EPAPS: Examining what defines the boundaries of quantum dots in our devices

There is a large body of experimental literature on transport through nanotubes. In most cases the device geometry is as shown below, with metal contacts either above or below the nanotube. When the coupling between the tube and the contacts is not very good (which is to say in most cases) the nanotube acts as a quantum dot.

In most cases, the quantum dot is found to be delimited by the contacts. This is thought to be because the nanotube is crushed by the contacts (if it is beneath them as shown above) or because kinks are formed in the nanotube as it is draped across the contacts (as shown below).
Nanotube A

While the scenario described above is true for the majority of cases, it can sometimes happen that the quantum dot is delimited by the length of the nanotube rather than by the contacts (see picture below and Ref. 19). This leads to lower charging energies than would be expected if the quantum dot were defined by the contacts.

For example, assuming that the whole 2µm length of nanotube A in our manuscript acts as a single dot, the charging energy $U$ is 2.3–2.8meV according to $C = 2\pi\varepsilon L/\ln(4h/d)$ and $U = e^2/C$. (Ref. 17) (Here $L = 2\mu$m, $h = 0.5\mu$m, $d = 1$–4nm.)

This is much closer to the observed value ($U = 3$–5meV) than the calculation in Table 1 which assumes that the dot is formed between the contacts.

We find that this explanation allows us to account for all of the unexpectedly low charging energies as shown in the following pages. We speculate that the addition of $C_{60}$ makes nanotubes more radially rigid and difficult to crush.
If we assume that the whole 4µm length of tube acts as a single dot, the charging energy $U$ is $1.3–1.5$meV according to $C = 2\pi \varepsilon L / \ln(4h/d)$ and $U = e^2/C$.

In this case we would have $L = 4\mu\text{m}$, $h = 1\mu\text{m}$, $d = 1–4\text{nm}$.

If we assume that there is one defect that splits the tube up into two parts of lengths $1.5\mu\text{m}$ and $2.5\mu\text{m}$, then we get charging energies $U_1 = 3.4–4.1$meV and $U_2 = 2–2.4$meV which agree with what is observed in the two devices on this tube: $U_1 = 3–4.5$meV and $U_2 = 1–3$meV.
Here we appear to have a defect between the contacts as the device looks like a double dot.

If we assume that the 2μm length of tube is split into two equal parts, we have \( L = 1\mu m, h = 0.5\mu m, d = 1–4\text{nm} \).

The charging energy \( U \) is then 4.6–5.6meV according to \( C = 2\pi\varepsilon L/\ln(4h/d) \) and \( U = e^2/C \) which is close to the observed value, \( U = 1–5\text{meV} \).