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Experimental Design for Finding and Verifying the Validity of the Unknown Quantized Resistance and Temperature of Carbon Nano Tubes

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ABSTRACT

The distinction of nano materials with other bulk materials lies in dimensionality of the systems. For instance, we cite the field of carbon nano tubes and other nano materials have in recent days been a promising and emerging area of research due to its dimensionality .When the particular dimension of a bulk matter is comparable or smaller than de-Broglie wavelength of the electron then electrons and holes are confined along this direction. As a result of the quantum confinement of electrons in 1-D carbon nano tubes, the energy and hence the resistance are found to be quantized. Here, in this paper a simple experimental set up has been made to estimate the unknown quantized resistance using the Wheatstone bridge principle of balanced condition first by employing four carbon nano resistors, secondly by employing one single resistance with the help meter bridge like arrangement. Finally, using the above principle, temperature of CNT has been tried to measure.

KEYWORDS: CNT, Wheatstone bridge, null point Potential well, quantum well, Wheatstone bridge.

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INTRODUCTION

We have obtained that Multi Walled carbon nano tubes to be scaled with number of conducting layers or conducting channels involved with the tubes[1,2,3,4,5]. That means if the MWCNTs have all together k number of conducting channels**,** the net conductance are expected to be k times of the conductance G_0

$$G = kG_0 = k\frac{2e^2}{nh}$$

n represents the quantum state as the authors of ref.[8,10] of have shown and experimentally that the actual conductance drops in the integral multiple of G_0 *not* $2G_0$.

Note that SWCNTs have 2 conducting layers but for multi walled the net conductance should be integral multiple of $2G_0$ *i.ek* times *of* $2G_0$ but due to the inter wall interactions some layers are blocked[8,11] , thereby resulting conductance is *k times of* G_0 as the alternate layers are supposed to be ineffective .For theoretical simplicity we justify the later consideration. Now, it is our turn to introduce simple electrical set up for the experimental verification of the quantized resistance obtained theoretically .Based on this , one can easily estimate the unknown resistance of the Carbon nano tubes. Hence, we switch over to the method to be followed to arrive at the desire objective. Any inaccuracy or departure from the theoretical result will be an indication of the requirement of the re justification of the theoretical model from different perspective and will demand a complete theoretical. In order to determine the unknown resistance and to estimate the quantum state, we follow very practical electrical Wheatstone bridge null method same as that of macro-circuit and the condition of null point

$$\frac{P}{Q} = \frac{R}{R_n} \quad \text{………………… (i)}$$

MATERIALS AND METHOD

For dealing with our problem we consider previous model[8] of CNT with the one dimensional quantum box model approach of carbon nano tubes in which electron is within the well of infinite depth ,so that electron is completely free to move within the well .

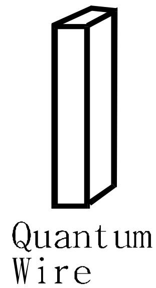

Fig-01. – Quantum Wire

That means electron is confined from transverse directions in the tube that results in the quantized nature of the total energy[1].This yields the quantized resistance, which could be used to find the unknown resistance of other CNTs. More over this quantized result may be checked by experimental set up under Wheatstone bridge balanced condition. Further, this experimental set up may be used to check the temperature dependence linear relation between the quantum state and temperature by plotting the recorded data.

Experimental Design

In the first step, precautions are to be made while making the contacts of CNTs with the macro wire or circuits as it is possible that contact resistance of CNTs play a vital role on current and may produce *contact resistance across the bridge arms.* That is, all the connecting ends of both sides of all the CNTs have to be identical and connections need to be ensured that the macro wires so connected have to be the identical in all respects so that the additional resistance if any introduced across the connecting wires should be the same and hence must cancel the effect of each other proportionally. That is the error in measuring the desired resistance can be nullified by taking all the connecting wires of same finite resistance by taking identical lengths and cross sections of the connecting wires.

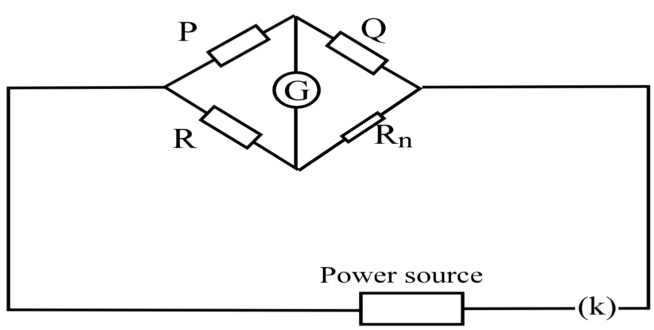

Fig-02

We consider four Carbon nano tubes **P, Q, R and R_n** connected across the Wheatstone bridges exactly as shown in the figure with a suitable power supply. Note that all the carbon nano resistors are mesoscopic components, yet the macro connecting wires are taken identical in all manners to get rid of any probable inclusion of errors. It is not necessary that all the carbon nano resistors should contain equal number of conducting layers or channels. In other words we consider the tubes with variety in numbers of conducting channels and more over contact resistances of the CNTS with the macro parts are measured with sensitive digital device to ensure equal contact barriers to current in the circuit.

Theoretical Calculation

Let us consider the carbon nano resistors are having k_1, k_2, k_3 *and* k_4 number of conducting channels or layers, then under balanced Wheatstone bridge condition $\frac{P}{Q} = \frac{R}{R_n}$

$$\Rightarrow \frac{\frac{n_1 h}{k_1 2e^2}}{\frac{n_2 h}{k_2 2e^2}} = \frac{\frac{n_3 h}{k_3 2e^2}}{\frac{n_4 h}{k_4 2e^2}} \qquad \Rightarrow \frac{n_1 k_2}{n_2 k_1} = \frac{n_3 k_4}{n_4 k_3}$$

$$n_4 = \frac{n_2 n_3 k_3 k_4}{n_1 k_2 k_3} \quad say \quad n_4 = n$$

$$n = \frac{n_2 n_3 k_1 k_4}{n_1 k_2 k_3} \qquad \ldots(ii)$$

If we take the exact tubes all of identical quantum state under the same temperature of baths then immediately it follows

$$k_4 = \frac{k_2 k_3}{k_1} \quad say \quad k = k_4 \quad then$$

$$k = \frac{k_2 k_3}{k_1} \;.. \qquad \ldots\ldots..(iii)$$

Thus, knowing the number of conducting channels of the any three of the CNTs , we can determine the number of conducting channels of the remaining CNT.

Let us we replace three of the carbon nano resistors by known resistance and keeping the fourth Carbon nano tube across the fourth arm and let it be having quantum resistance R_n and let us consider the other three resistances to be P,Q and R ,then as before under balanced Wheatstone bridge condition,

$$\frac{P}{Q}=\frac{R}{R_n} \quad \Rightarrow R_n=\frac{QR}{P}. \qquad \text{....................}(iv)$$

One can thus easily estimate the unknown resistance directly by Wheatstone bridge balanced condition from the above relation. It is here one can verify the validity of the quantized resistance of the nano tube as follows-

$$\frac{P}{Q}=\frac{R}{R_n} \quad \Rightarrow R_n=\frac{QR}{P}=\frac{nh}{k2e^2}$$

$$or \quad n=\frac{2ek^2QR}{hP} \qquad \text{...........................}(v)$$

$$G_n=k\frac{2e^2}{nh} \Rightarrow R_n=\frac{nh}{k2e^2}$$

where k is the number of conducting channels

Since, all the parameters Q, R, P are known while k can be estimated from manufacturers data, One can estimate the unknown quantum state can be estimated. Note that if n is found to be integers always ,it is an indication of the validity of the quantized resistance as in our theory n was found to be discrete which appeared from solution of Schrödinger time independent equation[8]. Never the less the contact resistances in the circuits may affect the calculation. However if the contact résistance exist and be measured with accuracy say of the same order of magnitudes r_1 , r_2, r_3 and r_4 in all the arms across the CNTs, then accurate balanced relation of the Wheatstone bridge comes out to be of the following form.

$$\frac{P+r_1}{Q+r_2}=\frac{R+r_3}{R_n+r_4} \quad \Rightarrow R_n=\frac{(Q+r_2)(R+r_3)}{(P+r_1)}-r_4 \qquad \text{.........................} \quad (vi)$$

However, if the contact resistances are somehow measured with adequate accuracy,one may expect the greater closeness of the theoretical result with experimental one .From the above one can again find the quantum state using the same relation as before with the help of the following relation

$$n = R_n 2k \frac{e^2}{h} \quad \text{..................}(vii)$$

k *is the number of conducting channels*

If n is found to be integers then our consideration was due in fact, which needs to be tested.

In an alternative approach one estimate the resistance and hence the quantum state of a carbon nano tube by using the same Wheatstone bridge principle but with wire bridge arrangement such as meter bridge instead of using four carbon nano tubes or or resistances .Note the following bridge arm similar to that of meter bridge arrangement .

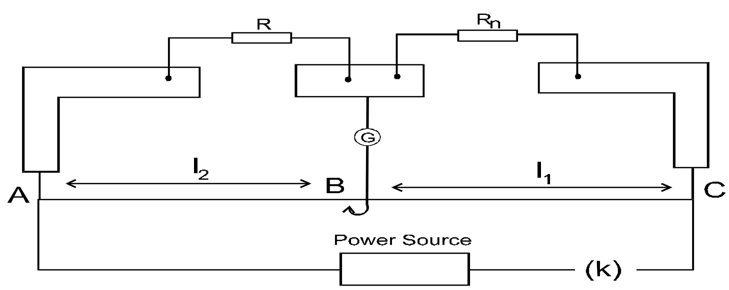

Fig-03

Let the bridge be balanced at a point when the jockey is at B across the wire and let R_n be the resistance of the carbon nano tube which is to be found out. R is the adjustable resistance of the bridge when null point is obtained .The bridge wire need to be of uniform area of cross section and composition to offer same resistance all along the length of the wire. At this stage, We can use the balanced Bridge condition which is as follows

$$\frac{R}{R_n} = \frac{l_1}{l_2} \quad \Rightarrow R_n = \frac{l_2 R}{l_1} \quad \text{...............................}(viii)$$

Thus, instead of measuring three resistance ,one would need only one resistance R to be known .Hence once the balance bridge length l_1, l_2 are known ,then we can easily estimate the unknown quantum resistance .Further introduction of contact resistance with the inherent quantum resistance of the Carbon nano tube may affect the result . Therefore, it needs justification and it is done by introducing the net contact resistance r_c *of* the CNT the following relation

$$\frac{R}{R_n + r_c} = \frac{l_1}{l_2} \Rightarrow R_n = \frac{l_2 R}{l_1} - r_c \qquad ....(ix)$$

The advantage of this method over the previous one that it seems to be easier to solve without involving tedious steps of measuring all the three bridge resistances and their contact resistances as before .Neither one need know the exact number of conducting channels, quantum states of the electrons in the CNTS nor the resistance of the bridge arms as before, just one has to easily to know the resistance to find the unknown quantum state at balanced position of the bridge. Then as before we can estimate quantum state of the electron in the CNT with the help of $n = R_n 2k \frac{e^2}{h}$.

Now, we invoke the idea of measuring the temperature of the CNTs or temperature of the bath .For that we keep the later design same as before, just we introduce various temperature of the bath where we keep the CNT. Let R_0, R100 and R_θ be the temperatures of the bath where the CNT is kept for a long time allowing the CNT to receive the temperature of the bath. If the resistance of the bath of the CNT at 0^0c, 100^0c and $\theta^0$are R_0, R_{100} and R_θ respectively then we have

$$R_\theta - R_0 = \alpha R_0 \theta \qquad ....(ix)$$

$$R_{100} - R_0 = \alpha R_0 100 \qquad ....(x)$$

Dividing the above two equations we have,

$$\theta^0 = \frac{R_\theta - R_0}{R_{100} - R_0} \times 100^0 \qquad ....(xi)$$

Varying the temperature of the bath (θ^0c) we will have different quantum resistance which can be found as already discussed in the previous section .Now, we can plot a graph between the quantum resistances and the temperatures of the baths ,which should be straight line as per theoretical consideration .This mean s the non linearity between the quantum state and the temperature if any in the plot (on the contrary to our earlier theoretical finding of linear dependence of the quantum state on the temperature) would necessitate another correct theoretical model for estimating the resistances of the CNTs.

One point need to be retained in mind that the direction of the current could be checked. If the $\frac{P}{Q} > \frac{R}{R_n}$ Or $\frac{n_1k_2}{n_2k_1}.> \frac{n_3k_4}{n_4k_3}$ or $\frac{n_1k_2}{n_3k_4}.> \frac{n_2k_1}{n_4k_3}$, the current would flow from the juncture of resistance R and R_n to the junction P and Q.

If $\frac{P}{Q} < \frac{R}{R_n}$ Or $\frac{n_1k_2}{n_2k_1} < \frac{n_3k_4}{n_4k_3}$ or $\frac{n_1k_2}{n_3k_4} < \frac{n_2k_1}{n_4k_3}$, the current would reverse the direction ,that flows from the juncture of resistance P and Q to the to the junction R and R_n.

CONCLUSION

The above all discussion in short gives the summary that we can determine the resistance of carbon nano tubes and estimate the quantum state even without knowing the number of conducting channels and the quantum state of other CNTs lying along the bridge arm as described already. Finally, the proposed Model could test the linear temperature dependence quantum state and linear temperature dependence quantum resistance. This means the non-linearity between the quantum state and the temperature if any in the plot (on the contrary to our earlier theoretical finding of linear dependence of the quantum state on the temperature) would necessitate another correct theoretical model for estimating the resistance of the CNTs.

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