Optical and electronic properties within DFT and TD-DFT of antiviral and anticancer drugs using carbon and boron nitride nanostructures carriers

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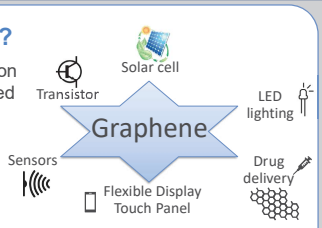
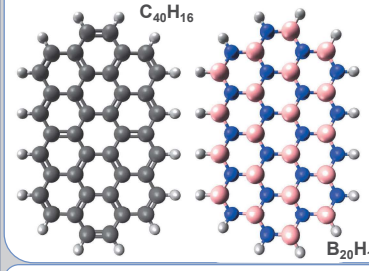
The synthesis and application of carbon and BN-nanostructures have in recent years been subject of great interest as drug carriers or drug detectors due to their particular physical and chemical properties such as great adsorbing capacity, high thermal stability, and low toxicity. Between the examples of target molecules in those drugs one can find: the pyrimidine analogue 5-Fluorouracil (5FU) as one of the most frequently used agents in drugs to treat many types of cancers and the Favipiravir molecule for the prevention of viral infections such as SARS-CoV-2. We propose a study of the electronic ground-state and excitation properties, calculated within a DFT scheme, and of the absorption spectra, obtained by a TD-DFT method, of the above mentions drug molecules and their carrier carbon/boron nitride nanostructures in the free and bound states. The DFT geometry optimizations have been performed using a localized gaussian basis-set combined with the hybrid exchange-correlation functional B3LYP, within an all-electrons computational code. In particular, through the DFT scheme we have obtained the ground-state and the electronic properties for all the systems under study. The time-dependent counterpart (TD-DFT) of this method has allowed us to calculate the optical properties and obtain the absorption spectra in the visible up to the middle ultraviolet (MUV) and far ultraviolet (FUV). We performed a detailed analysis of the modifications arising in the electronic and optical properties that take place in some linked configurations between the drug molecules and the carrier nanostructures. Moreover, possible applicative consequences of the use of spectroscopic techniques on drug-delivery nanostructures will be addressed.

Circumanthracene: why is it appealing?

Circumanthracene is a Polycyclic Aromatic Hydrocarbon (PAH) that can be considered as a finite nanometer-sized portion of the 2D material **graphene**. Due to their chemical and physical properties, 2D systems have important applications in various fields, including technological and bio-medical ones.

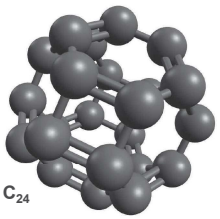


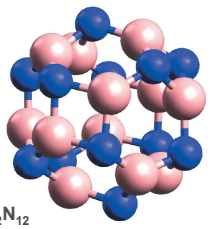


The **BN** molecular counterpart has the same number of electrons as the C system but different electronic and optical properties. BN-based 2D nanostructures have important applications in **electronic devices** (transistors, deep UV LEDs, ..), in the **bio-medical field** (drug delivery, ..) and in **vacuum technology.**

Small fullerenes: why are they interesting?

In the past, fullerenes of various sizes have been widely studied as basic research targets and for their applications in various fields. Recently, **smaller fullerenes** have become of interest, including C_{24}, which we have simulated here.

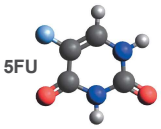




As with circumanthracene, the **BN** molecular counterpart has the same number of electrons but different properties. The applications are similar to those above, but BN-based devices may be more efficient depending on the field in which they are used.

A quick summary of bio-molecules

In our work we focus on the study of two bio-molecules: 5-fluorouracil (5FU) and favipiravir (T705).

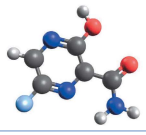


5-fluorouracil (5FU)

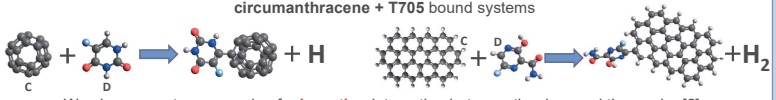
This biomolecule is often used in **chemotherapeutic drugs** to attack certain types of cancer.[1]
It has an uracil-like structure, obtained by substituting a peripheral fluorine atom in place of a hydrogen atom.

Favipiravir (T705)

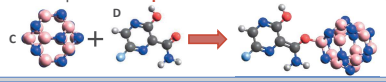
This bio-molecule is frequently used in **antiviral drugs**, for example, to treat diseases such as flu or even to fight the Ebola virus and recently SARS-CoV-2.[2]



These molecules were bonded to the chosen carrier through **covalent bonds** obtained by removing an H atom from the drug molecule. In this poster we present some of the **small fullerene + 5FU** and **circumanthracene + T705** bound systems



We also present an example of **adsorption** interaction between the drug and the carrier [2]



C = carrier
D = drug

Computational methods

Gaussian 16 [3] → DFT (6-31+G*/B3LYP)

DFT → TD-DFT (6-31+G*/B3LYP) Frequency space → Absorption spectra and optical properties [4]

Electronic ground-state and excitation properties [4]

- Total energy of neutral (E_0) and charged (± 1) species ($E^{+}_{v,a}$, $E^{-}_{v,a}$)
- Electron Affinity ($EA_{v\ a}$)
- Ionization Potential ($IP_{v\ a}$)
- Quasi-particle gap ($E^{\Delta SCF}_{gap}$)

Electron Affinity: $EA_{v,a} = E_0 - E^{-}_{v,a}$

Ionization potential: $IP_{v,a} = E^{+}_{v,a} - E_0$

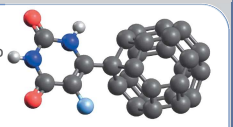
ΔSelf Consistent Field (QP gap): $E^{\Delta SCF}_{gap} = IP_v - EA_v$

Exciton binding energy: $E^{exc}_{bind} = E^{\Delta SCF}_{gap} - E^{TD-DFT}_{onset}$

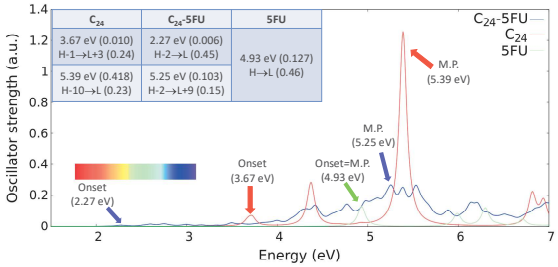
v : vertical
a: adiabatic

C_{24}-5FU

Optical and electronic properties of the bound system C_{24}-5FU compared to those of the isolated molecules.



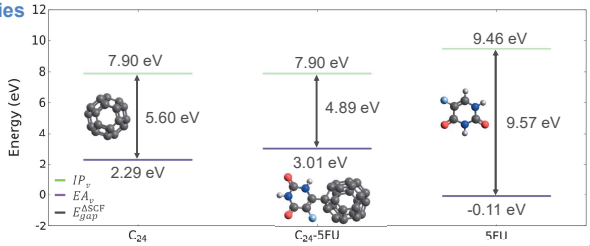
Absorption spectra



We note that the spectrum of the bound system is different from the spectra of the isolated molecules, and the levels involved in the transitions are different. The onset is shifted to the visible region (2.27 eV) and the Main Peak is close to that of C_{24} with much lower oscillator strength.

Electronic properties

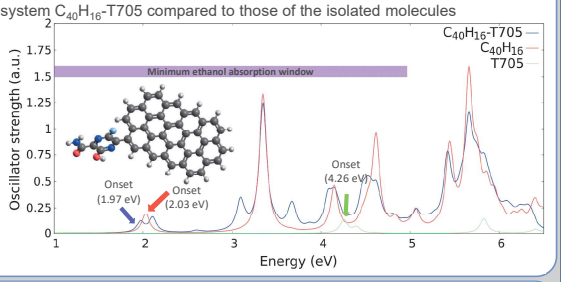
In the figure beside we show **ionization potential**, **electron affinity**, **ΔSCF gap**. The electronic properties of the bound system are closer to those of the carrier (C_{24}) than those of the biomolecule.



Absorption spectrum of $C_{40}H_{16}$-T705

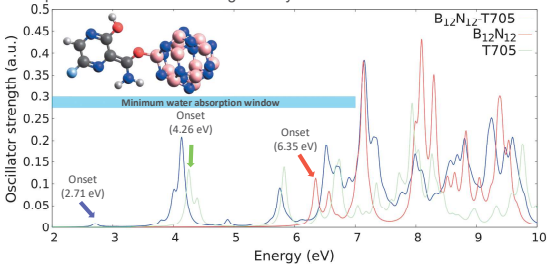
Absorption spectrum of the system $C_{40}H_{16}$-T705 compared to those of the isolated molecules

Again, we note the appearance of additional peaks in the bound system, however onset and main peak are almost coincident with those of circumanthracene.



Absorption spectrum of $B_{12}N_{12}$-T705

This spectrum is derived from a geometry studied in the work of Soliman and Aal.[2]



Unlike the systems presented above, this system has adsorption bonding, without the loss of hydrogen atoms. We can see how the spectrum of $B_{12}N_{12}$-T705 shows small differences from those of the isolated molecules in most part of the spectrum.

Conclusions

- We present calculated optical and electronic properties of isolated molecules and bound systems for drug delivery applications.
- The main purpose of the present work is to calculate absorption spectra and analyze the differences between the bound systems and the isolated molecules.
- Possible future developments could be:
  a) the study of optical and electronic properties in the presence of a solvent such as water or ethanol;
  b) a systematic study on different cases of adsorption.

References:

[1] G. Romàn *et al.*, Eur. Phys. J. E, vol. **41:107**,1-6 (2018).
[2] K.A. Soliman and S. Abdel Aal, Diamond and Related Materials, **117**, 108458 (2021).
[3] M J Frisch *et al.*, Gaussian, Inc., Wallingford CT (2016).
[4] P. Mocci *et al.*, PHYSICAL CHEMISTRY CHEMICAL PHYSICS, vol. **21**, p. 16302-16309 (2019).