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Charge-dependent spectral softenings of primary cosmic rays below the knee

膝区以下初级宇宙射线的电荷依赖性光谱软化

▲ 作者：The DAMPE Collaboration

▲链接：

https://www.nature.com/articles/s41586-026-10472-0

▲摘要：

在大多数粒子加速或传播理论中，由加速极限或传播相位变化导致的宇宙射线光谱特征是电荷依赖性的。然而，交互场景通常呈现出质量依赖的光谱特征。由于难以测量单个粒子直至极高能段的能谱，目前仍缺乏对自然界中究竟哪种关系实际起作用的观测验证。

研究组基于“ 暗物质粒子探测器 ” 9年的在轨数据，报道了碳、氧和铁能谱在约20吉伏至约100太伏（铁为60太伏）能量范围内的直接测量结果。并首次在这些能谱中直接探测到明显的光谱软化现象。

结合更新的质子和氦光谱，这种光谱软化普遍出现在约15太伏的刚度处。当置信水平高于99.999%时，光谱软化与核子质量相关的假设被排除。研究组讨论了这些结果的可能解释，包括附近存在宇宙射线源以及其他模型（如传播效应）。

▲ Abstract：

In most particle acceleration or propagation theories, the characteristic features of the cosmic ray spectra due to acceleration limits or propagation phase changes are charge-dependent. Alternatively, the interaction scenario would expect mass-dependent spectral features in general. The observational verification of which relation takes effect in nature is still lacking because of the difficulty in measuring the spectra of individual particles up to very high energies. Here we report direct measurements of the carbon, oxygen and iron spectra from about 20?gigavolts to around 100?teravolts (60?teravolts for iron) with 9?years of on-orbit data collected by the Dark Matter Particle Explorer. Distinct spectral softenings have been directly detected in these spectra for the first time, to our knowledge. Combined with the updated proton and helium spectra, the spectral softening appears universally at a rigidity of about 15?teravolts. A nuclei-mass-dependent softening is rejected at a confidence level of >99.999%. Possible interpretations of these results, including a nearby cosmic ray source and other models such as the propagation effect, are discussed.

物理学Physics

Quantum coherent manipulation and readout of superconducting vortex states

超导涡旋态的量子相干操纵与读取

▲ 作者：Ameya Nambisan, Simon Gü nzler, Dennis Rieger, Nicolas Gosling, Simon Geisert, Victor Carpentier, et al.

▲链接：

https://www.nature.com/articles/s41586-026-10441-7

▲摘要：

超导体的一个决定性特征是其倾向于排斥磁场，然而在超过某一临界阈值时，磁通量会以阿布里科索夫涡旋携带的离散量子形式穿透进入。

涡旋核心处的超导能隙完全被抑制，使其成为耗散的半经典实体，从而影响到从高电流密度导线到量子器件等各种应用。

由于在相干长度尺度上存在本征或涌现的颗粒性，材料无序可以驱动一种在核心处保留能隙的涡旋转变。尽管在这种有效隧道结机制中可能出现量子涡旋行为，且学界在不同系统中也已观测到相关特征，但尚未实现对涡旋态的相干操控。

研究组提供的证据表明，陷在颗粒超导薄膜中的涡旋可表现为二能级系统，展现出微秒量级的量子相干性以及达到几分之一毫秒的能量弛豫时间。

利用电路量子电动力学的方法，研究组在颗粒铝微波谐振器中实现了对涡旋态的相干操控和量子非破坏读取，这预示着量子信息处理、材料表征和传感等领域的未来发展方向。

▲ Abstract：

A defining characteristic of superconductors is their tendency to expel magnetic fields, yet above a critical threshold, magnetic flux penetrates in discrete quanta carried by Abrikosov vortices. The superconducting gap is completely suppressed at the vortex core, rendering them dissipative, semi-classical entities that impact applications from high-current-density wires to quantum devices. Material disorder can drive a crossover to vortices that preserve an energy gap at the core, owing to intrinsic5 or emergent granularity on the scale of the coherence length. Although quantum vortex behaviour could emerge in this effective tunnel-junction regime, and signatures have been observed in diverse systems, coherent manipulation of vortex states has remained elusive. Here we present evidence that vortices trapped in granular superconducting films can behave as two-level systems, exhibiting microsecond-range quantum coherence and energy relaxation times that reach fractions of a millisecond. Using the tools of circuit quantum electrodynamics, we perform coherent manipulation and quantum non-demolition readout of vortex states in granular aluminium microwave resonators, heralding future directions for quantum information processing, materials characterization and sensing.

材料科学Materials Science

Triple-junction solar cells with improved carrier and photon management

优化载流子与光子调控的三结太阳能电池

▲ 作者：Kerem Artuk, Deniz Turkay, Austin Kuba, Stefan Riemelmoser, Julian A. Steele, Julien Hurni, et al.

▲链接：

https://www.nature.com/articles/s41586-026-10385-y

▲摘要：

钙钛矿-硅三结光伏器件相比双结器件可显著效率，但代价是复杂性增加。

研究组解决了钙钛矿-硅基三结太阳电池中的两个关键瓶颈问题：宽带隙（WBG）顶电池的开路电压（VOC）降低，以及中间电池的光生电流受限。

非挥发性添加剂4-羟基苄胺（HBA）能够调控WBG钙钛矿的结晶过程并钝化缺陷，促进定向生长并抑制非辐射复合。结合改进的能级对齐，该策略实现了高达1.405 V的VOC，并提升了稳定性。

为克服中间电池的电流限制问题，研究组采用三步沉积策略来形成较厚的窄带隙钙钛矿吸收层，同时保持微观结构完整性并增强电子提取。

此外，积聚在纹理化硅底电池前谷区的低折射率SiOx纳米颗粒（SiOx-np）可作为光学中间反射层，增强了中间电池的光吸收。研究组将上述进展集成到1 cm2的钙钛矿-钙钛矿-硅器件中，最终获得了30.02%的认证效率。

▲ Abstract：

Perovskite – silicon triple-junction photovoltaics offer efficiency gains beyond dual-junction devices but at the expense of added complexity. Here we address two key bottlenecks in perovskite – silicon-based triple-junction solar cells: reduced open-circuit voltage (VOC) in the wide-bandgap (WBG) top cell and limited photocurrent generation in the middle cell. A non-volatile additive, 4-hydroxybenzylamine (HBA), regulates WBG perovskite crystallization and passivates defects, promoting oriented growth and suppressing non-radiative recombination. Together with improved energy-level alignment, this yields VOCs of up to 1.405 V and enhanced stability. To overcome the current limitations in the middle cell, a three-step deposition strategy enables the formation of thick, low-bandgap perovskite absorbers while preserving microstructural integrity and enhancing electron extraction. Also, low-refractive-index SiOx-nanoparticles (SiOx-np) that accumulate in the front valleys of the textured silicon bottom cell act as an optical middle reflector, enhancing light absorption in the middle cell. These advances are then combined in 1-cm2 perovskite – perovskite – silicon devices, achieving a certified efficiency of 30.02%.

化学Chemistry

Electronic origin of reorganization energy in interfacial electron transfer

界面电子转移中重组能的电子起源

▲ 作者：Sonal Maroo, Leonardo Coello Escalante, Yizhe Wang, Matthew P. Erodici, Jonathon N. Nessralla, Ayana Tabo, et al.

▲链接：

https://www.nature.com/articles/s41586-026-10311-2

▲摘要：

电子转移（ET）反应是生物和非生物系统中能量转换与化学转化的基础。任何ET过程的效率都依赖于在最佳驱动力范围内实现所需的ET速率。

Marcus理论提供了一个微观框架，用以理解ET中活化自由能（进而理解其速率）与一个关键参数（重组能）之间的关系。

在带电固液界面，长期以来人们普遍认为，只有电解质相中的因素决定了重组能，而电极的电子态密度（DOS）仅决定ET的热力学可及通道数量。

然而，研究组表明，电极DOS在调控重组能方面起着核心作用，其重要性远超传统认知。利用原子层状异质结构，研究组调控了石墨烯的DOS并测量了外层ET动力学。结果发现，由此引起的ET速率变化源于与电极中图像电位局域化相关的重组能显著调制。

这项工作重新定义了非均相ET动力学的传统范式，揭示了电极电子结构在界面反应性中更深层次的作用。

▲ Abstract：

Electron transfer (ET) reactions underpin energy conversion and chemical transformations in both biological and abiological systems. The efficiency of any ET process relies on achieving a desired ET rate within an optimal driving force range. Marcus theory provides a microscopic framework for understanding the activation free energy—and therefore the rate—of ET in terms of a key parameter: the reorganization energy. For electrified solid – liquid interfaces, it has long been conventionally understood that only factors in the electrolyte phase are responsible for determining the reorganization energy and that the electronic density of states (DOS) of the electrode only serves to dictate the number of thermally accessible channels for ET. Here we show instead that the electrode DOS plays a central role in governing the reorganization energy, far outweighing its conventionally assumed role. Using atomically layered heterostructures, we tune the DOS of graphene and measure outer-sphere ET kinetics. We find the ensuing variation in ET rate arises from strong modulation in a reorganization energy associated with image potential localization in the electrode. Here we redefine the traditional paradigm of heterogeneous ET kinetics, revealing a deeper role of the electrode electronic structure in interfacial reactivity.

Decarboxylative alkylation of alkenes

烯烃的脱羧烷基化

▲ 作者：Triptesh Kumar Roy, Federico Maria Tamborini, Roland Petzold, Jianhan Fu, Yiben Tang Tobias Ritter

▲链接：

https://www.nature.com/articles/s41586-026-10463-1

▲摘要：

烯烃是合成化学中广泛应用的官能团，对生产聚合物、洗涤剂、农用化学品及药物至关重要。烯烃与亲电试剂反应时，通常发生加成而非取代反应。

因此，化学家的工具箱中缺少一种直观的逆合成切断方式：即从母体烯烃出发构建取代烯烃。例如，将三取代烯烃转化为四取代烯烃，或对复杂烯烃进行后期烷基化，将能够获得目前难以构建的分子。

烯烃交叉复分解反应可对合适取代的烯烃实现形式烷基化，但其非对映选择性以及烯烃-烷基的组合仅限于特定情况，并且多类烯烃（如内烯烃或环烯烃）无法通过已知方法轻易实现烷基化。

研究组报道了一种烯烃的形式上区域选择性和非对映选择性的C-H烷基化反应，使用种类繁多、易于获得的羧酸作为烷基来源。

该方法的关键在于一种极性脱羧烷基化途径，它不同于现有基于羧酸衍生物自由基介导的C-C键形成模型，而是依赖于一种此前未被重视的途径：从氧化还原活性酯生成持久性烷基锌中间体。

通过钯催化的烷基锌物种与由烯烃制备的烯基噻蒽盐的交叉偶联，研究组实现了高非对映选择性获得取代烯烃。该转化可实现对具有不同烷基的环状、非环状、末端、内部、单取代、二取代及三取代烯烃的烷基化。

▲ Abstract：

Alkenes are widely used functional groups in synthetic chemistry, important for producing polymers, detergents, agrochemicals and pharmaceuticals. When treated with electrophiles, alkenes typically undergo addition, not substitution, reactions. As a consequence, the intuitive retrosynthetic disconnection to form a substituted alkene from the parent alkene does not exist in the toolbox of the chemist. For example, conversion of tri-substituted into tetra-substituted alkenes, or late-stage alkylation of complex alkenes, would provide access to molecules that are currently difficult to construct. Alkene cross-metathesis can formally alkylate appropriately substituted alkenes, but diastereoselectivity and alkene – alkyl combinations are restricted to specific cases, and several classes of alkenes, such as internal or cyclic alkenes, cannot be readily alkylated with known methods. Here we report a formal regio- and diastereoselective C?H alkylation of alkenes with carboxylic acids as alkyl source, readily available in large diversity. Key to the development is a polar decarboxylative alkylation that deviates from the current model of radical-mediated C?C bond formation from carboxylic acid derivatives, enabled by a previously unappreciated access to persistent alkylzinc intermediates from redox-active esters. A Pd-catalysed cross-coupling of the alkylzinc species with alkenyl thianthrenium salts accessed from alkenes affords the substituted alkenes in high diastereoselectivity. The transformation offers alkylation of cyclic, acyclic, terminal, internal, mono-substituted, di-substituted and tri-substituted alkenes with diverse alkyl groups.

地球科学Earth Science

Uncertain dynamic response of mid-latitude winter precipitation

中纬度冬季降水的不确定性动力学响应

▲ 作者：Lei Gu, Dominik L. Schumacher, Sebastian Sippel, Erich M. Fischer, Istvan Dunkl, Robin Noyelle, et al.

▲链接：

https://www.nature.com/articles/s41586-026-10474-y

▲摘要：

理解降水变化对人类社会与生态系统至关重要。已有研究明确了人为强迫和气候内部变率对降水趋势的各自贡献，但观测和模拟模式之间仍存在差异。

在北半球冬季，这类差异通常被归因于主导观测趋势的非强迫性气候内部变率。不过，越来越多的证据也表明，气候模型低估了降水对人为强迫的整体响应。

研究组发现，气候模型能够较好重现降水变化的热力学贡献，而动力学贡献则会出现较大偏差。

该研究通过分离1950年—2022年冬季降水趋势中人为强迫的热力学分量、动力学分量与气候内部变率，探究三者对趋势差异的影响机制。在地中海地区，气候模型模拟得到的强迫动力学信号仅能解释约10%的观测动力学趋势，探测难度陡增。

在持续人为排放情景下，预估的大气环流响应加剧，更接近观测到的趋势模式。

尽管观测记录中的气候内部变率可能助推了这种相似性，但研究结果表明，动力学响应在塑造区域冬季降水趋势中具有不确定但潜在的新兴作用。在气候模型中精准展现人为强迫下的大尺度大气环流响应，仍是提升区域降水预估可信度的关键所在。

▲ Abstract：

Understanding changes in precipitation is crucial for society and ecosystems. Studies have documented the respective contributions of anthropogenic forcing and internal variability to precipitation trends, yet discrepancies persist between observed and simulated patterns. In Northern Hemisphere winter, these mismatches are often attributed to unforced internal variability that dominates observed trends. However, growing evidence also indicates that climate models underestimate the total response of precipitation to human forcings. Here we show that the thermodynamic contribution is broadly reproduced by climate models, whereas the dynamic contribution can diverge more substantially. Our approach disentangles the anthropogenic forced thermodynamic and dynamic components from internal variability in winter precipitation trends (1950 – 2022) to investigate their contribution to the trend discrepancies. In the Mediterranean, the forced dynamic signal from model simulations explains only about 10% of the observed dynamic trend, making detection challenging. Under continued anthropogenic emissions, the projected circulation response intensifies and more closely resembles observed trend patterns. Although internal variability in the observed record may contribute to this similarity, the results indicate an uncertain yet potentially emerging role of dynamic response in shaping regional winter precipitation trends. A reliable representation of the forced large-scale circulation response in climate models remains key for increasing confidence in regional precipitation projections.

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