Reading in the dark

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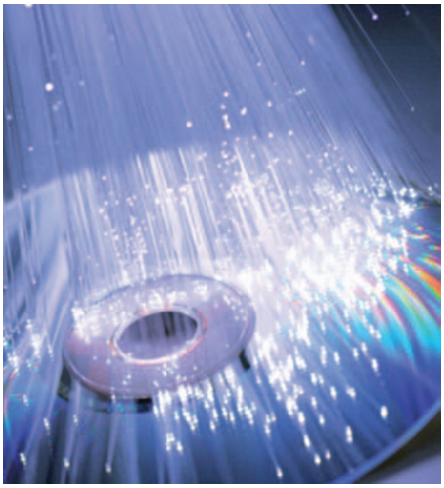

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Light is governed by statistics. The number of photons in a classical light state, from a laser or a light bulb for example, cannot be predetermined. However, controlled generation of single photons and entangled-photon pairs is becoming increasingly routine. Stefano Pirandola now presents theoretical calculations indicating that such non-classical light can retrieve more information from a data storage system than classical light.

Binary information — the 'ones' and 'zeroes' — are encoded into CDs and DVDs as areas of differing optical characteristics. Pirandola takes the simplest version of this idea: the bit stored in a particular cell is determined by the fraction of incident light it reflects. Consider then entangled-photon pairs sent to a detector — one going directly, the other via a reflection off the memory. Pirandola has found that no matter what value the two memory reflectivities take, such a transmitter outperforms the classical equivalent in terms of minimizing errors. He shows that the enhancement is particularly dramatic in the few-photon regime. Memories that operate in low light should be faster to read.

Cosmic-ray shock

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The latest data from PAMELA — a detector in orbit around the Earth on board the Russian Resurs-DK1 spacecraft — are raising questions about the origin of cosmic rays, particularly how they are accelerated to relativistic energies.

A favoured model envisages the acceleration of cosmic-ray particles in the shock waves generated by supernovae, followed by propagation through the interstellar medium. Charged particles are pummelled by galactic magnetic fields, to the extent that their resulting distribution is seemingly isotropic.

But measurements made using PAMELA, presented now by Oscar Adriani and collaborators, of protons and of helium nuclei in cosmic rays suggest that their spectra cannot be modelled using a single power law. That's the approach encapsulated in the most commonly used shock-acceleration models. It seems that the PAMELA data — which the authors demonstrate are consistent in many features with data from other experiments — signal rather that it may be necessary to mix into the models a greater variety of sources for cosmic rays.

The cost of local change

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At sufficiently low temperatures, the normal state of most metals is described as that of a gas of interacting electrons, known as the 'Fermi sea'. A fundamental question is what happens if an ideal, infinitely extended Fermi gas is perturbed locally. Rupert Frank and colleagues now present lower bounds for the shift in kinetic energy of such a gas when the density is changed locally (or, equivalently, for the change in total energy when a one-body potential is added).

The amount of energy that it costs to make — as Frank *et al.* put it — a hole in the Fermi sea can be estimated using a semiclassical approximation, in which a single quantum state is associated with each 'box' of well-defined phase-space volume. But that approach has limitations, and in many cases, physically less transparent perturbation-theoretical methods have been used.

The semiclassical approach, however, might be more versatile than thought: Frank *et al.* prove that in all dimensions strictly larger than one, the energy shift of an ideal Fermi gas on local perturbation is rigorously bounded from below by the value given by the semiclassical approximation, multiplied by a universal constant.

Alcoholic constancy

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Most of a proton's mass is determined by the nuclear binding energy that holds together its constituent quarks. Consequently, the value of the proton-to-electron mass ratio provides a measure of the fundamental interaction strength of the nuclear force. Moreover, if the value of this ratio were found to change with time or in different parts of the Universe, it would have profound implications for the universality of physical law. Analysis of the physical parameters that determine the microwave transitions of methanol molecules suggests that these transitions could act as sensitive probes to determine whether the proton-to-electron mass ratio does indeed vary.

Methanol is among the simplest molecules that undergo internal rotation. It is also one of the most abundant molecules and is responsible for prominent radio emission lines generated by astrophysical masers. Paul Jansen and colleagues have found that transitions that convert energy from internal rotations of the methyl (CH_3) and hydroxyl (OH) groups of methanol to gross rotation of the molecule as a whole depend strongly on the value of the proton-to-electron mass ratio. If this ratio were to change by a fraction, their calculations indicate that the emission frequency of this transition should change by 50 times the fraction.

A push on Heisenberg

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A straightforward way of reducing the statistical uncertainty of a measurement is to repeat it several times and average the individual results. The precision of the measurement can then be enhanced by a factor of $N^{-1/2}$, where N is the number of independent particles used to measure the parameter of interest.

This scaling can be improved when the probing particles share non-classical correlations — in which case the achievable precision is ultimately bounded by the Heisenberg uncertainty principle. In practical terms, this 'Heisenberg limit' implies a best-possible scaling of N^{-1}. But if, as well as such quantum tricks, nonlinear effects are exploited, an even better scaling can be obtained, as Mario Napolitano and colleagues demonstrate.

They have made use of nonlinear optical effects in an ensemble of cold atoms, which lead to interactions among the photons that probe the magnetization of the ensemble, and report a scaling that goes as $N^{-3/2}$. However, exactly when this improved scaling amounts to a practical advantage depends on the details of the experiment. Nonetheless, the demonstration of super-Heisenberg scaling underlines the promise of interaction-based quantum metrology.