université de BORDEAUX	**FALL TERM 2024-2025 - EXAM**	
	Semestre 9	**Code UE : 4TCH914U** **Molecular simulations** **J-C. Soetens**
	Date : 16/01/2025 **Without documents**	**You have 3h** **Number of points : 33**

A- Potential models *(5 points)*

In molecular simulations, the following potential is sometimes used to describe an interaction between two particles :
$U(r) = -1/r + 2/r^4$

Questions:

A-1) Draw approximately the evolution of this potential U(r).
A-2) Calculate the position and the energy of the minimum of U(r).
A-3) Give the expression for the force F accompanying this potential as a function of r.
A-4) Draw the evolution of the force F(r) on the previous plot in A-1). Be rigorous about the positions of the characteristic points.
A-5) Give the domains in r where this potential is attractive and repulsive

B- Principles of classical molecular simulations *(6 points)*

B-1) What is a 'microstate' in (classical) statistical mechanics ?
- (a) A set given by constant parameters ?
- (b) A point in phase space ?
- (c) A surface in phase space ?
- (d) All accessible points at a given temperature T in phase space ?
- (e) All accessible points at a given total energy E in phase space ?

B-2) Method of Molecular Dynamics: on which principle(s) is based this method. What is the fundamental goal of this method ?

B-3) How the temperature can be controlled in a Molecular Dynamics (MD) simulation ?

B-4) How the temperature can be controlled in a Monte Carlo simulation ?

B-5) What can one obtain from analyzing the particles velocities during an equilibrium MD simulation ?
Say Yes/No for each proposition and justify your answers :
- (a) The temperature ?
- (b) An infrared spectrum ?
- (c) The radial distribution functions (rdf) g(r) ?
- (e) The Maxwell-Boltzmann distribution of velocities ?
- (f) The kinetic energy ?
- (g) The intramolecular potential energies ?

B-6) How would you go about estimating how long it would take to run an MD simulation?
What information would you need to consider?

C- Molecular interactions *(4 points)*

Some Japanese people studied a few years ago the intermolecular interactions of CHF_3 dimer using ab initio calculations.

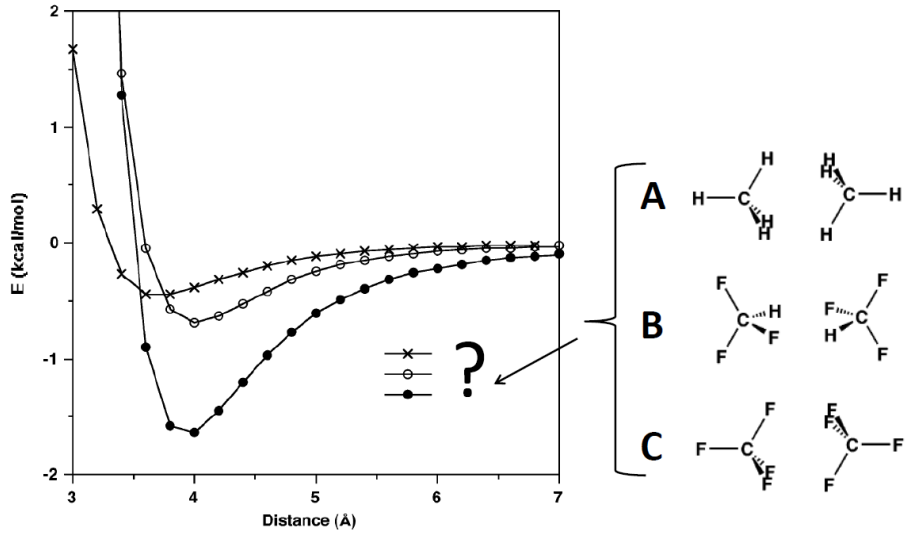
7962 *J. Phys. Chem. A* **2003,** *107,* 7962−7968

Ab Initio Calculations of Intermolecular Interaction of CHF_3 Dimer: Origin of Attraction and Magnitude of CH/F Interaction

Seiji Tsuzuki,*,†,§ Tadafumi Uchimaru,† Masuhiro Mikami,†,§ and Shingo Urata‡

National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8568, Japan, and Research Center, Asahi Glass Co., Ltd. (AGC), 1150 Hazawa-cho, Kanagawa-ku, Yokohama, Kanagawa 221-8755, Japan

In this paper, we can especially see the following figure which represents the interaction energies of the dimers A / CH_4-CH_4, B / CHF_3-CHF_3 and C / CF_4-CF_4 as a function of the carbon-carbon distance :



and the following table :

dimer	distance (Å)[b]	E_{total}[c]	E_{es}[d]	E_{rep}[e]	E_{corr}[f]
?	3.8	−0.44	0.04	0.24	−0.72
?	4.0	−0.69	0.17	0.36	−1.22
?	4.0	−1.63	−0.94	0.05	−0.74

where the energies are in kcal/mol. E_{total} in the total interaction energy, E_{es} the electrostatic contribution, E_{rep} the repulsion contribution and E_{corr} the electronic correlation contribution. We also know the boiling points of the differents species under 1 bar : 112 K for CH_4, 191 K for CHF_3 and 145 K for CF_4.

Question :

C-1) Use these informations to assign the three curves to the three dimers (I mean A, B, C with x, o and •).
Explain these results through an analysis of the nature of the intermolecular interactions inside these dimers.

D- Molecular Dynamics simulation of an ionic system *(7 points)*

We want to simulate an aqueous solution of LiCl. Thus, three species will be present in the system : Li^+, Cl^- and H_2O.

System size :

D-1) We want to build a cubic simulation box with 800 water molecules and 24 pairs LiCl. What should be the dimensions of this box so that the density of the system is 1.15 g/cm^3 ?

D-2) Calculate the molarity (in mol/l) of this solution ?

Structure : the radial distribution functions $g_{ab}(r)$ are used to characterize the structure of disorderd systems.

D-3) Toward which value do these functions tend at large r ? Why ?

D-4) In the present study, how far can these functions be calculated ?

D-5) How many site-site $g_{ab}(r)$ functions must be calculate to fully characterize the structure of the present system ? Give a full list of these functions.

D-6) Draw in particular on a first diagram the appearance of the functions $gOLi^+(r)$, $gHLi^+(r)$ and on a second diagram the appearance of the functions $gOCl^-(r)$, $gHCl^-(r)$. Pay a particular attention to the relative positions of the functions according to r.

Data : *Molar masses in g/mol : $M_O = 16$, $M_H = 1$, $M_{Li} = 7$ and $M_{Cl} = 35.45$, $N_{avogadro} = 6.02\ 10^{23}$*

E- Understanding an article *(11 points)*

Read the following article and answer to the questions :

THE JOURNAL OF PHYSICAL CHEMISTRY B

ARTICLE

pubs.acs.org/JPCB

Molecular Dynamics Simulation Studies of Caffeine Aggregation in Aqueous Solution

Letizia Tavagnacco,[§] Udo Schnupf,[†] Philip E. Mason,[†] Marie-Louise Saboungi,[‡] Attilio Cesàro,[*,§] and John W. Brady[*,†]

[†]Department of Food Science, Cornell University, Ithaca, New York 14853, United States

[§]Department of Life Sciences, University of Trieste, 34127 Trieste, Italy

[‡]Centre de Recherche sur la Matière Divisée, 1 bis rue de la Férollerie, 45071 Orléans, France

E-1) Give the useful technical details of the molecular dynamics simulations.

E-2) The authors do not explicitly mention the origin of the van der waals parameters for the caffeine molecule... Where do you think these parameters come from?

E-3) The parameterization of the partial charges of caffeine is described very precisely, not those of the water models, why ?

E-4) In the description of the development of the partial charge model of caffeine we can read (middle right of page 10959): *"It is also necessary to account for the effect of the aqueous environment. To refine the charges further, the force field development strategy outlined by MacKerell et al. was used. This procedure for charge adjustment requires that water molecules be strategically placed around the molecule, with the charges then adjusted to match the HF/6-31G* interaction energy (scaled by 1.16) between the molecule and water."*

Question : Give an argument in favor of this protocol and an argument critical of this protocol.

E-5) The computation time for the system containing 8 caffeine molecules is said to be equal to 50 days. Calculate the computation time (in seconds) of one full MD step on 1 processor of their computer.

E-6) In the figure 3, despite the shift, the red and black curves are very similar. Can you explain why ?

E-7 This figure 3 is quite difficult to analyze due to the shift. Which property could be calculated from these data to complete and illuminate this figure ?

E-8) The partial charge model of caffeine and the corresponding molecular dipole is crucial in this study so it is important to have a tool to do this calculation. Complete the Fortran code of a subroutine that must return the modulus of the molecular dipole of a molecule (in Debye).

Detach and complete this page 5 (without forgetting to indicate your anonymity number) and return it inside your exam copy.

Anonymity number :

subroutine molecular_dipole (natom, rx, ry, rz, q, dipole)

```
implicit none

integer           natom                ! input : number of atoms in the molecule
double precision  rx(*), ry(*), rz(*)  ! input : coordinates of atoms in Angstrom
double precision  q(*)                 !  input : charges of atoms in e
double precision  dipole               ! output : molecular dipole in Debye

double precision  cst_e, cst_debye     ! parameters
parameter         (cst_e = 1.6d-19)    ! electron charge in C
parameter         (cst_debye=3.3356d-30) ! Debye in C.m
```