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Desk-top X Ray cannon

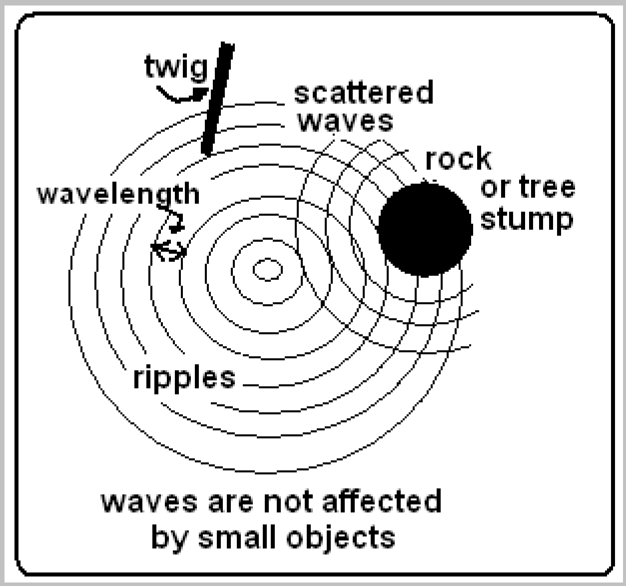
A lab size source of the hardest X Rays is set to make a difference, says S. Ananthanarayanan.

The way Roentgen discovered X Rays was that he saw they could pass through his hand but not his bones, which cast a shadow on a photographic film. It was soon understood that X Rays were just like light waves, but with a very short wavelength. This gave them high energy and the capacity to pass through soft tissue, and hence their great value in orthopaedics and medicine in general.

'Hand mit ringen' (hand with rings). Roentgen's X Ray of his wife's hand in December 1895

But another use of X Rays was because of their short wavelength alone. The short wave length helps X Rays act as sensitive probes to investigate things like the structure of crystals, which are the size of the X-Ray wavelength.

Waves in general are not affected by things that are much smaller than their wavelength. In the case of ripple on the surface of a pond, of instance, the ripple is scattered by a rock or a tree-stump, but hardly affected by a twig, whose girth is smaller than its wavelength.



The things that we see around us are all of far greater dimensions than the wavelength of visible light. Light is thus able to form sharp images and we are able to see things and get around. Even when it comes to microbes and germs, they are large enough, compared to the wavelength of light and a microscope can help us see them. But with really small things, even microscopes images get blurred, because the objects are of size comparable to the wavelength of light.

X Rays to the fore

This is where X Rays become useful. Because of their short wavelength, X Rays are scattered by small objects and they can image things too small to be detected by ordinary light. Of course, to 'see' with X Rays, we cannot use our eyes, but we use photo-film or other effects, like ionization, to detect which way the X Rays are scattered.

And then, with some neat mathematics, now done by computers, we can get sharp and precise pictures of things so small that there was no other way, even in theory, of our interacting and making them out!

This is all with fairly 'low energy' X Rays, which can be generated by bombarding a metallic target with a stream of electrons. This is the classic, X Ray gun, in which electrons jumping off a heated wire are speeded up by high voltages, and made to crash into the target. The atoms of the metal target get excited to high energy levels, and when they de-excite, they give off energy in photons which are in the X Ray region.

This kind of X Ray gun can create more X Rays by firing a larger current, or more energetic rays by firing at a higher voltage. With this kind of control, the correct X Rays for different medical or scientific purpose can be generated.

Not strong enough

Except that for getting close enough to atoms and to view atomic structure, this kind of X-Rays are not strong enough. The usual X Rays created have wavelengths of 10 to 0.01 nanometers, which can image crystal structure, where the inter-atomic distance is of this order. But to get closer to atoms themselves, to image matter at the atomic scale, we need waves which have even shorter wavelength, of the order of 0.001nanometers.

This kind of high energy X Ray cannot come from generators that depend on the de-excitation of atoms, where there is a limit. There has to be an entirely different method and that method is the emission that comes from accelerated charged particles. It is the nature of electrical charges that when they are accelerated, they send out a varying magnetic pulse, which in turn, induces an electric spike. The spike creates another magnetic pulse and so on, resulting in an electromagnetic wave.

Thus, if charged particles, like electrons, are accelerated, like in circular motion, they would emit electromagnetic.m. waves, the faster the motion the higher the wave energy. One device to generate high energy radiation, which is to say, very short wavelength X Rays, is the synchrotron.

This is a device in which a stream of electrons is accelerated and held in a tight circle with the help of electric and magnetic fields alternating at radio frequencies. The charged particles settle down in the circle where the two fields synchronise and by varying the fields, the motion can be made faster and faster, to reach nearly the speed of light, and to generate X Rays of the shortest wavelengths.

Another method is with the ‘free electron laser’. The usual laser is a device where atoms emit photons, by de-excitation of their bound electrons, in synchrony with waves of light of the same frequency, to create ‘stimulated emission’. In the ‘free electron’ device, high speed electrons are made to oscillate by in a chamber with alternating magnetic poles and emit radiation.

In these devices, the radiation is not only of very high energy but also of uniform wavelength, phase and direction and the devices have proved invaluable in atomic level research. But the trouble is that they need bulky, in fact kilometer scale, high energy, sources of electrons and there are not more than a few dozens in the world.

Lab size model

An alternative set up reported in ***Nature Letters*** is the use of a laser driven, plasma accelerator, which creates the necessary high speed electrons within a 1.5 cm chamber. The arrangement is to bombard a gas-cell with high energy laser pulses, which blasts the gas atoms apart, into electrons and atomic centres, a gas of charged particles that stay apart because of the high speeds, and this creates bursts of high energy electrons.

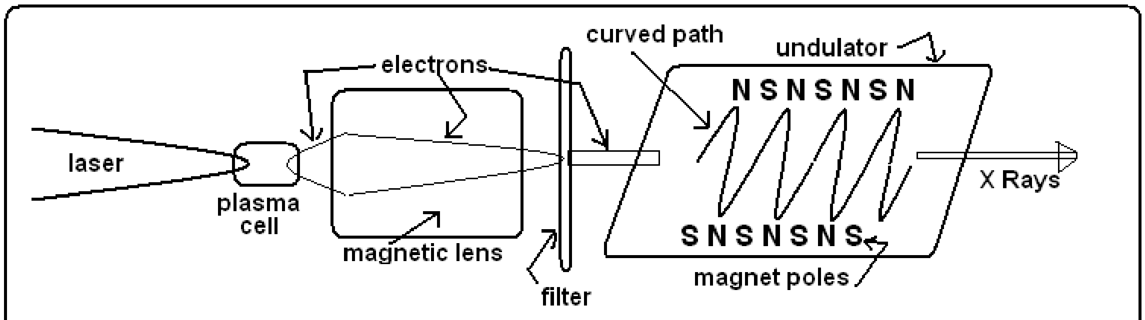


Table-top, laser, plasma and undulator X Ray gun

The electron beam is then passed through an ‘undulator’, a series of opposite pole magnets, just 30 cm long with magnets 5 mm apart, which twist the high speed electron beam into a rapidly curving path. The result is X Rays of the ultra short wavelengths of synchrotrons and free energy lasers, but through a table-top arrangement!

The electron beam that emerges from the plasma has a range of energies, which can be filtered, to produce of X Rays of tunable wavelengths. “Our experiment paves the way for a new generation of brilliant, compact X-ray sources with the potential for widespread application in university-scale laboratories”, say the authors of the paper.

A nanometer is a thousandth of a millionth of a metre, or the millionth of a millimetre. Visible light has wavelength of 400 to 700 nm. The everyday CD reader uses ‘pits’ on the CD surface which are about 100 nm deep and 500 nm wide. Visible light lasers are hence suitable for reading CDs.

Atomic distances are of the order of a tenth of a nm and another unit used by scientists is the Angstrom Unit, which is 0.1 nm. The dimensions of atoms are from 1.3 to 2.5 Angstroms, atoms of the densest metals packing their material into the nearly the same space as others. And inter-atomic distances are of the same order as atomic sizes.

Seeing detail within atomic collections thus needs X Rays of sub-Angstrom wavelength.