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物理学Physics

Particle exchange statistics beyond fermions and bosons

超越费米子和玻色子的粒子交换统计

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▲ 链接：https://www.nature.com/articles/s41586-024-08262-7

▲摘要：人们普遍认为，在量子力学中，除了二维的任意子，只有费米子和玻色子两种粒子交换统计。原则上，第二种例外被称为非统计。它延伸到二维之外，被认为在物理上等同于费米子和玻色子。

研究者证明了物理系统中可以存在与费米子或玻色子等价的非平凡准统计量。这些新类型的相同粒子遵循广义不相容原理，导致与任何自由费米子和玻色子系统不同的奇异自由粒子热力学。

他们通过发展粒子的第二次量子化来表述其理论。该理论自然地包括精确可解的非相互作用理论，并结合了诸如局部性等物理约束。

然后，他们在一维和二维中构建了一组精确可解的量子自旋模型，其中自由粒子以准粒子的形式出现，其交换统计量可以被物理观察到，且与费米子和玻色子明显不同。这证明了在凝聚态系统中存在一种新型准粒子的可能性，更有可能是以前未考虑过的基本粒子类型。

▲ Abstract：It is commonly believed that there are only two types of particle exchange statistics in quantum mechanics, fermions and bosons, with the exception of anyons in two dimensions. In principle, a second exception known as parastatistics, which extends outside two dimensions, has been considered but was believed to be physically equivalent to fermions and bosons. Here we show that non-trivial parastatistics inequivalent to either fermions or bosons can exist in physical systems. These new types of identical particle obey generalized exclusion principles, leading to exotic free-particle thermodynamics distinct from any system of free fermions and bosons. We formulate our theory by developing a second quantization of paraparticles that naturally includes exactly solvable non-interacting theories and incorporates physical constraints such as locality. We then construct a family of exactly solvable quantum spin models in one and two dimensions, in which free paraparticles emerge as quasiparticle excitations, and their exchange statistics can be physically observed and are notably distinct from fermions and bosons. This demonstrates the possibility of a new type of quasiparticle in condensed matter systems and—more speculatively—the potential for previously unconsidered types of elementary particle.

Excitons in the fractional quantum Hall effect

分数量子霍尔效应中的激子

▲ 作者：Naiyuan J. Zhang, Ron Q. Nguyen, Navketan Batra, Xiaoxue Liu, Kenji Watanabe, Takashi Taniguchi, D. E. Feldman J. I. A. Li

▲ 链接：https://www.nature.com/articles/s41586-024-08274-3

▲摘要：激子，即电子和空穴的库仑驱动束缚态，通常由整数电荷组成。然而，在受电荷分数化影响的双层系统中，可以出现一种更有趣的层间激子形式，其中在携带分数电荷的组分之间发生配对。尽管对这些分数激子有许多理论预测，但它们的实验观察仍未被探索。

研究者报道了分数量子霍尔效应态中激子对的输运特征。通过探测这些激子的组成及其对潜在波函数的影响，他们发现了两种新的物质量子相。

其中一个可以被看作是总填充为1的激子凝聚的分数对应物；而另一个则涉及一种更不寻常的激子类型，它遵循非玻色子量子统计，挑战玻色子激子的标准模型。

▲ Abstract：Excitons, Coulomb-driven bound states of electrons and holes, are typically composed of integer charges. However, in bilayer systems influenced by charge fractionalization, a more interesting form of interlayer exciton can emerge, in which pairing occurs between constituents that carry fractional charges.

Despite numerous theoretical predictions for these fractional excitons, their experimental observation has remained unexplored. Here we report transport signatures of excitonic pairing in fractional quantum Hall effect states. By probing the composition of these excitons and their impact on the underlying wavefunction, we discover two new types of quantum phases of matter. One of these can be viewed as the fractional counterpart of the exciton condensate at a total filling of 1, whereas the other involves a more unusual type of exciton that obeys non-bosonic quantum statistics, challenging the standard model of bosonic excitons.

化学Chemistry

Emergence of a distinct mechanism of C – N bond formation in photoenzymes

光酶中C-N键形成的独特机制的出现

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▲ 链接：https://www.nature.com/articles/s41586-024-08138-w

▲摘要：由于氮杂环在小分子药物和农用化学品中无处不在，C-N键的形成对现代化学合成是不可或缺的。烯烃与未活化烯烃的氢胺化反应是构建这些键的原子经济策略。然而，当制备完全取代的碳立体中心时，这些反应很难呈现不对称。

研究者报道了一种利用Baeyer-Villiger单加氧酶制备2,2-二取代吡咯烷的光酶烯烃氢胺化反应。5轮蛋白质工程获得了一个突变体，提供了良好的产物收率和立体选择性。

与依赖于胺或烯烃氧化形成C-
N键的相关光化学氢胺反应不同，这项研究利用了还原生成的苯基和氮孤对的空间相互作用。

这种反键相互作用降低了自由基的氧化电位，使电子转移到黄素辅因子。实验表明，酶微环境在实现创新的C-N键形成机制中是必不可少的，这在小分子催化中是没有类似的。分子动力学模拟研究了酶活性位点的底物，进一步支持了这一假设。

这项工作是非自然生物催化中新兴机制的一个罕见例子。在这种机制中，酶可以获得其单个组分所没有的机制。我们的研究展示了利用蛋白质工程增强紧急机制的潜力，为化学合成中未解决的挑战提供独特的机制解决方案。

▲ Abstract：C – N bond formation is integral to modern chemical synthesis owing to the ubiquity of nitrogen heterocycles in small-molecule pharmaceuticals and agrochemicals. Alkene hydroamination with unactivated alkenes is an atom-economical strategy for constructing these bonds. However, these reactions are challenging to render asymmetric when preparing fully substituted carbon stereocentres. Here we report a photoenzymatic alkene hydroamination to prepare 2,2-disubstituted pyrrolidines by a Baeyer – Villiger mono-oxygenase. Five rounds of protein engineering afforded a mutant, providing excellent product yield and stereoselectivity. Unlike related photochemical hydroaminations, which rely on the oxidation of the amine or alkene for C – N bond formation, this work exploits a through-space interaction of a reductively generated benzylic radical and the nitrogen lone pair. This antibonding interaction lowers the oxidation

potential of the radical, enabling electron transfer to the flavin cofactor. Experiments indicate that the enzyme microenvironment is essential in enabling a innovative C – N bond formation mechanism with no parallel in small-molecule catalysis. Molecular dynamics simulations were performed to investigate the substrate in the enzyme active site, which further support this hypothesis. This work is a rare example of an emerging mechanism in non-natural biocatalysis in which an enzyme has access to a mechanism that its individual components do not. Our study showcases the potential of enhancing emergent mechanisms using protein engineering to provide unique mechanistic solutions to unanswered challenges in chemical synthesis.

Li2ZrF6-based electrolytes for durable lithium metal batteries

用于耐用锂金属电池的Li2ZrF6基电解质

▲ 作者：Qingshuai Xu, Tan Li, Zhijin Ju, Guangxu Chen, Daiqi Ye, Geoffrey I. N. Waterhouse, Yingying Lu, Xuejun Lai, Guangmin Zhou, Lin Guo, Keyou Yan, Xinyong Tao, Hong Li Yongcai Qiu

▲ 链接：https://www.nature.com/articles/s41586-024-08294-z

▲ 摘要：锂（Li）金属电池（MNB）是一种很有前途的高能量密度可充电电池。然而，由高活性锂和非水电解质之间的反应形成的锂枝晶导致了安全性问题和快速的容量衰减。开发可靠的固体电解质界面对于实现高速率和长寿命的LMB至关重要，但在技术上仍然具有挑战性。

研究者证明了在含有LiPF6的LMB碳酸盐电解质中添加过量的m-Li2ZrF6（单斜晶体的）纳米颗粒，有助于在施加电压的驱动下将大量的ZrF62 -离子释放到电解质中，转化为t-Li2ZrF6（三方晶系），并在原位形成稳定的固体-电解质界面，具有高锂离子电导率。

计算电镜和低温透射电镜研究表明，富m-Li2ZrF6固电解质界面的原位形成显著增强了锂离子的转移，抑制了锂枝晶的生长。结果表明，采用LiFePO4阴极、三维锂碳阳极和Li2ZrF6基电解质组装的lmb在3000次循环后具有较高的容量保持率（>80.0%），大大提高了循环稳定性。这一成就代表了领先的性能，因此在实际的高速率条件下，为耐用的LMB提供了可靠的基于Li2ZrF6的电解质。

▲ Abstract：Lithium (Li) metal batteries (LMBs) are promising for high-energy-density rechargeable batteries. However, Li dendrites formed by the reaction between highly active Li and non-aqueous electrolytes lead to safety concerns and rapid capacity decay. Developing a reliable solid – electrolyte interphase is critical for realizing high-rate and long-life LMBs, but remains technically challenging. Here we demonstrate that adding excess m-Li2ZrF6 (monoclinic) nanoparticles to a commercial LiPF6-containing carbonate electrolyte of LMBs facilitates the release of abundant ZrF62 – ions into the electrolyte driven by the applied voltage, converting to t-Li2ZrF6 (trigonal) and creating a stable solid – electrolyte interphase in situ with high Li-ion conductivity. Computational and cryogenic transmission electron microscopy studies revealed that the in situ formation of the t-Li2ZrF6-rich solid – electrolyte interphase markedly enhanced Li-ion transfer and suppressed the growth of Li dendrites. As a result, LMBs assembled with LiFePO4 cathodes (areal loading, 1.8/2.2 mAh cm-2), three-dimensional Li – carbon anodes (50- m-thick Li) and Li2ZrF6-based electrolyte displayed greatly improved cycling stability with high capacity retention (>80.0%) after 3,000 cycles (1C/2C rate). This achievement represents leading performance and, thus, delivers a reliable Li2ZrF6-based electrolyte for durable LMBs under practical high-rate conditions.

生命科学Life Science

Learning-associated astrocyte ensembles regulate memory recall

学习相关星形胶质细胞群调节记忆回忆

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▲ 链接：https://www.nature.com/articles/s41586-024-08170-w

▲摘要：记忆形成和回忆的物理表现是尚未解决的基本问题。在细胞水平上，被称为记忆印痕的神经元集合被学习事件激活，并控制记忆回忆。星形胶质细胞靠近神经元，参与一系列支持神经传递和回路可塑性的活动。

此外，星形胶质细胞表现出经验依赖的可塑性，尽管星形胶质细胞的特定集合是否参与记忆回忆尚不清楚。

研究者发现学习事件诱导海马星形胶质细胞子集中的c-Fos表达，并随后调节小鼠海马回路的功能。学习事件后星形胶质细胞群与c-Fos的交叉标记表明它们与印迹神经元密切相关，这些星形胶质细胞群的重新激活刺激记忆回忆。

在分子水平上，学习相关星形胶质细胞（LAA）群表现出核因子I-A的表达升高，其在该群体中的选择性删除抑制了记忆回忆。综上所述，这一数据确定LAA集合是一种可塑性的形式，足以激发记忆回忆，并表明星形胶质细胞是印迹的活跃成分。

▲ Abstract：The physical manifestations of memory formation and recall are fundamental questions that remain unresolved1. At the cellular level, ensembles of neurons called engrams are activated by learning events and control memory recall. Astrocytes are found in close proximity to neurons and engage in a range of activities that support neurotransmission and circuit plasticity. Moreover, astrocytes exhibit experience-dependent plasticity, although whether specific ensembles of astrocytes participate in memory recall remains obscure. Here we show that learning events induce c-Fos expression in a subset of hippocampal astrocytes, and that this subsequently regulates the function of the hippocampal circuit in mice. Intersectional labelling of astrocyte ensembles with c-Fos after learning events shows that they are closely affiliated with engram neurons, and reactivation of these astrocyte ensembles stimulates memory recall. At the molecular level, learning-associated astrocyte (LAA) ensembles exhibit elevated expression of nuclear factor I-A, and its selective deletion from this population suppresses memory recall. Taken together, our data identify LAA ensembles as a form of plasticity that is sufficient to provoke memory recall and indicate that astrocytes are an active component of the engram.

Foundation models for fast, label-free detection of glioma infiltration

快速、无标记检测胶质瘤浸润的基础模型

▲ 作者：Akhil Kondepudi, Melike Pekmezci, Xinhai Hou, Katie Scotford, Cheng Jiang, Akshay Rao, Edward S. Harake, Asadur Chowdury, Wajd Al-Holou, Lin Wang, Aditya Pandey, Pedro R. Lowenstein, Maria G. Castro, Lisa Irina Koerner, Thomas Roetzer-Pejrimovsky, Georg Widhalm, Sandra Camelo-Piragua, Misha Movahed-Ezazi, Daniel A. Orringer, Honglak Lee, Christian Freudiger, Mitchel Berger, Shawn Hervey-Jumper Todd Hollon

▲ 链接：https://www.nature.com/articles/s41586-024-08169-3

▲ 摘要：胶质瘤治疗的一个关键挑战是在手术中检测肿瘤浸润以实现安全的最大切除。不幸的是，大多数胶质瘤患者术后可安全切除残余肿瘤，导致早期复发和生存率降低。研究者提出了一种快速（<10
s）和准确检测新鲜，未经处理的手术组织中胶质瘤浸润的视觉基础模型——FastGlioma。

该模型可在快速、无标记的光学显微镜下使用大规模自我监督（约400万张图像）进行预训练，并进行微调以输出一个标准化的评分。该评分表明肿瘤浸润程度在全片光学图像中。

在一项前瞻性、多中心、国际弥漫性胶质瘤患者检测队列（n = 220）中，FastGlioma能够检测并量化肿瘤浸润程度，其在受试者工作特征曲线下的平均面积为92.1±0.9%。在一项头部对头部的前瞻性研究中，该模型在手术期间检测肿瘤浸润方面的表现优于图像引导和荧光引导辅助手段（n = 129）。

根据世界卫生组织的定义，该模型在不同的患者人口统计、医疗中心和弥漫性胶质瘤分子亚型中表现仍然很高。该模型在其他成人和儿童脑肿瘤诊断中显示出零概率通用性，表明这一基础模型有可能被用作指导脑肿瘤手术的通用辅助工具。这些发现代表了医学基础模型在释放人工智能在癌症患者护理中的作用方面的变革潜力。

▲ Abstract：A critical challenge in glioma treatment is detecting tumour infiltration during surgery to achieve safe maximal resection. Unfortunately, safely resectable residual tumour is found in the majority of patients with glioma after surgery, causing early recurrence and decreased survival. Here we present FastGlioma, a visual foundation model for fast (<10 s) and accurate detection of glioma infiltration in fresh, unprocessed surgical tissue. FastGlioma was pretrained using large-scale self-supervision (around 4 million images) on rapid, label-free optical microscopy, and fine-tuned to output a normalized score that indicates the degree of tumour infiltration within whole-slide optical images. In a prospective, multicentre, international testing cohort of patients with diffuse glioma (n = 220), FastGlioma was able to detect and quantify the degree of tumour infiltration with an average area under the receiver operating characteristic curve of 92.1 ± 0.9%. FastGlioma outperformed image-guided and fluorescence-guided adjuncts for detecting tumour infiltration during surgery by a wide margin in a head-to-head, prospective study (n = 129). The performance of FastGlioma remained high across diverse patient demographics, medical centres and diffuse glioma molecular subtypes as defined by the World Health Organization. FastGlioma shows zero-shot generalization to other adult and paediatric brain tumour diagnoses, demonstrating the potential for our foundation model to be used as a general-purpose adjunct for guiding brain tumour surgeries. These findings represent the transformative potential of medical foundation models to unlock the role of artificial intelligence in the care of patients with cancer.

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