# Magical helium clusters

## The sizes of helium clusters in cryognic beams exhibit unexpected magic numbers

From Peter V.E. McClintock in the Physics Department at Lancaster University.

Physicists are well accustomed to the concept of magic numbers in size distributions. They crop up in many contexts, ranging from condensed matter physics to nuclear physics. Usually, such magic numbers correspond to states of enhanced ground state stability, and this is often also true for small atomic clusters, e.g. at the completion of structural shells in Van der Waals clusters, or when valence electrons fill closed shells in metal clusters. There are explicit theoretical predictions, however, that magic numbers of this kind should not occur for $^4$He clusters because the ground state properties are calculated to change smoothly with the number of atoms in the cluster. So it seems astonishing at first sight that Peter Toennies and colleagues in Göttingen, Burjassot, Valencia and MIT should have recently reported the observation of magic numbers for helium clusters (*Physical Review Letters* **92**, 185301).

Their experiment involved the creation helium clusters by free expansion of fluid helium at cryogenic temperatures, using the apparatus shown schematically in the figure. The collimated beam of clusters thus created was diffracted from a nanostructured transmission grating with a period of 100 nm, treating the clusters as matter waves. Because the de Broglie wavelength is inversely proportional to momentum – or, in this case also to mass because all the clusters were moving at the same velocity – the different cluster sizes diffracted at different angles enabling them to be distinguished. The cluster detector was a mass spectrometer. By plotting the mass spectrometer signal as a function of diffraction angle, the size distributions of the clusters could be plotted out with excellent resolution as shown in the lower part of the figure.

It is immediately evident that, contrary to expectation, certain cluster sizes appear to be favoured. The authors carried out several tests to check these results and to confirm that peaks were genuine, i.e. independent of conditions in the source region (where the authors varied the temperature and pressure) and in the detector (where they varied the ionizing electron impact energies). They also varied the angle of the diffraction grating relative to the incident beam of clusters. They conluded that there were definitely magic numbers corresponding to cluster sizes of 10/11, 14, 22, 26/27 and 44 atoms.

Why should this be? Preference for particular magic cluster sizes must presumably reflect events taking place during cluster creation in the source region. Usually, one would assume that these preferred sizes were more stable, and therefore energetically favoured during the creation processes. But this seems to be ruled out by the ground state energy calculations. However, there is no reason why stabilty considerations should be applied only to the ground state. Given the "heat" and turmoil leading to cluster production it seems highly plausible that they will often be created in excited states. Thus the stability of the latter may also be relevant.

So the authors calculated the energies of excited states of the cluster corresponding to radial modes and finite angular momentum. Their calculation was non-trivial, but seems to have produced some very interesting results. They compared the excitation energies with the chemical potential, i.e. with the binding energy of a single additional atom to the cluster. By this means they showed that there is a critical cluster size below which any given excited state cannot exist – because the cluster would then be unstable, and would presumably evaporate an atom to reduce its energy and get back into the stability regime. With one exception (the 22-atom cluster) the calculated critical cluster sizes correspond remarkably closely to the magic numbers measured in the experiments. The unexplained 22-atom peak inevitably provides a nagging worry that something important is missing from the understanding of the experiment, and one must hope that this possibly significant detail will soon be accounted for.

If the proposed interpretation is correct, these results represent the first experimental information about the excited state energy levels of helium clusters. They are also of interest for another reason, in that the authors seem to have identified a novel mechanism for the generation of magic numbers.

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**Figure**

Please "lift" Fig 1 from the PRL. In the interests of clarity, I suggest that it be redrawn in amended form. (I usually disapprove of PW redrawing figures, but here it would be helpful!). I suggest –

(a) Detete (omit) top section of figure.

(b) Separate the present inset of the apparatus and redraw it as a new top section of the figure.

(c) Omit all the thin vertical lines. However, note: the positions of the "wiggles" in the 4 curves should be reproduced very carefully to line up with the scale on the top abscissa asis.

Having done all that, the caption could read something like –

"Matter diffraction experiment on helium clusters. Top, schematic of the apparatus used by Brühl et al. Helium clusters produced from the cryogenic source on the left are collimated into a narrow beam by the 5 $\mu$m slit. Exploiting their wave properties, they are then diffracted by a grating of period 100 nm. Because clusters of different mass have different de Broglie wavelengths, the angle of the diffracted beam depends on cluster size. The clusters are detected with a mass spectrometer. Bottom, plotting the detector current as a function of diffraction angle yields the distribution of cluster sizes. The 4 curves refer to different conditions in the source."

If you modify the figure differently it will obviously need a correspondingly modified caption – but the figure in some form is essential, in my opinion, as the article will be impossible to understand without it.