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First-principles study of electronic ad dielectric properties of L-allo-isoleucine:D-leucine

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ABSTRACT

First-principles calculations based on Density Functional Theory have been done on an important amino acid – L-allo-isoleucine:D-leucine which is also known as (S,R)-2-amino-3-methylpentanoic acid:R-2-amino-4-methylpentaoic acid. Its structure has been simulated. The unit cell is triclinic with lattice parameters a=5.236Å, b=5.425Å and c=13.573Å showing a space group of P1. Bond lengths and bond angles have been estimated. Electronic Density of States calculations show that the material has a band gap of 4.16eV. Electronic band structure indicates that the material can be effectively used for NLO applications. The dielectric constant has been calculated and its value comes out to be 2.26, 2.22 and 2.13 along X, Y and Z axes respectively and its average value comes out to be 2.20. Phonon modes at gamma point have also been computed in L-allo-isoleucine:D-leucine and they range from 88cm^{-1} to 5782cm^{-1}.

KEYWORDS

L-allo-isoleucine:D-leucine;
(S,R)-2-amino-3-methylpentanoic acid:R-2-amino-4-methylpentaoic acid;
Dielectric constant;
Electronic density of states;
First-principles calculations.

INTRODUCTION

Amino acids are biologically important organic compounds made from amine (-NH2) and carboxylic acid (-COOH) functional groups, along with a side-chain specific to each amino acid. The key elements of an amino acid are carbon, hydrogen, oxygen, and nitrogen, though other elements are found in the side-chains of certain amino acids. Outside proteins, amino acids perform critical roles in processes such as neurotransmitter transport and biosynthesis. Because of their biological significance, amino acids are important in nutrition and are commonly used in nutritional supplements, fertilizers and food technology. Industrial uses include the production of drugs, biodegradable plastics and chiral catalysts[1].

Leucine is a branched-chain aliphatic amino acid (BCAA) that is an essential constituent of the diet[2]. As per the report of National Academy Press[3]; Blood and tissue concentrations of branched chain amino acids are altered by several disease and abnormal physiological states, including diabetes mellitus, liver dysfunction, starvation, protein-calorie malnutrition, alcoholism, and obesity. These and other conditions sometimes produce drastic alter-

Regular Paper

ations in plasma pools of BCAA. The branched-chain amino acids - leucine, isoleucine, and valine - differ from most other indispensable amino acids in that the enzymes initially responsible for their catabolism are found primarily in extrahepatic tissues.

It is also clear that although the free amino acids dissolved in the body fluids are only a very small proportion of the body's total mass of amino acids, they are very important for the nutritional and metabolic control of the body's proteins. Although the plasma compartment is most easily sampled, the concentration of most amino acids is higher in tissue intracellular pools. Typically, large neutral amino acids, such as leucine and phenylalanine, are essentially in equilibrium with the plasma[4].

Holecek M. et. Al.,[5] have studied the effect of chronic uremia induced by 5/6 nephrectomy (5/6NX) on changes in protein and branched-chain amino acid (BCAA; valine, leucine and isoleucine) metabolism and have concluded that marked activation of proteolysis occurs in severe chronic renal failure and is probably caused by metabolic changes related to acidosis development.

Bixel MG, et. Al.,[6] have also carried out studies on Leucine and clearly state that Leucine is rapidly metabolized in astroglial primary cultures. Therefore, it is considered as valuable fuel in brain energy metabolism. Only few of the leucine metabolites generated and released by astroglial cells have been identified. They have found that the astroglial cells generate and release into the extracellular fluid not only the leucine catabolites 2-oxoisocaproate and ketone bodies, but also several tricarboxylic acid cycle dependent metabolites.

Dietary leucine transported into the brain parenchyma serves several functions. Most prominent is the role of leucine as a metabolic precursor of fuel molecules, alpha-ketoisocaproate and ketone bodies. As alternatives to glucose, these compounds are forwarded by the producing astrocytes to the adjacent neural cells. Leucine furthermore participates in the maintenance of the nitrogen balance in the glutamate/glutamine cycle pertinent to the neurotransmitter glutamate. Leucine also serves as a regulator of the activity of some enzymes important for brain energy metabolism. Murin R, and Hamprecht B[7] have clearly narrated the current knowledge on the metabolic and regulatory roles of this essential amino acid in neural cells. Layman DK[8] has reviewed the unique roles of leucine in amino acid metabolism in skeletal muscle during and after exercise.

Dalhus B, and Gorbitz CH[9] have carried out reinvestigation of the crystal structure of the 1:1 mixture of the two racemates DL-isoleucine and DL-allo-isoleucine, with a detailed analysis of interatomic distances between alternative side-chain positions. *Di Blasio B et. Al.,*[10] *have carried out c*onformational studies of heterochiral peptides with diastereoisomeric residues showing the crystal and molecular structures of linear dipeptides derived from leucine, isoleucine, and allo-isoleucine.

Carl Henrik Görbitz et. al.,[11] have studied the structure of L-allo-isoleucine:D-leucine C12H26N2O4 using XRD and have reported that the unit cell contains 2-amino-3-methylpentanoic acid:R-2-amino-4-methylpentaoic acid (C6H13NO2;C6H13NO2) attached to each other by two hydrogen bonds. The reported triclinic lattice structure has the lattice parameters; a=5.236Å, b=5.425Å, c=13.573Å, alpha=87.416deg, beta=88.994deg and gamma=69.431deg with unit cell volume 360.59Å^3.

It has been found that any little modification in the structure and composition of a material will bring in sufficient changes in the properties of the material[12, 13]. Thus it is important to study the structure of the materials and look at the parameters which can be altered to get a better material for technological applications. First-principles calculation based on Density Functional Theory[14] has been proved to be an effective tool in the study of structural, electronic and dielectric properties of organic materials[15, 16]. L-allo-isoleucine:D-leucine and such cocrystalline compounds have attracted the scientific community in various aspects. With this in view, structure of L-allo-isoleucine:D-leucine has been simulated using First-principles calculations based on Density Functional Theory and computation of Electronic density of states, Dielectric constant and phonon modes have been done and the results have been reported in the present paper.

Regular Paper

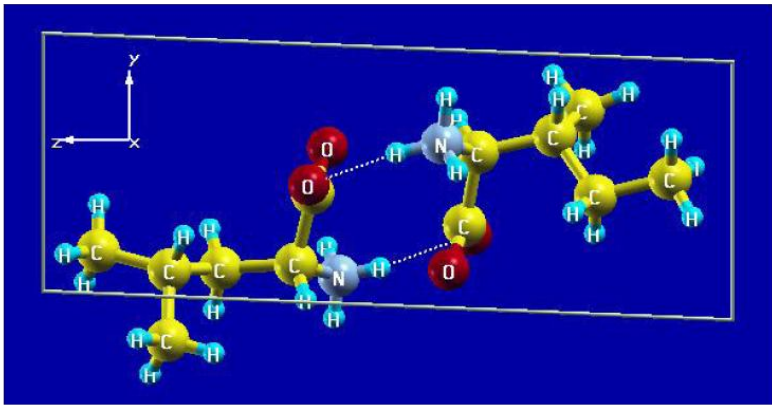

Figure 1 : Structure of unit cell of L-allo-isoleucine:D-leucine as viewed along X-axis

COMPUTATIONAL DETAILS

Several codes are available for the theoretical structure simulation[17]. The density functional theory approach has emerged as a well established computational method. It has been widely employed to arrive at the conformations of a large number of molecular systems. The practical applicability and sophistication of DFT is strongly sensitive to the good choice of exchange–correlation function along with the appropriate basis set.

Quantum espresso is an integrated suite of Open-Source computer codes for electronic-structure calculations and materials modelling. It is based on density-functional theory, plane waves, and pseudopotentials. Author has used plane wave self consistent field (PWSCF)[18] implementation of density functional theory (DFT), with a Local density approximation (LDA)[19] to exchange correlation energy of electrons and ultrasoft pseudopotentials[20], to represent interaction between ionic cores and valence electrons. Kohn-Sham wave functions were represented with a plane wave basis with an energy cutoff of 30 Ry and charge density cutoff of 180 Ry. Integration over Brillouin zone was sampled with a Monkhorst-Pack scheme[21] with appropriate k point mesh and occupation numbers were smeared using Methfessel-Paxton scheme[22] with broadening of 0.03 Ry. The structure was relaxed to minimize energy.

RESULTS AND DISCUSSION

In the present study, the Triclinic unit cell of L-allo-isoleucine:D-leucine was first simulated using "Avogadro"[23]. Later, atomic positions of the molecules have been used in the plane wave self consistent field calculations.

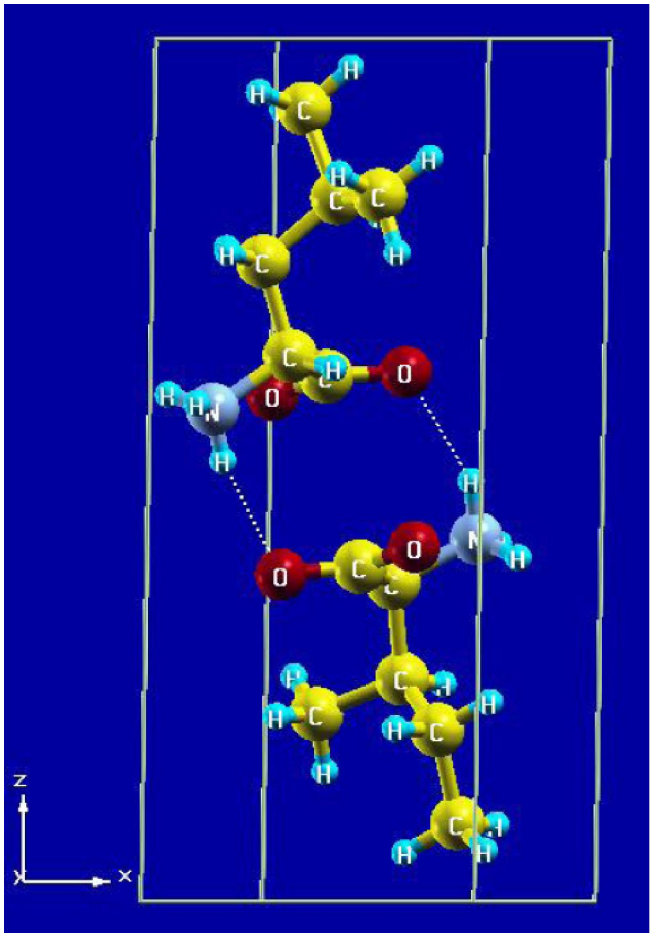

Figure 2 : Structure of unit cell of L-allo-isoleucine:D-leucine as viewed along Y-axis

The structure was relaxed and the optimized values of the unit cell parameters thus arrived at through minimization of energy are; a=5.236Å, b=5.425Å,

Regular Paper

c=13.573Å, alpha=87.42deg, beta=88.99deg and gamma=69.43deg "scf"" calculation was done using the final atomic positions obtained after relaxing the structure using the program 'pw.x' of Quantum espresso. The hydrogen bonds are indicated by dotted lines.

Completely relaxed structure of the unit cell was visualized using the program "XcrysDen"[24] and the structure of unit cell of L-allo-isoleucine:D-leucine as seen along X-axis, Y-axis and Z-axis are shown in Figures 1, 2 and 3 respectively. The bond lengths and bond angles in the relaxed structure of L-allo-isoleucine:D-leucine have been tabulated in TABLES 1 and 2 respectively.

EDOS calculation

Electron Density of States (EDOS) has been computed in L-allo-isoleucine:D-leucine using Electronic structure calculation code of Quantum espresso. EDOS in L-allo-isoleucine:D-leucine has been shown in Figure 3. Band gap in L-allo-isoleucine:D-leucine is found to be 4.16eV. This value is close to that exhibited by Non-linear optical (NLO) materials[25].

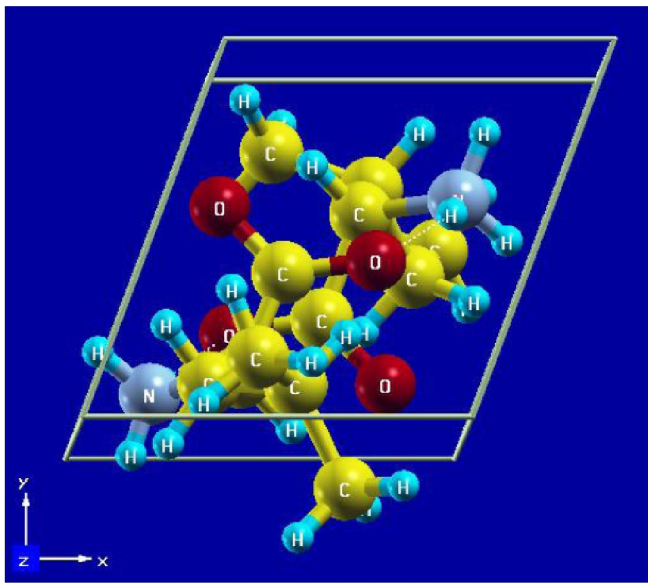

Figure 3 : Structure of unit cell of L-allo-isoleucine:D-leucine as viewed along Z-axis

TABLE 1 : Bond lengths in L-allo-isoleucine:D-leucine

Bond	Bond length (Å)
C – H	0.98
C – C	1.54
C – O	1.26
C – N	1.49
N – H	0.86, 0.92

TABLE 2 : Bond angles in L-allo-isoleucine:D-leucine

Bond	Bond angle (deg)
C – C – C	109.5 – 114.7
C – C – H	107.5 – 109.5
H – C – H	108 – 109
H – N – H	105, 110
H – N – C	109 – 113
N – C – C	108 – 110
N – C – H	108
O – C – C	117 – 118
O – C – O	126

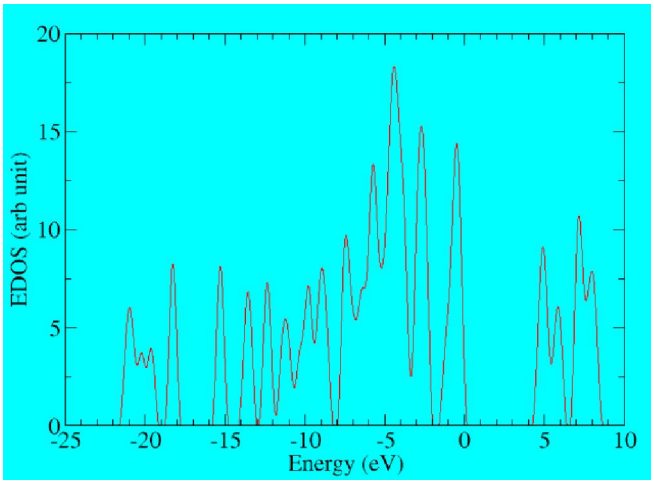

Figure 4 : Electron density of states in L-allo-isoleucine:D-leucine

Dielectric constant and phonon modes

Dielectric constant of the material has been computed in case of L-allo-isoleucine:D-leucine. The value of dielectric constant in L-allo-isoleucine:D-leucine comes out to be 2.26, 2.22 and 2.13 along X, Y and Z axes respectively and its average value comes out to be 2.20. Phonon modes at gamma point have also been computed in L-allo-isoleucine:D-leucine and they range from 88cm^{-1} to 5782cm^{-1}.

CONCLUSIONS

The simulated and optimized structure of L-allo-isoleucine:D-leucine is matching very well with the structural parameters reported in the literature. Band gap in case of L-allo-isoleucine:D-leucine comes

out to be 4.16eV. The value of dielectric constant in L-allo-isoleucine:D-leucine comes out to be 2.26, 2.22 and 2.13 along X, Y and Z axes respectively and its average value comes out to be 2.20. Phonon modes at gamma point have also been computed in L-allo-isoleucine:D-leucine and they range from 88cm^{-1} to 5782cm^{-1}. The value of Band gap is similar to that exhibited by NLO materials and hence the usage of this material for NLO applications can be explored.

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