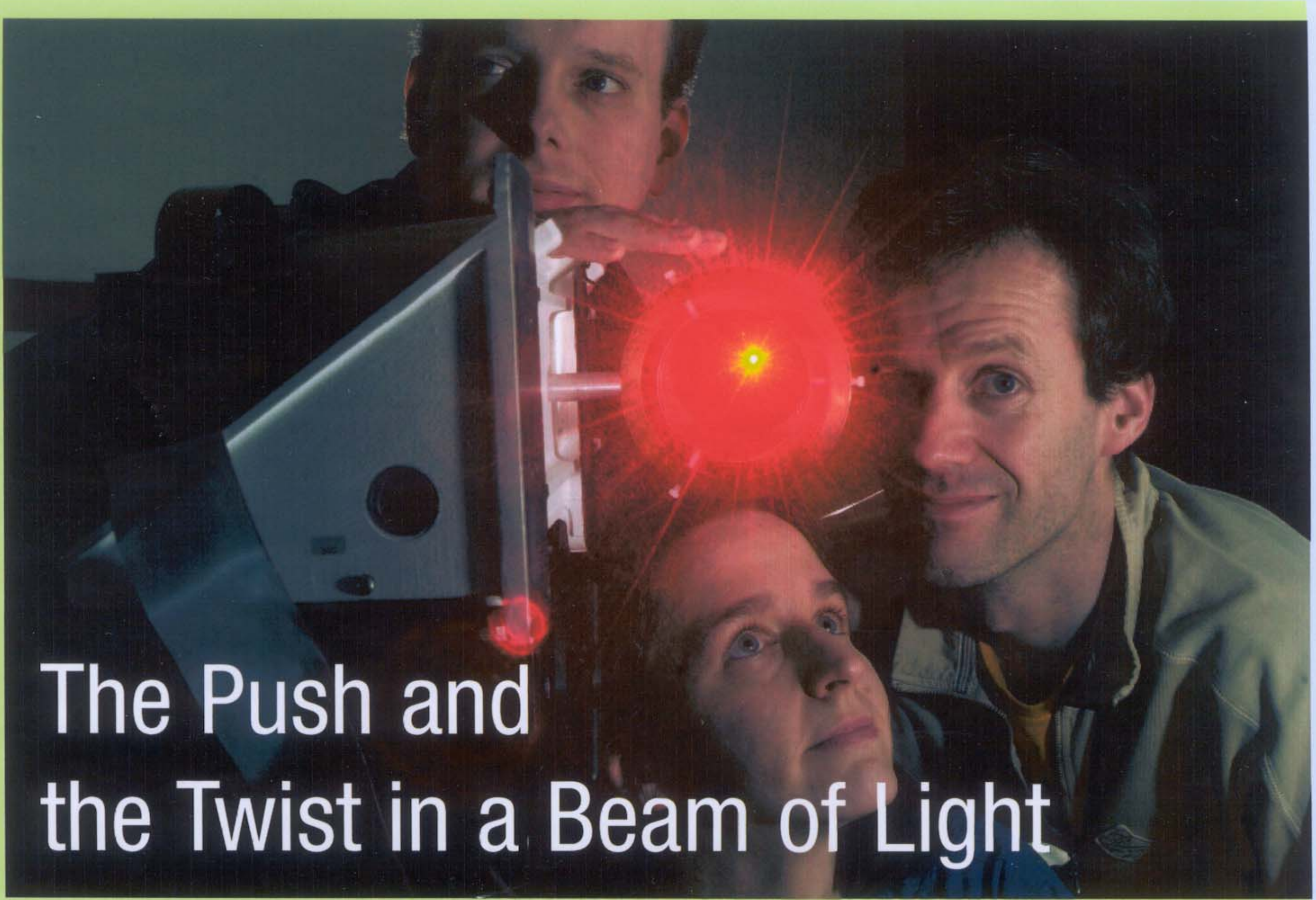


The Push and the Twist in a Beam of Light

Professor Miles Padgett has been interested in one thing over the last decade: light. Based at Glasgow University, he's been studying how light behaves and he's made some interesting discoveries. Most of us know that light, just one portion of the electromagnetic waves flying through space, has a unique mix of ray, wave or quantum properties in the visible spectrum. But Miles has been delving deeper and deeper into exactly how light behaves and how its unique properties can be better understood and put to use.

The fundamental basis of his research is the fact that light has momentum.

"Light actually has momentum. This is something we've known about since Keppler in the 1600's. What that means is that if I shine a light at you, you'll be very slightly pushed back by it. What they didn't know in the 1600's is that light also has angular momentum. You'll not only be pushed very slightly backwards by the light beam, you'll also be pushed slightly to one side. The beam has linear and angular momentum."

"Of course you're such a large object that the effect is infinitesimal, but if we shine a light beam on very small particles we can see the effect quite clearly."

Angular momentum has two key components: spin angular momentum and orbital angular momentum. The spin angular momentum of the earth is what gives us night and day: the earth spins and presents a changing face to the sun. Spin is a fundamental property of all elementary particles, and is present even if the particle is not moving. Orbital angular momentum however, results from a particle moving around something, like an electron around a nucleus. Orbital angular momentum gives us the seasons as the earth moves around the sun.

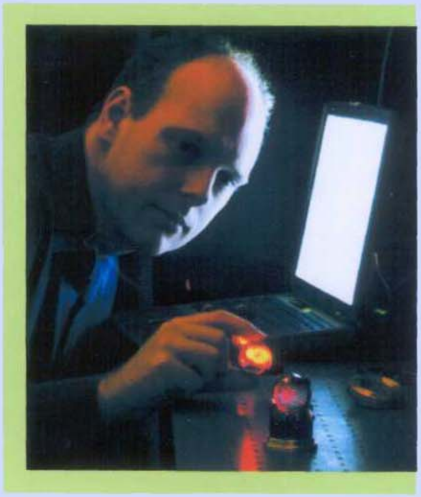
Orbital angular momentum results from the motion of a particle.

For example, an electron in an atom has orbital angular momentum, which results from the electron's motion about the nucleus, and spin angular momentum. The total angular momentum of a particle is a combination of spin and orbital angular momentum.

Light possesses both spin angular momentum and orbital angular momentum. Because angular momentum can never be 'created', only exchanged, just like energy, the absorption of a photon by a microscopic particle results in the photon's angular momentum being transferred to the particle, which will start to spin as a result.

By shining a tightly focused light beam down a microscope onto tiny microscopic particles, less than 1000th of a millimetre across, Professor Padgett has been able to demonstrate the effect of both forms of angular momentum on particles.

The spin angular momentum of light is a result of the polarisation of individual photons of light, and physicists have known about the spin angular momentum of light since the 1900's . The polarisation vector rotates in the transverse plane so the light beam possesses spin angular momentum in much the same way that rotating masses do. When this spin is transferred from light to a particle, the particle spins about its own axis, just like a spinning top.



In 1992, a team lead by Les Allen found the theoretical possibility that Laguerre-Gaussian light beams, a special type of laser beam with an intensity structure symmetric about the beam's axis, also possessed Orbital Angular Momentum. Since then, several groups have demonstrated the mechanical effects of orbital angular momentum on particles. Unlike spin angular momentum, when orbital angular momentum is transferred from a light beam to a microscopic particle, the particle does not spin on its own axis, it "orbits" about the beam's axis .

This has been demonstrated very elegantly by Professor Padgett's team and as a result they have developed what they refer to as an "Optical Spanner". A tightly focussed laser beam has momentum and the force of this momentum is strong enough to 'trap' small particles in the beam, allowing the particle to be positioned in three dimensions. Where the same light beam also transfers some of its angular momentum to the particle, the particle can be spun in a controlled manner and aligned directionally. Effectively the beam is a microscopic tool that can not only hold microscopic particles still, but also rotate them about the beam's axis, potentially a very useful device. It's possible to imagine a future where the same technology is used for a whole range of purposes from driving micro machines to running tiny pumps.

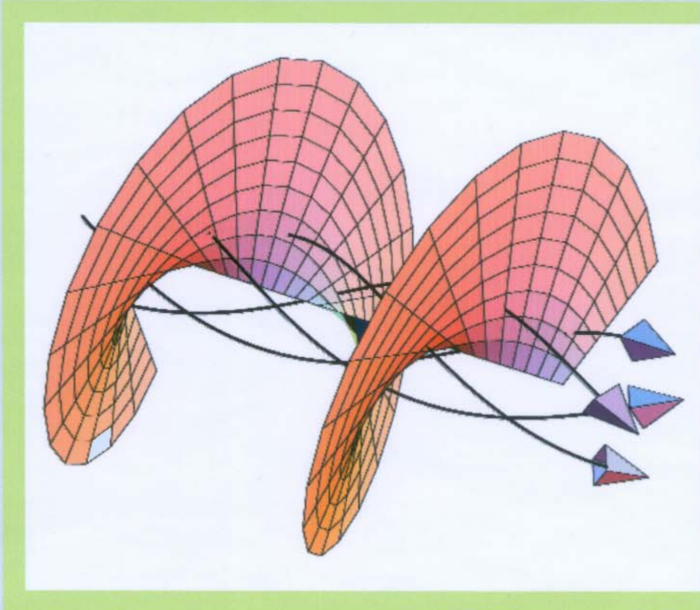
The Orbital Angular Momentum of light beams has equally interesting applications within the field of communications. Light beams are already used to transmit data in the modern world and at the moment there are two ways of doing this: one is to shine a light down an optical fibre and the second is simply to shine a light through the air.

The disadvantage to the last method is that the information is there for anyone to see and pick up. Spin angular momentum is already used in quantum cryptography to encode information but spin angular momentum only has two distinct states: left or right hand circular polarisation. Information can be coded using these two states but this is a laborious method of transmitting data, much like using Morse code, with only a dot or a dash to work with.

Orbital Angular Momentum is a much more useful property for communication with a number of distinct advantages. A single photon has, potentially, an infinite number of distinct Orbital Angular Momentum states. Information can therefore be encoded in the 'twist' of light, multiplying the number of distinguishable states and giving a major bandwidth advantage. In principle, a single photon can carry an arbitrarily large amount of information. While the possibility of such a method of transmitting information has been recognised for some time it wasn't until Professor Padgett and his team started working on the problem that a viable method for distinguishing all the possible different Orbital Angular Momentum states with efficiency was developed.

At the time the team were working on a different problem but it became apparent that a method for measuring the Orbital Angular Momentum of individual photons would not only be useful for the work in hand but would also have a multitude of interesting practical applications. Johannes Courtial, one of the team members came up with a design for the Orbital Momentum Angular sorter over a couple of days and the team have now developed the sorter to the point that they are able to transmit information from one end of a 20m corridor to another.

The sorter works by routing light beams, and in fact, individual photons, into different 'output ports' according to their



degree of 'twist'. Light passes through a series of interferometers, and each sorts the photon into one of two different classes. In principle, the number of output ports can be arbitrarily large and the device 'sorts' with perfect efficiency. The team still have quite a lot of work to do before they can produce results from their sorter to match the theoretical possibilities but the potential for useful applications of the technology is huge.

Miles predicts that in the future a sophisticated array of 'torches' mounted on the tops of high buildings will be able to send vast amounts of information without the need for expensive cable laying. In theory light beams will have eight times the capacity of fibre optic cable, thanks to the unique properties of the 'twist' the in the beam due to its Orbital Angular Momentum. And because information is transmitted using this 'twist' in the light, data will also be completely secure.

"It's an innate property of the twist that you can only measure it if you are sitting where the receiver is. If you're off to one side you can't measure it" says Miles.

The next step for the team is to test their theories by moving their demonstrator from the corridor onto the University roof tops.

"We know that at the moment we're the only people using this particular technology but there are lots of companies using wireless technology that may be very interested in what we're doing."

And in the future we could be living in a world where our communication networks are a grid of light in the sky instead of a mass of wires underground.

And all because a team in Glasgow worked out how to measure the twist and the thrust in a beam of light…

(http://www.physics.gla.ac.uk/Optics/Miles/)