# FTIR, FT – RAMAN and Density Functional Theory Calculations on Acetazolamide

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## Introduction

FTIR and FTR spectroscopic methods are being extensively used to identify the structural groups present in a compound [1-4]. Many research suggested an interesting method of assigning group frequencies observed in vibrational spectra. During the course of our investigation on the samples of pharmaceutical active compounds, our attention has been turned towards the Acetazolamide drug. It is an anticonvulsant. It is white (or) almost white, crystalline powder, almost odorless, exhibits polymorphism. It is used for controlling certain types of seizures and relieving pain in patients with nerve pain in the Congestive heart failure, Marfan's syndrome, Central sleep apena. The FTIR spectra of Acetazolamide have been thoroughly investigated and detailed vibrational band assignments have been made. The assignment of the fundamental frequencies is made on the basis of magnitude and relative intensities of the observed bands. Also the variations of the absorbance of maximum wavelength of the drug subjected to different temperature conditions have been analysed using UV-Visible spectral measurements. In the present work, FTIR, and FTR methods have been employed successfully in the present investigation and the results obtained are discussed.

## Experimental

The sample of Acetazolamide was procured from a reputed pharmaceutical firm of Puducherry, India and used as such. The FTIR spectrum of the compound are recorded over the region on 4000-400 $cm^{-1}$ using ABB-BOOMEN series at Pharma Analytical Lab, Puducherry. FT Raman spectrum has been recorded in the region 3500-50 $cm^{-1}$ excited with the 1064 nm radiation using Nd:YAG laser of a Thermo Electron Corporation FTRaman module about 1.5 w power at the sample at SAIF, IIT (M), Chennai. All sharp bands observed in the spectra are expected to have an accuracy of ±1$cm^{-1}$.

The molecular structure of Acetazolamide and pharmaceutical data are presented in Fig.1 and Table 1 respectively. The Vibrational spectra of Acetazolamide is presented in Fig.2.

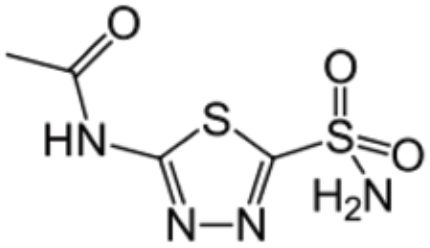


**Fig. 1 Molecular Structure of Acetazolamide**

**Table 1 Pharmaceutical data of Acetazolamide**

| | |
|---|---|
| Name | Acetazolamide |
| Formula | $C_4H_6N_4O_3S_2$ |
| Molecular weight | 222.245 g/mol |
| IUPAC Name | N-(5-sulfamoyl-1,3,4-thiadiazol-2-yl) Acetamide |

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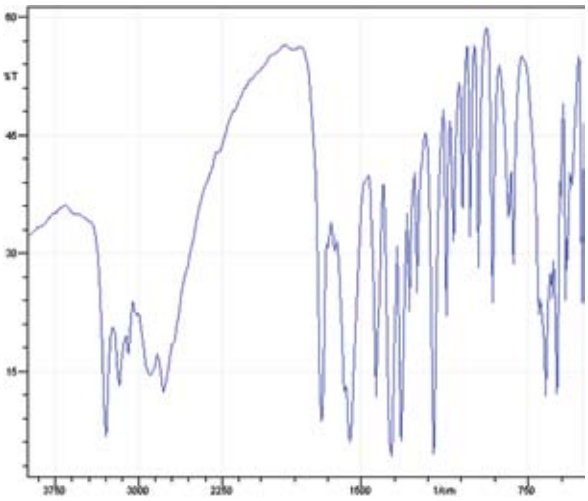
| | |
|---|---|
| Category | Anti convulsant, carbonic anhydrase inhibitors |
| Dose | 250mg daily |
| Description | White, Crystalline powder, Very slighty soluble in water, slightly soluble in alcohol |
| Solubility | 1 M $NH_4OH$: Soluble 50 mg/ml, DMSO:Soluble, methanol and ethanol: slighty soluble. |
| Storage | Store in well closed light resistance containers |

## Vibrational Analysis

Fourier transform infrared (FTIR) and UV spectroscopic methods are being extensively used to identify the structural groups present in a compound. The aim of the present work is to make thorough investigation on vibrational frequencies of Acetazolamide. In analogy with the vibrational band assignments of related compounds and the magnitudes and relative intensities of the bands. The vibrational band assignments of the compound are presented in Table 2. A qualitative discussion on the specific modes of vibration is discussed as follows.

**Table 2. Vibrational band assignments of Acetazolamide**

| Wavenumber ($cm^{-1}$) | | Vibrational band assignments |
|---|---|---|
| FTIR | FTR | |
| 511(s) | | N – C – S in plane bending |
| 555(w) | | N – C – O in plane bending |
| 621(s) | 623 | C – S stretching |
| 673(s) | 678 | C – S stretching |
| 704(s) | 711 | C – H out of plane bending |
| 818(m) | | N – H out of plane bending |
| 841(m) | | C – H out of plane bending |
| 912(s) | 913 | S – N stretching |
| 974(m) | 970 | C – H in plane bending |
| 1013(m) | | S = O stretching |
| 1045(m) | | C – H plane bending |
| 1068(m) | 1085 | C–H plane bending/ $NH_2$twisting |
| 1121(s) | 1118 | O = S = O symmetric |
| 1176(vs) | 1167 | C – H in plane bending |
| 1250(m) | 1258 | C – N stretching |
| 1266(s) | | C – N stretching |
| 1321(vs) | | O=S=O asymmetric stretching |
| 1366(vs) | 1384 | CH3 symmetric bending |



| Wavenumber ($cm^{-1}$) | | Vibrational band assignments |
|---|---|---|
| FTIR | FTR | |
| 1435(s) | 1433 | $CH_3$ asymmetric bending |
| 1553(vs) | | N – H in plane bending |
| 1574(s) | | C = N stretching |
| 1680(vs) | 1674 | C=O stretching/$NH_2$ scissoring |
| 2925(s) | 2931 | C – H symmetric stretching |
| 3113(s) | | C – H asymmetric stretching |
| 3300(s) | | N – H symmetric stretching |
| 3336(w) | | N – H asymmetric stretching |

vw-very weak, w-weak, m-medium, s-strong, vs-very strong

### *N-H Stretching Vibrations*

N-H stretching frequencies corresponding to the symmetrical and asymmetrical NH stretching vibrations for dilute solutions are occur near 3520 $cm^{-1}$ to 3480 $cm^{-1}$. In the spectra of solid samples are observed near 3350 $cm^{-1}$ to 3180 $cm^{-1}$ because of Hydrogen bonding [5]. Based on this, in the present investigation, N-H symmetric stretching vibrations are observed at 3300 $cm^{-1}$ and N-H asymmetric stretching occurred at 3336 $cm^{-1}$.

### *C-H Stretching Vibrations*

These bands occur in the region 3010 $cm^{-1}$ – 3200 $cm^{-1}$. Two moderately intense bands frequently occur in this region [6]. The appearance of two bands is attributed to Fermi resonance between the fundamental aldehydic C-H stretch and the first overtone of the aldehydic C-H bending vibration that usually appears near 1390$cm^{-1}$. Based on

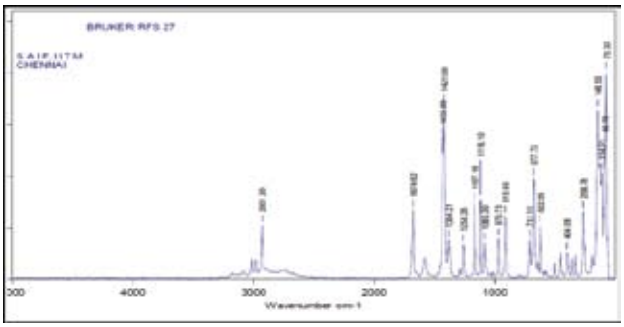


**Fig.2 Vibrational spectra of Acetazolamide**

this in the present investigation, the FTIR bands observed at 3113 and 2925 $cm^{-1}$ and FTR band identified at 2931 $cm^{-1}$ are assigned to C-H stretching vibrations.

### *C-N Stretching Vibrations*

Medium to weak absorption bands for the unconjugated C-N linkage in primary, secondary and tertiary aliphatic amines appear in the region of 1250-1020 $cm^{-1}$. Aromatic amines display strong C-N stretching absorption in the 1342-1266 $cm^{-1}$ region [7]. Hence in the present case the FTIR bands observed at 1250 and 1266 $cm^{-1}$ and Raman band occur at 1258 $cm^{-1}$ are assigned to C-N stretching vibrations.

### *C=O Stretching Vibrations*

The C=O absorption of lactams, 6 membered rings or larger is near 1650 $cm^{-1}$. The five membered ring lactams absorb in the range 1750-1700 $cm^{-1}$. The four membered ring lactams, unfused absorbs at 1760-1730 $cm^{-1}$ [8]. In the present investigation the FTIR and FTR bands identified at1680 $cm^{-1}$ and 1678 $cm^{-1}$ respectively are assigned to C=O stretching vibrations.

### *O = S = O Stretching Vibration*

Two intense infrared bands have been associated with sulphone stretching frequencies; one near 1350 – 1300 $cm^{-1}$ and the other near 1160 – 1120 $cm^{-1}$ because of the asymmetric and symmetric $SO_2$ stretching modes respectively. In the solid state, the range is lowered by 10 – 20 $cm^{-1}$ due to hydrogen bonding, the lower frequency band being less affected than the higher frequency band. Conjugation, as with the sulphoxide stretching frequency, has no effect on the sulphone stretching frequencies. The effect of group such as oxygen or chlorine attached to the sulphone is analogous to that observed for the sulphoxides, i.e. a shift to higher frequency with increasing electronegativity of the group or atom [9]. Based on this fact in the present investigation the IR band at 1121 $cm^{-1}$ and FTR band at 1118 $cm^{-1}$ are assigned to O = S = O symmetric stretching vibrations. A very strong infrared band observed at 1321 $cm^{-1}$ is assigned to O = S = O asymmetric stretching vibrations.

### *C = N Stretching*

Interaction between ring C=C and C=N stretching vibrations results in two strong medium intensity absorptions about 100 $cm^{-1}$ apart. These absorptions occur at 1615 – 1575 $cm^{-1}$ and 1520 – 1465 $cm^{-1}$, the higher frequency band and its low – frequency band often having another medium intensity band on its lower frequency side which is found at 1590 – 1555 $cm^{-1}$. A strong band is usually observed in the region 1000 – 985 cm [10] This band may be very weak or undetectable for 3 – substituted pyridines. In the present case, C=N stretching vibration is observed at a frequency 1640 $cm^{-1}$

### *$NH_2$ Group Vibrations*

The $NH_2$ group has two (N-H) stretching vibrations, one being symmetric and other asymmetric. The frequency of asymmetric vibration is higher than that of symmetric one. It has frequency range of 3300 $cm^{-1}$ to 3700 $cm^{-1}$.
In addition, $NH_2$ group has scissoring, rocking, wagging and torsion modes. The $NH_2$ scissoring mode has been suggested to lie in the region 1590 $cm^{-1}$ to 1650 $cm^{-1}$ in benzene derivatives containing an $NH_2$ group. In the present work $NH_2$ scissoring band occur at 1677 $cm^{-1}$. It is noted that frequency 1680 $cm^{-1}$ is in very strong region. Similarly $NH_2$ rocking vibration occurs at 1384 $cm^{-1}$ and $NH_2$ wagging vibrations occur at 673 $cm^{-1}$ [11]

### *Bending Vibrations*

The in plane, out of plane bending of a ring hydrogen atom is strongly coupled to adjacent hydrogen atoms. The position of absorption of the out of plane bending band is, therefore, characteristic of the number of adjacent hydrogen atoms on the ring. The bands are frequently intense and may be used for the qualitative determination of the relative

concentrations of isomers in mixtures. The absorption band that frequently appears in the spectra of substituted benzenes near 710-675 $cm^{-1}$ is attributed to out of plane bending [12]. In the present investigation the C-H out of plane bending bands occurs at 704 and 841 $cm^{-1}$. The IR bands observed at 1045, 1068, 1121 and 1176 $cm^{-1}$ are assigned to C-H in plane bending vibrations.

In the present work, the FTIR band observed at 1489 $cm^{-1}$ is referred as N-H in plane bending and bands occurs at 818 $cm^{-1}$ have been assigned to N-H out of plane bending vibrations respectively. Similarly the other vibrations are observed in the characteristic range.

### *Methyl Group Vibrations*

An examined of a large number of satured hydrocarbons containing methyl group showed in all cases, 2 distinct bands occurring at 2962 $cm^{-1}$ and at the first of these results from the asymmetrical stretching mode in which 2 C-H bonds of the methyl group are extending while the third one is contracting. The second arises from symmetrical stretching in which all 3 of the C-H bonds extended and contract in phase. The presence of several methyl groups in a molecule results in strong absorption of these positions. The bands appearing at 2965 $cm^{-1}$ and 2865 $cm^{-1}$ in the infrared spectrum of theophylline have been assigned to asymmetric and symmetric C-H stretching respectively[14]. Two bending vibrations can occur within a methyl group. The first of these, the symmetrical bending vibration involves in the in-phase bending of the C-H bonds. The second, the asymmetrical bending vibration occurs near 1375 $cm^{-1}$, the asymmetrical bending vibration near 1450 $cm^{-1}$. These symmetric bending are observed in the respective in the infrared spectrum of theophylline. In the present work the infrared bands observed 1366 $cm^{-1}$ has been assigned to $CH_3$ symmetric bending vibration and 1435 $cm^{-1}$ asymmetric bending vibration of the chosen drug. For the same vibrations the Raman bands are observed at 1384 and 1433 $cm^{-1}$ respectively. Similarly the other FTIR and FTRaman band observed and are assigned in the characteristic range. Also all the observed band are good in agreement with the literature values.

**Structural analysis using density functional theory**

Density functional theory (DFT) is a quantum mechanical theory used in physics and chemistry to investigate the electronic structure (principally the ground state) of many-body systems, in particular atoms, molecules and the condensed phases. DFT is among the most popular and versatile methods available in condensed matter physics, computational physics, and computational chemistry.

Computational chemistry is a branch of chemistry that uses computers to assist in solving chemical problems. It uses the results of theoretical chemistry, incorporated into efficient computer programs, to calculate the structures and properties of molecules and solids. While its results normally complement the information obtained by chemical experiments, it can in some cases predict hitherto unobserved chemical phenomena. It is widely used in the design of new drugs and materials.Examples of such properties are structure (i.e. the expected positions of the constituent atoms), absolute and relative (interaction) energies, electronic charge distributions, dipoles and higher multipole moments, vibrational frequencies, reactivity or other spectroscopic quantities, and cross sections for collision with other particles.

*Ab initio* methods are based entirely on theory from first principles. Other (typically less accurate) methods are called empirical or semi-empirical because they employ experimental results, often from acceptable models of atoms or related molecules, to approximate some elements of the underlying theory. Both *ab initio* and semi-empirical approaches involve approximations. These range from simplified forms of the first-principles equations that are easier or faster to solve, to approximations limiting the size of the system (for example, Periodic boundary conditions), to fundamental approximations to the underlying equations that are required to achieve any solution to them at all. For example, most *ab initio* calculations make the Born-Oppenheimer approximation, which greatly simplifies the underlying Schroedinger Equation by freezing the nuclei in place during the calculation. In principle, ab initio methods eventually converge to the exact solution of the underlying equations as the number of approximations is reduced. In practice, however, it is impossible to eliminate all approximations, and residual error inevitably remains. The goal of computational chemistry is to minimize this residual error while keeping the calculations tractable.

Density functional theory (DFT) methods are often considered to be *ab initio* methods for determining the molecular electronic structure, even though many of the most common functionals use parameters derived from empirical data, or from more complex calculations. In DFT, the total energy is expressed in terms of the total one-electron density rather than the wave function. In this type of calculation, there is an approximate Hamiltonian and an approximate expression for the total electron density. DFT methods can be very accurate for little computational cost. Some methods combine the density functional exchange functional with the Hartree-Fock exchange term and are known as hybrid functional methods.

In modern computational chemistry, quantum chemical calculations are typically performed within a finite set of basis functions. In these cases, the wavefunctions under consideration are all represented as vectors, the components of which correspond to coefficients in a linear combination of the basis functions in the basis set used.

A basis set in chemistry is a set of functions used to create the molecular orbitals, which are expanded as a linear combination of such functions with the weights or coefficients to be determined. Usually these functions are atomic orbitals, in that they are centered on atoms, but

functions centered in bonds or lone pairs have been used as have pairs of functions centered in the two lobes of a p orbital. Additionally, basis sets composed of sets of plane waves down to a cutoff wavelength are often used, especially in calculations involving systems with periodic boundary conditions.

There are hundreds of basis sets composed of Gaussian-type orbitals (GTOs). The smallest of these are called *minimal basis sets*, and they are typically composed of the minimum number of basis functions required to represent all of the electrons on each atom. A minimum basis set is one in which, on each atom in the molecule, a single basis function is used for each orbital in a Hartree-Fock calculation on the free atom.

The most common addition to minimal basis sets is probably the addition of polarization functions, denoted (in the names of basis sets developed by Pople) by an asterisk, *. Two asterisks, **, indicate that polarization functions are also added to light atoms (hydrogen and helium). These are auxiliary functions with one additional node. When polarization is added to this basis set, a p-function is also added to the basis set. This adds some additional needed flexibility within the basis set, effectively allowing molecular orbitals involving the hydrogen atoms to be more asymmetric about the hydrogen nucleus. This is an important result when considering accurate representations of bonding between atoms, because the very presence of the bonded atom makes the energetic environment of the electrons spherically asymmetric. Similarly, d-type functions can be added to a basis set with valence p orbitals, and f-functions to a basis set with d-type orbitals, and so on. Another, more precise notation indicates exactly which and how many functions are added to the basis set, such as (p, d).

Another common addition to basis sets is the addition of diffuse functions, denoted in Pople-type sets by a plus sign, +, and in Dunning-type sets by "aug" (from "augmented"). Two plus signs indicate that diffuse functions are also added to light atoms (hydrogen and helium). These are very shallow Gaussian basis functions, which more accurately represent the "tail" portion of the atomic orbitals, which are distant from the atomic nuclei. These additional basis functions can be important when considering anions and other large, "soft" molecular systems [13].

The most common minimal basis set is STO-nG, where n is an integer. This *n* value represents the number of Gaussian primitive functions comprising a single basis function. Commonly used minimal basis sets of this type are:

- STO-3G
- STO-4G
- STO-6G
- STO-3G* - Polarized version of STO-3G

Here is a list of commonly used split-valence basis sets of this type:

- 3-21g
- 3-21g* - Polarized
- 3-21+g - Diffuse functions
- 6-31g

Therefore in the present investigation DFT calculation has been used to study the vibrational spectra and other parameters of the chosen compound Acetazolamide.

*Results and discussion*

The DFT calculations were performed using Gaussian 03W [14] program package, invoking gradient geometry optimization [15]. The infrared intensities and Raman scattering activities have been computed at the HF/6-31G(d,p) , HF/6-311G(d,p) and B3LYP/6-31G(d,p) , B3LYP/6-311G(d,p) levels of theory. It has been utilized the gradient corrected density functional theory [16] with three-parameter hybrid functional for exchange part and the Lee-Yang-Parr correlation function [17] for the computation of vibrational frequencies and energies of optimized structure. The optimized structural parameters have been evaluated for the calculations of vibrational frequencies by assuming Cs point group symmetry.

The labeling of atoms in Acetazolamide using B3LYP/6-311G(d,p) set is presented in Fig.3.3. The optimized geometrical parameters (bond length and angles) by HF, DFT/B3LYP with 6-31G(d,p) and 6-311G(d,p) as basis set are presented in Table 3.3. It compares the calculated bond lengths and angles for AZM with those of experimentally available from X- ray data for acetazolamide.

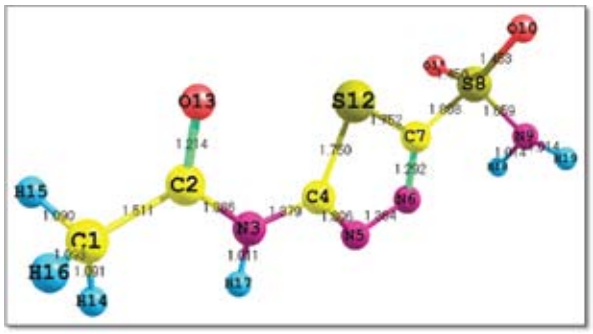



**Fig. 3.3 Labeling atoms in Acetazolamide**

The geometric structure is monoclinic, the space group $C_2$ with the cell dimensions: a = 42.9, b = 41.8, c = 72.9 Å and b = 104.5°. From the theoretical values, we find that most of the optimized bond lengths are slightly shorter as well as longer than the experimental value at HF and B3LYP levels due to the theoretical calculation belong to isolated molecules in gaseous phase and the experimental results belong to molecule in solid state. Comparing bond angles and bond lengths of HF and B3LYP as a whole the B3LYP calculated value correlates well compared with the experimental results.

**Table 3.3 Bond length and bond angles of Acetazolamide**

| **Bond length(A⁰)** | | | | | |
|---|---|---|---|---|---|
| C1-C2 | 1.506 | 1.506 | 1.512 | 1.511 | 1.510 |
| C1-H14 | 1.085 | 1.085 | 1.092 | 1.091 | 1.090 |
| C1-H15 | 1.079 | 1.079 | 1.093 | 1.090 | 1.090 |
| C1-H16 | 1.085 | 1.085 | 1.093 | 1.093 | 1.090 |
| C2-N3 | 1.375 | 1.377 | 1.386 | 1.386 | 1.350 |
| C2-O13 | 1.193 | 1.187 | 1.221 | 1.214 | 1.210 |
| N3-C4 | 1.372 | 1.373 | 1.379 | 1.379 | 1.390 |
| N3-H17 | 0.996 | 0.996 | 1.012 | 1.011 | 0.970 |
| C4-N5 | 1.281 | 1.278 | 1.312 | 1.306 | 1.320 |
| C4-S12 | 1.733 | 1.732 | 1.750 | 1.750 | 1.740 |
| N5-N6 | 1.357 | 1.356 | 1.367 | 1.364 | 1.260 |
| N6-C7 | 1.266 | 1.263 | 1.298 | 1.293 | 1.320 |
| C7-S8 | 1.780 | 1.781 | 1.804 | 1.808 | 1.760 |
| C7-S12 | 1.735 | 1.734 | 1.753 | 1.752 | 1.790 |
| S8-N9 | 1.617 | 1.614 | 1.666 | 1.659 | 1.660 |
| S8-O10 | 1.424 | 1.415 | 1.459 | 1.453 | 1.420 |
| S8-O11 | 1.422 | 1.416 | 1.457 | 1.450 | 1.420 |
| N9-H18 | 0.999 | 0.998 | 1.017 | 1.014 | 0.970 |
| N9-H19 | 0.998 | 0.999 | 1.016 | 1.014 | 0.970 |
| **BOND ANGLE(⁰)** | | | | | |
| C2-C1-H14 | 110.3 | 110.3 | 113.7 | 113.6 | 109.5 |
| C2-C1-H15 | 108.7 | 108.7 | 108.6 | 108.5 | 109.6 |
| C2-C1-H16 | 110.4 | 110.1 | 108.6 | 108.6 | 109.5 |
| H14-C1- H15 | 109.6 | 109.7 | 109.2 | 109.5 | 109.4 |
| H14-C1-H16 | 108.3 | 108.4 | 109.2 | 109.0 | 109.4 |
| H15-C1-H16 | 109.6 | 109.7 | 107.4 | 107.5 | 109.5 |
| C1-C2-N3 | 114.7 | 114.4 | 115.7 | 115.5 | 120.0 |
| C1-C2-O13 | 124.1 | 124.2 | 123.4 | 123.5 | 120.0 |
| N3-C2-O13 | 121.2 | 121.3 | 120.9 | 121.0 | 120.0 |
| C2-N3-C4 | 125.3 | 125.5 | 124.5 | 124.7 | 120.0 |
| C2-N3-H17 | 120.5 | 120.4 | 121.0 | 120.9 | 120.0 |
| C4-N3-H17 | 114.2 | 114.2 | 114.5 | 114.5 | 120.0 |

| **Parameters** | **HF/6-31 G(d,p)** | **HF/6-311 G(d,p)** | **B3LYP/6-31 G(d,p)** | **B3LYP/6-311 G(d,p)** | **Std. value** |
|---|---|---|---|---|---|
| N3-C4-N5 | 119.9 | 120.0 | 120.4 | 120.5 | 129.6 |
| N3-C4-S12 | 124.9 | 124.8 | 123.9 | 123.9 | 129.6 |
| N5-C4-S12 | 115.2 | 115.2 | 115.7 | 115.6 | 100.8 |
| C4-N5-N6 | 112.0 | 112.1 | 111.7 | 111.8 | |
| N5-N6-C7 | 113.0 | 113.0 | 112.6 | 112.7 | 120.7 |
| N6-C7-S8 | 121.2 | 121.3 | 121.0 | 121.0 | 100.1 |
| N6-C7-S12 | 115.3 | 115.3 | 115.7 | 115.7 | 129.9 |
| S8-C7-S12 | 123.5 | 123.5 | 123.3 | 123.3 | 129.9 |
| C7-S8-N9 | 105.1 | 105.2 | 104.3 | 104.6 | |
| C7-S8-O10 | 105.9 | 106.8 | 106.4 | 106.4 | 105.7 |
| C7-S8-O11 | 106.8 | 106.1 | 107.2 | 107.0 | 105.8 |
| N9-S8-O10 | 108.1 | 108.0 | 107.7 | 107.6 | |
| N9-S8-O11 | 108.0 | 108.1 | 107.5 | 107.4 | 105.7 |
| O10-S8-O11 | 121.8 | 121.7 | 122.4 | 122.5 | |
| S8-N9-H18 | 114.5 | 114.2 | 111.7 | 112.4 | 120.0 |
| S8-N9-H19 | 114.4 | 114.2 | 111.7 | 112.5 | 120.0 |
| H18-N9-H19 | 114.5 | 114.0 | 111.9 | 112.6 | 120.0 |
| C4-S12-C7 | 84.5 | 84.5 | 84.3 | 84.2 | 96.5 |

**Table 3.4 Computed values of Acetazolamide at HF/6-31G(d,p) level**

| FT-IR[a] | Computed[a] | **Corrected[a]** | **Red.[b]** | **Frc.[c]** | **I R[d]** | **R[e]** |
|---|---|---|---|---|---|---|
| 503 | 556 | 502 | 9.0 | 1.6 | 27 | 3.9 |
| 534 | 592 | 534 | 1.5 | 0.3 | | 1.4 |
| 551 | 611 | 552 | 3.2 | 0.7 | 26 | 1.1 |
| 586 | 650 | 586 | 3.0 | 0.7 | 16 | 1.1 |
| 597 | 661 | 597 | 2.1 | 0.5 | 2.4 | 0.1 |
| 617 | 684 | 617 | 7.7 | 2.1 | 10 | 0.4 |
| 642 | 711 | 642 | 9.8 | 2.9 | 33 | 2.2 |
| 651 | 722 | 652 | 5.3 | 1.6 | | 15 |
| 675 | 746 | 674 | 5.2 | 1.7 | | 2.8 |
| 690 | 764 | 690 | 6.7 | 2.3 | 64 | 4.3 |
| 792 | 876 | 791 | 9.0 | 4.0 | 3.9 | 1.9 |
| 875 | 969 | 875 | 4.9 | 2.7 | 78 | 11 |
| 958 | 1060 | 957 | 5.8 | 3.8 | 3.3 | 6.4 |
| 985 | 1091 | 985 | 1.6 | 1.1 | 32 | 1.6 |
| 1051 | 1163 | 1050 | 1.7 | 1.4 | 7.7 | 0.8 |
| 1085 | 1201 | 1084 | 1.2 | 1.0 | 1.0 | 2.4 |
| 1099 | 1217 | 1099 | 11 | 10 | 25 | 1.4 |
| 1143 | 1267 | 1144 | 9.3 | 8.8 | 72 | 18 |
| 1162 | 1287 | 1162 | 14 | 13 | | 7.2 |
| 1220 | 1351 | 1219 | 2.2 | 2.3 | | 0.8 |
| 1315 | 1457 | 1316 | 6.8 | 8.5 | | 0.8 |
| 361 | 1508 | 1362 | 13 | 18 | | 3.4 |
| 1388 | 1538 | 1389 | 1.2 | 1.7 | 31 | 5.6 |
| 1434 | 1588 | 1434 | 1.1 | 1.7 | 32 | 12 |
| 1452 | 1608 | 1452 | 1.0 | 1.5 | 9.7 | 17 |
| 1463 | 1621 | 1464 | 2.4 | 3.7 | 12 | 36 |
| 1566 | 1733 | 1565 | 3.5 | 6.2 | | 56 |
| 1568 | 1735 | 1567 | 11 | 19 | 8.1 | 29 |
| 1577 | 1745 | 1576 | 1.1 | 2.0 | 62 | 2.7 |
| 3300 | 3330 | 3007 | 1.1 | 7.2 | 4.0 | 75 |

FTIR[a] , Computed[a] and Corrected[a] - Frequencies($cm^{-1}$);
Red.[b] - Reduced masses(amu);
Frc.[c] - Force constants (m Dyne $A^{-1}$) ;
IR.[d] - IR intensity(Km $mole^{-1}$);
R.[e] - Raman scattering activities($A^4$ $amu^{-1}$)

**Table 3.5 Computed values of Acetazolamide at HF/6-311G(d,p) level**

| FT-IR[a] | Computed[a] | Corrected[a] | Red.[b] | Frc.[c] | IR[d] | R[e] |
|---|---|---|---|---|---|---|
| 503 | 557 | 503 | 8.2 | 1.5 | 31 | 4.0 |
| 524 | 581 | 524 | 1.5 | 0.3 | 97 | |
| 553 | 613 | 553 | 3.3 | 0.7 | 20 | 1.3 |
| 586 | 648 | 586 | 3.1 | 0.7 | 12 | 1.1 |
| 595 | 659 | 595 | 2.2 | 0.5 | 1.6 | 0.1 |
| 609 | 673 | 609 | 7.0 | 1.8 | 6.3 | |
| 634 | 702 | 634 | 9.8 | 2.8 | 25 | 2.6 |
| 651 | 720 | 651 | 6.5 | 2.0 | | 15 |
| 675 | 746 | 674 | 4.4 | 1.4 | | 2.6 |
| 686 | 760 | 687 | 6.1 | 2.1 | | 3.9 |
| 790 | 874 | 790 | 8.8 | 3.9 | 4.2 | 1.8 |
| 873 | 966 | 872 | 4.8 | 2.6 | 74 | 11 |
| 954 | 1057 | 954 | 5.8 | 3.8 | 2.6 | 6.4 |
| 979 | 1084 | 978 | 1.6 | 1.1 | 40 | 1.5 |
| | 1159 | 1047 | 1.8 | 1.4 | 6.7 | |
| | 1199 | 1082 | 1.2 | 1.0 | 1.9 | 2.5 |
| | 1208 | 1090 | 10.5 | 9.0 | 21 | 1.3 |
| | 1263 | 1141 | 9.4 | 8.9 | 90 | 19 |
| | 1281 | 1156 | 13.7 | 13.3 | | 6.7 |
| | 1341 | 1211 | 2.2 | 2.3 | | 0.8 |
| | 1446 | 1305 | 7.2 | 8.9 | | 0.9 |
| | 1499 | 1354 | 13.9 | 18.5 | | 2.8 |
| | 1525 | 1377 | 1.2 | 1.7 | 38 | 2.7 |
| | 1580 | 1427 | 1.1 | 1.7 | 31 | 11 |
| | 1598 | 1443 | 1.0 | 1.5 | 10 | 10 |
| | 1611 | 1454 | 2.4 | 3.6 | 5.2 | 38 |
| | 1723 | 1556 | 3.6 | 6.4 | | 28 |
| | 1741 | 1572 | 1.1 | 2.0 | 62 | 2.6 |
| | 1982 | 1790 | 9.9 | 23.1 | | 6.6 |
| - | 3182 | 2874 | 1.0 | 6.2 | 3.8 | 133 |
| | 3244 | 2930 | 1.1 | 6.8 | 10 | 61 |
| - | 3306 | 2985 | 1.1 | 7.0 | 5.5 | 73 |

FTIR[a] , Computed[a] and Corrected[a] - Frequencies($cm^{-1}$);
Red.[b] - Reduced masses(amu);
Frc.[c] - Force constants (m Dyne $A^{-1}$) ;
IR.[d] - IR intensity(Km $mole^{-1}$);
R.[e] - Raman scattering activities($A^4$ $amu^{-1}$)

**Table 3.6 Computed values of Acetazolamide at B3LYP/6-31G(d,p) level**

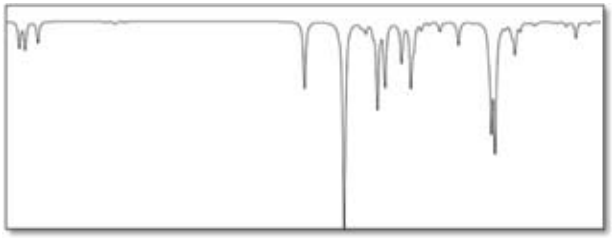
| FT-IR[a] | | Corrected[a] | Red.[b] | Frc.[c] | IR[d] | R[e] |
|---|---|---|---|---|---|---|
| 522 | 543 | 523 | 1.7 | 0.3 | 61 | 1.6 |
| 528 | 549 | 528 | 4.8 | 0.8 | 18 | 1.1 |
| 565 | 588 | 565 | 4.5 | 0.9 | 30 | 2.1 |
| 580 | 603 | 580 | 8.7 | 1.8 | 4.8 | 0.7 |
| 599 | 623 | 599 | 1.9 | 0.4 | 26 | 0.2 |
| 615 | 639 | 614 | 6.4 | 1.5 | 4.4 | 1.1 |
| 636 | 662 | 636 | 7.8 | 2.0 | | 28 |
| 663 | 689 | 662 | 7.2 | 2.0 | 18 | 9.2 |
| 675 | 700 | 674 | 2.9 | 0.8 | | 4.5 |
| 777 | 806 | 776 | 8.6 | 3.3 | 11 | 1.2 |
| 817 | 848 | 816 | 2.8 | 1.2 | 12 | 13 |
| 935 | 972 | 936 | 4.3 | 2.4 | 2.1 | 6.3 |
| 977 | 1016 | 977 | 1.7 | 1.0 | 24 | 3.0 |
| | 1058 | 1018 | 1.6 | 1.1 | 10 | 0.1 |
| | 1072 | 1031 | 11 | 7.8 | 16 | 8.2 |
| | 1102 | 1060 | 1.2 | 0.8 | 2.4 | 4.4 |
| | 1131 | 1088 | 10 | 7.9 | 94 | 49 |
| 1112 | 1157 | 1113 | 13 | 10 | | 12 |
| 1178 | 1226 | 1179 | 2.3 | 2.0 | 92 | 6.6 |
| | 1325 | 1275 | 5.8 | 6.0 | | 0.3 |
| | 1372 | 1320 | 12 | 13 | | 8.4 |
| | 1414 | 1360 | 1.2 | 1.4 | 29 | 26 |
| | 1444 | 1389 | 3.0 | 3.7 | 21 | 61 |
| | 1480 | 1424 | 1.0 | 1.3 | 7.2 | 16 |
| | 1482 | 1426 | 9.3 | 12 | 12 | 46 |
| | 1500 | 1443 | 1.1 | 1.5 | 9.7 | 20 |
| | 1560 | 1501 | 3.6 | 5.2 | | |
| | 1600 | 1540 | 1.1 | 1.6 | 40 | 5.3 |
| | 1788 | 1720 | 10 | 19 | | 50 |
| | 3066 | 2950 | 1.0 | 5.7 | 3.2 | |
| 113 | 3145 | 3026 | 1.1 | 6.4 | 1.2 | 97 |
| | 3152 | 3032 | 1.1 | 6.4 | 10 | 69 |
| | 3514 | 3380 | 1.0 | 7.6 | 41 | 88 |

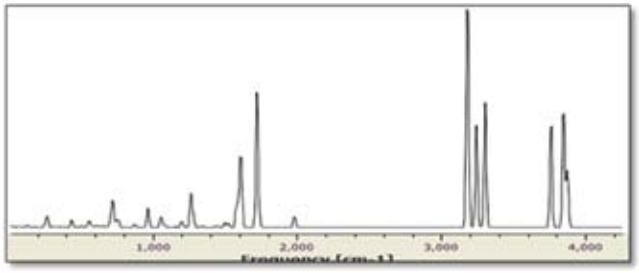
FTIR[a] , Computed[a] and Corrected[a] - Frequencies($cm^{-1}$);
Red.[b] - Reduced masses(amu);
Frc.[c] - Force constants (m Dyne $A^{-1}$) ;
IR.[d] - IR intensity(Km $mole^{-1}$);
R.[e] - Raman scattering activities($A^4$ $amu^{-1}$)

**Table 3.6 Computed values of Acetazolamide at B3LYP/6-31G(d,p) level**

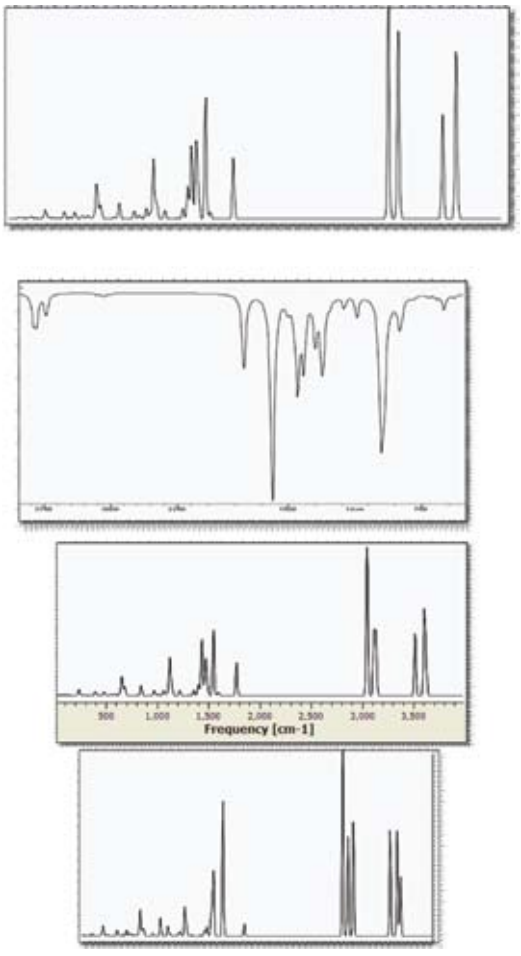
| FT-IR[a] | Computed[a] | Corrected[a] | Red.[b] | Frc.[c] | IR [d] | R[e] |
|---|---|---|---|---|---|---|
| 526 | 546 | 525 | 2.0 | 0.3 | 44 | 0.9 |
| 530 | 550 | 529 | 3.6 | 0.6 | 27 | 1.2 |
| 563 | 584 | 562 | 4.0 | 0.8 | 16 | 2.0 |
| 576 | 600 | 577 | 8.2 | 1.7 | 6.2 | 0.6 |
| 601 | 626 | 602 | 2.0 | 0.4 | 29 | 0.6 |
| 613 | 636 | 612 | 5.1 | 1.2 | 2.3 | 1.3 |
| 630 | 656 | 631 | 6.2 | 1.5 | 202 | 26 |
| 655 | 682 | 656 | 3.6 | 1.0 | 386 | 7.2 |
| 659 | 685 | 659 | 5.9 | 1.6 | 88 | 5.4 |
| 775 | 805 | 774 | 8.4 | 3.2 | 7.7 | 0.7 |
| 811 | 843 | 811 | 3.3 | 1.3 | 21 | 14 |
| 935 | 970 | 933 | 4.3 | 2.4 | 0.9 | 6.9 |
| 972 | 1011 | 972 | 1.7 | 1.0 | 32 | 2.4 |
| 1016 | 1056 | 1016 | 1.7 | 1.1 | 9.1 | 0.2 |
| 1022 | 1062 | 1022 | 11 | 7.3 | 14 | 7.5 |
| 1054 | 1095 | 1054 | 1.2 | 0.8 | 2.7 | 3.7 |
| 1081 | 1125 | 1082 | 10 | 7.9 | 117 | 53 |
| 1103 | 1147 | 1103 | 13 | 10 | 103 | 9.5 |
| 1172 | 1219 | 1172 | 2.3 | 2.0 | 103 | 6.7 |
| 1263 | 1312 | 1262 | 6.2 | 6.3 | 188 | 0.7 |
| 1305 | 1357 | 1306 | 12 | 13 | 203 | 7.1 |
| 1352 | 1403 | 1350 | 1.2 | 1.4 | 38 | 15 |
| 1382 | 1436 | 1382 | 2.9 | 3.5 | 13 | 79 |
| 1413 | 1469 | 1413 | 1.1 | 1.4 | 12 | 19 |
| 1417 | 1474 | 1418 | 5.3 | 6.8 | 9.8 | 32 |
| 1434 | 1490 | 1433 | 1.1 | 1.4 | 11 | 15 |
| 1492 | 1550 | 1491 | 3.2 | 4.6 | 538 | 91 |
| 1539 | 1599 | 1538 | 1.1 | 1.6 | 44 | 3.9 |
| 1706 | 1774 | 1706 | 9.9 | 18 | 160 | 46 |
| 2925 | 3048 | 2932 | 1.0 | 5.6 | 3.1 | |
| - | 3116 | 2998 | 1.1 | 6.2 | 6.2 | 83 |
| 3113 | 3135 | 3016 | 1.1 | 6.3 | 6.5 | 81 |
| 3336 | 3517 | 3383 | 1.0 | 7.6 | 47 | 87 |

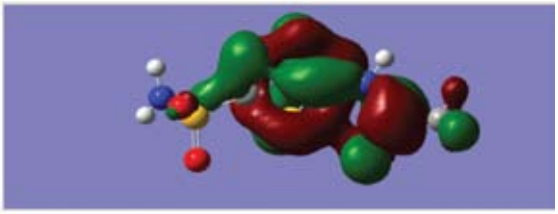
FTIR[a] , Computed[a] and Corrected[a] - Frequencies($cm^{-1}$);
Red.[b] - Reduced masses(amu);
Frc.[c] - Force constants (m Dyne $A^{-1}$) ;
IR.[d] - IR intensity(Km $mole^{-1}$);
R.[e] - Raman scattering activities($A^4$ $amu^{-1}$)

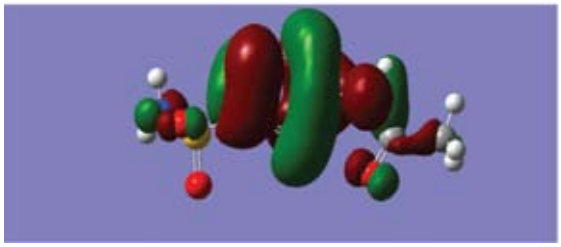




**FTIR spectra of Acetazolamide**





## Conclusion

Thus a complete vibrational band assignment of Acetazolamide has been carried out using FTIR and FTR spectra on the basis of their relative intensity, characteristic positions, correlation and vibrational bands of the related compounds. The structural analysis of the compound has been made using DFT method and the calculated frequencies are agreed very well with the literature values.

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