



The Unshifted Atom-A Simpler Method of Deriving Vibrational Modes of Molecular Symmetries

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ABSTRACT

The infrared and Raman spectroscopy are widely utilized to study molecular structures. Of great interest is the striking correlation between the molecular geometry and the infrared and Raman spectra of simple molecules and ions. This incredible correlation tends to be shadowed by deep theoretical and mathematical principles such that a good number of scholars are denied the joy of appreciating the correlation between molecular symmetry and infrared and Raman spectra. The 'unshifted atom' method presents a highly simplified approach based on basic knowledge of symmetry elements and the effect of symmetry operations on molecular geometries to determine the number of unshifted atoms (US_a). Inserting the Cartesian coordinates (X, Y, Z) on an unshifted atom and applying symmetry operations, the contributions to the character (X_{SO}) by the symmetry operations are obtained. A simple multiplication of the numbers of unshifted atoms (US_a) in a point group with the corresponding numbers of (X_{SO}) generates a REDUCIBLE REPRESENTATION from which the VIBRATIONAL MODES of a molecule/ion are deduced. Examples of different molecular geometries have been presented to illustrate the simplicity, flexibility and viability of the method.

Key words: Vibrational modes, Molecular symmetries, Spectroscopy.

INTRODUCTION

Infrared spectroscopy has been extensively used for both military and civilian purposes since its discovery by Herschel¹ in 1800. In chemistry, it has been utilized for the characterization of molecular structures of simple and complex molecules²⁻⁶. From the study of infrared spectra of a vast range of molecules, scientists have been able to design a chart of characteristic absorption frequencies of molecular functional groups⁷. Such an infrared chart is extremely useful

in predicting the type of functional groups from the infrared spectrum of an unknown sample or the expected absorption ranges of a sample whose molecular formula is known.

Symmetry and group theory principles have been utilized to interpret the bonding and the infrared and Raman spectra mainly of simple molecules^{2,8-11}. In the case of bonding, the molecular bonds are regarded as the basis set or vectors from which a Reducible Representation is generated¹². This is then decomposed into appropriate

Irreducible Representations from bonding information is derived. But in the case of infrared or Raman Spectroscopy, three Cartesian coordinates (x, y, z) are inserted on each atom of the molecule or ion under consideration^{8-9,11,13}. The reason for this is that a molecule possesses Translational, Rotational and Vibrational energies. These are resolved into x, y and z vectors for each of the atom in the molecule. This set of x, y and z coordinates form the BASIS SET for generating irreducible representation

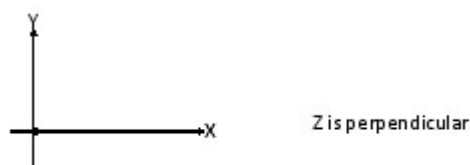
For instance, if CH₄ is being considered for bonding, only 4 vectors are taken into account whereas if IR or Raman Spectroscopy is being considered, 3x5 = 15 (3xN, N = number of atoms in the molecule) Cartesian coordinates will be considered. The use of 3N vectors is not only cumbersome but also the level of mathematical theory accompanying the explanation of IR and Raman spectroscopy⁸⁻¹³ tend to frighten or deny the joy of enjoying the correlation between molecular symmetry and the corresponding IR/Raman spectra of molecules/ions for chemists who may not have a good depth of physical chemistry. Although the concept of unshifted atom has briefly been used before¹⁴⁻¹⁵ no detailed account has been given. The aim of this article is to introduce in details a condensed simple unshifted atom method of deriving the expected number of IR/Raman peaks from the symmetry of simple molecule or ion. Hence, this paper hopes to popularize the unshifted atom method so as to put to rest the cumbersome

conventional and traditional method of dealing with the system of Cartesian coordinates attached to every atom in given molecule or ion to obtain vibrational modes.

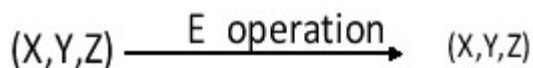
METHODS

The method involves first determining the point group of the molecule or ion. The second step is to determine the number of unshifted atoms (U_s) when acted upon by symmetry operations namely, E, σ_i, C_n and S_n. The final important step is to determine the character by the three coordinates on an unshifted atom. This is illustrated in the diagram below.

THE UNSHIFTED ATOM



IDENTITY (E) OPERATION



Contribution to character will be [(+1) + (+1) + (+1)] = 3.

This can more appropriately be derived from a matrix format as shown below.

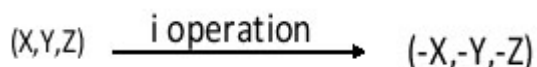
$$E \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

$$E \quad \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$X_E = 3$$

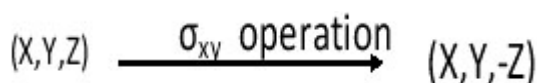
It is not necessary to be using matrices to derive the character of a symmetry operation as this can be easily extracted by inspection of the signs of the Cartesian coordinates after the effect of the symmetry operation.

POINT OF INVERSION (i)



Hence, the contribution to character is $[(-1) + (-1) + (-1)] = -3$.

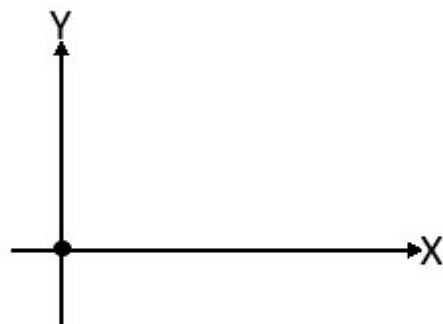
PLANE OF SYMMETRY (σ) OPERATION



Contribution to character will be $[(+1) + (+1) + (-1)] = +1$. In terms of the contribution to character, $\sigma_{xy} = \sigma_{xz} = \sigma_{yz} = +1$.

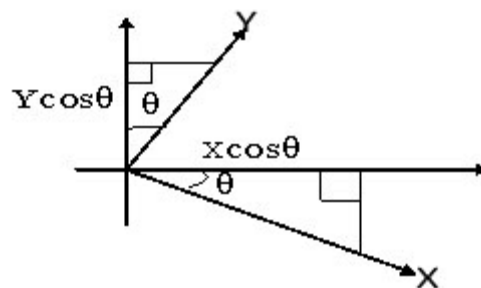
C_n OPERATION

Consider rotation of C_n clockwise through an angle θ



Z is perpendicular

↓ Rotation through θ , clockwise by C_n



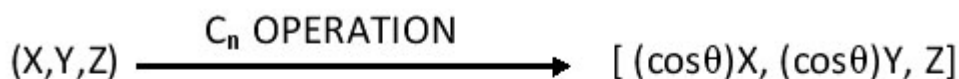
Z is perpendicular

The vector components contributions to the original directions are $X \cos\theta$ by X in the original x-axis and $Y \cos\theta$ by Y vector in the y-axis.

Hence, the contributions to the character by X-vector is $\cos\theta$, and the contribution to the

character by Y vector is also $\cos\theta$. The rotation is done via the principal axis C_n that coincides with z-axis. There is no change in Z vector since it coincides with the principal axis C_n .

Hence,

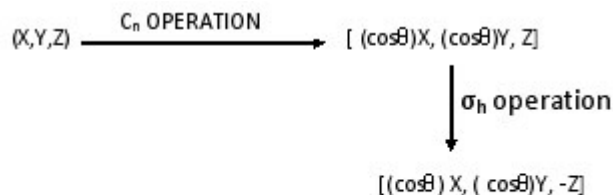


Therefore, $\chi_{C_n} = 2\cos\theta + 1$.

S_n OPERATION

We also know that $S_n = C_n \times \sigma_h$. Therefore,

its operation can be broken into the following operations.



Hence, $\chi_{S_n} = 2\cos\theta - 1$.

Table 1. Summary of symmetry operation contribution to character table.

Contribution to character, (χ so) by unshifted atom (US_a)

E	C _n	S _n	i	σ
+3	$1+2\cos\theta$	$-1+2\cos\theta$	-3	+1
<hr/>				
	n= 2	3	4	6
	C ₂ =-1	C ₃ =0	C ₄ =1	C ₆ =2
	S _n	S ₃ =-2	S ₄ =-1	S ₆ =0

Examples

Let us apply the above concepts to selected molecules/ions to illustrate the power of the method. Initially, we can apply the conventional

method of using all the Cartesian coordinates on a simple molecule such as water, H₂O. Later on we will apply the simpler method for comparison. Consider H₂O as an illustration in Fig.1.

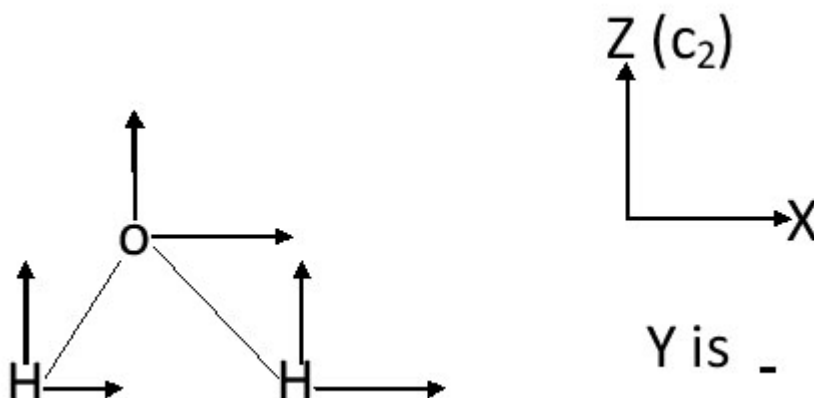


Fig.1: The Cartesian coordinate system of H₂O

Point group is C_{2v} . The identity symmetry operation, E leaves all the 9 Cartesian coordinates unchanged. Hence we insert 9 under E in the C_{2v} character table. The C_2 symmetry operation completely shifts all the Cartesian coordinates on the two H atoms. These contribute zero to the C_{2v} character table. However, $C_2(X,Y,Z)$ on the O atom gives rise to $(-X, -Y, +Z)$. The net contribution to the character of C_2 operation becomes, $[(-1)+(-1)+(1)]$

= -1. The symmetry operation $\sigma_{xz}(X, Y, Z)$ for the O atom, we get $(X, -Y, Z)$ giving a net contribution to the σ_{xz} character of +1. This is the same for each of the two H atoms. Hence, σ_{xz} the overall contribution to the character is +3. Similarly, σ_{yz} will have a contribution to character of +1. The entire set of numbers generated by symmetry operations are known as REDUCIBLE REPRESENTATIONS, Γ_{3N} . This is shown in table 2.

Table 2: The Reducible Representation of H_2O and the C_{2v} Character Table

C_{2v}	E	C_2	σ_{xz}	σ_{yz}
Γ_{3N}	9	-1	3	1
	h=4			
A_1	1	1	1	1
A_2	1	1	-1	-1
B_1	1	-1	1	-1
B_2	1	-1	-1	1

The Reducible representation is then decomposed into Irreducible representations using the following reduction formula.

$$N_{IR} = 1/h \sum X_R X_{IR}$$

N_{IR} = Number of irreducible representations,

h = order of the group (the sum of symmetry operations),

X_R = character of reducible representation,

X_{IR} = character of irreducible representation.

Applying the above formula, we get:

$$N_{A_1} = \frac{1}{4}[9 \cdot 1 + (-1) \cdot 1 + 3 \cdot 1 + 1 \cdot 1] = 3$$

$$N_{A_2} = \frac{1}{4}[9 \cdot 1 + (-1) \cdot 1 + 3 \cdot (-1) + 1 \cdot (-1)] = 1$$

$$N_{B_1} = \frac{1}{4}[9 \cdot 1 + (-1) \cdot (-1) + 3 \cdot 1 + 1 \cdot (-1)] = 3$$

$$N_{B_2} = \frac{1}{4}[9 \cdot 1 + (-1) \cdot (-1) + 3 \cdot (-1) + 1 \cdot (1)] = 2$$

$$\Gamma_{3N} = 3A_1 + A_2 + 3B_1 + 2B_2$$

Selection rules

Γ_{TRANS} = Transform as X, Y and Z

Γ_{ROT} = Transform as R_x , R_y , and R_z

Hence, $\Gamma_{TRANS} = A_1 + B_1 + B_2$ since they transform as X, Y and Z and $\Gamma_{ROT} = A_2 + B_1 + B_2$ since they transform as R_x , R_y , and R_z .

Since, $\Gamma_{3N} = \Gamma_{TRANS} + \Gamma_{ROT} + \Gamma_{VIB}$,

then $\Gamma_{VIB} = \Gamma_{3N} - \Gamma_{TRANS} - \Gamma_{ROT}$. Thus,

$$\Gamma_{VIB} = (3A_1 + A_2 + 3B_1 + 2B_2) - (A_1 + B_1 + B_2) - (A_2 + B_1 + B_2)$$

$$\Gamma_{VIB} = 2A_1 + B_1$$

Selection rules

IR_{ACTIVE} transform as x, y, and z

RM_{ACTIVE} transform as Products of x, y, and z.

IR_A = Infrared active and RM_A = Raman active.

Since $A_1 + B_1$ symmetries are IR and Raman active, we expect to see 3 PEAKS in both IR and Raman spectra. These are (cm^{-1}) 3657, 1595 and 3756.

Applying the simpler method on H₂O.AB₂ system**Table 3: Derivation of Reducible Representation of H₂O using shorter and simpler method.**

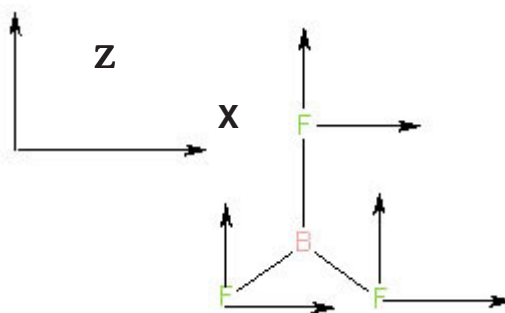
C_{2v}	E	C_2	σ_{xz}	σ_{yz}
US _a	3	1	3	1
χ_{SO}	3	-1	1	1
Γ_{3N}	9	-1	3	1

This means that determining the number of unshifted atoms (US_a) by each of the symmetry operations and the contribution to the character (χ_{SO}) by each symmetry operation and multiplying them easily produces (Γ_{3N}). Thus, $\Gamma_{3N} = (US_a) \times (\chi_{SO})$. Then, Γ_{3N} can be decomposed into Irreducible representations in the usual way as described above.

Let us take a few more examples to illustrate the power of the method.

AB₃ SYSTEM

Consider BF₃ as shown in Fig.2. This has a D_{3h} point group.

**Fig. 2: The coordinate system of BF₃**

The starting point is to generate the number of unshifted atoms (US_a) by each symmetry operation of the D_{3h} point group. Under E operation, all atoms of BF₃ are not shifted. Hence, we enter 4 under E operation. The number of unshifted atoms for C₃, C₂, σ_h, S₃, and σ_h are 1, 2, 4, 1 and 2

respectively. The corresponding contribution to character (χ_{SO}) by each symmetry operation obtained from Table 1 are also recorded. The product of US_a, χ_{SO} and the corresponding number of symmetry operations, produces the row of Reducible Representation Γ_{3N} . These are given in Table 4.

Table 4: Derivation of Reducible Representation for generating vibrational symmetries for BF₃

D _{3h}	E	2C ₃	3C ₂	σ _h	2S ₃	3σ _v
US _a	4	1	2	4	1	2
χ_{SO}	3	0	-1	1	-2	1
Γ_{3N}	12	0	-6	4	-4	6

Using the reduction formula, Γ_{3N} is the decomposed into Irreducible Representation symmetries which comprise of Γ_{TRANS} , Γ_{ROT} , and Γ_{VIB} . The symmetries of Γ_{TRAN} and Γ_{ROT} are extracted from D_{3h} character table. They are then subtracted from Γ_{3N} leaving Γ_{VIB} symmetries. Applying the selection rules to Γ_{VIB} symmetries, we can deduce how many are IR active or Raman active. In the case of BF_3 , we expect to observe 3 peaks in IR spectrum and 3 peaks in Raman spectrum with 2 peaks in common. This is what is observed* and is given in Table 5.

$$\begin{aligned}\Gamma_{3N} &= A1' + A2' + 3E' + 2A2'' + E'' \\ \Gamma_{\text{TRANS}} &= E' + A2'' \\ \Gamma_{\text{ROT}} &= A_2' + E'' \\ \Gamma_{\text{VIB}} &= A_1' + 2E' + A2'' \\ \text{IR}_A &= \checkmark \quad \checkmark \rightarrow 3 \text{ peaks} \\ \text{RM}_A &= \checkmark \quad \checkmark \rightarrow 3 \text{ peaks}\end{aligned}$$

Table 5: IR and Raman Spectral data² of BF_3

$\text{BF}_3(\text{g})$	A1'	A2''	E'	E'
cm ⁻¹	888	718	1505	482
	RM_A	IR_A RM_A	IR_A RM_A	IR_A

$$\begin{aligned}\Gamma_{3N} &= A_1 + E + T_1 + 3T_2 \\ \Gamma_{\text{TRANS}} &= T_2 \\ \Gamma_{\text{ROT}} &= T_1 \\ \Gamma_{\text{VIB}} &= A_1 + E + 2T_2 \\ \text{IR}_A &= \checkmark \quad \checkmark \rightarrow 2 \text{ peaks} \\ \text{RM}_A &= \checkmark \quad \checkmark \quad \checkmark \rightarrow 4 \text{ peaks}\end{aligned}$$

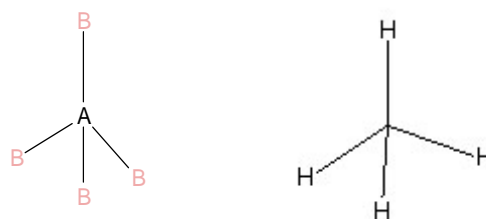
2 in common

As can be seen from tables 6 and 7, the theoretical model is consistent with the experimental data.

AB₄ SYSTEM TETRAHEDRAL (T_d)

Example

The reason why this method is so easy is that it eliminates the burden of visualizing the set of all coordinates on the atoms within the molecule/ion. It only focuses on the unshifted atom(s) by a symmetry operation (US_a) and the corresponding contribution to the character (χ_{so}) by the symmetry operation. When this approach is applied to CH_4 shown in Fig.3. the results obtained are given in Table 6.

Fig. 3: Tetrahedral geometry of CH_4 Table 6. Derivation of Reducible Representation for generating vibrational symmetries for CH_4

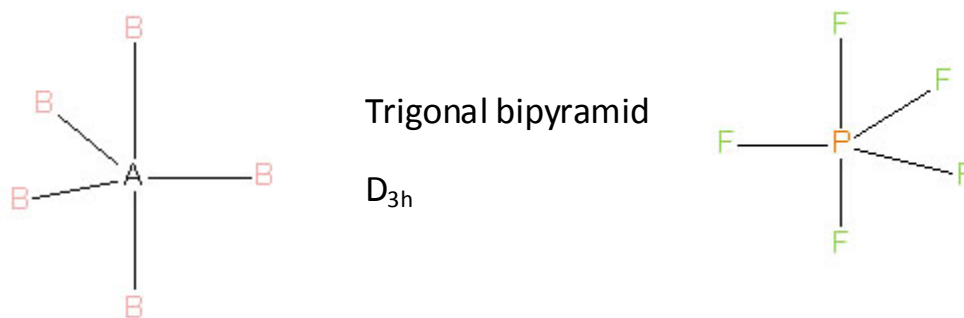
T_d	E	$8C_3$	$3C_2$	$6S_4$	$6\sigma_d$
US_a	5	2	1	1	3
χ_{so}	3	0	-1	-1	1
Γ_{3N}	15	0	-3	-6	18

Table 7: IR and Raman Spectral data² of CH_4

CH_4	A ₁	E	T ₂	T ₂
cm ⁻¹	2917	1534	3019	1306
IR_A			\checkmark	\checkmark
RM_A	\checkmark	\checkmark	\checkmark	\checkmark

AB₅ SYSTEM

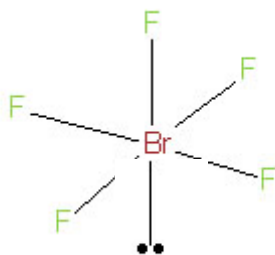
The application of the method to PF_5 shown in Fig. 4 gives us the results shown in tables 8 and 9.

Fig. 4: The trigonal bipyramid of PF_5 Table 8: Derivation of Reducible Representation for generating vibrational symmetries for PF_5

D_{3h}	E	$2C_3$	$3C_2$	σ_h	$2S_3$	$3\sigma_v$
US_a	6	3	2	4	1	4
X_{so}	3	0	-1	1	-2	1
Γ_{3N}	18	0	-6	4	-4	12
Γ_{3N}	$2A_1'$	A_2'	$4E'$	$3A_2''$	$2E''$	
Γ_{TRANS}			E'	A_2''		
Γ_{ROT}		A_2^D			E''	
Γ_{VIB}	$2A_1'$		$3E'$	$2A_2''$	E''	
IR_A			√	√		5 peaks
RM_A	√		√		√	6 peaks
3 COMMON						

Table 9: IR and Raman Spectral data² of PF_5

$PF_5(g)$	A_1'	A_1'	A_2''	A_2''	E'	E'	E'	E''
	817	640	944	575	1026	532	300	514
IR_A			√	√	√	√	√	√
RM_A	√	√			√	√	√	√

 AB_6 molecules including one lone pairFig. 5: The square pyramidal geometry of BrF_5 .

The unshifted atom method indicates that BrF_5 molecule is expected to show 6 and 9 peaks in IR and Raman respectively with 6 peaks in common. This is shown in Table 10 and is consistent with the experimental data in Table 11.

Table 9: IR and Raman Spectral data² of BrF₅

BrF ₅	A ₁	A ₁	A ₁	B ₁	B ₁	B ₂	E	E	E
cm ⁻¹	682	570	365	535	281	312	644	414	237
IR _A	√	√	√		√	√	√		
RM _A	√	√	√	√	√	√	√	√	√

Table 10: Derivation of Reducible Representation for generating vibrational symmetries for BrF₅

C _{4v}	E	2C ₄	C ₂	2σ _v	2σ _d	
US _a	6	2	2	4	2	
X _{so}	3	1	-1	1	1	
Γ _{3N}	18	4	-2	8	4	
Γ _{3N}	4A ₁	A ₂	2B ₁	B ₂	5E	3N=18
Γ _{TRANS}	A				E	
Γ _{ROT}		A ₂			E	
Γ _{VIB}	3A ₁		2B ₁	B ₂	3E	3N-6=12
IR _A	√				√	6 peaks
RM _A	√		√	√	√	9 peaks

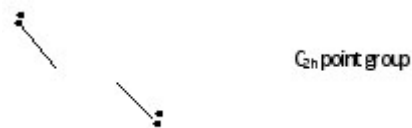
More examples

Due to the viability of the method, let us apply it to a few more molecular geometries.

The theoretical and experimental data are given in tables 10 and 11.

ISOMERS OF N₂F₂

TRANS ISOMER

**Fig. 6: The geometry of trans-N₂F₂****Table 10: Derivation of Reducible Representation for generating vibrational symmetries for PF₅**

C _{2h}	E	C ₂	i	σ _h	
US _a	4	0	0	4	
X _{so}	3	-1	-3	1	
Γ _{3N}	12	0	0	4	
Γ _{3N}	4A _g	2B _g	2A _u	4B _u	3N=12
Γ _{TRANS}			A _u	2B _u	
Γ _{ROT}	A _g	2B _g			
Γ _{VIB}	3A _g		A _u	2B _u	3N-6=6
IR _A			√	√	3peaks
RM _A	√				3 peaks
	no peaks in common				

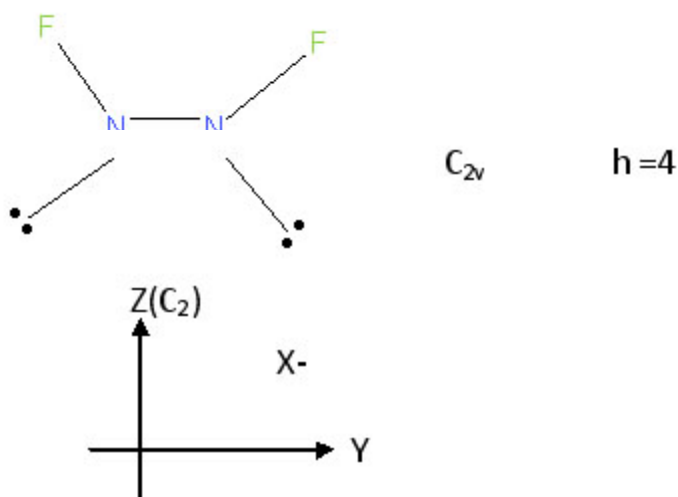
Table 11: IR and Raman Spectral data² of Trans N₂F₂

Trans-N ₂ F ₂ (l)	A _g	A _g	A _g	B _u	B _u	A _u
cm ⁻¹	1010	1522	600	990	423	364
IR _A	√	√	√			
RM _A				√	√	√
no peaks in common, total 6 peaks						

The data clearly shows that a molecule with a centre of symmetry, the IR spectrum and Raman spectrum have no peaks in common.

CIS ISOMER

The theoretical and experimental data for the cis-N₂F₂ are given in Tables 12 and 13.

**Fig. 7: The geometry of cis-N₂F₂****Table 12: Derivation of Reducible Representation for generating vibrational symmetries for Cis- N₂F₂**

C _{2v}	E	C ₂	σ _{xz}	σ _{yz}	
US _a	4	0	0	4	
X _{so}	3	-1	1	1	
Γ _{3N}	12	0	0	4	
Γ _{3N}	4A ₁	2A ₂	2B ₁	4B ₂	
Γ _{TRANS}	A ₁		B ₁	B ₂	
Γ _{ROT}		A ₂	B ₁	B ₂	
Γ _{VIB}	3A ₁	A ₂		2B ₂	
IR _A	√			√	5 peaks
RM _A	√	√		√	6 peaks
5 peaks in common					

Table 13: IR and Raman Spectral data² of Cis-N₂F₂

Cis-N ₂ F ₂ (l)	A ₁	A ₁	A ₁	B ₂	B ₂	A ₂
cm ⁻¹	896	1525	341	952	737	550
IR _A	√	√	√	√	√	
RM _A	√	√	√	√	√	√
	5 peaks in 'common'					

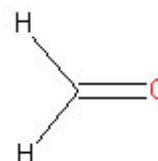
It is also interesting to note that the less symmetrical a molecule is, the more peaks are observed.

The A-X stretching frequencies

The vibrational stretching frequencies are extremely useful in characterizing molecular structures. The stretching modes refer to the stretch between two atoms (A-X). A-X can refer to two atoms such as C-H, C=O, C-Cl, N-H and C-S.

Let us take H₂CO molecule as an illustration. It has a C_{2v} geometry as shown below.

Using the 'unshifted atom method', it is predicted that 6 peaks to be observed. Furthermore, two C-H stretching frequencies and one CO stretching frequency are expected. This is in agreement with the experimental data. This is summed up in Table 14.

**Fig. 8: The geometry of H₂CO****Table 14: Derivation of Reducible Representation for generating vibrational symmetries for H₂CO as well the spectral data of H₂CO**

C _{2v}	E	C ₂	Γ _{xz}	Γ _{yz}		
US _a	4	2	4	2		
X _{so}	3	-1	1	1		
Γ _{3N}	12	-2	4	2		
Γ _{3N}	4A ₁	A ₂	4B ₁	3B ₂		
Γ _{TRANS}	A ₁		B ₁	B ₂		
Γ _{ROT}		A ₂	B ₁	B ₂		
Γ _{VIB}	3 A ₁		2 B ₁	B ₂		
IR _A	√		√	√	6 peaks	
RM _A	√		√	√	6 peaks	
C-H	2	0	2	0		
Γ _{CH}	A ₁		B ₁		2 peaks	
C=O	1	1	1	1		
Γ _{CO}	A ₁				1 peak	
H ₂ CO ³	2783	1746	1500	2843	1249	1167
	A ₁	A ₁	A ₁	B ₁	B ₁	B ₂
C-H	√			√		
C=O		√				

Metal carbonyls

Consider the C≡O stretching frequencies. Hence use C≡O bonds as the as the BASIS SET.

The C≡O stretching frequency can be used for structural analysis of carbonyls. This is illustrated by the examples of Ni(CO)₄, and the distinction of the isomers of MX₂(CO)₄. The results are given in Tables 15-17.

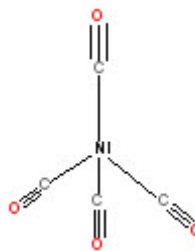


Fig. 9: The geometry of Ni(CO)₄

Table 15: Derivation of Reducible Representation for generating vibrational symmetries for C≡O stretching frequencies of Ni(CO)₄

T _d	E	8C ₃	3C ₂	6S ₄	6σ _d
CO	4	1	0	0	2
Γ _{CO}	4	8	0	0	12
Γ _{CO}	A ₁	T ₂			
IR _A		√			1 peak
RM _A	√	√			2 peaks

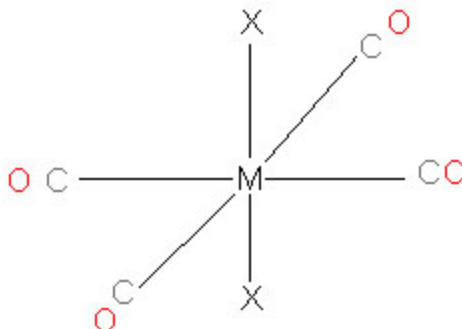
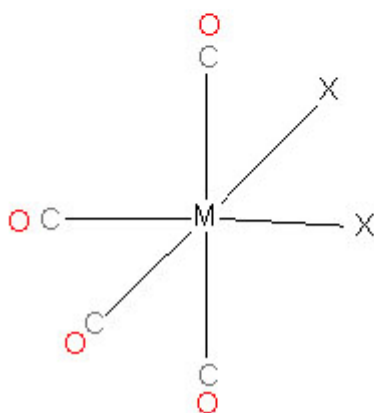
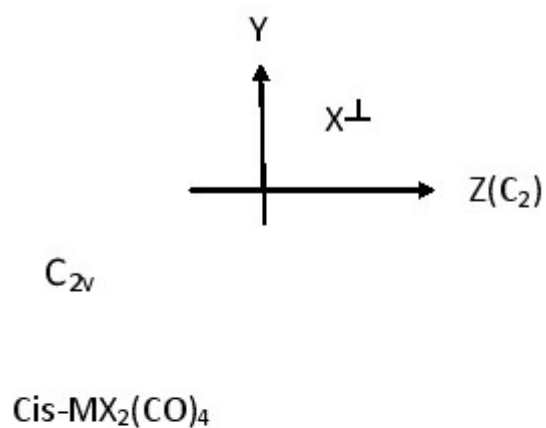


Fig. 10: The geometry of trans-MX₂(CO)₄

Table 16: Derivation of Reducible Representation for generating vibrational symmetries for C≡O stretching symmetries of Trans-MX₂(CO)₄

D _{4h}	E	2C ₄	C ₂	2C ₂ ^D	2C ₂ ^{D D}	i	2S ₄	σ _h	2σ _v	2σ _d
CO	4	0	0	2	0	0	0	4	2	0
Γ _{CO}	4	0	0	4	0	0	0	4	4	0
Γ _{CO}	A _{1g}	B _{1g}	E _u							
IR _A			√							1 peak
RM _A	√	√								2 peaks
	no peaks in common									

Fig. 11: The geometry of $cis-MX_2(CO)_4$ Table 17: Derivation of Reducible Representation for generating vibrational symmetries for C≡O stretching symmetries of $Cis-MX_2(CO)_4$

C_{2v}	E	C_2	σ_{xz}	σ_{yz}	
CO	4	0	2	2	
\tilde{A}_{CO}	$2A_1$	B_1	B_2		
IR_A	√	√	√		4 peaks
RM_A	√	√	√		4peaks
	all in common				

It should be noted that when considering stretching frequencies, the filtration of Γ_{TRANS} and Γ_{ROT} is not involved. on

CONCLUSION

This paper aims to appeal to many readers of science so as to greatly appreciate the correlation

between the symmetry and point group of a molecule/ion on one hand and its infrared/Raman spectrum on the other. The molecule could be as simple as C_2H_4 or P_4 to more complex ones such as C_6H_6 or C_{60} . It is hoped that from various backgrounds such biology, biochemistry, chemistry, physics, mathematics and geology among others will enjoy reading this article.

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