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The electron sheep-dog

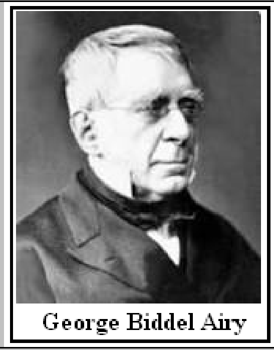
A way of making light waves stay together has been applied to electrons, says S.Ananthanarayanan.

The fact that light consists of waves and not particles led to the understanding that light does not exactly move in straight lines and never casts sharp shadows. The same property also made for a way to weave light waves together, so that they formed into regular shapes, like the rainbow, or could be steered into a narrow beam, which did not spread, or could even be made to twist and turn. Very small particles, like electrons, also behave like waves of very short wavelength and the techniques that have been developed with light could be used to manipulate small particles.

Prof Ady Arie

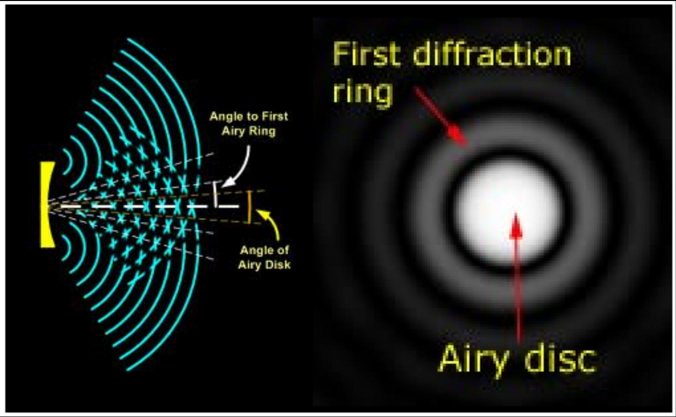
Prof ***Ady Arie*** and his students, ***Noa Voloch-Bloch, Yossi Lereah, Yigal Lilach & Avraham Gover, at Tel Aviv University,*** report in the journal, ***Nature***, that they have created .a beam of electrons that does not spread and stays intact even when disturbed.

Diffraction

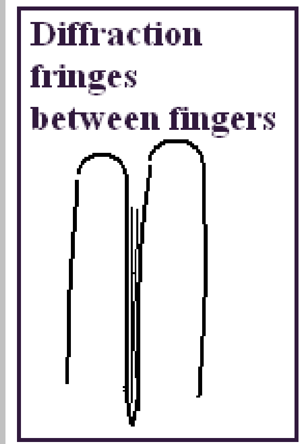


George Biddel Airy

The behaviour of light waves was studied deeply by the British astronomer ***George Biddel Airy*** in the 1830s His well known work is to explain why the image of a point source of light, like a distant star, as formed by a lens, is not a single bright spot, but a bright spot surrounded by a set of circles of brightness that rapidly get closer together and dimmer and dimmer. Airy worked it out that while the reason the image is formed at the focus, on the axis of the lens, is that it is at the focus that waves of light coming through different parts of the lens have traveled the same effective distance, there are points off centre, where the difference in the distance traveled by light from different parts is a whole number of wavelengths of light.

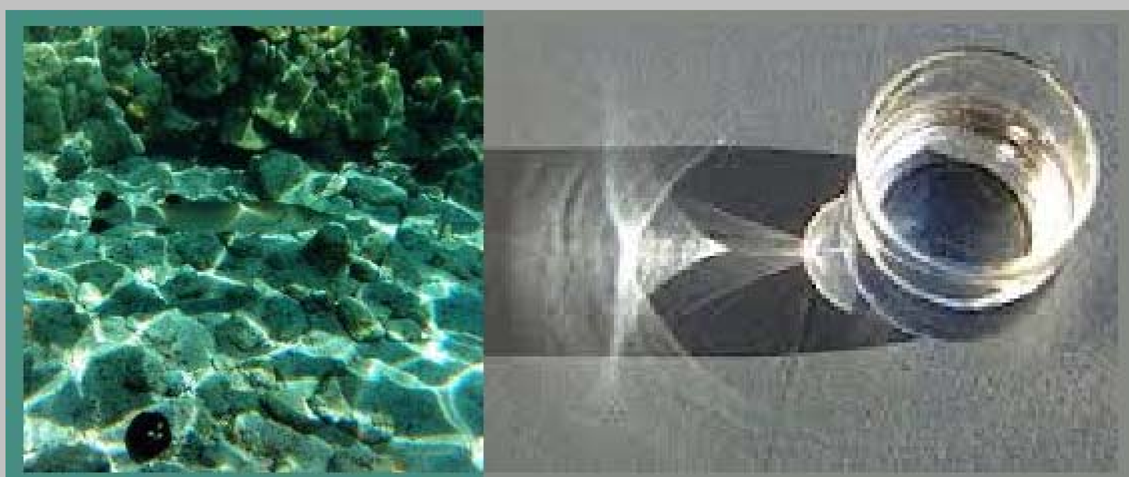


In this way, secondary wavelets of light also form images around the central image, as surrounding circles, forming a pattern which is called the ***Airy pattern***. And this manner of the energy of the beam of light getting used up to form secondary images, is called ***diffraction***



A handy way to experience diffraction is to look through the gap between two fingers held close together. As we bring the fingers closer, we can see a dark band or banks forming, bands that are in fact the secondary images of the edges of the two fingers.

Airy did a whole body of work on the way the wave nature of light forms concentration of light, one of them being the way sunlight coming through droplets on a rainy day form an arc in the sky. And as light of different colours, which is to say, different wavelengths, form slightly different arcs, we get the colours of the spectrum in the rainbow! Other forms of light getting concentrated are the curved shapes of light passing through a drinking glass, or the pattern at the bottom of a pond when light passes through the ripples on the surface. These patterns are like the way sunlight can be concentrated and made to burn things, a property that has given this field of study the name, ***caustic optics.***



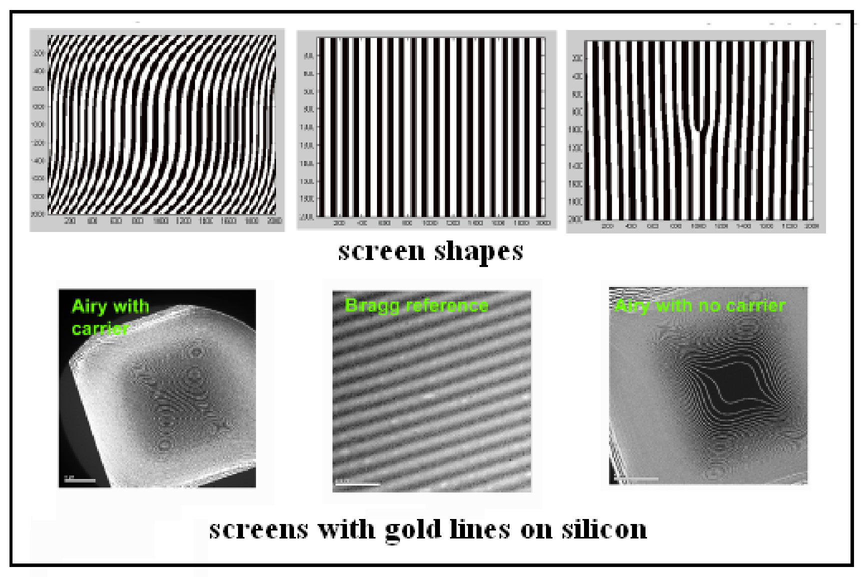
bottom of pond — light through drinking glass

A consequence of ***Airy's discs*** is that if light is passed, backwards, through a screen that is dark or transparent like the ***Airy pattern***, then light coming through the transparent bands will all travel a whole number of wavelengths when they reach the lens and they will create a packet of waves that will go straight back to where the original object was, without suffering any diffraction on the way. It transpires, from the mathematics of waves, first worked out by Airy, that a group of waves which are 'out of step' in this specific way, affect each other and cancel out the spreading effect of diffraction. In 1979, ***Sir Michael Berry of UK and Hungarian born physicist Nandor Balazs*** developed the theory for a packet of waves that can be created so that the waves form a sleeve within which the light travels, staying within the sleeve even if the sleeve is disturbed by small obstacles. Such a ***non-spreading wave packet,*** which uses concepts developed by ***G B Airy***, is called an ***Airy beam***, The ***Airy beam*** was realized in practice in 2007 by ***Georgios Siviloglou, John Broky, Aristide Dogariu, and Demetrios Christodoulides at the University of Central Florida.*** The pattern of out-of-step waves to form the wave packet was imposed on the waves by passing them through an array of liquid crystal droplets. The relationship that the droplets introduce between the waves of light makes them form into a packet that stays contained and does not spread, or it behaves like a particle, rather than a wave. The work has now advanced and there are techniques to bring about relationships among waves so that they concentrate along tailor-made surfaces or shapes, or can pass around obstacles or turn corners.

The course of physics in the last century has been to marry wave-like properties with the equations of motion of particles, and the fact that energy is exchanged in discrete units, or ***quanta***, rather than in a continuous stream. The resulting mechanics of particles which show wave properties, or ***quantum mechanics***, has proved enormously successful in describing the subatomic world and is the science behind the ***transistor*** and the ***laser*** and much else in the modern world. The development of the ***Airy beam***, in fact, was to use the same mathematics that applies to particles and show that a packet of waves can move without spreading out, like a particle.

Electron beam

What the group at Tel Aviv University report in ***Nature***, is that they have used the same method which was used to realize an Airy beam with light, with the wave equivalent of particles, in this case, high speed electrons. Small particles, like electrons also show wave-like behaviour, which makes then hop from one energy level to another, as the electron in an atom. The method of quantum mechanics is working with this wave nature of small particles and to work out how nature moves at small dimensions. Thus, even beams of electrons suffer diffraction and other optical effects, and this is the way very small scale microscopy works in the electron microscope, for instance. What the Tel Aviv group has done is to take the wave nature of the electron and form this wave into a particle, by using the methods that were developed for the ***Airy beam***.



The wave form of the electron consists of waves of exceedingly small wavelength. Manipulating these waves and introducing differences in their state of oscillation, or ***phase shifts***, required very small dimension apparatus. The Tel Aviv group did this with the help of metal rulings, or lines, spaced very close together, to act like the screen made according to the Airy pattern. A 10 nanometre layer of gold was first deposited on a 50 nanometre thick silicon chip. The gold layer was then ground with the help of a **Focussed Ion Beam**, which created closely spaced lines of gold, through which the electron beam could be passed. The properties of the wave packets that formed were studied from different angles and planes and it was seen that the shapes developed were like the curved ones seen with ordinary light. Packets were also seen to move without spreading and they \could resume their original outline after passing over an obstacle "This method of generation of electron Airy beams opens up new avenues for steering electronic wave packets like their photonic (ie, optical) counterparts, because the wave packets can be imprinted with arbitrary shapes or trajectories," say the authors in the paper.