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Pear Shaped at heart

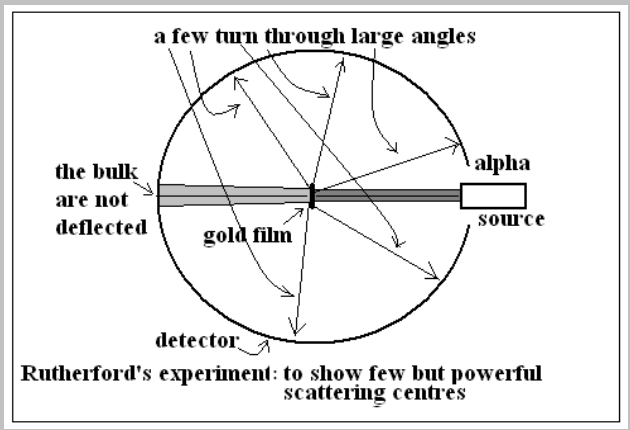
Finding unusual shapes of atomic nuclei could help solve puzzles of physical theory, says, S.Ananthanarayanan.

Since the discovery of the nucleus of the atom, in 1910, there has been phenomenal progress in understanding the atom, but only surmises about the nucleus. We know that radioactivity is in the nucleus and nuclear physics is a vast field, but the dynamics of nuclear internals is out of reach. One question is the very shape of the nucleus. There are all reasons to think it is round, or symmetrical, at least. But a report in the journal, ***Nature***, that the nucleus can be shaped like a pear, could make us re-examine fundamentals.

At many thousands of times smaller than the atom itself, the nucleus does not easily reveal things about itself. As it has electric charge and mass, it can be used as a projectile and can be detected. But there is no other probe than can come close enough to the nucleus and come away with information about its structure. A group of 53 scientists, from the UK, USA, Germany, Switzerland, Belgium, Finland, Sweden, Poland, France and Spain report in their paper their experiment where the emissions from some nuclei shows that their shape was lopsided.

The nucleus

Ernest Rutherford discovered the nucleus by an experiment akin to discovering a pea hidden in a haystack. The method was to fire a stream of charged projectiles, consisting of a basic nucleus, that of the helium atom, through a gold leaf which was just a few atoms thick.

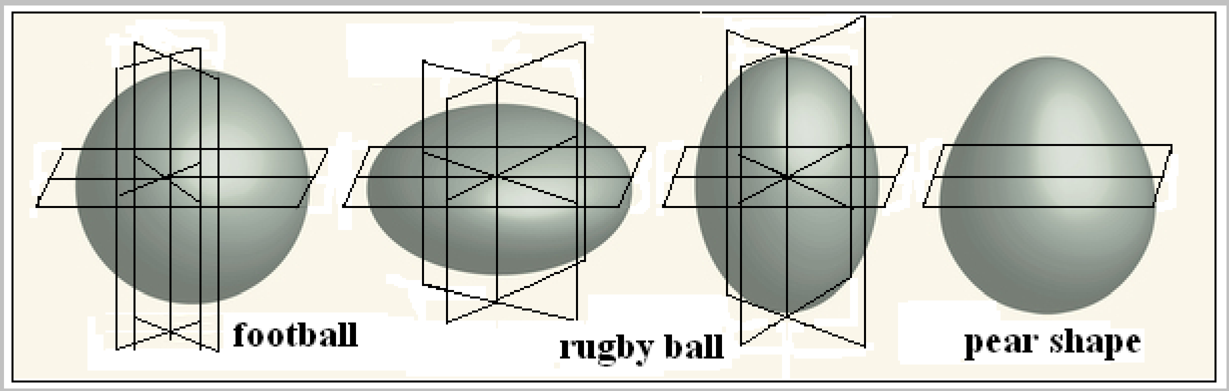


Rutherford's experiment: to show few but powerful scattering centres

The pattern of scattering of the projectiles, that very few were scattered but these were through large angles, showed that the scattering centres were sparse, but had all the charge of the atom – which showed that the charge was concentrated at a point that occupied hardly any of the volume of the atom. This discovery led to the model of the atom with a positively charged centre, surrounded by electrons in orbit, the rules for stable orbits, and all else.

The components of the nucleus, that is, the proton, which is positively charged, and the neutron, which is neutral, have since been discovered. The protons, which repel each other, stay together in the nucleus because of a strong attractive force that kicks in at very small distances. The neutrons, which also have the ***strong force***, and are not affected by electric charge, play an important role in the stability of the nucleus. The helium nucleus, which is the simplest composite nucleus, after the hydrogen nucleus, has two protons and two neutrons. This number is in fine balance from a variety of standpoints and the helium nucleus is not only stable but it is also a perfect unit, as the alpha particle, to extract when a large nucleus breaks up. Or for two heavy hydrogen nuclei, which are a proton and a neutron, to form when they merge, in nuclear fusion.

We can see that this two and two combination, which is stable, is also clearly symmetric. Similarly, in the higher elements, which have more protons, the number of neutrons keeps closely in pace and in their stable form, the elements assume as well balanced a structure of charged particles as possible. With varying and odd numbers of nuclear particles, it is not always a spherical, or ball-like shape that is the most stable, and an elongated shape, like a rugby ball, or a flattened shape, like a discuss, is a better form for the nuclear particles. As a result, a good number of nuclei are slightly off the spherical form, except for a few, with the so called ***magic number*** of nuclear particles : **2, 8, 20, 28, 50, 82, and 126.** But even elongated or flattened shapes, while not the same in all directions, are still symmetric about reflection through any axis.



Symmetry

This stability of only symmetrical forms is really a consequence of physical laws being the same on mirror reflection and even on reversal of time. So long as we hold on to this underlying assumption, it is not feasible to develop a model of the nucleus in which such symmetry does not hold. And it is based on this assumption that most of the successful current theory of matter, the ***Standard Model*** has been developed. And just as there are situations where symmetries do not hold, it is possible, for certain combinations of protons and neutrons in nuclei, to consider a nucleus that has only partial symmetry, and assumes a pear-shaped profile. In such a case, the charge would not be uniformly distributed and the variation of charge density would result in situation like having a pair of opposite charges, or a ‘dipole’ - which would be affected by electric fields.

The ***Standard Model***, which encompasses the work done through the last century, seeks to explain the forces between the components of matter and also the nature and structure of matter. It has been enormously successful in explaining a host of sub-atomic phenomena and has been dubbed the '***theory of almost everything***'. But it falls short of '***everything***' because it does not deal fully with the force of gravity, some problems of cosmology and other problems of symmetries. It is in this context that detecting '***beyond the Standard Model***' phenomena is of great interest. And finding a nucleus that shows asymmetry and hence behaves like an electric dipole would be significant.

Pear shape

The theoretical prediction of nuclei that could show such behaviour is of nuclei that have well over the number of nuclear particles found naturally. Theoretical ***magic number*** beyond 128, viz, 184 and 258, which would be trans-uranic elements, were thought of as good candidates. But it is found that these nuclei were unstable and the series of spherical form cannot be extended. Instead, there is the possibility of pear-shaped, banana-like or pyramid forms, though rarely encountered, and the group of researchers writing in ***Nature*** investigated some artificial, radioactive forms of radium, thorium and uranium, which were predicted as most likely to take the pear-like shape.

The method they used was the same as what Rutherford used 112 years ago, but instead of studying the target, this time the study was of the projectile. The isotopes of interest were first created in nuclear reactions and accelerated to 10% of the speed of light. They were then fired on a film of nickel, cadmium or tin, to deflect the fast moving nuclei through large angles. Atomic nuclei even in the normal course, have some electric dipole properties, because of the distribution of charge, albeit symmetrical. The neutron, for instance, is electrically neutral, but still has a magnetic moment, which is due to the angular momentum of charged constituents. In this experiment, the pear-like shape was expected to enhance the dipole behaviour and create characteristic signals of levels of rotation of the electric dipoles in the nuclei.

The group reports unmistakable findings. The nuclei of radon, with 86 protons, showed modest enhancement. Radium, with 88 protons, showed stronger enhancement, and thorium and uranium, with 90 and 92 protons, showed the strongest enhancement. Current sources of radioactive particles are not able to provide nuclei with more protons, for continuing the experiment. But with new reactors and facilities coming up, this area of asymmetric nuclei will make progress and the hunt for asymmetric behaviour will warm up. Study of pear shaped nuclei would help track down the source of electric dipole effects of nuclei and peer beyond the Standard Model.