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Magnetic Rotation of Coulomb Clusters in a Complex Plasma

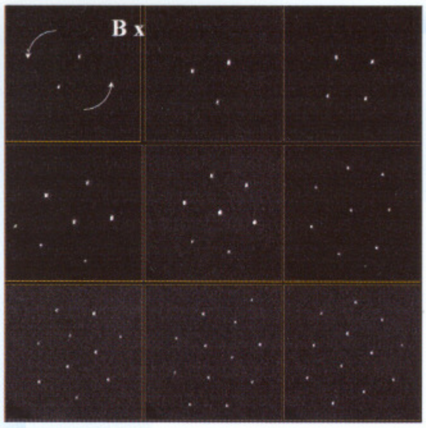
Finite Coulomb clusters consist of a small number of charged particles confined by an external field. Such cluster configurations were the basis of Thomson's classical model of the atom. Experimentally, Coulomb clusters have been successfully realised by trapping a finite number of electrons and ions using artificial confining potentials. Examples are the radiofrequency trapping of electrons and ions in a plasma, heavy ion storage rings, electrons on a liquid helium surface, and electrons in quantum dots.

Novel types of finite Coulomb clusters can be formed in a complex plasma. In this case Coulomb clusters can be thought of as a collection of very, very small dust particles, which are a hundredth of a millimeter in diameter, trapped by a parabolic electric potential well. Because of their unique physical properties due to their small size, along with the relative ease of monitoring the individual particles, Coulomb clusters have been a hot topic of theoretical and experimental studies in complex plasma physics. Currently there is a strong interest in the dynamical behaviour of these Coulomb clusters. Such interest arises because a better understanding of the particle dynamics may allow control of the dust particles as a group, or one by one. If successful, this knowledge can be used in a wide range of applications from everyday life to specific industry needs in the future. Such examples include the removal of dust contamination in semiconductor plasma processing, surface deposition on novel materials, the fabrication of micro- and nano-scale mechanical devices, and the explanation for the motion observed in planetary rings and space nebula in astronomy.

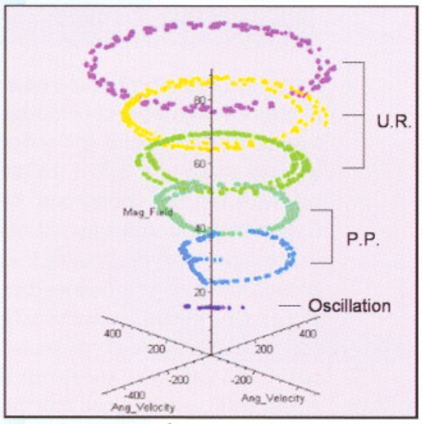
Cluster rotation is one type of particle dynamics that has been observed and reported in the recent years. In the experiment performed here at the Complex Plasma Laboratory, a weak magnetic field was applied perpendicular to the plane of the Coulomb cluster. Small clusters undergo rotational motion as a rigid body, the direction of the rotation depending on the direction of magnetic field. The cluster angular velocity increases as the magnetic field becomes stronger. The saturation effect for double ring clusters was discovered. This phenomenon was explained taking into account the influence of magnetised electrons.

It was found that different clusters show different rotational motion at different magnetic field strengths. But in general, the Coulomb cluster undergoes oscillatory motion rather than rotation if the magnetic field is weak. The cluster experiences periodic pauses (i.e. non-uniform rotation) if the magnetic field is at moderate settings. If the magnetic field strength is relatively high, the cluster rotates uniformly. From the analysis of such plots we were able to reconstruct the shape of the confining potential well as a function of magnetic field strength as shown in the figure on the far right.

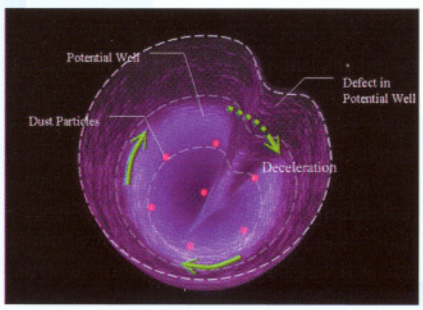
For further information, please visit our website at http://www.physics.usyd.edu.au/plasma/complex/index.html



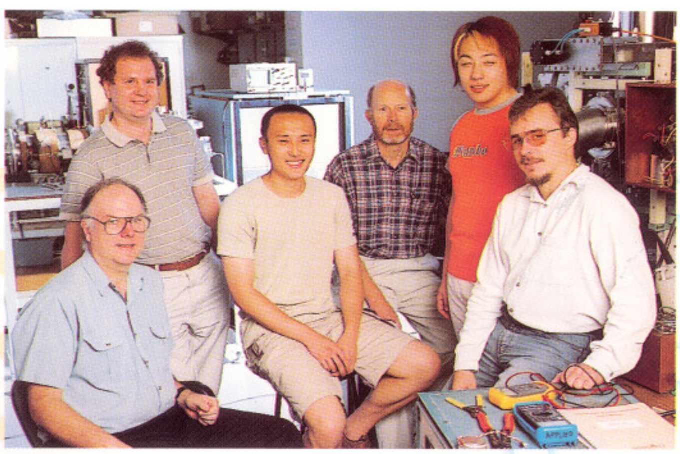
Examples of Coulomb clusters.



Plots of the angular velocity of coulomb clusters as a function of angle. At low magnetic field strengths the Coulomb cluster merely oscillates back and forth. At slightly higher field strengths the Coulomb cluster experiences periodic pauses (PP) giving rise to the distortions to otherwise circular paths. At high magnetic field strengths the Coulomb cluster rotates uniformly (UR), as indicated by the circular track in the plot.



From the rotational behaviour of the Coulomb clusters shown in the plot to the left, the team were able to deduce the shape of the potential well confining the Coulomb clusters as a function of magnetic field. A 3-D representation is shown here.



The complex plasmas research group, from left, Neil Cramer, Sergey Vladimirov, William Tsang, Brian James, Felix Cheung and Alex Samarian.