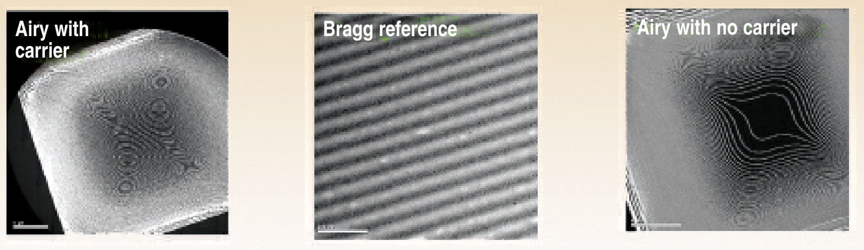
C M Y K

The electron sheepdog

A way of making light waves stay together has been applied to electrons, says s ananthanarayanan

Screen shapes



Screens with gold lines on silicon

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. Professor Ady Arie and his students, Noa Voloch-Bloch, Yossi Lereah, Yigal Lilach and 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.

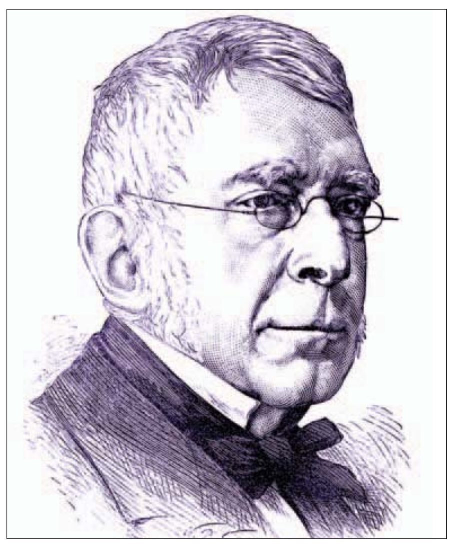
Diffraction

The behaviour of light waves was studied deeply by British astronomer George Biddell 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 travelled the same effective distance, there are points off centre where the difference in the distance travelled 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 what 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*.

Bottom of pond

Light through drinking glass

Professor Ady Arie

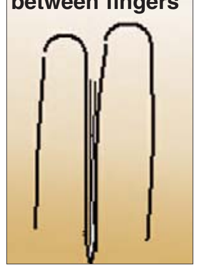


George Biddell Airy

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.*

Diffraction fringes between fingers



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 the 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 GB Airy, is called an *Airy beam.*
The *Airy beam* was realised 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 that 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

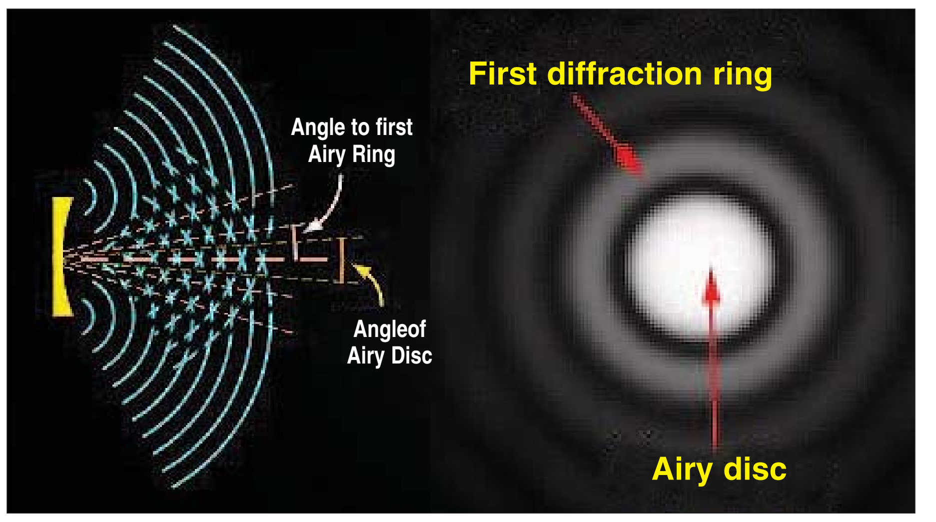
What the group at Tel-Aviv University report in *Nature* is that they have used the same method that was used to realise an Airy beam with light, with the wave equivalent of particles, in this case high-speed electrons. Small particles, like electrons, also show wave-like behaviour, which makes then 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.



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Sleeping with half their brain at a time

Biologists claim that 'half asleep' seals may solve the mystery of how and why humans snooze. sophie warnes **reports**

AN international team of biologists has successfully identified some of the brain chemicals that may help clarify some unanswered questions about how humans sleep. The research — conducted by the University of California, Los Angeles and the University of Toronto — focused on seals and the chemicals found in their brain, as they are able to sleep with half their brain at a time.

Professor John Peever of the University of Toronto said, "Seals do something biologically amazing — they sleep with half their brain at a time. The left side of their brain can sleep while the right side stays awake. Seals sleep this way while they're in water, but they sleep like humans while on land. Our research may explain how this unique biological phenomenon happens."

The study's first author, PhD student Jennifer Lapierre, measured how the brain chemicals change while the seals are asleep and awake. She found that acetylcholine — an important brain chemical — was at low levels on the sleeping side of the brain, but high levels on the waking side. This discovery suggests that acetylcholine may be responsible for brain alertness.

They also discovered — to their surprise — that the chemical serotonin was present in both sides of the brain, whether the seal was awake or asleep. It was previously thought that serotonin caused brain arousal.

Researchers hope that the discovery of the chemicals may make a breakthrough in understanding and curing sleeping disorders. The study's senior author, Jerome Siegel from Ucla's Brain Research Institute added, "Understanding which brain chemicals function to keep us awake or asleep is a major scientific advance. It could help solve the mystery of how and why we sleep."

the independent

Monkeys & peanuts

tapan kumar maitra **presents a poser to explain actual enzyme-catalysed reaction**

IF Mexican jumping beans are helpful in understanding free energy, you might appreciate an approach to enzyme kinetics based on the analogy of a roomful of monkeys ("enzymes") shelling peanuts ("substrates"), with the peanuts present in varying abundance. Try to understand each step first in terms of monkeys shelling peanuts, then in terms of an actual enzyme-catalysed reaction.

For our model, we need a troop of 10 monkeys, all equally adept at finding and shelling peanuts. Let's assume the monkeys are too full to eat any of the peanuts they shell, but nonetheless have an irresistible compulsion to go on shelling. (To make the model a bit more rigorous, we should insist that the peanuts are a new hybrid variety that can be readily stuck back together again and that the monkeys are just as likely to put the peanuts back in the shells as they are to take them out. But these considerations need not concern us here; we are interested only in the initial conditions in which all the peanuts start out in their shells.)

Next, we need a Peanut Gallery, a room of fixed floor space with peanuts scattered equally about on it. The number of peanuts will be varied as we proceed, but in all cases there will be vastly more peanuts than monkeys in the room. Moreover, because we know the number of peanuts and the total floor space, we can always calculate the "concentration" (more accurately, the density) of peanuts in the room. In each case, the monkeys start out in an adjacent room. To start an assay, we simply open the door and allow the eager monkeys to enter the Peanut Gallery.

For our first assay, let's start with an initial concentration of one peanut per square metre. We assume that, at this concentration of peanuts, the average monkey spends nine seconds looking for a peanut to shell and one second shelling it. This means that each monkey requires 10 seconds per peanut and can thus shell peanuts at the rate of 0.1 peanut per second. Then, since there are 10 monkeys in the gallery, the rate (let's call it the velocity "v") of peanut-shelling for all the monkeys is one peanut per second at this particular concentration of peanuts — which we will call (S) to remind ourselves that the peanuts are really the substrate of the shelling action. All of this can be tabulated as follows:

(S) = Concentration of peanuts (Peanuts/m^2)	1
Time required per peanut:	
To find (sec/peanut)	9
To shell (sec/peanut)	1
Total (sec/peanut)	10
Rate of shelling	
Per monkey (peanut/sec)	0.10
Total (v) (peanut/sec)	1.0

For our second assay, we herd all the monkeys back into the waiting room, sweep up the debris and arrange peanuts about the Peanut Gallery at a concentration of three peanuts per square metre. Since the peanuts are now three times more abundant than previously, the average monkey should find a peanut three times more quickly than before, so that the time spent finding the average peanut is now only three seconds. But each peanut, once found, still takes one second to shell, so the total time per peanut is now four seconds and the velocity of shelling is 0.25 peanut per second for each monkey, or 2.5 peanuts per second for the roomful of monkeys. This generates another column of entries for our data table:

(S) = Concentration of peanuts (Peanuts/m^2)	1	3
Time required per peanut:		
To find (sec/peanut)	9	3
To shell (sec/peanut)	1	1
Total (sec/peanut)	10	4
Rate of shelling		
Per monkey (peanut/sec)	0.10	0.25
Total (v) (peanut/sec)	1.0	2.5

To find out what eventually happens to the velocity of peanut-shelling as the peanut concentration in the room gets higher and higher, all you need do is extend the data table by assuming ever-increasing values for (S) and calculating the corresponding "v". For example, you should be able to convince yourself that a further tripling of the peanut concentration (from three to nine peanuts/m^2) will bring the time required per peanut down to two seconds (one second to find and another second to shell), which will result in a shelling rate of 0.5 peanut per second for each monkey, or 5.0 peanuts per second overall.

Already you should begin to see a trend. The first tripling of peanut concentration increased the rate 2.5-fold, but the next tripling only resulted in a further doubling of the rate. There seems, in other words, to be a diminishing return on additional peanuts. You can see this clearly if you choose a few more peanut concentrations and then plot "v" on the /-axis (suggested scale: 0-10 peanuts/sec) versus (S) on the x-axis (suggested scale: 0-100 peanuts/m^2).

What you should find is that the data generate a hyperbolic curve that looks striking. And if you look at your data carefully, you should see the reason your curve continues to "bend over" as (S) gets higher (ie, the reason you get less and less additional velocity for each further increment of peanuts). The shelling time is fixed and therefore becomes an increasingly prominent component of the total processing time per peanut as the finding time gets smaller and smaller. You should also appreciate that it is this fixed shelling time that ultimately sets the upper limit on the overall rate of peanut processing, because even when (S) is infinite (ie, in a world flooded with peanuts), there will still be a finite time of one second required to process each peanut.

Finally, you should realise that there is something special about the peanut concentration at which the finding time is exactly equal to the shelling time (it turns out to be nine peanuts/m^2); this is the point along the curve at which the rate of peanut processing is exactly one-half of the maximum rate. In fact, it is such an important benchmark along the concentration scale that you might even be tempted to give it a special name, particularly if your name were Michaelis and you were monkeying around with enzymes instead of peanuts!

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