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Lasers help get electron close-ups

Scientists are doing to atoms with lasers what microwaves have done with the water molecule, says S.Ananthanarayanan.

Lasers that work at the frequencies that match the rhythms of electrons are helping create images of the way electrons change position during chemical reactions. All chemical reaction involves atoms exchanging and sharing electrons. But the dimensions of atoms and the distribution of electrons are so small that viewing them, using an appropriate frequency of light, would disturb their state and render the view useless. Using the electric and magnetic fields of laser light is a new way that seems to beat this limit to how small a thing we can see.

Using waves

Light and electromagnetic waves have been the scientists' partners since long. When studying the light emitted by atoms or in the use of X Rays to image bones in animal bodies, it is the energy of the light waves we are using, rather than their special nature as waves. The dimensions of waves of even visible light are so small that the wave nature is not relevant with ordinarily observable things. It is the longer waves, like those in the radio band, that have found use through their effect of setting up electric currents in antennae. And shorter radio waves, but not waves of visible light, have proved useful in microwave communication and in radar.

The thing about these last two applications of electromagnetic waves is that the waves have been directly generated and the waves emerge as a stream, 'orderly and in step'. This is unlike the case of emission of light from atoms in a hot wire or the emission of X Rays from a beam of electrons striking a target of a heavy metal. In these cases the light is coming from individual atoms, in random order. Each burst of energy acts on its own and has no relation with the previous one or the next. The bursts then do not act in concert.

The microwave oven

The small dimensions of shorter wavelength light become meaningful, however, when we go down to the scale of atoms and molecules. The domestic 'microwave oven' works because the frequency of microwaves, around 100 trillion per second, matches the rotational frequencies of water molecules. The water molecule is best because it has 2 hydrogen atoms placed not quite symmetrically on either side of the oxygen atom. The makes the water molecule behave a little like a magnetic needle. An alternating field, like a microwave, can then make it turn around. As microwaves come regularly, like soldiers marching 'in step' and the frequency is about right, microwaves are able to set the water molecules spinning rapidly – which heats things that contain water – and there, we have the microwave oven! But the important thing is that microwaves and the miniscule water molecule share a common frequency range.

Atomic frequencies

If molecular frequencies are high, to react to the frequency of microwaves, then the speed of the electron going around an atom is high indeed. And this rapidity matches the frequency of light in the visible range. However, to ‘needle’ and probe electrons in atoms we need not just random bursts of light at the correct frequency, we need a continuous stream of waves marching ‘in step’.

This, fortunately, is exactly what the laser is. Just like radio waves are created, wave crest after wave crest, in electronic equipment, laser light is emitted, one wave setting off the next, in atoms themselves. Laser light, then, like radio waves or microwaves, is not a burst of energy but a continuous, coherent stream.

Keeping time with electrons

Scientists trained short pulses of laser on a nitrogen molecule, which is 2 nitrogen atoms sharing their electrons. The resonance of the light and the electron motion resulted in the electrons going to higher energy states and back, with emission of light that interfered with the laser. Interference is like what happens when light falls on a thin layer of oil floating on water. We may all have seen the rainbow colours because of interference of light reflecting off the upper and lower surfaces of the oil sheet.

A similar thing happens with the nitrogen molecule and the laser pulses. Studying the interference patterns helps form images of the electron cloud around the molecule – a glimpse of nature at short range!