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The Optical Phenomena of Interplay between Nanobio Complexes: A Theoretical Insight into Their Biomedical Applications

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Additional information is available at the end of the chapter

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Abstract

The subnanometer-sized coinage metal nanoparticles (NPs) have attracted more attention due to their unique electronic structures and subsequent physical, chemical and excellent photoluminescent properties. The DNA-stabilized metal clusters had become a remarkably good choice for the selection of fluorescent color by the sequence of the stabilizing DNA oligomer. Similarly, the single-wall carbon nanotubes (SWCNTs) also have unique optical properties which make them useful in many applications. The interaction of DNA and SWCNT is also useful in molecular sensors and it is assumed that amplification of the DNA sensing element may be necessary in the presence of SWCNTs. As the application of NP-CNT system represents a great interest in nanobiotechnology, it can be used for the design of the electronic mobile diagnostic facilities for blood analysis and the chemical or drug delivery inside the living cell. The SWCNTs are used as a drug delivery vehicles used to target the specific cancer cells. Separately, along with DNA-NP, the DNA-CNT system also represents a great interest, nowadays, in biomedical applications due to diagnostics and treatment of oncology diseases. So combining the DNA-NP-SWCNT system can represent a potential target of modern research. The interplay of DNA, NP and SWCNTs has now become a current topic of research for further nanobiomedical applications.

Keywords: NP, SWCNT, DNA, optical properties, cancer

1. Introduction

Nanotechnology has become the latest emergent field which involves the production and use of nanostructures at a nanoscale. As the particles at atomic and molecular levels led to

new materials with less than 100 nm showing unique and unusual physical, chemical and biological properties which enabled their applications in diversified fields. The biological properties of nanoparticles are determined by the different characteristics of nanoparticles, which are their size, shape, surface charge, chemical properties and solubility, and degree of agglomeration [1–6]. In the exploding field of nanoscience and nanotechnology, coinage metal clusters and CNTs have attracted considerable attention owing to their unique optoelectronic properties for a wide range of potential applications [7–11]. These SWCNTs are used as components in the third generation of electronic and optical devices, including transistors, photodetectors [12–15], and biological sensors [16–18]. The subnanometer-sized coinage metal clusters have attracted more attention due to their excellent photoluminescent properties. These metal nanoparticles exhibit unique optical characteristics with an exponential decay of the absorption profile with Mie scattering [19–22]. Meanwhile, the UV-Vis absorption is more dominated by the plasmon resonance peaks in visible region for these metals. The UV absorption exhibits molecular-like optical transitions which are due to the quantum confinement and quasicontinuous electronic energy band structures [23–26].

CNTs are also used in construction of biochemical sensors especially in the field of supporting materials. The high surface area of CNTs made it possible to load nanoparticles to enhance their properties. The controlled synthesis of these carbon nanotubes (CNTs), which requires a nanoscale catalyst metal, is crucial for their application to nanotechnology. Chirality control is the most important issue for the electronic/photonics applications of CNTs [27]. For biomolecular nanotechnology, DNA is also a promising material due to the unique recognition capabilities, physicochemical stability, mechanical rigidity, and high precision process ability. The interplay of this CNT/coinage metal-DNA has broad applications as diagnostic sensors, biomarkers, and drug delivery nanorobotic design [17, 18, 28].

In this chapter, we will discuss the interplay between these nanobio complexes, their properties and applications separately by dividing these combination materials in three sections.

These sections are as follows.

1.1. DNA-SWCNTs hybrid systems

As the dispersion of hydrophobic CNTs in solution can be facilitated by noncovalent functionalization with helically wrapped single-stranded DNA, the DNA wrapped nanotube material is used for electronic and optical device applications [29]. DNA-associated CNTs have been used in molecular sensing and the potential use of DNA-wrapped CNT platforms shows promise in multiple applications. These nanotubes offer the potential of providing the scaffold on which the DNA molecules can be oriented, manipulated, and studied without the need for chemical functionalization which is given in **Figure 1**.

1.2. DNA-NP complexes

The unique optical properties of coinage metals in conjugation with the remarkable recognition capabilities of DNA molecules could lead to the development of miniaturization of

biological electronics and optical devices to include probes and sensors. The schematic representation of NP-DNA complexes are given in **Figure 2**.

1.3. DNA-SWCNT-NP complexes

The tertiary system of nucleotide chain-coinage metals-CNTs also represents a great interest in the modern research and applications of nanobiotechnologies, for example: electronic mobile diagnostic facility and nanorobotic design for a drug delivery inside living cell. The small nucleotide chain represents an important stage in the understanding of the interaction mechanism of a full DNA (**Figure 3**).

Now we will discuss the theory of these hybrid systems in more elaborative manner as follows.

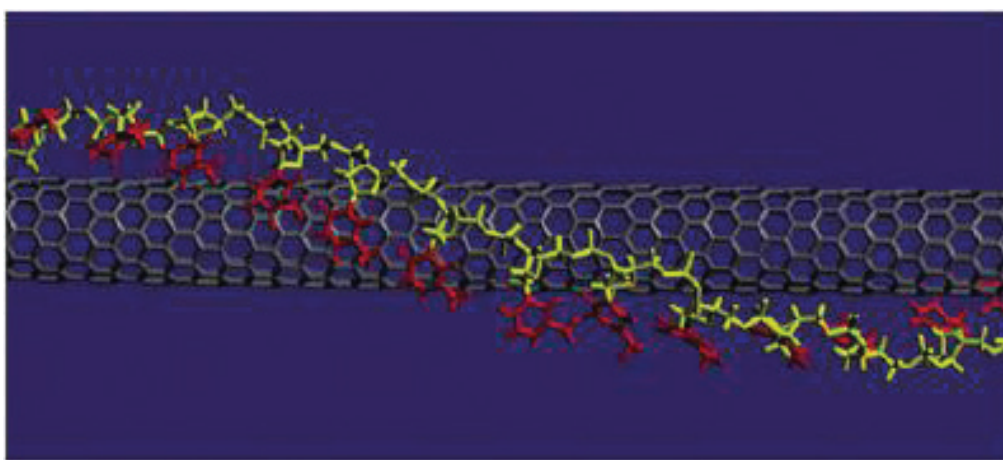


Figure 1. Theoretical model of structure of single stranded DNA (ss-DNA)-CNTs hybrids.

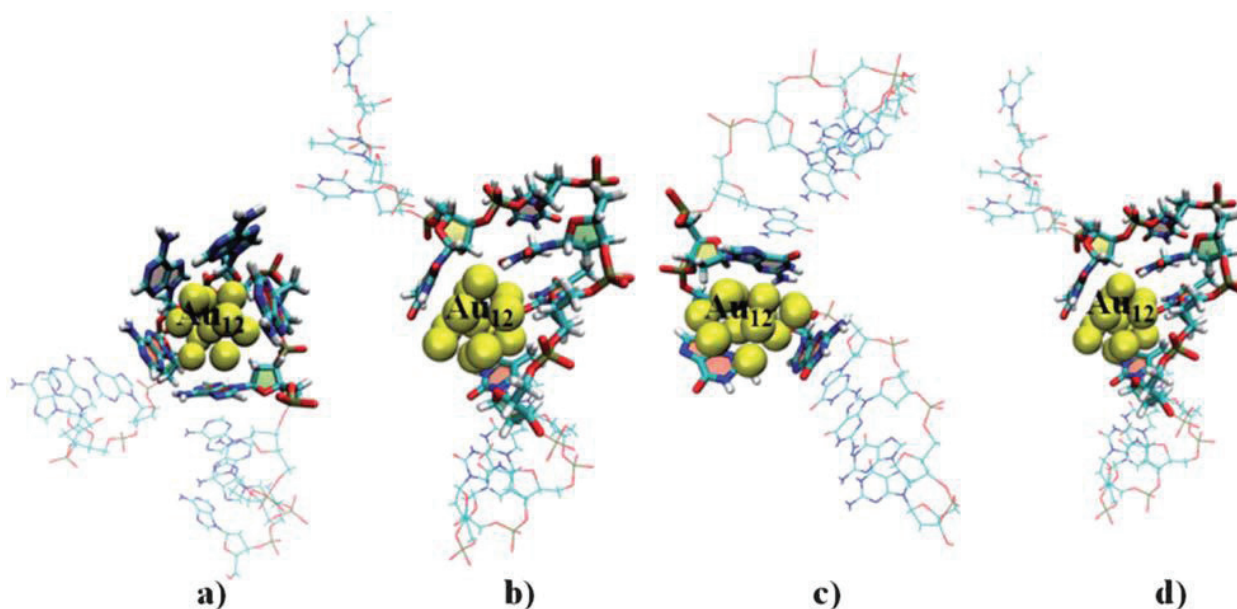


Figure 2. Schematic representation of (a) Au_{12} -ssdA $_{12}$ (b) Au_{12} -ssdT $_{12}$ (c) Au_{12} -ssdG $_{12}$ (d) Au_{12} -ssdC $_{12}$ gold metal-nucleobases.

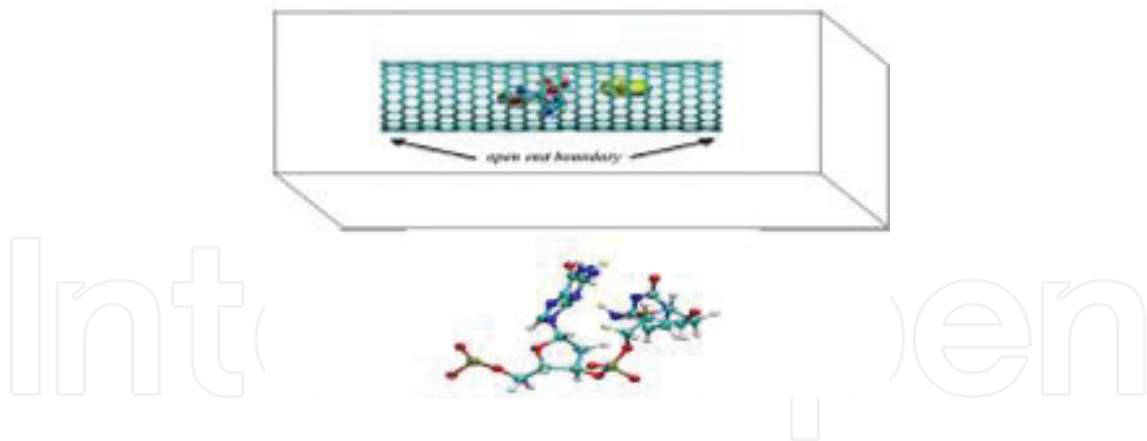


Figure 3. Schematic view of the simulation system of two nucleotide chain (NC)-gold nanoparticles (NPs)-carbon nanotube (CNT).

2. Theoretical section

2.1. DNA-SWCNTs hybrid systems

Carbon nanotubes (CNTs) belong to the family of synthetic carbon allotropes and are characterized by a network of sp^2 hybridized carbon atoms [30]. These nanotubes can be described as helical microtubules of graphitic carbon, which generate this material by an arc discharge evaporation process designed for the production of fullerenes (**Figure 4**).

Theoretically, we can construct the CNTs by rolling up a graphene sheet into cylinder with the hexagonal rings which can be joined seamlessly. The major parameters that play an important role are the chirality and (n, m) indices. By changing these parameters, diversified structures of single wall carbon nanotubes (SWCNTs) can be constructed, which defines the orientation of the hexagonal carbon rings in the honey comb lattice relative to the axis of the nanotube. Depending on the (n, m) indices, their metallic or semiconducting behavior is determined which is represented in **Figure 5**. The UV/Vis/NIR spectroscopy has proven to be the powerful tool on their characterization, making high information density related to the physicoelectronic properties through readily available and inexpensive techniques. SWCNTs represent one of the most direct realizations of the 1D electron system, attracting much theoretical interest. Due to the unifying electronic and photonic properties, they become the leading candidates to function in nanoscale circuits. The optoelectronic properties of SWCNTs were initiated by the discovery of bandgap photoluminescence (PL) from individually suspended SWCNTs in aqueous solution.

In absorption spectroscopy, the optical transitions of the SWCNTs are probed, which arises from the energy levels with significantly high density of states (van Hove singularities). These are caused by rolling-up the 2D graphene sheet into 1D carbon nanotube. Due to absorption of light, the electrons in the van Hove singularities of the valence band are elevated to the corresponding energy levels in the conduction band. The same process occurs in the case of metallic SWCNTs. However, the spacing between the van Hove singularities is larger so that only M_{11} transitions can probe in the UV/Vis region.

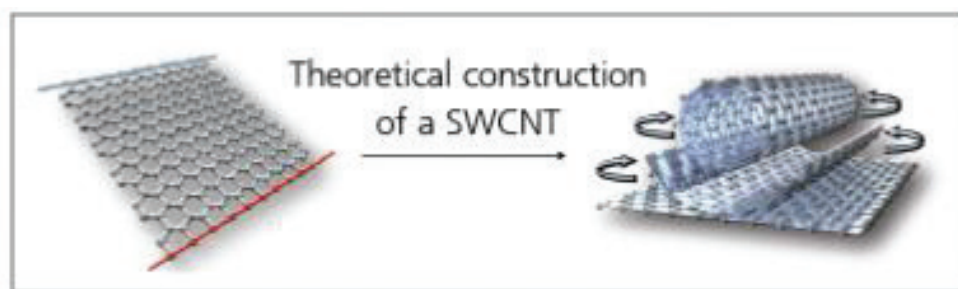


Figure 4. Schematic representation of SWCNT as a hollow cylinder of a rolled-up graphene sheet.

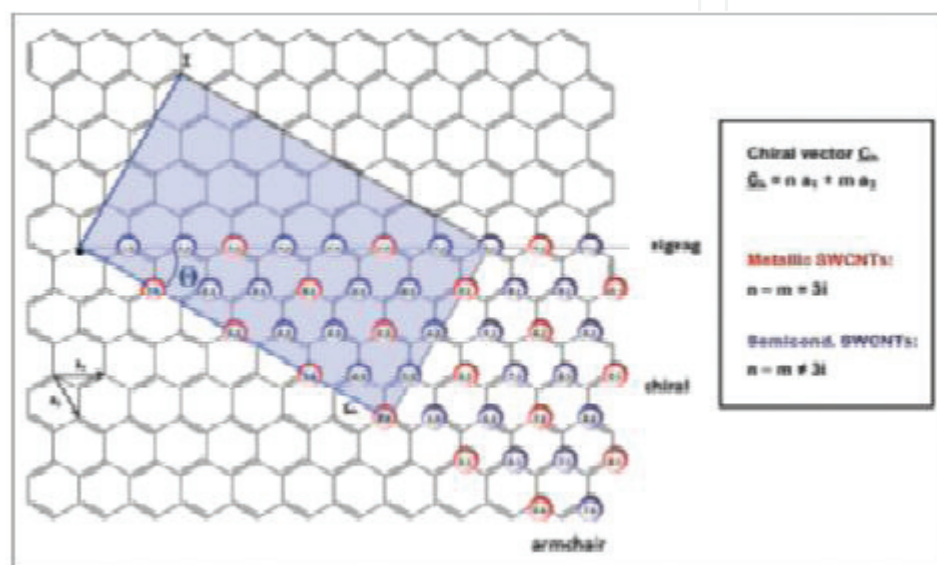


Figure 5. Schematic representation of unrolled graphene layer of carbon nanotube with the unit cell vector \vec{a}_1 and \vec{a}_2 which define the chiral vector \vec{C}_k .

The most important thing is the symmetry breaking of the DNA wrap, which influence the electronic structure of SWCNTs, while for nonchiral tube, the helical perturbation causes natural optical activity. The structures of these SWCNTs are specified by integer pair (n, m) describing the chiral vector $\vec{C} = n\vec{a}_1 + m\vec{a}_2$. The general rule to represents these tubes are (i) (n, n) armchair tubes are metals, (ii) (n, m) with $n - m = 3j$ (j nonzero integer) are semiconductors (gap = 1–100 meV), and (iii) others are semiconductors with (gap = 0.5–1 eV). The dispersion relations and corresponding density of states of armchair ($n = m$) and semiconducting nanotubes are shown in **Figure 6**. It is seen in the figure that metallic armchair nanotubes are gapless and nonarmchair nanotubes have small curvature-induced bandgaps [30–38].

The optical properties of SWCNTs are measured from dispersed/solubilized samples in the transmission mode. Impressive progress has been made in separating the SWCNTs by type, diameter, and chirality. The size-dependent colors of suspended colloidal particles have two distinctly different coloration mechanisms. On the front head is the quantum confinement, which plays the fundamental role, while the coloration mechanism depends on the metallic or semiconducting behavior of SWCNTs. Size-dependent fundamental bandgap

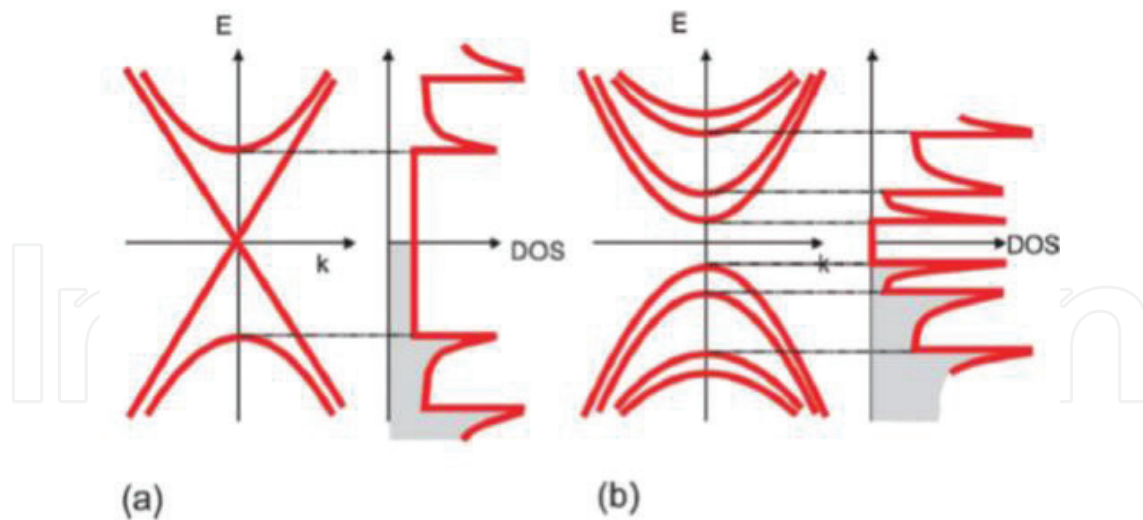


Figure 6. Schematic electronic energy dispersion relations and densities of states (DOS) of (a) metallic (b) semiconducting single wall carbon nanotubes (SWCNTs). Adapted with permission from Ref. [34].

(HOMO-LUMO gap) is the key parameter of the color determination for semiconducting nanoparticles, which changes with the quantum confinement [39–43].

For metallic nanoparticles, the colors are determined by the free carrier plasma resonance, whose frequency depends on the following factors: electron density, particle size, and particle shape. The potential applications of SWCNTs can be accomplished through covalent or noncovalent SWNT functionalization as the requirement is that they may be isolated from one another. The noncovalent approach preserves the intrinsic electrical, optical, and mechanical properties of SWNTs and can be achieved by dispersing SWNTs in aqueous solution using surfactants, polymers, or biomacromolecules such as DNA or polypeptides. The surfactants have the effect of lowering the energetic cost of hydrophilic/hydrophobic surfaces, which allows for water insoluble materials to be dispersed in the aqueous phase. These hydrophobic inorganic materials are also incorporated in modern biomedical materials [44–47]. Various surfactants are used to modify these hydrophobic surfaces to impart dispersability and biocompatibility. These functionalized materials can be conjugated with peptide or DNA for biological applications as biomarkers and biosensors. The absorption spectrum of different SWCNTs dispersed in aqueous solution of SDBS is given in **Figure 7**.

In one of the study, a separation method by various DNA sequence corresponding to chirality was reported [48]. Individual DNA-SWNTs dispersed in solution show photoluminescence [49, 50]. It occurs due to the recombination of the photoexcited electron and its hole, exciton [51]. As SWCNT is a monolayer material, so the exciton binding energy is highly affected by the environmental effect [52, 53]. However, it is not easy to define the environmental effect of DNA due to the various oligonucleotide sequences and the overlapping of buffer reagents and the effect of solution. It was observed that the PL peaks are red shifted compared to the SWCNTs suspended in air/vacuum [54–56]. The studies carried out by Homma et al [56] have experimentally shown the effect of DNA adsorption on the optical transitions of SWCNTs.

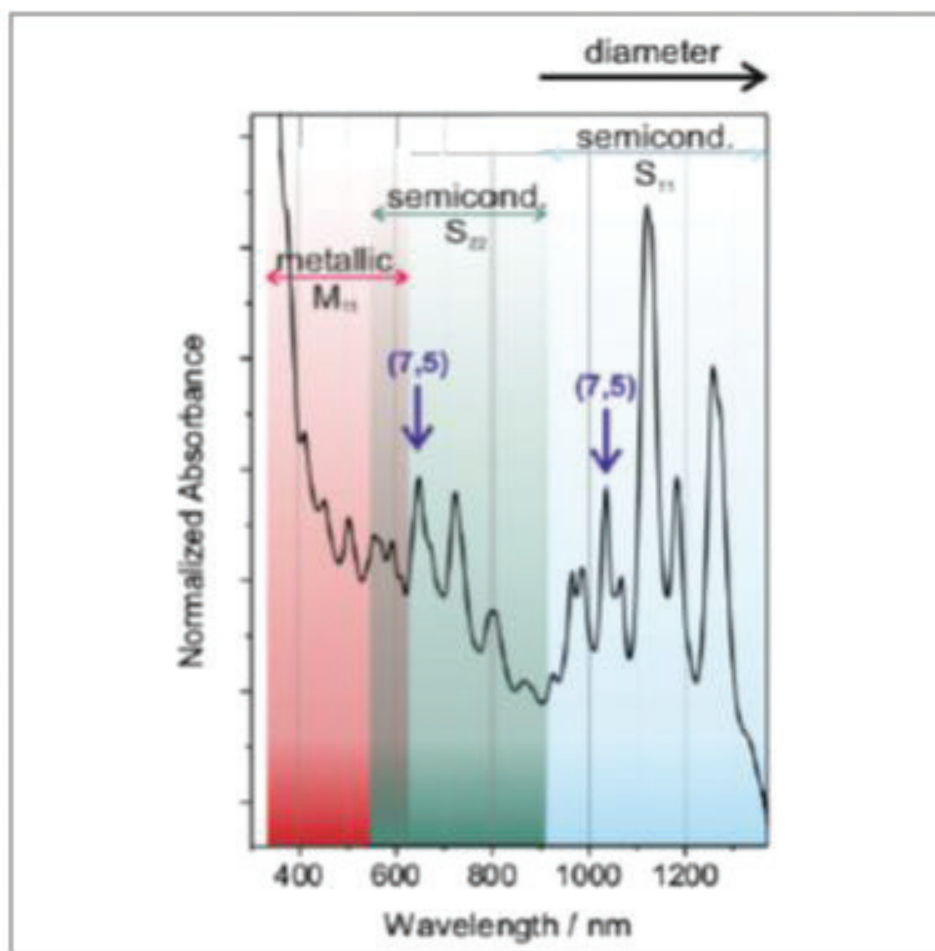


Figure 7. The absorption spectrum of different SWCNTs dispersed in aqueous solution of SDBS. The transitions of metallic and semiconducting SWCNTs are indicated by different colored shaded region. Adapted with permission from Ref. [55].

In the studies, the isolated DNA-SWCNTs were prepared under the dry condition and the intrinsic properties of single-stranded DNA-SWCNTs were studied. The homosequenced ssDNA was used to evaluate the effect of base type (A, T, G, C) and the absorption spectra are given in **Figure 8**.

Very interesting features of absorption spectra were investigated by molecular dynamics (MD) simulations [57, 58] and transition electron microscopy (TEM) [59]. Results indicated that the π - π interactions are responsible for the binding of ssDNA-SWCNTs. The significant red shift is caused by the strong π - π stacking of surfactant with SWCNTs [60–62]. The H- π interaction of DNA-SWCNT is not negligible [63]. Another interactions that play an important role are the n- π interactions of the -OH, -O-, and the -NH₂ group [64–65]. The contributions of each interaction have been taken by the MD simulation techniques. It is observed that the trend of absorption energies on the SWCNT surface is C < A < T < G [66–68] which is consistent with the experimental work on graphitic surfaces [69]. Though some other groups have reported the absorption energy trend as T < A < C < G [70, 71], which also justifies the experimental facts [72].

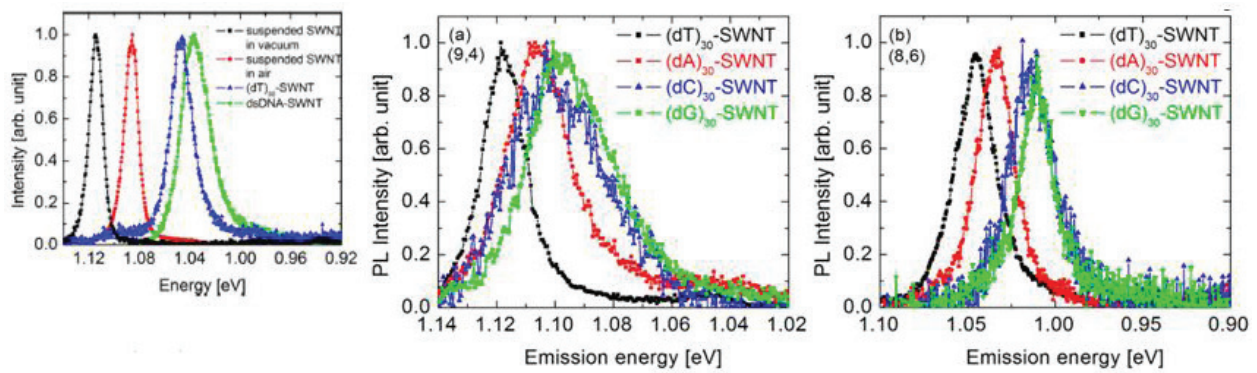


Figure 8. PL emission spectrum change depending on the DNA base type $(dT)_{30}$, $(dA)_{30}$, $(dC)_{30}$, $(dG)_{30}$ for (9,4) SWCNT (a) and (b) (8,6) SWCNT. Adapted with permission from Ref. [55].

One more interesting feature was observed that the excitons in the ssDNA-SWNT are less sensitive to the environment compared with ssDNA-SWNT as no difference was observed between PL spectra from dsDNA-SWNT in solution and those in air.

2.2. Coinage metal-DNA interaction

Nanoscale particles have significantly different physical and chemical properties as compared to the corresponding bulk structure due to the quantum effect [73]. These size-specific physicochemical properties are widely used in molecular electronics and biosensor technology. The “bottom-up” approaches involve the self-assembly of small sized clusters into larger structures which utilizes the biohybrid complexes, where DNA, peptides, and biological molecules act as the templates [74–82]. The amine group of peptides assembles coinage metal cations and caps the growing nanoparticle surface, adsorption of single stranded DNA on gold surfaces, mercapto-group mediators and silver clusters as fluorescent probes for sensitive detections are few of the structural features of the biomolecular-metallic nanoparticle complexes [83]. DNA exhibits many capabilities as catalytic activities, specific binding affinities, and/or chemical stabilities [84]. Coinage metals also possess unique size and shape-dependent optical properties, biocompatibility, high stability, and large surface area [85]. These properties enable the extensive use of DNA with coinage metals in optical biosensors. DNA-conjugated coinage metal nanoparticles have been used as optical probes for various targets due to high sensitivity and selectivity as they are biocompatible, easy to prepare, and molecule-like optical properties. In the presence of ligand thiolates, polymers, proteins, phosgene, and DNA, these Au/Ag NCs possess fluorescence at different wavelengths with different quantum yields due to the high emission rates as of larger stokes shift for the coinage metal clusters [86–90]. DNAs are used as templates for coinage metal NCs preparation due to the stabilization of Ag^+ ions by mismatched cytosine-cytosine pairs (duplex DNA) [91–93]. In some thiol complexes, fluorescence quenching is observed, as it is weakened by the interactions between the Ag NCs and DNA templates and cause partial oxidation of Ag NCs binding [94, 95]. The highly fluorescent and water soluble DNA-NC NCs have some characteristics as long lifetime, long stokes shift, and their sizes as compared to the biocompatibility and ease in bioconjugation.

For these reasons, they have become an attractive tool for ions detection, DNA, small organic molecules and proteins for cell staining [96–98]. They can be used for detection of proteins due to the specific interactions of the aptamers with their target proteins which produce the fluorescence due to the induced conformational changes in the aptamers [99]. They are also used for cytosol delivery [100–102] and as a potential candidate for analysis of biological and environmental samples, cell imaging, and diagnosis of diseases. These nanoparticles also have a negative impact on the environmental hazards. Prolonged exposure of nanoparticles causes allergies and diseases [103] yet gold nanorods in near infrared region is used for many biochemical applications. DNAs are used as templates to form stable complex with Ag^+ for the preparation of stable and fluorescent DNA-Ag NCs [104]. Ag-NCs containing silver atoms (1–6) atoms exhibit the fluorescence excitation and emission spectra maxima in the visible region [102, 105, 106]. The emission spectra of C_{12} -Ag NCs (2–7 atoms) give the excitation and emission maxima for 650 and 750 nm, respectively. However, the understanding of the mechanism of the bonding between NC-DNA and factors, which control the efficiency, is rather limited and the bonding and optical properties of these complexes are still not known. Theoretical understanding of this cluster-DNA pair interaction stability of different isomers requires various structures which can be achieved by varying some important parameters as DNA sequences, the molar ratio of base/metal ions, reducing agents, ionic strength, and buffer pH [90, 107, 108]. Kryachko and Remacle [109] studied the gold-nucleobase interactions and explain the bonding of Au–N and Au–O anchor bond and the nonconventional N–H–Au hydrogen bonding. They further explained the Watson-Crick pair patterns with gold clusters on the proton affinities and deprotonation energies. The increase in cluster size to 6 results in short gold-gold bond and strengthened GC pairing. Kumar et al. [110] studied the neutral and anionic $\text{Au}_{4,8}$ clusters interaction with AT–GC pairs. Optimizing the singlet and triplet states for neutral and doublet and quartet states for anionic cluster they stated that singlet states are more stable than the triplet states. Furthermore, they model the eight gold atom clusters in two-four gold atom pairs. The schematic representation is given in **Figure 9**. It was found that in neutral complexes, the significant charge is transferred from the base pairs to the cluster and in anionic clusters the excess charge is localized at the gold clusters.

Metiu and Soto-Verdugo [105] studied the silver-DNA pair interactions up to six cluster size. In the studies, they found that the cluster prefer binding to the doubly bonded nitrogen rings and the strength of this bonding is strong in cytosine (C), guanine (G), and adenine (A) and weak in thymine (T) while A, G, and C show mild charge transfer than the T. They analyze the absorption spectra and find that the low energy peak lower in energy and reduced in the strength when the position of two bases is perpendicular in middle panel. The binding sites of these cluster-base pairs are given in **Figure 10**.

The computational work has been carried out by using the generalized gradient approximation (GGA) approximations of density functional theory, and projector augmented-wave (PAW). The wave function is represented by a plane wave basis set with a cut-off energy of 400 eV. Large orthorhombic cells used as the clusters are bound to the single and two bases. The entire calculations were performed by Vienna Ab initio simulation package (VASP) [111ad]. The time-dependent DFT (TDDFT) absorption spectra were carried out in real space and real time as implemented in OCTOPUS [112] code. The studies carried out by them shows that

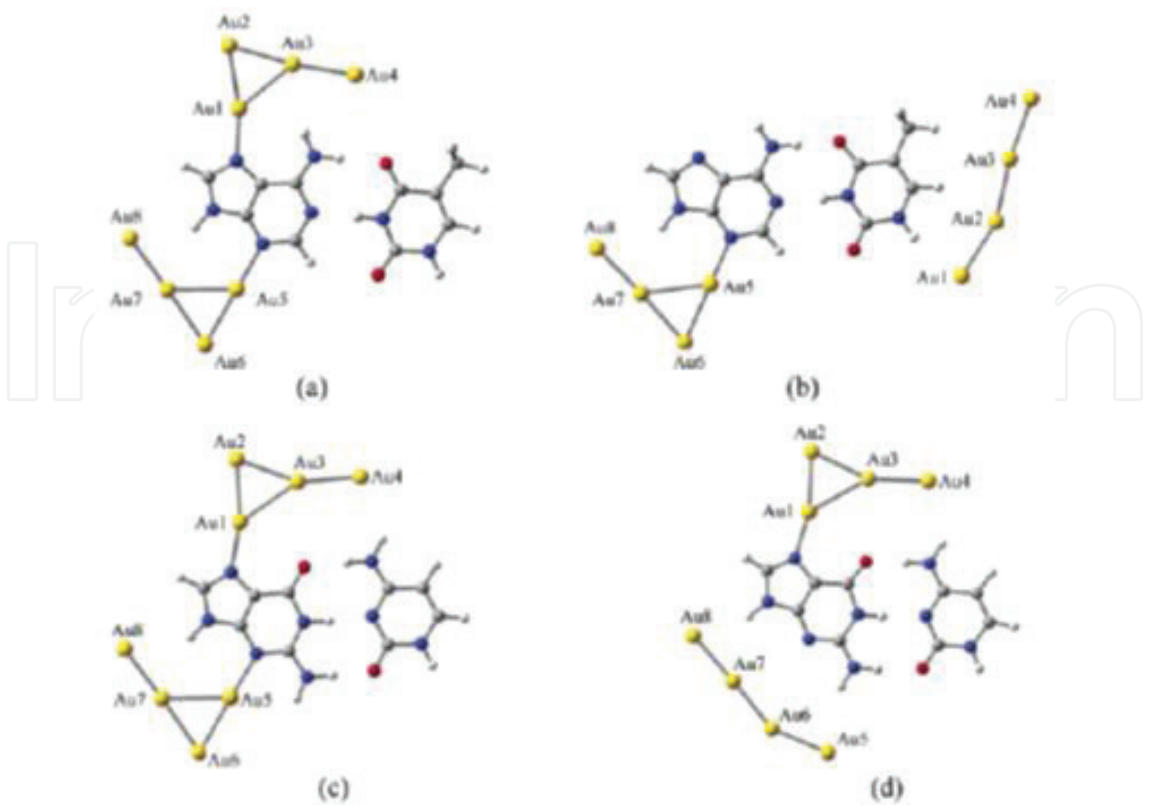


Figure 9. Schematic representations of A-Au₈ complexes in (a) singlet and (b) doublet states and GC-Au₈ complexes in (c) singlet and (d) doublet states.

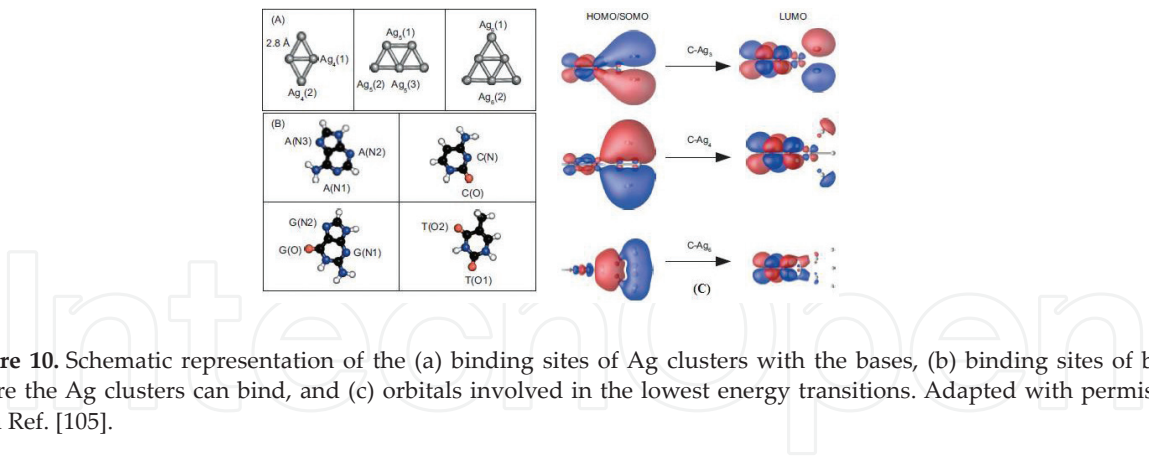


Figure 10. Schematic representation of the (a) binding sites of Ag clusters with the bases, (b) binding sites of bases where the Ag clusters can bind, and (c) orbitals involved in the lowest energy transitions. Adapted with permission from Ref. [105].

the clusters are planer structures. The absorption spectra produce new absorption peaks at low energies that strengthen and red shift the binding. The TDDFT calculations show that the absorption spectra of these isomers can have different spectra and the spectra of these planer cluster show sensitivity to the relative orientations of the base and cluster planes. The absorption spectra of these binding sites for silver-DNA bases are given in **Figure 11**.

In another study of propene-silver cluster [113] molecules, some geometry-energy configurations were used to select the preferred sites and bonding of cluster-base interaction. Studies by Shukla et al. [114] for Au_n even neutral (2–12) clusters on nucleic acid purine

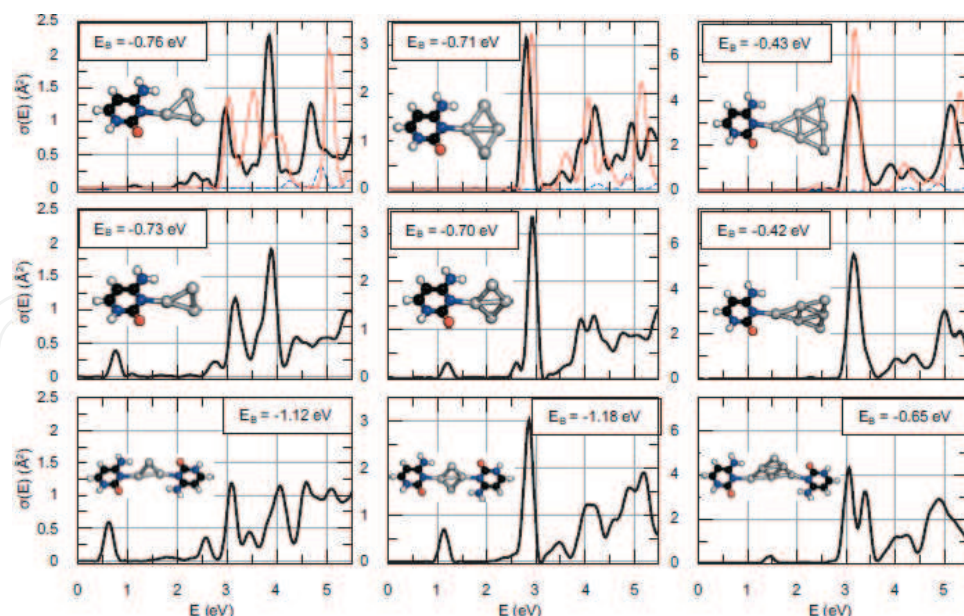


Figure 11. Absorption spectra of C-Ag₃₄ complexes. Top row consists of cluster bound to single base with both lies in the same plane. Second row consists of cluster and base perpendicular to each other. Bottom row consists of two bases in the same plane perpendicular to the cluster. Adapted with permission from Ref. [103].

base guanine (G) and the Watson-Crick GC pairs reveal that the gold clusters have strong interaction to the GC pair rather to the isolated guanine base. They focused the studies on the anchor bond Au—N7 major groove site and singlet states of gold clusters. By the natural population analysis they considered the NBO charges and find that electronic charge is transferred from G/GC pairs to the gold clusters. In the studies they predicted that gold clusters would form more stable complexes with GC base pairs rather than the guanine alone. Furthermore, it was predicted that the GC base pair slightly open the hydrogen bond to the major groove of the DNA. The schematic representation of the Au_n-G/GC bases is given in **Figure 12**. The substantial amount of charge transfer occurs between the G/GC base pairs to the clusters. The oxidation of gold clusters is more pronounced for WC pair rather than the isolated amino acid. As the electron attachment occurs at the gold cluster site, so these free electrons will protect the DNA. Further they concluded that the one-electron oxidation of these G/GC-Au_n complexes can trigger the oxidation through the π back donation of electronic charges to the gold clusters.

Motivated by the recent studies carried out by Verdugo et al. on Ag_n-DNA interactions $n = (1-6)$, we have extended our studies for Ag_n-A, G/WC pair interactions and their absorption spectra studies for $n = 8, 10$, and 12 neutral clusters. We have shown the ability of DNA bases and Watson-Crick pairs to form directly stable anchoring sites with silver clusters. It is demonstrated that the DNA base clusters are stabilized not only by the anchoring Ag—N site but also by Ag—O bond site. The photophysical properties of Ag-DNA strands in solution are affected by the dipole interactions of water molecules. The spectral sensitivity of TDDFT results also help us to identify the base site bonding to the clusters, the size of the cluster, dipole interaction of silver-DNA pairs and the relative orientation of cluster-base planes. The schematic representation of these Ag₈₋₁₂-DNA/WC bases is given in **Figure 13**. We characterized in detail the properties of

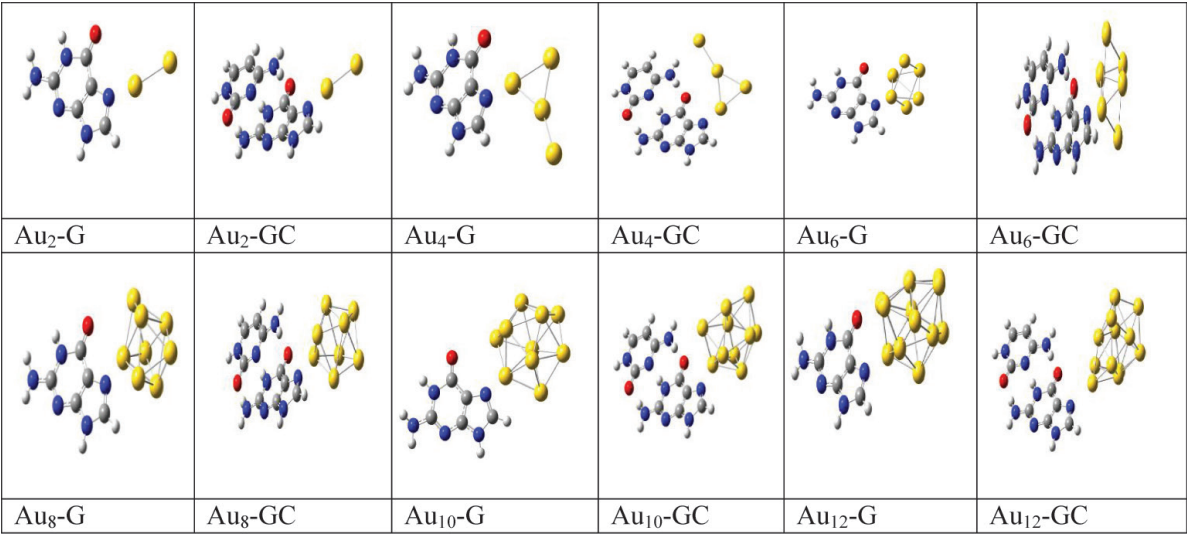


Figure 12. Schematic representation of G/GC-Au_n complexes for $n = 2-12$.

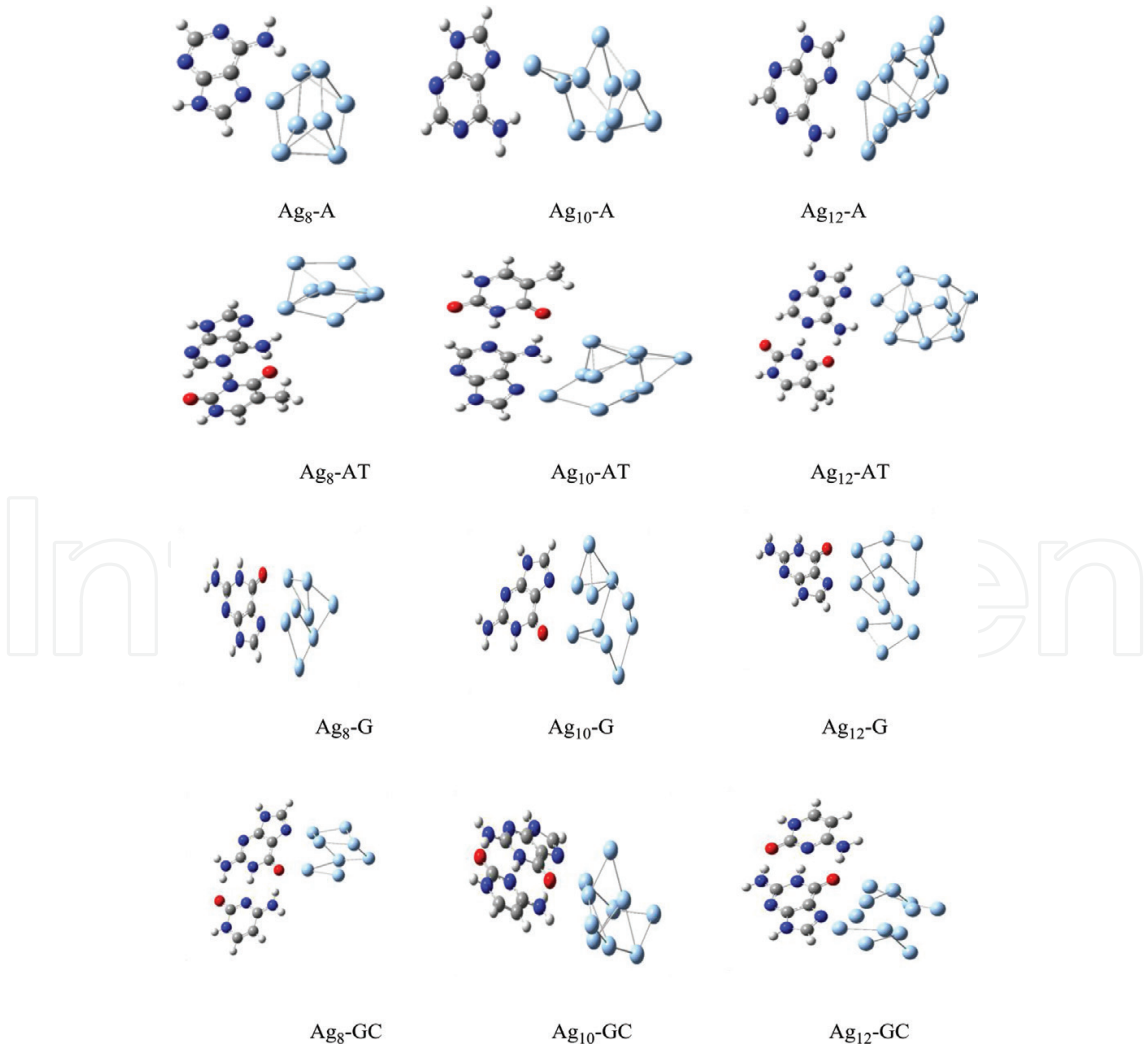


Figure 13. Optimized structures of DNA(A,G)/WC-Ag_n complexes for $n = 8-12$. [115].

these DNA base in order to identify the factors controlling their formation with special emphasis of the Ag cluster size and of the coordination of the Ag atom both on the anchor and of the nonconventional hydrogen bonding. Since we have not taken the solvent effects, the calculations present here are not able to decide the cluster-DNA binding in solution. Mulliken charge analysis was carried out to characterize the cluster-base charge transfer mechanism [115].

We have observed that the silver clusters form stable complexes with WC complexes rather than with the isolated A, G bases. It was also seen that the interaction of silver to the WC pair shorten the hydrogen bond distance to the major groove of the DNA site. Further, the amount of electronic charge transfer to the silver clusters is more for Ag_n -WC complexes. The absorption spectra for these base complexes lie in the visible region. As the UV (absorption-excitation) studies predict that the fluorescence proceeds via the nucleobases so we hope that the studies can provide new path for understanding the photophysics of these complexes and its utility in the discovery and purification of most stable Ag-DNA complexes [116, 117].

An interesting study was carried out by Schultz and Gwinn [118] in which it was predicted that the magic numbers in nucleotide-silver complexes lead to magic colors. The fluorescent products were formed from experimental testing of small sets of C-rich or G-rich cluster stabilized DNA oligomers, which applied to the specific application. Generally the randomly selected at least three out of four oligomers, with equal chances of placing A, C, G, or T bases at each site. Fluorescent Ag_n -DNA solutions are obtained by excluding the combination of less than a total of three C plus G bases (**Figure 14**).

Another study on combined molecular dynamics (MD) and density functional theoretical approach (DFT) was applied by Pati et al. [119] to investigate the $(Ag/Au)_{12}$ -ssDNA complexes. It was observed that these individual ssDNA undergoes various conformational changes in MD simulations for 1.5 ns in aqueous media. Another interesting fact which comes in light is that ssdA12 shows greater binding affinity toward the Au_{12} cluster while ssdG12 interacts strongly with the Ag_{12} cluster. The optical absorption characteristics are less affected in the presence of DNA scaffold. It might be due to that the frontier orbital, which is localized mainly on the metal clusters or ssDNA. Further, the theoretical work was verified by the experimental results (**Figure 15**).

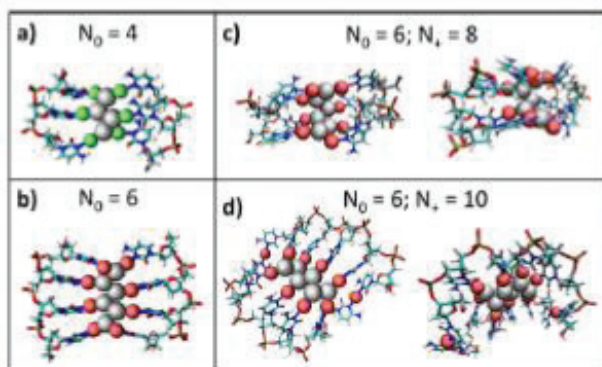


Figure 14. Schematic representations of Ag_n -DNA simulations for (a) $N_0 = 4$, (b) $N_0 = 6$, (c) $N_0 = 6$, 8, and (d) $N_0 = 6$, 10 simulations. Adapted with permission from Ref. [118].

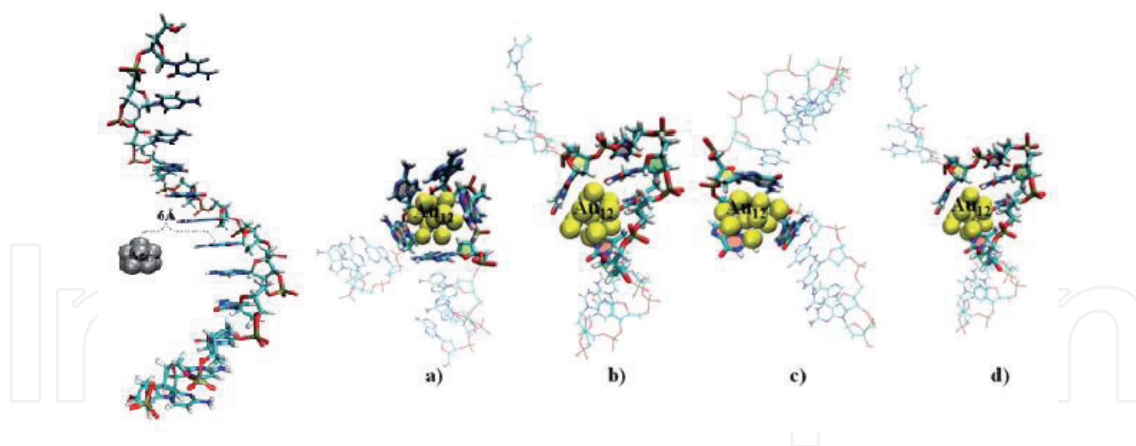


Figure 15. Schematic presentation of Au_{12} -DNA complexes. configurations of (a) Au_{12} -ssdA12, (b) Au_{12} -ssdT12, (c) Au_{12} -ssdG12, and (d) Au_{12} -ssdC12 nanocomposites after 1.5-ns simulation time. Adapted with permission from Ref. [119].

The computed absorption spectra of [1] (a) Ag_{12} -ssdA12, (b) Ag_{12} -ssdT12, (c) Ag_{12} -ssdG12 and (d) Ag_{12} -ssdC12 and [2] (a) Au_{12} -ssdA12, (b) Au_{12} -ssdT12, (c) Au_{12} -ssdG12 and (d) Au_{12} -ssdC12 are given in **Figure 16**.

The entire work was carried out on GROMACS [120] software and visualized by VMD [121] software. Further, the results showed that ssdG12 binds strongly with silver (Ag_{12}) cluster and ssdA12 with gold (Au_{12}) clusters and ssdT12 prefers to bind with Ag_{12} and Au_{12} cluster by O-site, while other DNAs bind by π stacking.

2.3. Nucleotide chain (NC)-gold nanoparticles (NPs)-carbon nanotube (CNT)

The tertiary system of NC-NPs-CNT system has now become an important tool in biotechnology. The development of electronic mobile diagnostic facilities, nanorobotic design for drug delivery inside living cell etc. are the latest development which is emerging in this field. These small Nucleotide chain plays an important role in the interaction mechanism of the full DNA complex with the nanoparticles and CNTs. These combinations have now become a

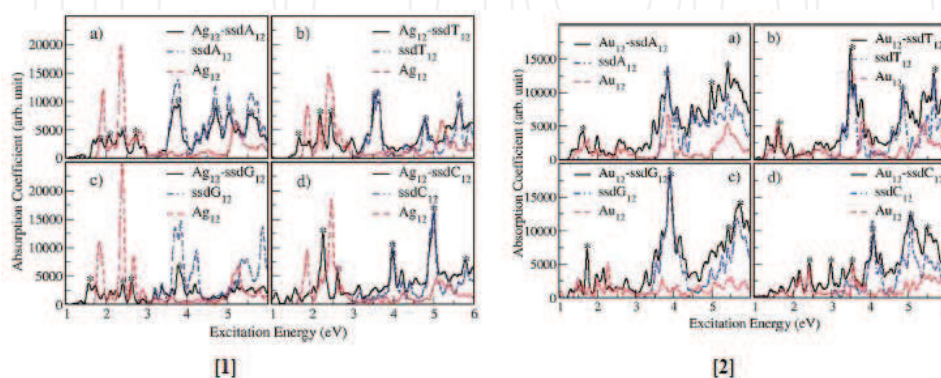


Figure 16. Computed absorption spectra of [1] (a) Ag_{12} -ssdA12, (b) Ag_{12} -ssdT12, (c) Ag_{12} -ssdG12, and (d) Ag_{12} -ssdC12; [2] (a) Au_{12} -ssdA12, (b) Au_{12} -ssdT12, (c) Au_{12} -ssdG12, and (d) Au_{12} -ssdC12. Adapted with permission from Ref. [119].

powerful tool for the diagnostic applications in the chemical or drug delivery. Though metal matrix nanocomposites with CNTs have good mechanical properties as high temperature and abrasion resistance, high shear resistance, their properties are mainly focused on the macro-mechanical properties rather than the microscopic properties. As the interface test are difficult to conduct, so md simulation techniques are used to study the interfacial behavior. The peculiarities of the NC-NP interactions and bond formation were investigated by Khusenov et al. [122] with the structural and dynamical behavior. MD simulations were carried out using the weak van der Waals interaction and intermolecular vibrations to enlighten for the molecular systems in which the quantum chemistry is used.

The entire interaction mechanism of whole ternary nucleic acid-gold particles-carbon nanotubes is very interesting and has found a broader interest in the field of nanobiotechnology, electronics, and biomedical field. There are so many applications where these systems are used. These systems have a great interest in the design and development of the electronic diagnostic units to express the blood analysis, the chemical and drug delivery inside a living cell. It was seen that the mechanical properties of the composites can be improved by modified coating of CNT with large volume fraction and large diameter. These properties determine the interfacial strength of the CNTs. It was seen in the studies that with fixed diameter of CNTs, the metal-coated CNT has yield, interfacial strength, and high elastic modulus than without metal matrix. This property can be used in design for high performance CNT/metal composites.

The CNTs has been used as drug delivery vehicles which have shown a potential interest because it targets to specific cancer cells with low dosage. They are used as a preferential candidate in the cell drug delivery as nucleic acid DNA aptamer. The conformational transition of aptamers around CNT may cause some modification in the charge distribution on the CNT surface. The charge conductivity is dependent on the conformational transitions of aptamers. So we can say that the nucleic acid-CNT interactions can change the charge distribution and consequent charge transfer through the CNT surface. Various suggested scheme can provide application in diagnostic purposes of DNA-CNT interaction process in target protein [123–132].

The simulations involve the DNA interactions with metallic NPs to targeted cancer therapy through the injections of metal, micro, or nanoparticles into the tumor tissue with laser or local microwave heating. The response of this DNA-NP, the DNA-CNT system presents a great interest due to diagnostic and treatment of oncology diseases. The stability predictions of DNA duplex and the accuracy vary largely from sequence length, base compositions and experimental conditions. Problem arises when the prediction occurs for the stability of DNA duplex from base sequences. The thermodynamic nearest-neighbor model (TNN) is a state of art approach to determine the stability of single or a pair of DNA (RNA) based on pairwise interactions and structural conformations.

These CNTs are based on the enhancing of sufficient solubility and efficient tumor targeting. Because of these aspects, CNTs are prevented from being toxic and alter the function of immune cells. The studies involve the DNA interaction with metal nanoparticles or highly localized proton beams. As the nanoparticles are having good electrical conductivities, so

they can destroy only the tumor cell and the normal cell remain undamaged. In spite of that, such treatments are usually painful and kill normal cells apart from producing side-effects. In this work, the MD simulations were performed on a small nucleotide chain to investigate its interaction and binding process with gold particles and the carbon nanotube matrix.

The concept of these ternary systems is that the NC models interacting with the system have to possess a lot of similarities with a full nucleotide system interacting with NP/CNT environment. Carbon nanomaterials have been investigated not only for manufacturing new nanoscale devices as sensors, actuators, electromechanical switches, but also in the fabrication of biomechanical systems. These CNTs are ideal candidates for the encapsulation of drugs, nanofiltration membranes, atomic/molecular encapsulation, and hydrogen storage for powering green vehicles. Some metals as manganese ion (Mn^{2+}), gold atom (Au), platinum (Pt), sodium ion (Na^{1+}), and lithium ion (Li^{1+}) were investigated and it was found that Mn^{2+} and coinage metals candidate for drug delivery while Li^{1+} can be perfectly used for high-energy density rechargeable alkali batteries.

The 6–12 Lennard-Jones (L-J) potential in the MD simulation technique was employed assuming that carbon atoms are evenly distributed across the surface of carbon nanostructures. This assumption was taken so that the total potential energy between various nonbonded carbon nanomolecules can be determined analytically by performing a surface integral. These potential energies can be used to investigate the relative motions of the nanostructures, such as the oscillatory motion of a fullerene inside a single-walled carbon nanotube and to study the encapsulation of drug molecules inside single-walled nanotubes as the “magic bullet” [133, 134] and the encapsulation of hydrogen atoms inside metal-organic frameworks for hydrogen storage [135].

Though few physical properties such as electron charge exchanges, optical properties of the graphene sheet, and structural effects are explained, the local deficits of graphene are yet to be explained. The other properties as average physical quantities, the minimum intermolecular spacing, and the diffusion time for various atoms/ions are predicted by the group 126 using the simple formulae.

The CNT-DNA interactions are investigated by the Tersoff potential in combination to the classical trajectory calculations. These hybrid approaches are based on force fields and particle interactions. In this approach the molecules are described as a set of spheres and springs. In the MD simulations, it was observed that there is encapsulation-like behavior of DNA chain inside the CNT system. So we can say that this binary system can be the suitable candidate for the drug delivery and related systems. The quantum chemistry methods provide greater accuracy while for bonds formation/broken, the MD simulations techniques are used. Generally, Tersoff potential is used for MD simulations in carbon, silica, and germanium. Tersoff potential is pair wise potential, but coefficient in attractive term depends on local environment. Thus, Tersoff potential possesses a many body nature. The classical molecular dynamics was performed with the proper NVT ensemble and the time step with more than 100,000 with the temperature scaling interval with each 10 step. Two nucleotides were relaxed with gold particles and the nucleotide chain was located from gold atoms at distance of 5–10 Å. The entire calculations were performed by DL_POLY_2.20 all-purpose general code [135]. The representation of these structures is given in **Figure 17**.

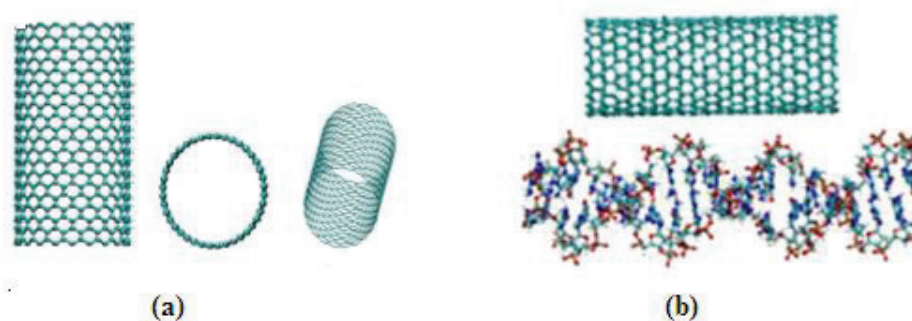


Figure 17. Structural representation of (a) CNT, and (b) CNT (top), and DNA (bottom).

Depending on their chemical structure, CNTs can be used as an alternative to organic, inorganic semiconductors as well as conductors. Nanotubes align themselves into “ropes” held together by van der Waals forces. The nature of the bonding of a nanotube can be explained by orbital hybridization [136, 137].

The simulation process was designed with three component system of two nucleotide chain (NC), gold nanoparticles, and a carbon nanotube (CNT) under different temperature conditions ($T=100, 200, 300\text{K}$). Three different models were taken with 1, 2, 3 gold particles with NC chains. Three different interactions as: weak, intermediated, and strong interactions were studied.

The entire ternary system was allowed to interact with each other via the vdW potential only. The quantum chemistry Tersoff potential (hybrid quantum chemistry and classical trajectory approach) has been used to investigate the NC interactions with CNT. The results were shown for three different temperatures for these ternary systems. The curve of **Figure 18** demonstrates the increase of the interaction potential energies with the temperature. It has been seen that the potential energy of the system is modified by adding one more gold atom to the system. So we can anticipate the potential energy will change for larger gold clusters.

The results predict that there is a probability of three (weak, intermediate, strong) bonds, within a CNT matrix. NC chain form close contact with the nearer gold atom. The NC-NPs interactions are modified at higher temperatures. Fluctuations occur for more NC intramolecular oscillations. Understanding this system at the micro level will help us to build a great understanding of full nucleotide-CNT-NP interactions. This mobile electronic device will definitely represent great interest for the purpose of nanorobotic design, delivery of drug

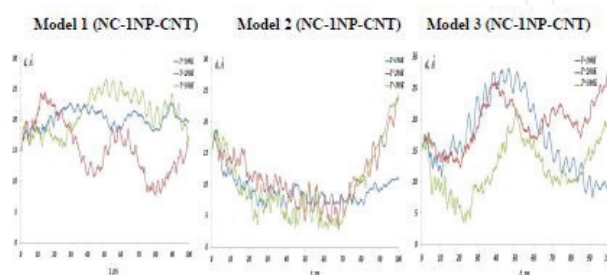


Figure 18. The graphical representation of NC-NP-CNT distances for different model configurations. Adapted with permission from Ref. [122].

delivery inside living organisms and diagnostic applications. In recent years the study of peptides and proteins adsorption onto metal surfaces has received wide attention. As the biomolecules play a significant role in determining biocompatibility of metal implants used in modern medicine, they can also be used in the preparation of new biosensors [138]. The main purpose of the implant material is to supply a surface to which biomolecules can be adsorbed and thus contribute to the healing processes. As it is the new emerging field, so many more researches should be needed to carry out in near future [139, 140].

3. Conclusions

In order to understand the dynamics of intracellular networks, signal transduction and cell-cell interactions, novel fluorescent sensors with versatility, high resolution, and sensitivity have made great progress in recent years. Carbon nanotubes are becoming a promising building block for biosensor technology. The first biosensors with integrated carbon nanotubes were electrical or FET sensors, several examples of optical carbon nanotube-based sensors were demonstrated in the past few years. Optical carbon nanotube-based sensors have shown their potential in several challenging biosensing applications. Some of the intrinsic carbon nanotube properties such as near-infrared fluorescence make them unique building blocks for biosensor devices and have advantages compared to other materials.

The two critical problems considered for the application of fluorescence microscopy in live cells is the cell autofluorescence in the visible spectrum and the requirement of long observation times. So, new fluorescent probes with near-infrared (NIR) emission and with more stable emission than current organic fluorophores are needed for the next generation of imaging techniques in biology. However, the good water-solubility, low toxicity, good photostability, and high biocompatibility of subnanometer-sized metal nanoclusters render them attractive alternatives as fluorescent probes for biological imaging. Moreover, large Stokes shifts of metal nanoclusters can prevent spectral cross-talk and thus, enhance the detection signal. The change in optical property due to the self-assembly of DNA-linked nanoparticles demonstrates that the system has potential to be used as a novel technology for DNA detection. Similarly, the DNA-NP-CNT system represents a great interest in many aspects of modern biochemical and nanotechnological research. These devices can be used for the purpose of diagnostic applications, for the drug delivery inside the living cells and related nanorobotic design. Although several milestones have been achieved, ongoing efforts are necessary to engineer new biosensing devices for the medicinal applications.

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