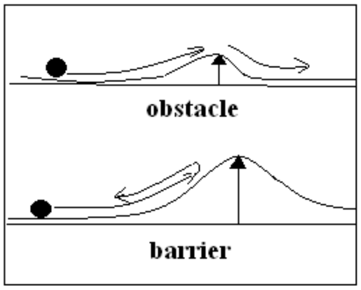
Electron action falls to lensman

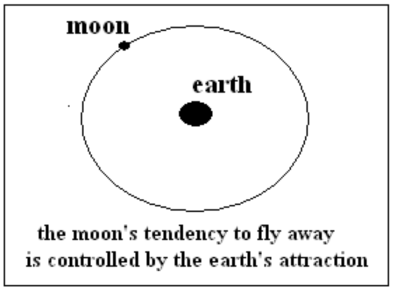
Quantum effects inside atoms have again revealed a little of themselves, says S.Ananthanaryanan.

Ferenc Krausz and colleagues at the Max Plank Institute for Quantum-Optics in Germany have recorded the time it takes for an electron trapped inside an atom to ‘tunnel’ through the electromagnetic prison-bars – a classic quantum-mechanical, counter-intuitive phenomenon.

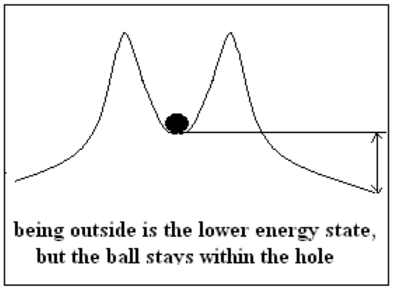
Crossing barriers

An obstacle impedes progress because it takes energy to be overcome. But if the system does not have enough energy, it is trapped and the obstacle becomes a barrier. The moon in orbit around the earth or a golf ball inside the hole are examples of objects trapped inside a barrier of energy that has to be overcome to escape.





the moon's tendency to fly away is controlled by the earth's attraction



being outside is the lower energy state, but the ball stays within the hole

One more instance is of an electron in orbit around the nucleus of an atom. It is bound to the atom by ‘binding energy’ or the amount of work that has to be done to set it free. When an external effect, like a photon or other particle striking the atom takes place, an electron can get the energy to escape and get knocked out. The atom then has one electron less and is left with a net charge and is said to be ‘ionised’.

The remarkable thing about atoms is that quantum mechanical effects permit an electron to escape even without the necessary energy, in an effect called ‘tunneling’.

Uncertainty and Tunneling

A tunnel is a path through a hill, which enables a train to get to the other side without climbing up or going around the hill. It is built by blasting rock and with much energy and cost. In atoms, electrons get past the energy barrier for free, once in a way, depending on the height of the barrier.

One way of understanding how this happens is with the help of the uncertainty principle. At very small dimensions, like in atoms, a thing is not really at a specific spot or exactly at rest, but is located in a little fuzzy area, and also moving about a bit. If we try to reduce the uncertainty of location, the uncertainty of motion gets large. And if we try to be correct about the movement, just where the particle is becomes unclear.

The same thing also works with energy and time. The energy of anything is not exact, but spreads over a range. Low energy states that have little uncertainty can last indefinitely. But high energy states, when the uncertainty is high, can last only for an instant.

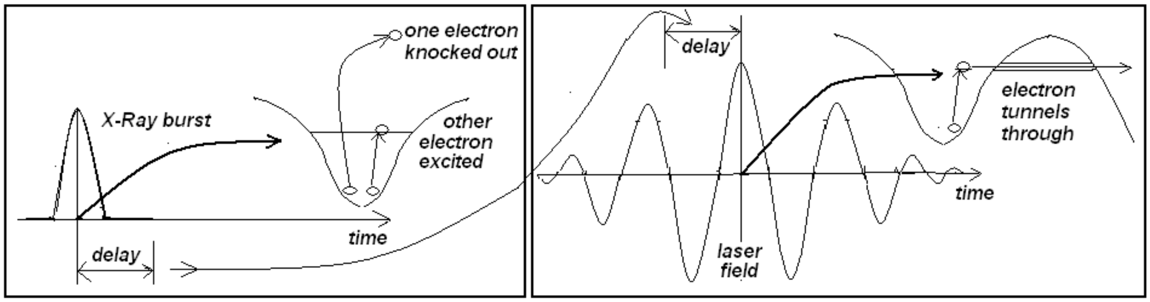
In the case of a particle like an electron in an atom, this allows the electron to have a tiny probability of being in a high energy state, but just for an instant. During such an instant, the electron could get past the 'binding energy' barrier, crossing through a 'tunnel' as it were.

Matter of timing

How long this kind of electron state transition takes has been of interest, generally. The time is of the order of attoseconds or a millionth of a billionth of a second. The way the scientists at the Max Plank Institute measured such time intervals was with the vibration in X Ray waves as a clock. X rays have very short wavelengths, a hundred millionth of a metre or less and frequencies from 10,000 to ten million times a billion waves a second. With this kind of frequency, counting successive waves of X Rays could help time electron events.

The method was to bathe a gas jet in a laser field whose waves had cycle time of around 2,700 attosecs. The gas gave off X Ray pulses, of the same frequency and 'in step' with the laser, the pulses being just 250 attosecs long. The pulses then struck a sample of Neon gas and were strong enough to knock one electron out, to create Ne^+ and to leave the next electron exited, but not enough to be knocked out.

The X Ray pulse was followed by the laser beam, slightly 'delayed'. This is done, for instance, by passing the laser through a thin film, which slows it by a cycle or two. Now, the laser waves can again perturb the exited electron and in the peaks of the cycles, can nudge the electron to tunnel and escape, to leave doubly ionized Ne^{++}.



The accumulation of Ne^{++} depends on the delay between the X Ray pulse and the laser pulse – the yield increasing in steps as additional peaks in the laser pulse become available, as delay is varied. Tuning the delay indicates that excitation and tunnel ionization must occur within a total time of 300 attoseconds.