2D graphene and silicene. Compared to the vast spectrum of theoretical approaches in the nanosciences and spintronics, the gauge theoretic is a small but an important part. This article provides a direct linkage of the gauge theoretic approaches to the spin and the magnetic phenomena. On the other hand, this article could also be useful to the community of gauge-field or high energy theorists seeking to venture into the world of condensed matter and nanosciences.