

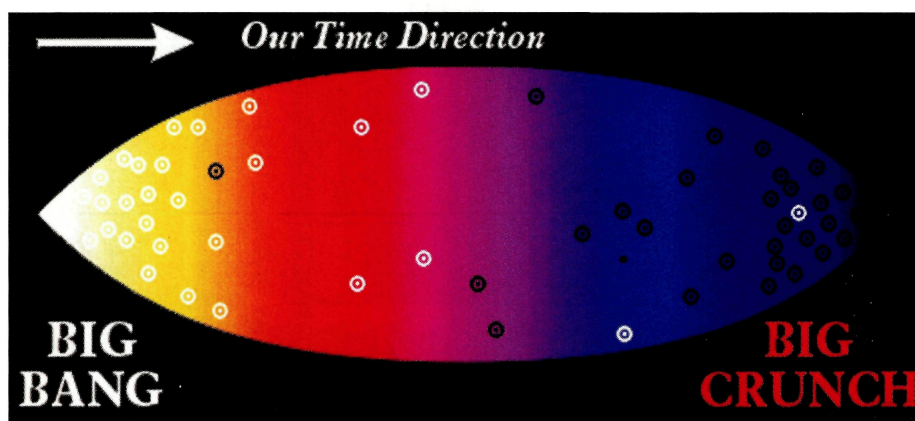
Arrows of time run in reverse?

The laws of physics are mostly time-symmetric – they work whether time runs backwards or forwards. However, we certainly perceive an “arrow of time” whenever we smash an egg or drop a wineglass – the egg and glass will not reassemble themselves. Linking this arrow of time defined by thermodynamics to the cosmological arrow of the expansion of the universe defines, for us, a forward direction.

Why does the arrow point that way? Could there be pockets in the universe where the arrow points in the opposite direction, where time seems, to us, to run backwards?

Lawrence Schulman of Clarkson University in New York has been tackling this question. He claims that it is possible to have opposite-running time regions and that some “small” degree of contact between them will not destroy the arrows of time. However, on the question of causality (whether someone in a time-forward region could warn someone in a time-backward region that an event is about to happen), Schulman admits that his calculations rely on some assumptions to avoid paradoxes.

How could regions of opposite-running time have formed? In the same way that electrons



The direction of time follows the expansion of the universe, but perhaps there are regions of backward-running time (black circles), evolving in reverse from a possible Big Crunch at the end of our universe, and appearing to us like dark matter.

and positrons run in opposite time directions, Schulman suggests a cosmological picture with a timeline running between the Big Bang and the “Big Crunch” – the massive contraction marking the end of our universe. Then what would appear to us as time-reversed regions are just matter following the timeline in reverse.

Although current cosmological thinking

disfavours the Big Crunch scenario, if it does happen, it is still certainly a very long time away. Therefore, if there are galaxies with backward-running time, following the timeline from Big Crunch to Big Bang, at this instant they are very old and hence not very luminous, although they are still exerting a gravitational pull – exactly the hallmark of dark matter.

Photon teleportation achieved

Teleportation – the instantaneous transportation of an object (like Captain Kirk in *Star Trek*) across space – may seem to be solely the stuff of science fiction. However, at the quantum level, the dream has already become a reality.

Experiments in Austria and Italy pioneered “teleported” information about photon polarization (not the photon itself) from a sender to a receiver using the trick of “entanglement” – a deep quantum mechanical connection between particles that was first pointed out by Einstein, Podolsky and Rosen.

For example, with two entangled photons (A and B), determining the polarization of one of them (say, 0°) automatically defines the polarization of the other – the second photon

must “collapse” into the complementary state (90°). Therefore to teleport the information “ 45° polarization”, a messenger photon of 45° polarization is made to entangle with photon A, thus obliging A then to be in the complementary polarization state. This in turn means that photon B now has the same polarization as the messenger photon, which is complementary to that of A. Then measuring the 45° polarization of B means “message received”.

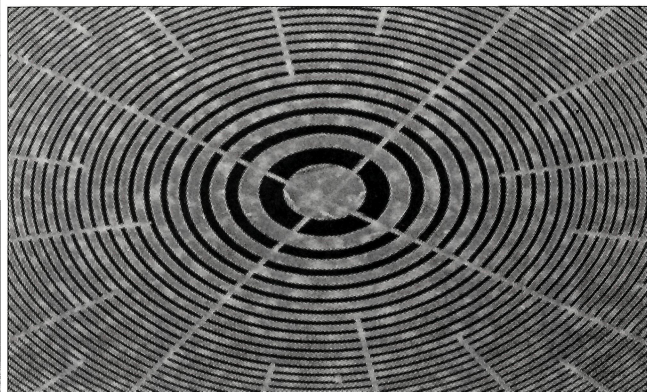
Experimenting with entangled photons is quite difficult, however. Now UK researchers are proposing a much simpler technique of conveying information – by teleporting the quantum state of an atom trapped in a cavity to a second atom in a distant cavity.

Laser traps electrons

Physicists at Rochester, New York, have trapped electrons in a laser beam. They make a laser “ring” by directing an intense beam through a half-wave plate to add a phase shift to the inner portion of the beam. Half of the incident field is shifted, causing destructive interference at the focus. With the central null field enveloped in the laser field, the trap is primed.

Electrons in the oscillating electromagnetic field drift under the ponderomotive force into low-intensity regions, becoming “trapped” in the centre ring. The force makes the electrons “quiver” – harmonic or anharmonic motion depending on whether they are non-relativistic or relativistic. The electrons emit light by Thomson scattering. Matching this radiation pattern to the results of computer simulations indicates the success of the trap.

Fresnel plate sharpens focus of helium beam



Exploiting wave-particle duality, researchers can focus beams of helium atoms to spots of $2\text{ }\mu\text{m}$ across by diffraction at a Fresnel zone plate. Imaged by a scanning electron microscope, the central zone of the plate is $10.4\text{ }\mu\text{m}$ in diameter, while the outermost slit is only 100 nm wide.

A team of German physicists has taken a step closer to the realization of an atomic de Broglie microscope. Exploiting the wave-particle duality of quantum theory, they have produced a highly focused and intense beam of helium-4 atoms.

Traditionally, imaging microscopes have

used only electrons or photons, as either particle can be focused easily. However, imaging with helium atoms is an attractive alternative: at thermal energies ($5\text{--}100\text{ meV}$), chemically inert helium-4 atoms are non-penetrating and would not damage the subject of the imaging process. This is obvi-

ously useful in the imaging of biological samples. Also, the de Broglie wavelength of such atoms is only a few tenths of a nanometre, giving much better resolution than optical or electron microscopes for comparable energies of incident particles.

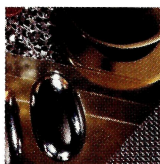
The problem is focusing a helium beam. Ground-state helium-4 atoms have low polarizability and no spin, so standard techniques cannot be used. However, wave-particle duality means that helium-4 atoms are diffracted by the slits of a grating just like waves. The effect is to focus the atoms into a narrow band – the central maximum of the diffraction pattern.

The researchers used a custom-made Fresnel zone plate – a grating of 100 nm slits in concentric rings. They saw a focused spot of less than $2\text{ }\mu\text{m}$ in diameter and of an intensity 1000 times as high as that achieved by any previous experiment.



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