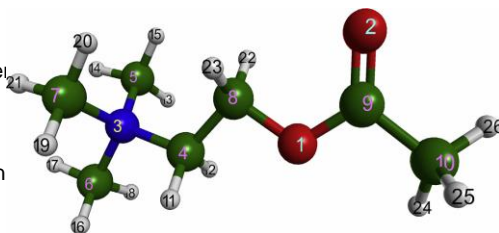


## Introduction

- We are interested in quantum features of acetylcholine (ACh) and its complexes, because ACh is a prominent neurotransmitter of the peripheral and the central nervous system. The synaptic release of ACh, called cholinergic transmission, is widespread, occurring centrally, deep in the cortex, and in the distal periphery, where motoneurons contact muscles.
- The quantum mechanical electron correlation interaction density functional theory (DFT) methods (i.e., high precision quantum mechanical simulations) were used to investigate ACh molecule and their dimers in various charged and spin multiplicity states.
- Target object – stable acetylcholine (ACh) neutral molecular radical. Using DFT quantum calculations we proved that this molecule possesses stable localized electron spin, which may represent a qubit in quantum information processing.

## Target Object



**Fig.1.** The structure of an acetylcholine molecule. Carbon atoms and their associated covalent bonds are shown as green spheres and sticks, blue, nitrogens – blue, hydrogens – gray, oxygens – red.

The neutral radical ACh molecule is not regular, because its nitrogen possesses four chemical bonds with carbon atoms, even though it typically forms only 3 single bonds.

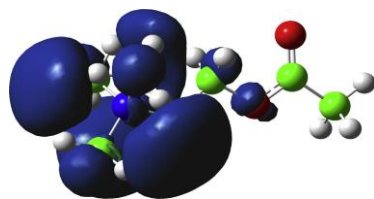
Atomic pair	Interatomic distance	Bond order	Atomic pair	Interatomic distance	Bond order
3 4	1.511	0.854	3 5	1.496	0.889
3 6	1.516	0.871	3 7	1.496	0.889
5 13	1.101	0.889	5 14	1.100	0.892
5 15	1.095	0.924			
1 8	1.452	0.834	1 9	1.344	1.129

It is found that the total energy of the positively charged ACh molecule is 0.082 atomic units (2.238 eV) higher than that of the neutral ACh radical molecule (atomic units (Hartree) vs eV = 27.2114) using the PBE0/6311G\*\* potential/basis set in Gamess-US package. The similar results were observed at PBE/TZVP level in Gaussian (G09) where the total energy of the positively charged single ACh molecule is higher in energy by 0.087 atomic units (2.374 eV) than that of the neutral ACh radical molecule.

**Table 1.** Selected interatomic distances (in Angstroms) and bond orders of the ACh neutral radical molecule calculated using the GAMESS-US unrestricted PBE0/6311G\*\* potential/basis set.

## Results

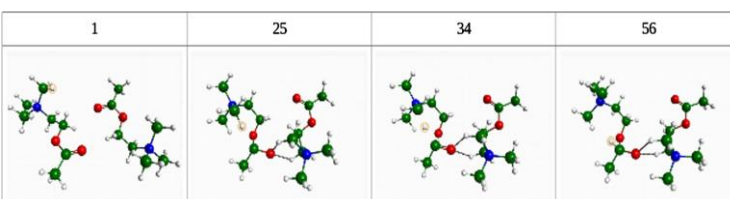
Atom number	Nucleus charge	Atomic electron spin density
1	8	0.004
3	7	0.068
4	6	-0.289
5	6	-0.283
6	6	-0.320
7	6	-0.209
8	6	-0.030
11	1	0.189
12	1	0.268
13	1	0.103
14	1	0.180
15	1	0.160
16	1	0.235
17	1	0.120
18	1	0.174
19	1	0.200
20	1	0.128
21	1	0.160
22	1	0.067
23	1	0.039
Total amount of electron spin density	On the group -N-(CH <sub>3</sub> ) <sub>3</sub>	0.967



**Fig. 2.** Electronic spin density of ACh neutral radical molecule is spatially on the group -N-(CH<sub>3</sub>)<sub>3</sub>. The dark blue clouds show the electronic spin density on atoms of the group -N-(CH<sub>3</sub>)<sub>3</sub>.

Individual transitions	Weight of individual transition	Energy (eV)	Wavelength (nm)
HOMO → LUMO + 8	0.239	2.812	440.94
HOMO → LUMO + 9	0.878		
HOMO → LUMO + 10	0.385		

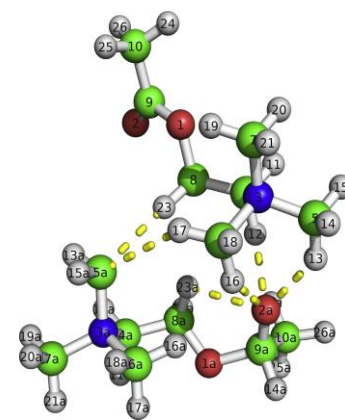
**Table 2.** Excitation transition energies of neutral radical ACh molecule calculated by using TD PBE0/TZVP potential/basis in Gaussian09 program package. The weight of the individual excitations is only given if larger than 0.1.



**Fig. 3.** The migration of the movable proton during the geometry optimization of a neutral dimer of ACh molecules in the singlet electronic state. The first row gives the step number within the geometry optimization process. The migrating proton is marked by a yellow circle. The series of small dark spheres seen in steps 25, 34, and 56 indicate hydrogen bonds. Geometry optimization calculations were performed using DFT with the PBE0/TZVP potential/basis set.

Atomic pair	Interatomic distance	Bond order	Atomic pair	Interatomic distance	Bond order
2a 12	1.942	0.169	2a 13	2.063	0.123
2a 16	1.975	0.138	2a 23a	2.308	0.062
5a 17	2.356	0.121	5a 23	2.356	0.121
9a 14a	1.109	0.939	9a 2a	1.323	1.295
9a 1a	1.497	0.808	9a 10a	1.530	0.963

**Table 4.** Selected interatomic distances (in Angstroms) and bond orders of a dimer of ACh neutral radical molecules are calculated using the PBE0/TZVP potential/basis set in Gaussian09 program package.



**Fig. 4.** The final (lowest energy) configuration of a dimer of ACh molecules. The series of small yellow spheres indicate the 6 hydrogen bonds responsible for the binding of the two ACh molecules. Geometry optimization calculations were performed using DFT with the PBE1PBE/TZVP potential/basis set.

## Conclusions

- The possibility of breaking of the neutral radical ACh molecule C(8)-O(1) bond was predicted by our unrestricted TD-DFT quantum calculations. That is corroborated by the experimentally recorded hydrolysis of ACh molecule.
- It is possible to say that ACh neutral radical molecule possesses spatially localized electronic spin density on the group -N-(CH<sub>3</sub>)<sub>3</sub>, i.e., possesses approximately one electron spin, which may represent a qubit in quantum information processing.
- The DFT calculations proved that the dimer of neutral radical ACh molecules is stable.