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Eddies and whorls in a beam of light

Light waves may be the forceps for the nano-watchmaker, says S.Ananthanarayanan.

Light, the weightless, electromagnetic wave, which can yet behave as a particle, and buffet atoms into place, is proving useful in the world of the very small. Dr Mark Dennis and colleagues at the University of Bristol report in the journal, ***Nature*** their advance in manipulating light, literally to ‘knot light waves like a shoelace’.

Light and leverage

A stream of water or a blast of air is movement of physical things, the molecules of water or air, which have mass, can exert pressure and flow smoothly or with eddies and turbulence. But light is just a ‘push-pull’ of electric and magnetic effects, which are caused by and cause each other, rushing forward like radiating circles of water bobbing up and down in a pond where a stone has been thrown. But unlike the ripples, there is nothing material that moves in a light wave.

And yet, as electric and magnetic effects spread out, these can have effects at distant places and they carry away energy as they move. And, as energy and mass are equivalent, a light wave has momentum too, and exerts force when it is absorbed or is reflected. The recent discoveries about light is that it behaves like a stream of air or water not only in pushing and eroding things that come in its way, but also in forming eddies and whirlpools, which could be designed in specific shapes, to manipulate tiny things in a sensitive way!

The light wave

We all know that in an ocean wave moving in some direction, water is not actually flowing in that direction, it is just a sequence of up-down movement of water whose succession creates the impression of a wave ‘on the move’. This kind of wave, where the action is not in the direction of the wave, but in a ‘transverse’ direction, is called, what else, a ‘transverse wave’. Light is also this kind of wave, with the magnetic and electric effects zig-zagging, growing one way, then shrinking, growing the opposite way, shrinking again, and so on, transverse to the direction of the light beam. But there is a difference – The ocean wave is made of water, which has weight, and must move up-down, because of gravity – in the vertical plane, that is, not side to side. In the case of light, gravity has no importance and the electric and magnetic effects can ‘swing’ in any plane. In fact, ordinary light is a mixture of waves of electromagnetic effects in all possible planes.

When light is passed through special materials so that the movement of the electric effects is only in one plane (this also fixes the plane of the magnetic effects), then the light is said to be ‘polarised in that plane. The whole of this kind of light, then, will not pass through another plate of the same material if it is not oriented the same way.

This effect, of polarization, in fact, is a manifestation of cyclic variation and if it’s different components are differently affected, then the plane of polarization can itself begin to rotate which is a case of ‘circular polarisation’. In this case, the electric part of the wave (or the magnetic part) is describing a ‘helix’, as it progresses. In this case, the wave can show not only forward momentum, like a cricket ball, but also spin momentum, like a spinning cricket ball!

Light and interference

Because light consists of waves, the waves can also be ‘in step’ and help each other or ‘out of step’ and cancel each other. We may have seen this in action at the sea shore, where there are waves coming in and waves going back. If both waves are ‘in step’ we get a large one, and if they are not, then the wave becomes a ‘dud’. The same thing happens with light and this is the reason that sharp images form, at the focus, where the waves reinforce, after passing through a lens.

It is this property of light, where the wavelength is very small, the size of nano things, that helps us develop microscopes, to see very small objects. This is also the property that comes in the way of and prevents us from seeing things smaller than the wavelength of light - that light is able to simply ‘pass over’ such things, without forming images.

This is also the property that helps capture very detailed pictures of 3D objects, when a light source and the light bouncing off the objects are allowed to interfere. The complex pattern of light and dark areas, then captures the entire shape of the object, which can be retrieved by viewing the light source through the interference pattern. The only requirement is that the source should be a laser, which produces a consistent wave chain, like the ocean waves, and not a jumble of waves that emerge from ordinary sources, like an electric bulb or the sun. This interference pattern, when photographed and frozen, to recreate the original, is called a ***hologram***.

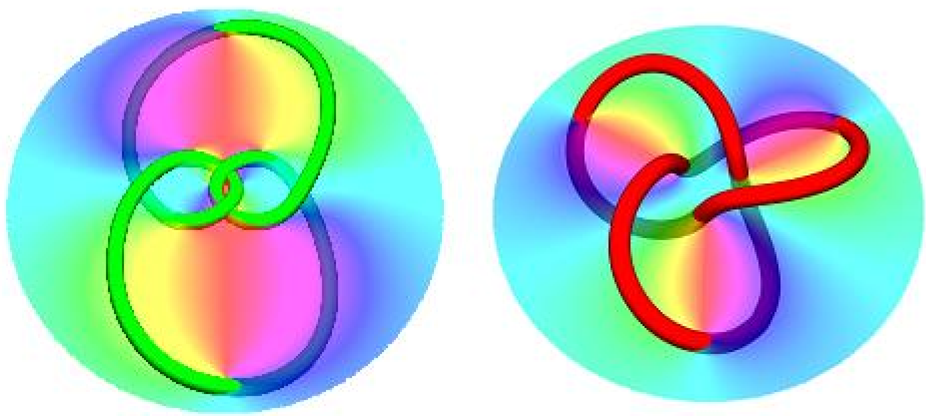
The light vortex

The work of the Bristol group uses these properties of light with the help of a lens which has a gradually increasing, spiraling thickness. In such a lens, the slowing down of light as it traverses the lens describes a circle. A lens like this can be made so that light twists like a corkscrew and light along the axis of the lens is extinguished by interference. Such a lens will work for one frequency and will display an annulus of light, or a ring with a dark centre.

The character of light manipulated like this is that the electric effects are controlled and small electrically sensitive objects, even molecules, can be moved at will. A focused laser beam itself was seen to draw such material to its centre, and devices based on this were known as '***optical tweezeres***'. The development of vortices in light beams is a large step forward, as it enables more sensitive movement of nano particles with the help of controlled light beams.

While the development of glass or plastic lenses for complex vortex forms may be challenging, an alternative is to make use of holograms, to create the optical vortices. While holograms to capture shapes are made photographically, holograms for vortex formation can be designed on the computer. And with the computer, even complex vortex forms can be created.

The University of Briston group made use of an abstract form of mathematics called '***knot theory***', a formal examination of knotty situations that arise when shoelaces get messed up. With the help of this formalism, they were able to generate holograms which resulted in very complex optical control.



Complex optical vortices emerge from holograms

The development is seen as promising for the development of optical manipulation of objects of the dimensions of the wavelength of light.

<u>Optical vortex helps find exoplanets</u>

The optical vortex that 'extinguishes light at the centre' has found application in the quest for earth-like planets in orbit around distant stars.

The great difficulty in detecting such planets is that at the great distances of these systems, the tiny image of the planet, in reflected light, can hardly be made out against the glare of the mother star. The effective methods have thus been indirect – one is by using the effect of the planet on the stability of the star – the planet creates a 'wobble', which can be detected by its effect on the wavelength of light emitted. But this method can be used only for large, and therefore 'earth-unlike' or planets very near the mother star, and therefore frightfully hot, planets of the distant stars.

The other method is to spot the planet as it passes before the star, through the slight drop in the total light reaching us.

But now, it is possible to view the star as an optical vortex, and the centre, the star, is blocked out. The planet, which is not at the centre, and is thus not affected, would then stand out, as the glare of the planter has been blanked!