A contour plot showing the inverse of the oscillator temperature as a function of gate-voltage detuning for a single electron transistor (SET)-oscillator system, taken from the article ‘Quantum nanoelectromechanics with electrons, quasi-particles and Cooper pairs: effective bath descriptions and strong feedback effects’ by Aashish A Clerk and Steven Bennett 2005 New Journal of Physics 7 238.


The numerically calculated velocity profile for a ferrofluid placed in a rotating magnetic field, taken from the article ‘Pumping fluid by magnetic surface stress’ by Robert Krauß, Mario Liu, Bert Reimann, Reinhard Richter and Ingo Rehberg 2006 New Journal of Physics 8 18.

A computer simulation of a carbon nanocone held together by van der Waals forces, taken from the article ‘Curved nanostructured materials’ by Humberto Terrones and Mauricio Terrones 2003 New Journal of Physics 5 126.

A numerical analysis of the instabilities of rotating spirals showing spiral breakup over time, taken from the article ‘Breakup of spiral waves caused by radial dynamics: Eckhaus and finite wavenumber instabilities’ by Markus Bär and Lutz Brusch 2004 New Journal of Physics 6 5.

A snapshot of the pressure fluctuation in a three-dimensional compressible plume head, taken from the article ‘Interactive desktop analysis of high resolution simulations: application to turbulent plume dynamics and current sheet formation’ by John Clyne, Pablo Mininni, Alan Norton and Mark Rast 2007 New Journal of Physics 9 301.

A numerical simulation modeling the three-dimensional dynamics of the coherent field in a monolithic multi-quantum-well microresonator, taken from the article ‘3D self-organized patterns in the field profile of a semiconductor resonator’ by L Columbo, I M Perrini, T Maggipinto and M Brambilla 2006 New Journal of Physics 8 312.

A space-time diagram showing the behaviour of a travelling solar dynamo wave in a magnetic field, taken from the article ‘Magnetic helicity effects in astrophysical and laboratory dynamos’ by A Brandenburg and P J Käpylä 2007 New Journal of Physics 9 305.

Superposition of plane waves with random phases, taken from the article ‘Exploring the colours of dark light’ by Sir Michael Berry 2002 New Journal of Physics 4 74.
Celebrating 10 years of publishing excellence

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Continuous and rapid growth in article submissions (see top figure) also reveals how NJP has become an increasingly attractive journal for authors. With guaranteed high article visibility (an NJP paper is downloaded, on average, more than 700 times within one year of publication), NJP authors and their work benefit from exposure to a new, wider audience, in addition to maximised citations and impact (the middle figure shows the on-going growth in the NJP Impact Factor since 2002). As a result NJP now boasts a truly international authorship of leading figures in subject areas extending across the whole of physics (the subject distribution of NJP’s content is shown in the bottom figure).

This celebratory 10th anniversary collection showcases, via a series of summaries written by the original authors themselves, a selection of just some of the article highlights published in NJP since 1998 from across physics. Identified by my colleagues on the Editorial Board, and NJP publishing staff on the basis of a range of criteria including referee endorsements, readership and citation levels, and simple broad appeal, the work compiled here provides a real flavour of the diversity, breadth and quality of NJP’s content so far.

On behalf of the whole journal I thank all of the authors featured inside for publishing with NJP, and for contributing to what I think is a very special anniversary compilation. I hope that you as readers enjoy it too!

Eberhard Bodenschatz, Editor-in-Chief
# CONTENTS

## QUANTUM PHYSICS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decoherence-free states for quantum computing</td>
<td>8</td>
</tr>
<tr>
<td>A Beige, D Braun and P L Knight</td>
<td></td>
</tr>
<tr>
<td>Rotation of the universe, time travel and quantum gyroscopes</td>
<td>8</td>
</tr>
<tr>
<td>A Delgado, W P Schleich and G Süssmann</td>
<td></td>
</tr>
<tr>
<td>Quantum cryptography: from basic physics to real world applications</td>
<td>8</td>
</tr>
<tr>
<td>D Stucki, N Gisin, O Guinnard, G Ribordy and H Zbinden</td>
<td></td>
</tr>
<tr>
<td>Entanglement on the move</td>
<td>9</td>
</tr>
<tr>
<td>M B Plenio, J Hartley and J Eisert</td>
<td></td>
</tr>
<tr>
<td>Optical qubus computation</td>
<td>9</td>
</tr>
<tr>
<td>W J Munro, K Nemoto and T P Spiller</td>
<td></td>
</tr>
</tbody>
</table>

## COSMOLOGY AND GRAVITATION

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity, geometry and the quantum</td>
<td>10</td>
</tr>
<tr>
<td>A Ashtekar</td>
<td></td>
</tr>
<tr>
<td>Spacetime in string theory</td>
<td>10</td>
</tr>
<tr>
<td>G T Horowitz</td>
<td></td>
</tr>
<tr>
<td>Modified-source gravity suggests an alternative to dark energy</td>
<td>10</td>
</tr>
<tr>
<td>S M Carroll, I Sawicki, A Silvestri and M Trodden</td>
<td></td>
</tr>
<tr>
<td>A dark future for dark energy?</td>
<td>11</td>
</tr>
<tr>
<td>L M Krauss, K Jones-Smith and D Huterer</td>
<td></td>
</tr>
</tbody>
</table>

## HIGH ENERGY PARTICLE PHYSICS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watching for neutrinos with the SuperNova Early Warning System</td>
<td>11</td>
</tr>
<tr>
<td>Status of global fits to neutrino oscillations</td>
<td>12</td>
</tr>
<tr>
<td>M Maltoni, T Schwetz, M Tórtola and J W F Valle</td>
<td></td>
</tr>
<tr>
<td>Ultra-high energy cosmic rays from gamma-ray bursts</td>
<td>12</td>
</tr>
<tr>
<td>C D Dermer and A Atoyan</td>
<td></td>
</tr>
<tr>
<td>Neutrinos sent from CERN to the OPERA detector at the Gran Sasso Laboratory</td>
<td>13</td>
</tr>
<tr>
<td>A Ereditato (on behalf of the OPERA Collaboration)</td>
<td></td>
</tr>
</tbody>
</table>
### ATOMIC AND MOLECULAR PHYSICS

<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A magnetic butterfly made of ultracold atoms</td>
<td>D Jaksch and P Zoller</td>
<td>13</td>
</tr>
<tr>
<td>Modeling the dynamics of a weakly coupled chain of quantum systems</td>
<td>F S Cataliotti, L Fallani, F Ferlaino, C Fort, P Maddaloni and M Inguscio</td>
<td>14</td>
</tr>
<tr>
<td>High Tc quantum magnetism with ultracold atoms?</td>
<td>E Altman, W Hofstetter, E Demler and M D Lukin</td>
<td>14</td>
</tr>
<tr>
<td>Transporting, splitting and merging of atomic ensembles in a chip trap</td>
<td>P Hommelhoff, W Hänsel, T Steinmetz, T W Hänsch and J Reichel</td>
<td>14</td>
</tr>
<tr>
<td>Stopping atoms with pulsed magnetic fields</td>
<td>E Narevicius, C G Parthey, A Libson, J Narevicius, I Chavez, U Even and M G Raizen</td>
<td>15</td>
</tr>
</tbody>
</table>

### OPTICS AND IMAGING

<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colours of darkness</td>
<td>M V Berry</td>
<td>15</td>
</tr>
<tr>
<td>Visualizing invisibility</td>
<td>U Leonhardt</td>
<td>16</td>
</tr>
<tr>
<td>Diffraction-unlimited far-field optical microscopy resolves nanoparticle assemblies</td>
<td>K I Willig, J Keller, M Bossi and S W Hell</td>
<td>16</td>
</tr>
</tbody>
</table>

### QUANTUM OPTICS AND LASERS

<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation of photon number states</td>
<td>E Waks, E Diamanti and Y Yamamoto</td>
<td>17</td>
</tr>
<tr>
<td>New prospects for attoscience</td>
<td>G D Tsakiris, K Eidmann, J Meyer-ter-Vehn and F Krausz</td>
<td>17</td>
</tr>
<tr>
<td>Improved fidelity of triggered entangled photons from single quantum dots</td>
<td>R J Young, R Mark Stevenson, P Atkinson, K Cooper, D A Ritchie and A J Shields</td>
<td>18</td>
</tr>
<tr>
<td>A first step towards entanglement connection of matter systems</td>
<td>J Laurat, C-W Chou, H Deng, K S Choi, D Felinto, H de Riedmatten and H J Kimble</td>
<td>18</td>
</tr>
</tbody>
</table>

Continues...
### PLASMA PHYSICS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The dual personality of Jupiter’s atmosphere</td>
<td>19</td>
</tr>
<tr>
<td>N Achilleos, S Miller, R Prangé, G Millward and M K Dougherty</td>
<td></td>
</tr>
<tr>
<td>Experiments on plasma turbulence</td>
<td>19</td>
</tr>
<tr>
<td>O Grulke and T Klinger</td>
<td></td>
</tr>
<tr>
<td>PKE- Nefedov: plasma crystal experiments on the International Space Station</td>
<td>20</td>
</tr>
<tr>
<td>G E Morfill, H M Thomas, V E Fortov and V I Molotkov</td>
<td></td>
</tr>
<tr>
<td>Cold plasma: a practical decontamination/sterilization technology</td>
<td>20</td>
</tr>
<tr>
<td>M Laroussi, D A Mendis and M Rosenberg</td>
<td></td>
</tr>
</tbody>
</table>

### CONDENSED MATTER

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broken parity superconductors take a spin</td>
<td>21</td>
</tr>
<tr>
<td>P A Frigeri, D F Agterberg and M Sigrist</td>
<td></td>
</tr>
<tr>
<td>Exotic properties of hard materials caused by soft electrons</td>
<td>21</td>
</tr>
<tr>
<td>E Dagotto</td>
<td></td>
</tr>
<tr>
<td>Measurement of the upper critical field of optimally-doped YBa2Cu3O7 in megagauss fields</td>
<td>21</td>
</tr>
<tr>
<td>T Sekitani, Y H Matsuda and N Miura</td>
<td></td>
</tr>
<tr>
<td>Dimensionally constrained D’yakonov Perel’ spin relaxation in n-InGaAs channels: transition from 2D to 1D</td>
<td>22</td>
</tr>
<tr>
<td>A W Holleitner, V Sih, R C Myers, A C Gossard and D D Awschalom</td>
<td></td>
</tr>
</tbody>
</table>

### NANOSCALE PHYSICS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanoengineering of carbon nanotubes for nanotools</td>
<td>23</td>
</tr>
<tr>
<td>Y Nakayama and S Akita</td>
<td></td>
</tr>
<tr>
<td>Characterizing carbon nanotubes with Raman spectroscopy</td>
<td>23</td>
</tr>
<tr>
<td>A Jorio, M A Pimenta, A G Souza Filho, R Saito, G Dresselhaus and M S Dresselhaus</td>
<td></td>
</tr>
<tr>
<td>VHF, UHF, and microwave frequency nanomechanical resonators</td>
<td>24</td>
</tr>
<tr>
<td>X M H Huang, X L Feng, C A Zorman, M Mehregany and M L Roukes</td>
<td></td>
</tr>
</tbody>
</table>

### SURFACE SCIENCE AND THIN FILMS

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does one-dimensional adatom and cluster diffusion of Pt on the Pt(110)-(1 × 2) surface lead to one-dimensional ripening?</td>
<td>24</td>
</tr>
<tr>
<td>T R Linderoth, S Horsch, L Petersen, E Lægsgaard, I Stensgaard and F Besenbacher</td>
<td></td>
</tr>
<tr>
<td>Magnetic periodicitities in Cr(110) films</td>
<td>25</td>
</tr>
<tr>
<td>E Rothenberg, B K Freelon, H Koh, A Bostwick, K Rossnagel, A Schmid and S D Kevan</td>
<td></td>
</tr>
<tr>
<td>Structured metal films allow for terahertz pulse shaping using surface plasmon-polaritons</td>
<td>25</td>
</tr>
<tr>
<td>A Agrawal, H Cao and A Nahata</td>
<td></td>
</tr>
</tbody>
</table>
### Soft Matter and Biophysics

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic mechanism for conduction block in heart tissue</td>
<td>26</td>
</tr>
<tr>
<td>J J Fox, M L Riccio, P Drury, A Werthman and R F Gilmour Jr</td>
<td></td>
</tr>
<tr>
<td>A polymer with a handle at a surface</td>
<td>26</td>
</tr>
<tr>
<td>C Friedsam, A Del Campo Bécares, U Jonas, M Seitz and H E Gaub</td>
<td></td>
</tr>
<tr>
<td>Ultralow interfacial tension driven demixing dynamics</td>
<td>27</td>
</tr>
<tr>
<td>D G A L Aarts, R P A Dullens and H N W Lekkerkerker</td>
<td></td>
</tr>
<tr>
<td>Biomolecular dynamics in model biological membranes</td>
<td>27</td>
</tr>
<tr>
<td>M Smits, A Ghosh, J Bredenbeck, S Yamamoto, M Müller and M Bonn</td>
<td></td>
</tr>
</tbody>
</table>

### Statistical Physics and Complex Systems

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle clustering in strong turbulence</td>
<td>28</td>
</tr>
<tr>
<td>L R Collins and A Keswani</td>
<td></td>
</tr>
<tr>
<td>Taming thermal motion</td>
<td>28</td>
</tr>
<tr>
<td>C Van den Broeck, P Meurs and R Kawai</td>
<td></td>
</tr>
<tr>
<td>Tectonic plates taken for a spin in the laboratory</td>
<td>28</td>
</tr>
<tr>
<td>R F Katz, R Ragnarsson and E Bodenschatz</td>
<td></td>
</tr>
<tr>
<td>Swimming in curved space: the Baron and the cat</td>
<td>29</td>
</tr>
<tr>
<td>J E Avron and O Kenneth</td>
<td></td>
</tr>
<tr>
<td>A synthetic turbulent dynamo</td>
<td>29</td>
</tr>
<tr>
<td>M Bourgoin, R Volk, N Plihon, P Augier, P Odier and J-F Pinton</td>
<td></td>
</tr>
</tbody>
</table>

### List of Editors

Editorial Board Members and Guest Editors since 1998

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elena Belsole</td>
<td>Publishing Editor</td>
</tr>
<tr>
<td>Joanna Dingley</td>
<td>Publishing Administrator</td>
</tr>
<tr>
<td>Christopher Ingle</td>
<td>Production Editor</td>
</tr>
<tr>
<td>Caroline King</td>
<td>Senior Marketing Executive</td>
</tr>
<tr>
<td>Tim Smith</td>
<td>Publisher</td>
</tr>
<tr>
<td>Andrew Wray</td>
<td>Group Publisher</td>
</tr>
</tbody>
</table>

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Decoherence-free states for quantum computing

A Beige¹, D Braun² and P L Knight³

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² Laboratoire de Physique Théorique, Université Paul Sabatier, Toulouse, France
³ Blackett Laboratory, Imperial College, London, UK

Driving atoms into decoherence-free states’ A Beige et al 2000 New Journal of Physics 2 222

Quantum information processing rests on our ability to manipulate the state of a quantum system in a controlled way. However, quantum systems do not exist independent of their environment. Uncontrollable interactions with the environment might lead to dissipation and the irreversible loss of information. An important step towards the practical realisation of quantum computing was therefore the identification of a large set of states, which do not couple to the environment. These became known as decoherence-free states.

In this paper we give a detailed description of the decoherence-free states of a system consisting of \( N \) atoms trapped inside an optical cavity. Moreover, we proposed how to manipulate these states very efficiently with the help of weak laser pulses. Normally, local interactions like these cannot create entanglement between atomic qubits. However, we could show that the presence of relatively large spontaneous decay rates renders the behaviour of the system dramatically. It suppresses the population of non decoherence-free states so that the laser driving transfers the system in general into an entangled state. This shows that one can actually use dissipation to perform quantum computational tasks.

Since the publication of our manuscript, many quantum computing schemes have been proposed in which dissipation and measurements are an integral part in generating and manipulating stable qubits. Our work mainly focuses on the design of simpler, more robust and scalable quantum computing architectures based on the use of environment-induced measurements, which are readily available.

Quantum cryptography: from basic physics to real world applications

D Stucki¹, N Gisin¹, O Guinnard², G Ribordy² and H Zbinden¹

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² id Quantique SA, Geneva, Switzerland

‘Quantum key distribution over 67 km with a plug&play system’ D Stucki et al 2002 New Journal of Physics 4 41

Quantum physics is well known for being counter-intuitive or even bizarre. Now, during the last decade it has been widely realized that it can also be useful for practical applications. Quantum cryptography, or more exactly quantum key distribution (QKD), is the first application of quantum physics at the individual quanta level. It takes advantage of the Heisenberg...
uncertainty relations or, equivalently, of the no-cloning theorem to provide an absolutely secure communication scheme. In 2002 we demonstrated a turn-key QKD system on several long distance optical cables outside the laboratory with a real physical distance between Alice (the emitter) and Bob (the receiver). Some cables were terrestrial, some under Lake Geneva and some aerial. The latter was possibly the most significant, since the stability of qubits encoded in single photons is then especially critical. The system proved to be so robust and simple that it was used in the first commercial products.

Since 2002 many subsequent demonstrations of various QKD schemes have been reported, but only very few over long distances outside the lab with a real physical distance; and almost none in aerial cables. Today, almost every country has its QKD research lab and several working systems have been developed, both by large companies (mostly Japanese) and by small start-up companies.

Entanglement on the move

M B Plenio, J Hartley and J Eisert
Blackett Laboratory, Imperial College, London, UK

‘Dynamics and manipulation of entanglement in coupled harmonic systems with many degrees of freedom’ M B Plenio et al 2004 New Journal of Physics 6 36

Tap your clothes-line at one end and you will see that the perturbation is propagated along its length. Tap it in the middle and you will see perturbations travel in opposite directions. In the first case you have transmitted a signal, in the second case you created correlations between different parts of your clothes line. Indeed, when you observe a perturbation a distance d to the left of the center then there will also be one the same distance d to the right of the center. In both cases the system, our clothes line, is, for small amplitudes, harmonic and one may replace it by a chain of harmonic oscillators coupled by springs. The featured work examines questions of this type, and much more, at the quantum mechanical level. You may of course propagate quantum states along the harmonic chain (this was discovered here independently of related work in spin systems) and by creating localized perturbations in a coupled chain of harmonic oscillators you can, for example, create quantum mechanical correlations, i.e. entanglement between distant parts in a chain. This is intuitive from the classical analogues, but you can do more. By changing global properties of the chain, e.g. the coupling strengths, you will again be able to generate dynamics leading to entanglement between different parts of the chain. This is interesting for various reasons. Firstly, the quantum information propagation and entanglement generation does not need much detailed experimental control and may thus be relatively easy to implement. The propagation may also be made perfect either by tuning the coupling strengths in the chain or other tricks [see M B Plenio and F Semião 2005 New J. Phys. 7 73]. Finally, studying the dynamics of quantum-many-body systems is interesting as it involves not just ground state properties but those of excited states as well [see M Hartmann, M Reuter and M B Plenio 2006 New J. Phys. 8 94]. The featured work has led to a whole range of follow-up activity by the authors as well as many colleagues in this area.

Optical qubus computation

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1 National Institute of Informatics, Tokyo, Japan
2 Hewlett-Packard Laboratories, Bristol, UK


It is well known that using quantum information can enable certain communication and computation tasks that cannot be performed with conventional IT, or improve some that can. The widely accepted approach for quantum communication is to use quantum states of light fields. There is thus considerable motivation for developing quantum processing technologies also based on photons — this would avoid the need for inter-conversion of quantum information and naturally enable distributed quantum computing, which could be the key for useful few-qubit applications. Linear optics quantum computing is expensive on photon resources, and non-linear optical approaches based on direct interactions between photons require stronger non-linearities than are currently available. We therefore propose a new approach to non-linear optical computing. Photons do not interact directly, but separately interact with an intense coherent state of light, which therefore acts as a ‘bus’, to mediate interactions between photon qubits. The strength of the coherent state bus effectively magnifies the non-linearity, thus enabling optical quantum processing with realistically weak non-linearities. Our approach does not force a choice of computation scheme or processor architecture; rather, it provides building blocks which can be put together to suit the task at hand. This, along with the very high resource efficiency, makes our approach extremely flexible. In the short term it provides a new way forward to distributed few-qubit technologies based on scarce resources, and in the longer term it provides a new approach to efficient, scalable optical quantum computing either between separated nodes or within a node.

Schematic diagram illustrating a two-photon parity gate mediated by a coherent quantum bus.
Cosmology and Gravitation

Gravity, geometry and the quantum

A Ashtekar
Institute for Gravitational Physics and Geometry, Pennsylvania State University, PA, USA

‘Gravity and the quantum’ A Ashtekar 2005 New Journal of Physics 7 198

This article appeared in a focus issue celebrating the 100th anniversary of Einstein’s miraculous year and was therefore addressed to non-experts. It began with a historical account of how quantum gravity developed and then discussed a background independent, non-perturbative approach called loop quantum gravity (LQG). In LQG, not only is the space–time geometry dynamical as in general relativity but it is quantum mechanical. Its fundamental excitations are one-dimensional, rather like polymers. Basic geometrical quantities such as areas of surfaces and volumes of regions are represented by non-commuting operators with discrete eigenvalues. The familiar Riemannian geometry of general relativity emerges only in a semi-classical, coarse-grained approximation. In ordinary situations effects of quantum geometry are completely negligible. However, in extreme conditions, such as those near black holes and the big-bang, these effects dominate and can then resolve seemingly unsolvable difficulties, making fundamental physics coherent. For example, the quanta of geometry that make up a black hole horizon are sufficiently numerous to account for its huge entropy. Secondly, if the space–time curvature approaches the Planck scale, a new repulsive force emerges, rises sharply and overwhelms the familiar gravitational attraction. In the last couple of years, several cosmological models were studied in detail where this force resolves the big-bang singularity. The resulting quantum space–times are much larger than what Einstein had us believe. This opens up new paradigms in cosmology and black hole physics which are being investigated vigorously.

An artist’s representation of the extended space–time of loop quantum cosmology. Time runs vertically. General relativity provides only the top half of this space–time which originates in the big-bang. Quantum Einstein’s equations extend this space–time to the past of the big-bang. The pre-big-bang branch is contracting and the current post-big-bang branch is expanding. The band in the middle represents the ‘quantum bridge’ which joins the two branches and provides a deterministic evolution across the ‘deep Planck regime’ (image courtesy of Dr Cliff Pickover, www.pickover.com).

Spacetime in string theory

G T Horowitz
Department of Physics, University of California at Santa Barbara, CA, USA

‘Spacetime in string theory’ G T Horowitz 2005 New Journal of Physics 7 201

Our view of space and time changed dramatically with Einstein’s general theory of relativity. It is expected that a quantum theory of gravity — such as string theory — will result in another dramatic change. This article summarizes the current status of spacetime in string theory. Since the theory is not yet fully developed, the final picture is not yet clear. However, we already know that the properties of space and time in string theory are radically different from general relativity. Not only does string theory predict extra spatial dimensions, two spacetimes which are physically different in general relativity can be completely equivalent in string theory. In some cases, space and time emerge ‘holographically’ from a more fundamental dual theory.

One consequence of this new view of space and time is the following. General relativity predicts that the topology of space (the way that it is connected) cannot change in a smooth way. If you try to construct a solution in which the topology changes, you encounter singularities — regions of infinite gravitational field or infinite spacetime curvature. This is not the case in string theory. Several examples are now known in which the topology of space changes smoothly without producing singularities. General relativity also predicts that gravitational collapse will result in a singularity where time ends. Cosmological models of expanding universes like our own, also must begin with a singularity (the big bang) where time begins. Whether this is also true in string theory is one of the main open questions in the field. It is currently a topic of active research.

Modified-source gravity suggests an alternative to dark energy

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‘Modified-source gravity and cosmological structure formation’ S M Carroll et al 2006 New Journal of Physics 8 232

The universe is accelerating, but we’re not sure why. The favored explanation is dark energy — a smooth, persistent form of energy density pervading every point in space. However, acceleration occurs over a huge length scale (the present Hubble radius, about ten billion light years), while experimental tests of General Relativity (GR) probe much smaller length scales. Thus, a reasonable question is whether cosmic acceleration might be a sign that gravity is deviating from GR on large scales.

Modifications of GR typically run afoul of experimental constraints because they introduce new degrees of freedom. The evolution of a homogeneous and isotropic universe, however, is described by the Friedmann equation — a part of Einstein’s equation in GR that is a constraint, rather than a dynamical equation of motion. We are therefore free to imagine modifying

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it without introducing new degrees of freedom. In this article we constructed a family of such theories, dubbed modified-source gravity.

Modified-source gravity faces strong experimental constraints from higher-order couplings not seen in particle-physics experiments. Nevertheless, it provides an interesting toy model against which observations may be compared. We therefore studied cosmological perturbation theory and extracted predictions for the growth of large-scale structure, to understand how upcoming measurements may probe the differences between the modified theory and the standard dark-energy model.

The evolution of the inferred equation of state of dark energy as a function of redshift in the modified source gravity model.

**A dark future for dark energy?**

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“Dark energy, a cosmological constant, and type Ia supernovae” L M Krauss et al 2007 New Journal of Physics 9 141

The discovery of the acceleration of the Universe, using observations of distant supernovae established the existence of ‘dark energy’ associated with otherwise empty space as the dominant form of energy in the universe, and was one of the most exciting discoveries in cosmology in recent times. It has completely changed our picture of the current universe, and its future. The nature and origin of dark energy, however, remains a mystery. A key question thus becomes: how can we further cosmological observations address these deep mysteries? Our paper was an attempt to explore how observational uncertainties may combine with theoretical uncertainties to ultimately limit what we may be able to observationally infer in the near future about the nature of dark energy. In particular, the major theoretical question of interest is whether the dark energy is due to a cosmological constant, or some other form of exotic energy. The only way to distinguish this would be to look for time evolution in the dark energy density. However, without a good model for what this time evolution is, a comparison of theoretical expectations and observations becomes difficult. By examining what might be possible in future supernova surveys, we demonstrate that without significant improvements in our ability to measure the cosmic distance scale as a function of redshift we are unlikely to observationally resolve whether or not the dark energy is due to a cosmological constant.

**HIGH ENERGY PARTICLE PHYSICS**

**Watching for neutrinos with the SuperNova Early Warning System**

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When the core of a massive star collapses, a supernova explosion with luminosity rivalling that of a galaxy ensues. However, the energy of the explosion is only a tiny fraction of the total energy of the event: most of the energy is radiated away as weakly interacting neutrinos. A unique feature of the neutrino signal is that it is prompt — neutrinos emerge on a timescale of tens of seconds, while the first observable photons may not show up for hours or even days. Therefore, neutrinos can provide an early alert that could allow astronomers a chance to make unprecedented observations of the very early turn-on of the supernova light curve.

A number of large underground neutrino detectors are sensitive to a Milky Way core collapse. SNEWS (SuperNova Early Warning System) is an international network of these experiments. Each experiment scans its data in real time for a burst of neutrino signals; if it finds a burst, it sends a datagram to the SNEWS computer located at Brookhaven National Laboratory. If this computer finds a coincidence of bursts within ten seconds, it sends an alert to the astronomical community, including amateurs. The coincidence requirement allows the alert to be sent out within minutes of core collapse, skipping the human check required for an individual experiment alert to the community.

Current SNEWS participants are the Super-Kamiokande experiment in Japan, the Large Volume Detector in Italy, and AMANDA/IceCube at the South Pole. The Sudbury Neutrino Observatory participated until it completed operation in November 2006.
Neutrino physics has undergone a revolution in the last ten years or so. Experiments observing neutrinos produced inside the Sun, in the Earth's atmosphere, in nuclear power plants, and in particle accelerators have finally established a phenomenon called neutrino oscillations, a quantum effect which occurs when neutrinos have mass. In the Standard Model of elementary particles neutrinos are massless. Hence, the discovery of neutrino oscillations has far-reaching consequences, since it is the first evidence for physics beyond the Standard Model and requires an extension of the model. Neutrino oscillations also have astrophysical implications since neutrinos provide an important probe of the interior of stars and the early Universe.

Our work describes the present status of neutrino oscillations through a global fit to world data. A concise determination of the parameters governing neutrino oscillations is obtained by the interplay of complementary information from various experiments. Neutrino mass splittings are determined by experiments where neutrinos are produced in nuclear reactors or particle accelerators, and observed in detectors located several hundreds of kilometres away from the neutrino source. In contrast, the mixing angles relevant for the leading oscillations are determined best by observations of natural neutrino sources like the Sun or the Earth's atmosphere. We also explore in detail the bound on the last unknown mixing angle, which emerges from an interplay of global neutrino data. This mixing angle governs CP violation in neutrino oscillations to be probed in the next generation of experiments. Our work also scrutinizes the robustness of the oscillation interpretation of current neutrino data with respect to the possible existence of sterile neutrinos, solar magnetic fields, and non-standard neutrino interactions.

In amazingly prescient articles, Ken Greisen in the US and Vadim Zatsepin and Georgiy Kuzmin in the USSR predicted in 1966 that the cosmic-ray spectrum must end above energies of $10^{20}$ eV due to photohadronic loss interactions of the highest energy cosmic rays with photons of the cosmic microwave background. Only in the last year has this prediction been confirmed by the HiRes and Auger Observatories, meaning that ultra-high energy cosmic rays (UHECRs) originate from astrophysical sources. UHECRs detected with energies exceeding $10^{20}$ eV must originate within the Greisen–Zatsepin–Kuzmin (GZK) radius of order 100 Mpc.

To test the hypothetical GRB origin of UHECRs, clues in the form of ultra-high energy cosmic rays from gamma-ray bursts (GRBs) as the sources of UHECRs, an idea which has generated great interest since it was proposed in 1995. GRBs are the most luminous radiation sources of radiation in the universe during the brief time that they burst, are sources of energetic $\gamma$ radiation, and are thought to be triggered by stellar core collapse to a black hole, and can occur within the GZK radius.

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To test the hypothetical GRB origin of UHECRs, clues in the form of ultra-high energy cosmic rays, soon detectable with km-scale experiments such as IceCube, $\gamma$ rays observable with $\gamma$-ray telescopes, and fits to the UHECR spectrum, are reviewed. This article poses the main predictions that will soon be tested with the Gamma ray Large Area Space Telescope GLAST, scheduled for launch in 2008, IceCube, which reaches its design sensitivity early in the next decade, and the Auger Observatory in Argentina, already reporting major discoveries.
On 18 August 2006, the official start of the CNGS run produced the first Gran Sasso Laboratory. The experiment aims at the direct observation of νμ appearance from νμ→ντ oscillations, a process of great importance for particle physics. The observation of the interaction of νμ’s with the OPERA detector will clearly confirm the oscillation hypothesis for the first time in the so-called ‘appearance’ mode, whereas disappearance of ‘oscillating’ neutrinos has already been observed by previous experiments. OPERA consists of a 1.3 kton neutrino target made of lead/photographic-film sandwiches, and of electronic detectors. Photographic films provide a ‘microscopic’ image of the neutrino interaction point in order to identify the appearance of ντ over the most probable νμ events.

On 18 August 2006, the official start of the CNGS run produced the first νμ bunches to be observed by OPERA. At the end of this first short run OPERA observed 319 events, in good agreement with expectations. This paper reports on that first observation, to be followed by more events gathered in the 2008 run. The experiment will last a few more years with the goal of confirming the hypothesis for the first time in the so-called ‘appearance’ mode, whereas disappearance of ‘oscillating’ neutrinos has already been observed by previous experiments. OPERA consists of a 1.3 kton neutrino target made of lead/photographic-film sandwiches, and of electronic detectors. Photographic films provide a ‘microscopic’ image of the neutrino interaction point in order to identify the appearance of ντ over the most probable νμ events.

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Condensated matters systems in magnetic fields have been the subject of intense research over the past few decades. Several unexpected effects were discovered in the course of these studies like fractional quantum Hall effects which clearly indicated strong quantum correlations. For charged particles moving on a lattice in very large magnetic fields Hofstaedter predicted fractal energy spectra remniscent of a butterfly (see figure (a)). This magnetic butterfly has so far escaped direct observation due to the high magnetic fields required.

This work proposed the creation of huge artificial magnetic fields for neutral ultracold atoms moving on a two dimensional optical lattice by irradiating them with lasers. The lasers drive atom hopping between lattice sites simultaneously imprinting a phase on their wave function. By judiciously choosing the laser setup these phases mimic a magnetic field (see figure (b)) and break time reversal symmetry normally associated with conservative optical lattice potentials. The number of flux quanta \( \alpha \) penetrating each lattice plaquette can easily be varied between 0 < \( \alpha \) < 1. A value \( \alpha \) of order one corresponds to unattainably large magnetic fields in customay condensed matter systems and enables Hofstaedter’s butterfly to be studied with ultracold atoms.

This proposal has stimulated numerous studies on properties of ultracold atomic lattice gases in magnetic fields investigating e.g. the influence of two particle interactions and extensions to non-abelian gauge potentials. In contrast to rotating a lattice for simulating a magnetic field it does not suffer from the requirement to balance centrifugal terms by trapping potentials which proves experimentally difficult. The method provides another invaluable tool for engineering ultracold atom systems.

**New Journal of Physics** has been able to offer incredibly fast publication for my papers, while keeping a very high standard for peer-review. This is a real asset of the journal.”

**Stefan W Hell**, Max Planck Institute for Biophysical Chemistry, Goettingen, Germany
Modeling the dynamics of a weakly coupled chain of quantum systems

In this work we described the experimental observation of different regimes in an array of Josephson junctions realized with Bose–Einstein condensates trapped in a one dimensional optical lattice. The transition occurs between a superfluid and an insulator regime and is accompanied by a loss of coherence through the array even though each condensate in the array is still described by a coherent state. The experimental findings have been compared with the prediction of a 1D theoretical model based on a discrete nonlinear Schrödinger equation (DNLSE). This model is found to qualitatively describe the different stable regions but fails to quantitatively describe the system close to the transition where a full 3D simulation of the Gross–Pitaevskii equation is needed.

The paper follows in a series of theoretical and experimental works that successfully established the parallel between the dynamics of Bose–Einstein condensates in 1D optical lattices and the widely used DNLSE. Such an equation is common to a large class of discrete non-linear systems, including polarons, optical fibers, waveguides, and biological molecules, and the established parallel helped in opening a new interdisciplinary route.

In the last five years many other Hamiltonians common to many physical systems have been reproduced using quantum degenerate gases in optical potentials thus rediscovering Feynman’s ideas suggesting that an ideal system with a ‘quantum logic’ can be used to study open problems in quantum physics. The upsurge of interest of the scientific community has been remarkable, and some perspectives disclosed by trapped-atom ‘labs’ have been already explored: the observation of the superfluid–Mott insulator quantum phase transition and the analysis of the Tonks–Girardeau regime in strongly interacting bosons were relevant achievements for condensed matter physics.

High $T_c$ quantum magnetism with ultracold atoms

Experiments with ultracold atoms in optical lattices have opened fascinating prospects for studying many-body phenomena associated with strongly correlated systems in a highly controllable environment. One of the most intriguing directions is to investigate the fundamental physics of quantum magnetism. This can be done by loading the lattice and controlling the interactions between two boson species associated with a pair of hyperfine states of the atom. The two species act as two components of an effective spin-1/2 degree of freedom. Deep in the Mott insulating phase, effective spin interactions can be described by the super-exchange mechanism known from conventional magnetic solids. But how do those spin interactions carry over to the vicinity of the superfluid–insulator transition where fluctuations in site occupation can no longer be treated perturbatively? In this paper, we investigated this problem by developing a new approach that allows spin and density fluctuations to be treated on the same footing. The new treatment allowed the authors to map the phase diagram of two component bosons for all interaction strengths. In particular the spin fluctuations were shown to have a strong impact on the transition to the superfluid phase, making it first rather than second order for a range of parameters. This analysis also demonstrated that magnetic states realized deep in the insulating phase continue smoothly all the way to the superfluid–insulator transition where the magnetic energy is maximal and the magnetic transition temperature concomitantly high. By demonstrating the possibility of observing such magnetic phenomena under realistic conditions these results stimulated recent exciting experimental developments.

Transporting, splitting and merging of atomic ensembles in a chip trap

These days, spectacular experiments in the realm of quantum mechanics are performed with extremely cold clouds of atoms. Only when these tiny clouds are less than a milliinch of a degree away from absolute zero do they exhibit quantum behavior. This is why intricate techniques had to be developed to hold the atoms in place without heating them ever so slightly.
Magnetic traps are one commonly used way. Combined with new cooling techniques, they lead to the achievement of Bose–Einstein condensation in 1995. At that time, the magnetic trap was no more than a bottle with immaterial walls. It took another four years until our group and others had developed a miniaturized version that now gives us not only more precise control over the atoms, but also completely new ways of manipulation. For example (and that is what this article is about) cold atoms and Bose–Einstein condensates can now be transported over millimetre distances, can be split into two and even recombined — all without destroying the delicate ensembles of atoms. To achieve this goal, our group introduced what is now known as ‘atom chips’ or ‘chip traps’. The idea is to generate the magnetic fields not with macroscopic coils located far away from the atom cloud, but with microscopic, lithographically fabricated, current-carrying wires on a substrate. This resembles a micro-electronic chip, hence the name. Atom chips have since been used to study atom–surface interactions in a new regime, to realize atom interferometers and, most recently, to observe cavity quantum electrodynamics effects with BECs.

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The assembled atomic coilgun used to slow atoms, before it was put into a vacuum chamber.

Stopping atoms with pulsed magnetic fields

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‘An atomic coilgun: using pulsed magnetic fields to slow a supersonic beam’
E Narevicius et al 2007 New Journal of Physics 9 358

This paper reported the experimental demonstration of a new method to produce cold and trapped atoms which should be widely applicable to most of the periodic table. While the standard method to control atomic motion has been laser cooling, this approach only works for a small set of atoms in the periodic table that have a closed two-level transition that is accessible with a tunable laser. The starting point for the current work is the supersonic beam of noble-gas atoms, a source that provides a high flux of atoms that is very cold in the co-moving frame but also very fast. These atoms are emitted in bunches as a valve is opened for a short time. Other atoms or molecules can be introduced into the flow by seeding or entrainment near the output of the nozzle. A series of magnetic field coils is timed with the firing of the valve, and slows the atoms by making them climb a magnetic hill and then removing the hill before they have time to roll off. The group will apply these methods to trapping of atomic hydrogen isotopes for precision spectroscopy, and tests of the fundamental physics of the beta decay of tritium.

Universal colours and light intensity of white light near an isolated interference zero.

Colours of darkness

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‘Exploring the colours of dark light!’ M V Berry 2002 New Journal of Physics 4 74
‘Coloured phase singularities’ M V Berry 2002 New Journal of Physics 4 66

Optics and Imaging

Colours of darkness

M V Berry
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‘Exploring the colours of dark light!’ M V Berry 2002 New Journal of Physics 4 74
‘Coloured phase singularities’ M V Berry 2002 New Journal of Physics 4 66

Interference patterns made with white light are coloured, because the conditions for phase matching for different wavelengths are satisfied at different places in the field. This has been known for centuries, but it was surprising to discover that the colours are most intense where interference is destructive, and that the pattern of colours in an image is universal if the points of perfect destructive interference for each of the contributing wavelengths are well separated. The pattern (see figure) consists of red, orange and blue rings — no green — in a characteristic arrangement with a precise mathematical description. It seems paradoxical that the universal colours are concealed in the darkest parts of the pattern. But they can be dramatically revealed by the ‘chromoscope’ — an image-processing algorithm computer to intensify the dark parts of images while preserving the colours. Universality means that the colours occur in many situations, for example random waves and near caustics, and can be generated by appropriately created diffraction gratings. The colours predicted theoretically were soon observed (see J Leach and M J Padgett 2003 Observation of chromatic effects near a white-light vortex New J. Phys. 5 154).
Abbe’s discovery of the diffraction barrier about 130 years ago has lead to the notion that a light microscope cannot resolve spatial structures that are closer than about half of the wavelength of light. Near-field optical microscopy overcomes this limit by scanning with a subdiffraction sized tip, but this technique is difficult to operate and is limited to imaging surfaces. Stimulated emission depletion (STED) microscopy is the first far-field fluorescence microscopy modality which, although still relying on regular lenses and visible light, radically overcomes the limiting role of diffraction. In fact, the resolution $\Delta r$ of a STED microscope follows a new law given by:

$$\Delta r \approx \frac{\lambda}{2n \sin \alpha \sqrt{1 + \zeta}}$$

where $\lambda$ and $n \sin \alpha$ are the wavelength of light and the numerical aperture of the lens, respectively. The equation differs from Abbe’s resolution law by the square-root term in the denominator, where $\zeta \gg 1$ defines the magnitude of STED. Evidently, letting $\zeta \to \infty$ implies that the resolution can be improved down to the molecular scale.

The emerging power of STED-microscopy is exemplified by revealing the spatial order of densely packed biological and non-biological nanopatterns. Unlike confocal microscopy, which is the best-resolving standard used in the far-field, STED microscopy resolves fluorescent nanoparticles that are of 40 nm diameter ($\lambda/15$) as well as nanosized aggregates of a neuronal protein in a cell membrane. Similarly, images of colloidal nanoparticles demonstrate the potential of STED-microscopy for colloidal physics. Finally, STED microscopy records images of protein distributions in a cell with regular lenses and visible light that feature a resolution that is about twice the size of an antibody (20 nm).

Defying Abbe’s law in lens-based optical microscopy, whereas the confocal microscopy image (a) renders blurred patches, the image provided by STED-microscopy (b) resolves every 40 nm bead in a densely packed agglomeration. Panels (c) and (d) compare confocal with STED imaging (plus linear deconvolution) of the neuronal protein SNAP-25, naturally agglomerated in a cell membrane. The fundamentally increased spatial resolution brought about by STED microscopy holds great promise for addressing fundamental issues in many areas of physics, chemistry, and biology.
Generation of photon number states

Photons play an important role in quantum optics. These states exhibit effects such as photon anti-bunching and negativity of the Wigner function that contradict classical electromagnetic theory. They also have important applications in the areas of optical telecommunication, quantum information processing, and interferometry. In this work, we prepared photon number states containing up to four photons using a unique photon counter called the visible light photon counter (VLPC). Unlike conventional photon counters that cannot distinguish between one and more than one simultaneous photons, the VLPC puts out a voltage pulse whose height is proportional to the number of detected photons.

In order to generate number states, we used the number counting capability of the VLPC in conjunction the non-linear optical process of parametric down-conversion. Parametric down-conversion creates a twin pair of number correlated beams. By measuring the correct number of photons in one arm of the twin beams, we prepared the other arm in the appropriate number state. These number states were verified by detection with a second VLPC. This work could open up the door to a broad range of new experiments in quantum optics and quantum information processing.

a) Experimental setup for generating photon number states. Twin photons are generated from a non-linear crystal and detected by two VLPCs.

b) Pulse height distribution of VLPC 1 shows a series of peaks corresponding to 1–4 photons detected.

c) Photon number distribution measured by VLPC 2 conditioned on the number of photons detected by VLPC 1. The distributions show generation of one, two, three, and four photon number states.
**Improved fidelity of triggered entangled photons from single quantum dots**

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‘Improved fidelity of triggered entangled photons from single quantum dots’
R J Young et al 2006 New Journal of Physics 8 29

Entangled photon pairs have interconnected properties, such that measuring one photon changes the other. This unusual property makes entangled light a key resource for new applications in quantum information.

One example is the quantum repeater, which could extend the distance that quantum communication can operate over. At present the most widely used techniques for generating entangled photons are nonlinear optical processes that produce a probabilistic number of pairs per excitation cycle. The scaling of quantum information applications requires a source for which single entangled pairs are generated in a regular stream. We have produced a semiconductor device which acts as a triggered source of entangled photons. It is based upon a two-photon cascade in a single quantum dot. Prior to this work experiments indicated that an energetic splitting of the intermediate exciton state in the cascade provided ‘which-path’ information destroying the entanglement. By controlling the growth conditions for the dot, we have removed the exciton splitting and thus now generate entangled photon pairs. The fidelity of the total source emission (without background subtraction) to the ideal entangled state is ~70%, nine standard deviations in excess of the classical limit, proving that the source generates entangled pairs. Thus the ideal entangled state is achieved in the coherent quantum opticians have powerful capabilities that complex procedures, confirming the increasingly effective and improved memory time are directions currently explored. Beyond quantum communication, this experiment incorporates many powerful capabilities that complex procedures, confirming the increasingly powerful capabilities that quantum opticians have achieved in the coherent control of the quantum states of light and matter, and their interface.

**A first step towards entanglement connection of matter systems**

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‘Towards experimental entanglement connection with atomic ensembles in the single excitation regime’
J Laurat et al 2007 New Journal of Physics 9 207

Entanglement, one of the most striking features of quantum mechanics, leads to strong correlations between the various components of a system, regardless of the distance separating them. Entanglement distribution enables quantum protocols, such as quantum cryptography, where the security is guaranteed by the laws of physics, or quantum teleportation, where a quantum state is faithfully transferred from one place to another. One property of entanglement is also that it can be swapped from one pair of systems to another. The creation of entanglement for two pairs of physical systems and the subsequent joint measurement of one system from each pair (called Bell measurement) projects the remaining systems into an entangled state. Beyond its fundamental interest, entanglement connection is also a key element in quantum information science, where it is crucial for quantum repeaters, which would extend the range of quantum communication to long distances.

The reported experiment demonstrates an essential step towards entanglement connection of matter systems, namely the transfer of quantum coherence between two atomic systems that have never interacted. It involves two pairs of atomic ensembles separated by 3 metres. The ensembles are clouds of cold cesium atoms. With real-time control of the quantum states, entanglement is generated on each pair, and stored in the atoms. Next, a Bell measurement is performed between two ensembles belonging to different pairs to project them into an entangled state. Finally, the transfer of coherence is verified by way of an interference measurement.

A successful entanglement transfer still requires large improvements of current setups. Multiplexing of atomic ensembles, photon-number resolving detection, and improved memory time are directions currently explored. Beyond quantum communication, this experiment incorporates many powerful capabilities that complex procedures, confirming the increasingly powerful capabilities that quantum opticians have achieved in the coherent control of the quantum states of light and matter, and their interface.

"The progress New Journal of Physics has made over the last ten years is exciting to see and provides a real indication that the editorial activity we carry out towards expanding our authorship and readership is working."

Tim Smith, Publisher, New Journal of Physics

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An illustration of a quantum dot based device emitting polarisation-entangled photon pairs. When a measurement is made on one of the photons from a pair it has an effect on the second photon.
The dual personality of Jupiter’s atmosphere

The upper atmosphere of Jupiter — a region known as the thermosphere — contains hydrogen gas. Some of this gas is ionized as it absorbs energy from sunlight — this forms the ionosphere. The auroral rings or ovals surrounding Jupiter’s magnetic poles receive a continual ‘rain’ of energetic charged particles which heats and ionizes the hydrogen, causing beautiful displays of light similar to the Earth’s northern and southern lights. But is this auroral heating able to explain the high (up to 1000 K) temperatures of the thermosphere of Jupiter? (Sunlight alone cannot heat Jupiter’s atmosphere to these levels.) We attempted to answer this question by using a computer model of Jupiter’s thermosphere and ionosphere regions. The results were surprising — instead of a constant outflow of energy from the auroral regions to the rest of the planet, it was found that the wind systems on Jupiter tend to be controlled by the planet’s rapid rotation (period 10 hours) and giant size (10 Earth radii = 1 Jupiter radius). Hydrogen flowing into the auroral ovals is slowed down in its rotation by the ‘auroral rain’. The resulting balance between centrifugal force (very strong at Jupiter), gravity and pressure forces then acts to accelerate this hot gas towards the poles, confining it to high latitudes. At higher altitudes, the flow of gas looks very different but cannot carry the enormous heat energy required.

Thus, the search for the mysterious ‘extra heat’ continues, but we have learned much about the influence of giant planets’ aurorae on their wind systems, and how this compares with the situation for the Earth.

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**Experiments on plasma turbulence**

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‘Large-scale fluctuation structures in plasma turbulence’ O Gruinke et al 2002

*New Journal of Physics* 4 67
PKE-Nefedov: plasma crystal experiments on the International Space Station

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‘PKE-Nefedov: plasma crystal experiments on the International Space Station’
A P Nefedov et al 2003 New Journal of Physics 5 33

PKE stands for ‘Plasma Kristall Experiment’. In reality the ‘experiment’ was a fully programmable laboratory — the first natural science facility on the ISS. Its purpose — to study the recently discovered plasma state of soft matter in microgravity. It may seem like a contradiction to talk about the ‘plasma state of soft matter’, since the essential properties summarized by the late Nobel Prize winner Pierre-Gilles de Gennes involve elasticity, supramolecularity and the existence of excited states etc, whereas plasmas are generally accepted as the most disordered state of matter with none of the above properties. This is not so in the case of ‘complex plasmas’ however. These systems contain a supramolecular (microparticle) component, can exist as crystals and liquids and satisfy the conditions summarised by de Gennes. Why microgravity? The added plasma component — the microparticles — are many billions of times heavier than atoms, so that certain precision experiments need to be carried out in space. Whilst the investigation of this new state of matter is important in its own right, there are two additional features. First, they can be studied at the most elementary individual particle level at all relevant time scales, and second, they allow generic studies of nonlinear and critical phenomena at this most basic level for the first time — providing new insights into diverse topics such as turbulence, phase transitions, non-Newtonian fluids, visco-elasticity, gelation, solitons and shocks. Even more exciting, the successor laboratory — PK-3 Plus — recently discovered that complex plasmas are electrorheological — a property which will allow scientists in future to ‘design’ the particle interaction potential using externally applied electric fields. This could possibly open up a completely new approach in materials science and therefore provides a truly fascinating outlook.

The picture on the left shows the Russian Cosmonaut, Sergei Krikalev with PKE-Nefedov. The right figure shows the string fluid transition of an electrorheological plasma under microgravity conditions (PK-3 Plus).

Cold plasma: a practical decontamination/sterilization technology

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‘Plasma interaction with microbes’ M Laroussi et al 2003 New Journal of Physics 5 41

Non-equilibrium low temperature plasmas, such as the one shown in the photograph, have recently attracted a lot of interest because of their relatively simple and practical designs and the range of applications for which they can be used. Amongst the novel applications, their use in the biomedical field is of particular focus. Ongoing multidisciplinary works on wound healing, the surface modification of biocompatible materials, and the sterilization of reusable heat-sensitive medical instruments are showing promising results. This paper shows a clear correlation between the theoretically predicted electrostatic tension caused by charging effects of bacterial cells submerged in a plasma and experimental observation of morphological changes of these cells. Scanning electron microscopy shows that cells exhibiting ‘rough’ surface texture (such as some gram-negative bacteria) experience loss of integrity of their cell wall/membrane after exposure to a plasma. This is attributed to an outward electrostatic stress that overcomes the tensile strength of the outer membrane and causes its rupture. Subsequently, the cell loses its cytoplasm, ultimately leading to its demise. Therefore it is concluded that charging effects can be one of the mechanisms whereby nonthermal plasmas inactivate bacteria.

Photograph of a nonthermal atmospheric pressure plasma used to destroy bacteria (photo courtesy of M Laroussi, Old Dominion University, Norfolk, VA, USA).

“For the last ten years, New Journal of Physics has been dedicated to serving the whole physics community by publishing free-to-read, cutting-edge research of the highest quality.”
Eberhard Bodenschatz, Editor-in-Chief
Inversion symmetry, coupled with Pauli’s exclusion principle, plays a central role in determining how electrons pair when they become superconducting. Even parity is linked with spin singlet and odd parity with spin triplet pairing. What happens when inversion symmetry is removed? Cooper pairs become a mixture of spin-singlet and spin-triplet. Can this be seen experimentally? This is the question that is addressed in this paper and the answer is yes: It requires a measurement of the spin response to a magnetic field. Such a spin susceptibility measurement depends crucially on a single electron spin–orbit coupling characteristic to systems without inversion symmetry. In such non-centrosymmetric superconductors (NSC) the spin-susceptibility becomes essentially universal, behaving qualitatively the same for all types of superconducting interactions. While this behavior is masked by antiferromagnetism in the NSC CePt$_3$Si, recent experiments on CeRhSi$_4$ and CeIrSi$_4$ are completely compatible with this prediction.

The properties of several metallic materials can be accurately described using a so-called one electron approximation, where the Coulombic forces between electrons are neglected. However, there are many other compounds where this assumption is not valid and new paradigms are needed for their theoretical understanding. The study of these materials led to the current vast interest in the area of research called ‘strongly correlated electrons’ (SCE) [see E Dagotto 2005 Science 309 257 and references therein]. These compounds have rich phase diagrams, with several competing states that can have drastically different properties (metals, Mott insulators, superconductors, ferro- and antiferro-magnets, heavy fermions, multiferroics, etc). The close proximity in the phase diagrams of these states suggests that their energies are similar. Moreover, experimentally it has been observed that SCE materials often present inhomogeneous states (regularly organized, as in stripes, or randomly distributed, as in cluster glasses) and also giant responses to small external fields (as in the so-called colossal magnetoresistance effect).

Recent theoretical investigations, as reported in this article suggest that all these effects are related: phase competition causes both the inhomogeneous states and the giant responses. The main idea is sketched in the figure. In the absence of sources of disorder or strain, ‘clean’ SCE materials should often present first-order transitions separating two competing states (phase I and phase II in the figure). However, a variety of perturbations (such as disorder introduced by chemical doping) smear the first-order transition into a region with ‘mixed’ characteristics, where electrons behave in several respects as soft matter. Theory has shown that this mixed regime is spatially inhomogeneous and, moreover, it presents nonlinear responses to particular perturbations (such as magnetic fields in Mn oxides). The scenario described in the figure is very general and should apply to a variety of materials. Once considered exotic and puzzling properties, theoretical studies suggest that inhomogeneous states and giant nonlinearities in SCE materials should actually be vastly more general than previously anticipated. Extensions to the underdoped regime of high temperature superconductors have been proposed [see G Alvarez et al 2005 Phys. Rev. B 71 014514] and novel applications of these effects may emerge in the growing field of oxide multilayers [see Yunoki et al 2007 Phys. Rev. B 76 064532 and references therein].

The green and orange Cooper pairs are each 1/2 spin-triplet and 1/2 spin-singlet. An unequal balance is a result of broken parity and leads to a mixture of spin-singlet and spin-triplet.

**Conclusions**

Inversion symmetry, coupled with Pauli’s exclusion principle, plays a central role in determining how electrons pair when they become superconducting. Even parity is linked with spin singlet and odd parity with spin triplet pairing. What happens when inversion symmetry is removed? Cooper pairs become a mixture of spin-singlet and spin-triplet. Can this be seen experimentally? This is the question that is addressed in this paper and the answer is yes: It requires a measurement of the spin response to a magnetic field. Such a spin susceptibility measurement depends crucially on a single electron spin–orbit coupling characteristic to systems without inversion symmetry. In such non-centrosymmetric superconductors (NSC) the spin-susceptibility becomes essentially universal, behaving qualitatively the same for all types of superconducting interactions. While this behavior is masked by antiferromagnetism in the NSC CePt$_3$Si, recent experiments on CeRhSi$_4$ and CeIrSi$_4$ are completely compatible with this prediction.
The recent advances in high magnetic field technology have enabled us to carry out various high precision experiments in the megagauss range well above 100 Tesla. In this study we observed for the first time a clear transition from the superconducting state to the normal state in optimally doped YBCO in a wide temperature range, employing very high pulsed magnetic fields up to 600 Tesla generated by electromagnetic flux compression. For measuring the conductivity in the very short pulsed fields, we developed a contactless radio frequency transmission technique. It was revealed that for magnetic field parallel to the CuO$_2$ plane (B||CuO$_2$), the transition field is 250 Tesla at 5 K, and gradually decreases as the temperature is increased, towards zero at $T_c$. The entire phase diagram on the temperature–magnetic field plane was constructed for both B||CuO$_2$ and B⊥CuO$_2$. A good fit of the experimental phase diagram to the conventional theory (WHH theory) was obtained only when we took account of a large spin–orbit interaction effect, indicating the importance of the spin effect.

In the emerging field of spintronics, it is important to explore carrier spin relaxation mechanisms in nanostructures as a function of dimensionality. In two and three dimensions, elementary rotations do not commute, with significant impact on the spin dynamics if the spin precession is induced by spin–orbit coupling. Spin–orbit coupling creates a randomizing momentum-dependent effective magnetic field; the corresponding relaxation process is known as the D’yakonov-Perel’ mechanism. In an ideal one-dimensional system, however, all spin rotations are limited to a single axis, and the D’yakonov-Perel’ spin relaxation is suppressed. The experimental work reported in this article demonstrates a progressive slowing of the D’yakonov-Perel’ spin relaxation in the regime approaching the one-dimensional limit. The experiments were performed on narrow channels of semiconductor heterostructures, containing InGaAs quantum wells, in which the spin–orbit interactions are dominated by structural inversion asymmetry. Such solid-state systems have been proposed as candidates for spintronic devices, including spin transistors, due to their potential scalability and compatibility with existing semiconductor technology.

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Nicolas Gisin, University of Geneva, Switzerland

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Nicolas Gisin, University of Geneva, Switzerland
This paper describes well-controlled nanoprocesses of carbon nanotubes which have been developed for fabricating nanotube probes and nanotube tweezers that operate in a scanning probe microscope (SPM). The first crucial process is to prepare a nanotube array, called a nanotube cartridge, in which arc-discharge-produced multiwall nanotubes were aligned at the knife-edge using ac electrophoresis.

The second important process is to transfer a nanotube from the nanotube cartridge onto a conventional SPM tip under scanning electron microscopy (SEM) observation. The advantages of the nanotube probes have been clarified for the observation of biological and nonbiological samples. The nanotube tweezers have demonstrated their motion in SEM and the operation for carrying nanomaterials in SPM.

The electron ablation process of the tip of nanotubes to adjust their length and the current-induced sharpening process of the tip of nanotubes have also been developed. For the sharpening process, the free end of a nanotube protruding from the cartridge was attached to a metal-coated SPM tip and a current in the saturation regime was applied to the nanotube. The current decreased stepwise with time, corresponding to the sequential destruction of individual nanotube layers from the outer. The nanotube was finally cut at the middle, and its tip was sharpened to have an inner layer.

It has been shown that the maximum current in each layer during the stepwise decrease depends on its circumference rather than the cross section of the nanotube, and the force for extracting the inner layer with ~5 nm diameter is ~4 nN.

Illustration and SEM images of nanotube tweezers. (a) Tweezers formed on a Si cantilever with electrode wires, (b) open state at the applied voltage of 0 V and (c) closed state at >4.5 V.

Characterizing carbon nanotubes with Raman spectroscopy

Raman spectroscopy has become one of the most valuable tools for carbon nanotube sample characterization, addressing aspects like purity, quality, metallicity, length, diameter, chirality and environment. This work overviews the basic theoretical concepts and experimental characteristics for each Raman feature of carbon nanotube samples. The radial breathing modes give the tube diameters in a sample. The graphite-like G band strongly depends on doping (chemical or applied voltage) and is different for metallic and semiconducting nanotubes. The disorder-induced D band indicates the presence of carbonaceous impurities and defects in the nanotube crystalline structure, and it is a probe for covalent functionalization. The G band (D band overtone) is highly sensitive to the electronic structure and can be used to probe small interactions. Many other disorder-induced, combination and overtone modes enrich the spectra and provide routes for new studies. Raman spectroscopy can be performed on all types of samples, including carbon nanotubes in bundles, in solution, dispersed in different matrices (e.g. polymers), isolated on different substrates or suspended over trenches. It is a non-destructive and non-invasive tool and can be used for in situ characterization of tubes in conjunction with other experiments/devices, including under operation and extreme conditions.

As a referee I can only congratulate New Journal of Physics for leading the way yet again; it is a great feeling to get a £100 discount on the article charge as an acknowledgement of the time spent on the review process. I've acted as a referee for many journals, and this is the first time I feel so good about it!

Sebastien Guenneau, University of Liverpool, UK
Doubly-clamped beam nanoresonators based upon nanoelectromechanical systems (NEMS) with operating frequencies up to the microwave L-band have been achieved, through the development of improved materials and novel detection techniques. This milestone in NEMS enables a broad range of applications including next-generation high resolution sensors and actuators, and high speed signal processing components. However, the first microwave NEMS resonators exhibit decreasing quality factors as the device frequency is increased. This could significantly restrict the range of applications for this developing technology. In this invited paper, after outlining the fabrication and measurement of these NEMS devices, we discuss our initial attempts to address this important problem and our efforts to improve measurement techniques at these frequencies.

Dissipation arising from clamping losses in NEMS devices is found to increase as the aspect ratio of these doubly-clamped beams is reduced. We have demonstrated that the SiC free-free beam nanomechanical resonators offer significant improvement in quality factor compared to a doubly-clamped beam design operating at similar frequencies.

By examining devices made from SiC wafers with different roughness, a strong correlation between surface roughness and quality factor is established from experiments. Furthermore, eddy current damping inherent to the widely-used magnetomotive transduction scheme is experimentally measured using a top-down nanofabricated SiC nanowire device.

This dissipation effect becomes particularly important for large aspect ratio beam resonators. Further work towards understanding dissipation mechanisms and improving the quality factors of ultrahigh and microwave frequency resonators is crucial for the wide spectrum of potential applications promised by these devices.

Electromechanical resonances measured from a typical pair of UHF nanomechanical resonators using a balanced-bridge detection scheme with magnetomotive transduction. Resonances are detected as the B field is swept from 1 to 8 Tesla. The noise floor of detection is measured to be ~0.14, corresponding to a ~7.1 K noise temperature. This arises from a combination of cryoamp noise, and the Johnson noise from the metallic resistors on the resonator beams. (inset) Data from both the 590 MHz and the 712 MHz devices show the resonance peak amplitude is a quadratic function of the B field, as expected. A Lorentzian fit to the de-embedded data traces give Q ~1700 for the 590MHz resonance and Q ~900 for the 712 MHz peak.

New Journal of Physics: 10th Anniversary Highlights

Doubly-clamped beam nanoresonators based upon nanoelectromechanical systems (NEMS) with operating frequencies up to the microwave L-band have been achieved, through the development of improved materials and novel detection techniques. This milestone in NEMS enables a broad range of applications including next-generation high resolution sensors and actuators, and high speed signal processing components. However, the first microwave NEMS resonators exhibit decreasing quality factors as the device frequency is increased. This could significantly restrict the range of applications for this developing technology. In this invited paper, after outlining the fabrication and measurement of these NEMS devices, we discuss our initial attempts to address this important problem and our efforts to improve measurement techniques at these frequencies.

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A spin-density-wave (SDW) is a sinusoidal modulation of the magnetization in an antiferromagnet, as visualized in figure (a), for example, in chromium. What determines the SDW wavelength? For 40 years it has been thought that electronic transitions in momentum ($k$-) space drive the SDW, but the relationship between real- and $k$-space has never been experimentally tested in Cr. The angle-resolved photoemission results in figure (b) show a cut through the Cr Fermi surface, that is, the allowed $k$-space states near the Fermi level $E_F$ in a thick Cr(110) film. Two possible transitions between parallel or nested sections of the Fermi surface stabilize the SDW by modifying the generalized magnetic susceptibility of the material. The resulting nesting is incommensurate by a factor $\delta = 0.05\pm0.005$, in agreement with the SDW incommensurability determined with neutron and x-ray scattering. This finding confirms the conventional SDW theory for bulk Cr.

The actual SDW periodicity can be determined directly in our experiments by looking at ‘backfolded’ or replica bands seen at binding energies away from $E_F$ (figure (c)). Moreover, the SDW incommensurability $\delta_{SDW}$ can be determined directly from the splitting of these replica bands. Surprisingly, we find that the measured SDW wavelength does not always match the wavelength determined by the Fermi surfaces, that is, $\delta_{SDW} \neq \delta$. $\delta_{SDW}$ goes smoothly to zero as the film thickness is reduced. We have recently shown that a competition between nesting of 3D bulk states and 2D surface states can explain these unusual results.

Free-space broadband terahertz radiation is efficiently coupled to surface plasmon-polariton waves on a metal film containing concentric annular grooves around a subwavelength aperture. The shape of the THz pulse exiting the aperture depends on the geometry and location of individual grooves.

Surface plasmon-polaritons (SPPs), which are composed of electromagnetic waves coupled to a collective excitation of electrons at a metal-dielectric, have elicited renewed attention in recent years. Much of this interest arises from the possibility of subwavelength field localization, creating opportunities for applications in a range of nanophotonics applications. In this article, we demonstrated a novel approach for THz pulse shaping by modifying the coupling and scattering characteristics of SPP waves propagating along structured metal films. The technique relies on appropriately varying the cross-sectional parameters and location of each individual groove fabricated into a metal film allowing for the generation of arbitrarily complex THz pulse shapes. This ability to alter the spectral and temporal properties of THz pulses using structured metal films is expected to be important for applications in THz communications and coherent control. Based on this approach, we have recently demonstrated a simple, flexible approach to couple freely propagating broadband THz radiation to shaped THz pulses on a cylindrical metal wire waveguide.

We are currently extending this work to develop surface plasmon based waveguide devices. Although a number of other approaches are being pursued in this research direction, plasmonic waveguides offer several attractive features, including the possibility for a simplified device topology, subwavelength field localization, and low-loss transmission of THz radiation. At a time when THz technology is still maturing, this ability to manipulate radiation at a sub-wavelength scale and over a wide spectral range holds great promise for the development of frequency selective devices for THz optoelectronic applications.
Catastrophic rhythm disturbances of the heart, such as ventricular fibrillation (VF), are the major cause of death in the United States. Although there currently is some controversy concerning the exact mechanism for fibrillation, all hypotheses invoke wave break and conduction block, secondary to spatial heterogeneity of electrical properties in the ventricle. One hypothesis, the restitution hypothesis, proposes that the spatial heterogeneity required for the induction and maintenance of fibrillation can arise dynamically. Dynamically-induced heterogeneity has been characterized extensively under the condition of constant rapid pacing. However, it is unlikely that this scenario applies directly to the clinical situation, where the induction of VF often is associated with the interruption of normal cardiac rhythm by several premature beats. Therefore, we have been investigating the effects of small numbers of premature stimuli as they relate to the development of VF. These studies began with a coupled maps lattice 1D cable model, and a theoretical analysis of a similar model. The main result from this paper is that certain sequences of premature stimuli were found to induce spatial heterogeneity and conduction block in the 1D cable model. Experimental tests of this idea have thus far been consistent with the theoretical predictions (see figure). Further elucidation of the mechanism for dynamically-induced heterogeneity and subsequent wave break is likely to lead to new, more effective methods for preventing or treating VF.

The interactions between polymers and surfaces govern the properties of man-made as well as natural composite materials such as bone, wood, paper, enforced plastics, or any kind of polymer coatings on surfaces. Bio-compatible materials or self-cleaning surfaces are determined by these interactions but also such phenomena as lubrication or bio-fouling. At the same time these technologically and economically extremely relevant systems pose most interesting questions for basic research. Basically it boils down to the question, what happens when a flexible 1D-object meets a rigid 2D-object.

Up to now, both structure and dynamics of the polymer/solid interface were investigated in ensemble average. With the development of single molecule techniques, however, the interaction of individual polymers with selected surfaces became accessible. In this article we covalently attached individual polymers to the tip of an AFM cantilever and employed the cantilever as a ‘handle’ for this polymer. We brought this polymer in contact with different surfaces and allowed it to interact under various conditions. We studied the adhesion process and characterized the underlying physics by measuring the adhesion force as a function of the surface properties, which we adjusted using self-assembled monolayers with chosen chemistry. We were able to modulate the Coulomb-contribution to the adhesion forces and to tune the adhesion force of our model polymer poly-acrylic acid in a range between 40 and 85 pN. We furthermore discovered that despite the quasi-irreversible adsorption of the polymers their lateral mobility may remain extremely high.
Ultralow interfacial tension driven demixing dynamics

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‘Interfacial dynamics in demixing systems with ultralow interfacial tension’

Whenever one tries to mix water and oil, one observes that the system quickly phase separates. One of the driving terms of this demixing is the interfacial tension, which leads to considerable velocities in the phase separation process. In order to study this process in more detail we resort to colloid–polymer mixtures.

Mixtures of colloids and polymers display rich phase behaviour, involving colloidal gas (rich in polymer, poor in colloid) and colloidal liquid (poor in polymer, rich in colloid) phases. Due to the colloidal lengthscale the interfacial tension is much lower than in the molecular case (nN m⁻¹ instead of mN m⁻²). Consequently, the demixing can be followed in great detail.

Using laser scanning confocal microscopy clear and well-defined images are obtained, which makes quantitative comparisons with theory possible, and is highly instructive. Simple scaling arguments can be given as to why in a single experiment three steps of the phase separation can be observed: an interfacial-tension-driven coarsening, gravity-driven flow and finally the interface formation. The first stage can be quantitatively described by an interfacial-tension-driven coarsening, gravity-driven flow and finally the interface formation. The first stage can be quantitatively described by...
Particle clustering in strong turbulence

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‘Reynolds number scaling of particle clustering in turbulent aerosols’
L R Collins et al 2004 New Journal of Physics 6 119

For decades researchers have known that inertial particles cluster in turbulence due to a ‘centrifuge’ effect that causes them to be expelled from vortical regions of the flow and to collect in the high-strain regions between the vortices (see figure). This phenomenon, sometimes called ‘preferential concentration’, affects a broad range of aerosol processes. For example, it has been hypothesized to play a role in accelerating the development of clouds in the atmosphere, and in creating the conditions necessary for planets and solar systems to form from the initially homogeneous matter of the early Universe.

In 1997 Sundaram and Collins showed that particle collisions are enhanced by clustering by as much as 2 orders of magnitude, and they identified the radial distribution function (RDF) as the precise correction to the collision kernel for this effect. The RDF is known to be a strong function of the particle Stokes number, defined as $St = \frac{\tau_p}{\tau}$, where $\tau_p$ is the particle response time and $\tau$ is the time scale of the Kolmogorov eddies. However, its dependence on Reynolds number is less well understood. This dependence is crucial for applications such as atmospheric clouds and astrophysics, as they involve extremely large values of this parameter. The results from direct numerical simulations (DNS) showed the dependence of the RDF on Reynolds number over the range of the study to be weak, and furthermore the RDF appeared to approach an asymptote with increasing Reynolds number. Recent experimental measurements of the RDF in a turbulence box with particles are in quantitative agreement with these DNS, confirming the findings. This result stands in stark contrast to many other turbulence statistics, such as velocity derivatives and structure functions, which show power-law dependencies on Reynolds number over the range that has been studied. A physical explanation for the puzzling difference in the scaling of the RDF versus other velocity statistics remains elusive.

Taming thermal motion

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Does the second law of thermodynamics apply to small devices? This question, posed by Maxwell around 1870, has today become quite relevant since it is now possible — through the advances in nano and biotechnology — to measure, manipulate and even construct objects at a very small scale.

Smoluchowski and later Feynman showed on the basis of phenomenological arguments that an asymmetric device like the ‘ratchet and pawl’ (figure (a)) cannot rectify thermal fluctuations from a single heat bath, but can operate as a kind of Carnot engine when in contact with two heat baths. In this paper, we introduce the first microscopic model for which an exact analytic study of this question can be performed on the basis of first principles. The construction is basically a simplification of the Smoluchowski Feynman model, with the ratchet replaced by a triangular unit, rigidly joined to a blade residing in another reservoir (figure (b)). Rotational motion is replaced by longitudinal motion. In the limit of dilute gases, the motion of the device is described by a linear Boltzmann equation, which can be solved analytically (albeit via a perturbation development). The results are in full agreement with the second law of thermodynamics. Furthermore, the efficiency is found to be well below Carnot efficiency, in particular due to the fact that the object will — through its own fluctuations — conduct heat, a fact overlooked by Feynman. More recent research has completed the picture. First one can, invoking Onsager symmetry, show that the device can also operate as a Brownian refrigerator. This observation is reminiscent of the traditional Carnot engine which can function as a refrigerator when operating in reverse. Second, Carnot efficiency can in principle be attained, but it requires stringent architectural constraints. Finally, a 3D rotational model has now been solved in full detail (figure (c)). The results confirm the technological potential of the construction.

Schematic representations of (a) the Feynman ‘ratchet and pawl’ device, (b) the simplified construction of the Smoluchowski Feynman model, with the ratchet replaced by a triangular unit, rigidly joined to a blade residing in another reservoir and (c) the three-dimensional rotational construction.

Tectonic plates taken for a spin in the laboratory

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The surface of the solid Earth is tessellated with rigid tectonic plates that slowly drift, colliding in some places, spreading apart in others. Plate spreading occurs along the global mid-ocean ridge system on the sea floor. In the 1970s, ship-based surveys of the ridge system revealed small tectonic plates; these were termed microplates. Sea-floor microplates are characterized by spiral patterns of bathymetry that are suggestive of plate rotation about a vertical axis at a sluggish rate of about 20 degrees per million years. Impatient with such slow kinematics, we developed a wax analogue spreading ridge in the laboratory. In our experiments, a tray of wax is heated from below and cooled from above. Two skimmers embedded in the solid wax at the surface steadily diverge, causing spreading at a rift between the wax tectonic plates. Molten wax upwells at the rift, acr...
Swimming in curved space: the Baron and the cat

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‘Swimming in curved space or the Baron and the cat’ J E Avron et al 2006 New Journal of Physics 8 68

In empty Euclidean space conservation of linear momentum implies that a body at rest cannot move its own center of mass. Conservation of angular momentum does not imply similar restriction on rotations, a fact advantageously used by falling cats, because angular momentum cannot be used to define a ‘center of mass orientation’. As the notion of center of mass is intrinsically Euclidean and has no analog in curved space, the possibility is opened for Baron von Munchhausen to displace himself, an observation made by Jack Wisdom his article ‘Swimming in spacetime: motion by cyclic changes in body shape’ [J Wisdom 2003 Science 299 1865–9]

In inhomogeneous spaces strictly rigid bodies are locked to positions where their geometry fits the geometry of the ambient space. Rigid body motion is possible in symmetric spaces, and swimming of deformable bodies then becomes a viable possibility. In these spaces Killing fields are natural generalizations of the notions of translations and rotations and a key result of the theory is that swimming (with zero momentum) is proportional to the curl of the corresponding Killing field.

For small swimmers that perform small strokes, we find an explicit formula for the curl of the corresponding Killing field.

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Magnetic fields of planets and stars are believed to originate from the dynamo effect; a process in which a fraction of the kinetic energy of motion of an electrically conducting fluid (liquid iron in the case of the Earth’s core) is converted into magnetic energy. Flows with differential rotation and helical streamlines are particularly favourable. But in order for magnetic induction to overcome the Joule dissipation, the fluid motions must be very intense and turbulence must be fully developed. Its role in the dynamo generation process remains a longstanding open question.

We have built a versatile fluid experiment in liquid gallium. It implements a synthetic dynamo cycle which mimics an alpha-omega dynamo (a model commonly used in astrophysics) and for which the flow turbulence is fully included and has a leading role. Counter-rotating impellers impart motion to the fluid. Above a threshold (in revolutions per second) the system shows ‘on-off’ intermittent bursts of magnetic field generation with random axial polarity. As the impellers rotation rate is further increased, the dynamo field is always ‘on’ and reverses its polarity at irregular time intervals.

As believed for the Earth’s core, the time for a reversal is short compared to the duration of each polarity. In this experiment, part of the dynamo cycle is externally prescribed.

The versatile setup reported in this article allows direct study of the contribution due to turbulence. In the future it will be used to investigate broader classes of dynamo generation mechanisms.

A synthetic turbulent dynamo

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As believed for the Earth’s core, the time for a reversal is short compared to the duration of each polarity. In this experiment, part of the dynamo cycle is externally prescribed.

The versatile setup reported in this article allows direct study of the contribution due to turbulence. In the future it will be used to investigate broader classes of dynamo generation mechanisms.

In empty Euclidean space conservation of linear momentum implies that a body at rest cannot move its own center of mass. Conservation of angular momentum does not imply similar restriction on rotations, a fact advantageously used by falling cats, because angular momentum cannot be used to define a ‘center of mass orientation’. As the notion of center of mass is intrinsically Euclidean and has no analog in curved space, the possibility is opened for Baron von Munchhausen to displace himself, an observation made by Jack Wisdom his article ‘Swimming in spacetime: motion by cyclic changes in body shape’ [J Wisdom 2003 Science 299 1865–9].

In inhomogeneous spaces strictly rigid bodies are locked to positions where their geometry fits the geometry of the ambient space. Rigid body motion is possible in symmetric spaces, and swimming of deformable bodies then becomes a viable possibility. In these spaces Killing fields are natural generalizations of the notions of translations and rotations and a key result of the theory is that swimming (with zero momentum) is proportional to the curl of the corresponding Killing field.

For small swimmers that perform small strokes, we find an explicit formula for the curl of the corresponding Killing field.

The notion of the center of mass of two point masses located at points where geodesic intersect is ambiguous.
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