

Structural and Antimicrobial Studies of Coordination Compounds of Phenylalanine and Glycine

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Abstract

Coordination compounds of glycine and phenylalanine were synthesized, characterized using electronic and infrared spectroscopy, magnetic susceptibility measurement and mass spectrometry. The ligands coordinated to the metal in a bidentate fashion using N and O donor atoms. Square planar geometry is proposed for the Mn(II), Co(II), Ni(II) and Cu(II) complexes based on the results obtained from their characterization. Tetrahedral geometry is however proposed for the Cd(II) complexes. The *in-vitro* biological effect of the synthesized compounds was investigated. The compounds were tested against three gram-negative bacteria, *E. coli*, *P. aeruginosa*, *P. vulgaris*, three gram positive bacteria, *S. aureus*, *B. subtilis*, MRSA and a fungus *C. Albicans*. A comparative study of the zones of inhibition observed for the ligand and coordinated synthesized compounds indicated that the synthesized compounds, in some cases, showed higher zones of inhibition than that of the free ligands. It is therefore suggested that increasing the number of chelate rings may increase the lipophilicity of the coordinated complex and therefore its antimicrobial activity.

Keywords: Phenylalanine, Glycine, Lipophilicity, Antimicrobial agent, Coordination, Gram-Positive, Gram-negative

1. Introduction

The study of coordination compounds has received much attention in recent years. This interest was generated by the discovery of the anti-bacterial, -fungal and -cancer activities of several coordination compounds. As a result, studies have been carried out on the structure and chemical behavior of several metal complexes (Chohan et al., 2006). Various *in-vivo* studies have shown that biologically active compounds become more bacteriostatic and carcinostatic upon chelation (Chohan et al., 2006; Hussein et al., 2008). Amino acids, which are also components of proteins, offer excellent ligands for binding to metal ions (Zhang & Lippard, 2003; Kostova, 2006). The properties of coordination compounds are influenced to a considerable extent by the nature and the oxidation state of the central metal atom. A method of studying this influence is by comparing the compounds formed by a series of metal atoms in a given oxidation state with a particular ligand (Komiya et al., 2008).

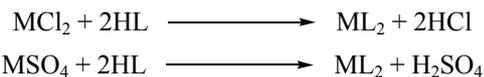
Although coordination compounds of amino acids, such as histidine (Nomiya et al., 2000), arginine, glutamic acid (Legler et al., 2001) have been synthesized and their antimicrobial properties studied, little attention has been focused on hydrophobic amino acids, such as phenylalanine. Chelation of bulky ligands to metal cations reduces the polarity of the ion. Due to the glycolipophilic nature of the cell wall, an increase in the lipophilicity of a coordination compound enhances its ability to penetrate bacterial cell membrane. This concept has been applied to the molecular design of coordination complexes of phenylalanine (**1**). Phenylalanine is a hydrophobic amino acid with a bulky benzyl R side chain. The results obtained are then compared with that of similar coordination complexes of glycine (**2**), (the simplest amino acid).

This paper reports the synthesis and characterization of coordination compounds of manganese (Mn), cobalt (Co), copper (Cu), cadmium (Cd) and nickel (Ni) with phenylalanine (**1**) and glycine (**2**), metal to ligand ratio 1:2 and the evaluation of their antimicrobial activities.

2. Materials and Methods

2.1 General

All reagents and solvents used were of analytical grade. The complexes were prepared according to a modification of literature procedure (Nomiya & Yokoyama, 2002). The infrared spectra were recorded on a Genesis II FTIR spectrophotometer in the range 450-4200 cm^{-1} (KBr discs). The solid reflectance electronic absorption spectra of the complexes in the range 200-1000 nm were obtained with a Genesys UV-Vis spectrophotometer. Melting points or decomposition temperatures (M.P/D.T.) was measured using open capillary tubes on a Gallenkamp (variable heater) melting point apparatus. The magnetic susceptibility for some of the complexes was measured at room temperature using a MSB-AUTO (Sherwood scientific) Gouy balance. Mass spectra were obtained with a GCT premier mass spectrometer, by direct insertion electron impact ionization with a time of flight (TOF) analyzer. The general equations for the reactions are as follows:



Where M = Co(II), Cu(II), Mn(II), Ni(II), Cd(II); L = phenylalanine and glycine.

2.2 Preparation of Coordination Complexes

The coordination compounds were prepared by the addition of 0.01 M (2.46, 2.61, 2.38, 1.72 and 2.11 g) of the appropriate metal salt (manganese, cobalt, nickel, copper, and cadmium respectively) to a solution of the ligand (**1**) 0.02 M, 3.37 g and (**2**) 0.02 M, 1.52 g. The mixture was then heated to reflux for 1 h, using a water bath. Precipitates were formed within the refluxing time for majority of the complexes, while some required concentration on a water bath and cooling before solid products were obtained. The products obtained were filtered and washed with methanol. Products were then dried *in vacuo* at 60 °C.

2.3 Antimicrobial Activity using Disc Diffusion Assay

The *in vitro* antimicrobial properties of the complexes were performed at the Pharmaceutics laboratory at the department of Pharmaceutics, Faculty of Pharmacy Obafemi Awolowo University, using a modification of literature procedure (Murray et al., 1995). The strains used were *Escherichia coli* NCTC 8196, *Pseudomonas aeruginosa* ATCC 19429, *Staphylococcus aureus* NCTC 6571, *Proteus vulgaris* NCIB, *Bacillus subtilis* NCIB 3610 and Methicillin resistant *S. aureus* clinical isolate for bacteria and *C. albicans* NCYC 6 for fungi. The standard strains were from stocks of culture collections maintained in the laboratory. Bacteria were maintained on nutrient agar slants and fungi on Sabouraud Dextrose Agar slants at 4 °C and subcultured monthly. Each test agent (20 mg) was dissolved in 1 ml sterile distilled water boiled gently in a Bunsen flame. Discs of Whatman No 1 filter paper (ϕ 6 mm) were soaked with 2 drops of the test agent using a sterile Pasteur pipette and allowed to dry at room temperature.

Two colonies of a 24-hour plate culture of each organism were transferred aseptically into 10 ml sterile distilled water in a test tube and mixed thoroughly, using an electric shaker, for uniform distribution. A sterile cotton swab was then used to spread the resulting suspension uniformly on the surface of oven-dried Mueller Hinton Agar (Oxoid) and Sabouraud Dextrose Agar plates (Sterillin) for bacteria and fungi, respectively. These were incubated for an hour at 37 and 25 °C for bacteria and fungi, respectively. Sterile forceps were used to aseptically place each of the discs on the agar plates and the plates were then refrigerated for 30 min at 4 °C following which, the inoculated plates were incubated at 37 °C for 24 hours for bacteria strains and at 25 °C for 72 hours for the fungal strain. Antimicrobial activity was evaluated by noting the zone of inhibition against the test organisms (Murray et al., 1995).

3. Results and Discussion

3.1 General

All the complexes were sparingly soluble in general organic solvents. The melting points or decomposition temperatures are shown in Table 1, most of the complexes decomposed before melting. A square planar structure is proposed for the complexes with exception of the cadmium complexes. Based on the valence bond theory for a d^{10} system, a tetrahedral geometry is proposed for the cadmium complexes. Attempts to isolate suitable crystals for single X-ray structural determination have not been successful so far.

3.2 Electronic Spectra

The electronic spectra data are presented in Tables 2 and 3. Analysis of the spectra was carried out by the comparison of the spectra of the complexes with that of their respective ligands. This revealed a shift in some of the bands observed in the ligand and the appearance of new bands in the visible region for the complexes.

3.2.1 Phenylalanine Complexes

Ligand (1) exhibited absorption bands at 196 nm (λ_1), 217 nm (λ_2), attributed to the $n \rightarrow \pi^*$ and 233 nm (λ_3), 268 nm (λ_4), $\pi \rightarrow \pi^*$ of the carbonyl, amino and benzene ring. A shift was observed generally for all the complexes indicating coordination. The Co(II) complex exhibited a band at 496 nm and 526 nm which is assigned to ${}^2A_{1g} \rightarrow {}^2B_{2g}$, and ${}^2A_{1g} \rightarrow {}^2E_{1g}$ transition, typical for a paramagnetic d^7 Co(II) configuration (Konstantinovic et al., 2003). The electronic spectra of the copper complex showed two bands at 541 and 565 nm, with a shoulder at 595 nm which can be assigned to ${}^2B_{2g} \rightarrow {}^2A_{1g}$, ${}^2B_{1g} \rightarrow {}^2B_{2g}$, and ${}^2B_{1g} \rightarrow {}^2E_{1g}$ transitions (Miessler & Tarr, 1999; Lever, 1984). The electronic spectrum of the nickel complex showed two bands at 538 and 547 nm which are attributed to ${}^1A_{1g} \rightarrow {}^1A_{2g}$ and ${}^1A_{1g} \rightarrow {}^2B_{2g}$ transitions (Cotton et al., 1999) indicating a distorted square planar geometry and is supported by the magnetic moment. Manganese complex exhibited bands at, 499, 538, 547 nm and assigned as ${}^6A_{1g} \rightarrow {}^4T_{1g}$; ${}^6A_{1g} \rightarrow {}^4E_g$; ${}^6A_{1g} \rightarrow {}^4E_g$ respectively. The Cd(II) complex spectra showed no d-d transition. This is expected, since cadmium has a filled $4d$ orbital in the ground state (Greenwood & Earnshaw, 1997).

3.2.2 Glycinato Complexes

Ligand (2) exhibited absorption bands at 199 nm, 211 nm, attributed to the $n \rightarrow \pi^*$ 244 nm, $\pi \rightarrow \pi^*$ of the carbonyl and amino moiety. A shift was observed generally for all the complexes indicating coordination. The Co(II) complex exhibited two bands at 511 and 820 nm with a shoulder at 523 nm. These are assigned to ${}^2B_{1g} \rightarrow {}^2A_{1g}$, ${}^2B_{1g} \rightarrow {}^2E_{1g}$ and ${}^2B_{1g} \rightarrow {}^2B_{2g}$ transitions respectively, typical for square planar configuration around Co(II) (Cotton et al., 1999; Konstantinovic et al., 2003). Two bands were observed in the electronic spectrum of the copper complex, at 637 nm and 820 nm which can be assigned to ${}^2B_{1g} \rightarrow {}^2B_{2g}$ and ${}^2B_{1g} \rightarrow {}^2E_{1g}$ transitions (Miessler & Tarr, 1999). The electronic spectrum of the nickel complex showed two bands at 526 nm and a shoulder at 541 nm which are attributed to ${}^1A_{1g} \rightarrow {}^1A_{2g}$ and ${}^1A_{1g} \rightarrow {}^2B_{2g}$ transitions (Cotton et al., 1999). The spectrum for the manganese complex showed transition bands at 433, 496 and 541 nm, respectively assigned as ${}^6A_{1g} \rightarrow {}^4T_{1g}$; ${}^6A_{1g} \rightarrow {}^4E_g$; ${}^6A_{1g} \rightarrow {}^4E_g$. The Cd(II) complex spectra showed no $d-d$ transition. This is expected, since cadmium has a filled $4d$ orbital in the ground state (Greenwood & Earnshaw, 1997).

3.3 Infra-red Spectra

The IR spectral assignment of the metal complexes was achieved by comparing their vibration frequencies with those of the free ligands and literature reports of similar compounds. Relevant IR band frequencies are shown in Tables 4-5.

3.3.1 Phenylalanine Complexes

The bands observed for the various moieties are in close agreement with those reported for phenylalanine complexes by Saunders, 2009.

The COO^- stretching frequencies of complexes of amino acids have been reported to be affected by coordination, and as such, are useful tools in the structural elucidation of amino acid complexes (Nakamoto, 1986; Pavia et al., 2001). In the free ligand, the COO^- bond is symmetric and the two bond lengths are equal (3). Two bands are therefore observed, the symmetric and the asymmetric stretching frequency bands (4a, 4b). On coordination (5), the asymmetric stretching frequency shifts to higher energy, while the symmetric stretching to lower. The absorption bands at 1626 cm^{-1} and 1566 cm^{-1} in the free ligand are attributed to the COO^- .

The asymmetric frequency bands were shifted to higher values on coordination except in complexes of cadmium and copper. On the other hand, bathochromic shifts was observed for the symmetric bands. The N-H bending vibration band in aromatic compounds, often overlap the aromatic C=C ring absorption band, which also appears

in this region (Nakamoto, 2009). Consequently, a distinct C=C band was not obtained for most of the complexes. The -NH_2 stretching frequency reduced on coordination, attributable to the reduction in bond order on coordination (Nakamoto, 2009). N-H \cdots O interaction was also observed in all the complexes.

In complexes of amino acids, hydrogen bonding has been reported to occur between carboxyl oxygen atoms, which are not coordinated to the metal, and the amino group of the neighbouring molecule (Nakamoto, 2009; Saunders, 2009). Consequently, the COO^- stretching frequencies are affected by coordination and intermolecular interactions. This was observed in all the complexes synthesized. Hydrogen atoms of the amino group interact with the uncoordinated oxygen atom of the carboxylate group, giving N-H \cdots O interaction. The result of this are the sharp extended bands observed at $\sim 3340\text{-}3870\text{ cm}^{-1}$ in. Band frequencies observed at $469\text{-}472\text{ cm}^{-1}$ are assigned to (M-N) bond. The participation of the lone pairs of electrons on the N of the amino group in the ligand is supported by this band frequency (Osunlaja et al., 2009). New bands were observed in the region of $693\text{-}699\text{ cm}^{-1}$, indicating formation of M-O bond and support the coordination of the ligand to the central metal ions via the oxygen atom of the carboxylate group (Nakamoto, 2009).

3.3.2 Glycine Complexes

The glycine ligand $\nu_{\text{asy}}(\text{COO}^-)$ was observed at 1615 cm^{-1} and the $\nu_{\text{sy}}(\text{COO}^-)$ at 1457 cm^{-1} . Sharp extended bands were observed in the expected region. This is expected as a result of the zwitterionic nature of the ligand in the crystalline form. On coordination, hypsochromic shifts were observed for the asymmetric stretching frequencies. This is in agreement with reported literature (Nakamoto, 2009). Sharp extended bands at $\sim 3280\text{-}3870\text{ cm}^{-1}$ were also observed in all the complexes, indicating hydrogen bonding between the uncoordinated oxygen atom of the carboxyl group and the amino group of neighbouring molecule. The band frequencies at $502\text{-}530\text{ cm}^{-1}$ were assigned to (M-N) bond and those at $718\text{-}742\text{ cm}^{-1}$ to the M-O stretching.

3.4 Magnetic Moments

Measurements of the effective magnetic moments of coordination compounds can be used to estimate the number of unpaired electrons. The stereochemistry and bond type of the coordinated metal ion can then be determined from the information derived from it (Greenwood & Earnshaw, 1997). The magnetic moments for some of the complexes were obtained and the results are presented in Table 5.

3.4.1 Nickel(II) Complexes

There is no clear cut distinction between the magnetic moments of tetrahedral and octahedral Nickel(II) complexes. This is because they both have the same number of unpaired electrons in the d -orbital. However, the square planar Nickel(II) complex is diamagnetic. A magnetic moment of 1.15BM was observed for $\text{Ni}(\text{phe})_2$. This is interpreted as an indication of a low-spin-high-spin equilibrium mixture with paramagnetic Nickel(II) species and agrees with what was reported by Woods and Patel (1994).

3.4.2 Cobalt(II) Complexes

The $\text{Co}(\text{phe})_2$ complex has a magnetic moment of 2.32 BM which indicates a square planar geometry having one unpaired electron (Greenwood & Earnshaw, 1997).

3.4.3 Cadmium(II) Complexes

The magnetic moment of the Cadmium complex was zero. This value indicates that the complex has no unpaired electron. It is diamagnetic. This is expected for a d^{10} system in which the $4d$ orbital is completely filled. The value observed is in accordance to that reported on other Cadmium(II) complexes (Anaconda et al., 2005).

3.4.4 Copper(II) Complexes

Copper coordination compounds have magnetic moments in the range of 1.9-2.2 BM, indicating that it has one unpaired electron (Greenwood & Earnshaw, 1997). The observed magnetic moments of 1.93 BM is therefore similar and indicates a single unpaired electron as expected for a d^9 system. This is also supported by evidence from the UV-Vis spectra, indicating a square planar complex.

3.4.5 Manganese(II) Complexes

The Mn (II) complex, Mnphe_2 , has a high spin magnetic moment of 5.29 BM, expected for a d^5 system with five unpaired electrons. The zero Crystal Field Stabilisation Energy (CFSE) of the high-spin configuration confers no advantage of any particular stereochemistry for Mn(II) ion (Greenwood & Earnshaw, 1997). Hence magnetic moment values are unlikely to be of significance in discriminating between the metal ions in octahedral or tetrahedral field symmetries. However, the value obtained agrees well with works published for d^5 Mn(II) systems (Anaconda et al., 2005).

3.5 Mass Spectrum

The low resolution electron impact (E.I) mass spectra of that of the ligands and Cd(phe)₂ were obtained. The probable fragmentation patterns are presented in Figures 1-3 and are shown below.

3.5.1 Phenylalanine

A weak molecular ion m/z 165, 2 % was observed in the mass spectrum of phenylalanine. The fragmentation pattern of the molecular ion followed three pathways, X, Y, Z. Pathway X involves the loss of the carboxylic acid radical COOH to give the positive ion at m/z 120, 57 %. This fragments further by rupturing of the C-N bond, leading to the loss of NH₂ to give a peak at m/z 103, 10 %. Pathway Y involves the α bond cleavage leading to the loss of the benzylic radical to give the ion at m/z 74, the base peak. In pathway Z the molecular ion loses m/z 74, to give the benzylic cation at m/z 91, 63 %, with subsequent rearrangement to give the tropylium ion. The ion expels C₂H₂ (acetylene) giving the peak at m/z 65, 6 % and this fragmentation give gives rise to a metastable ion at $65^2/91 = 46$. The benzylic cation also fragments to give the phenyl cation m/z 77, 15 %, with subsequent extrusion of C₂H₂ to give a peak at m/z 51, 6.5 %. This is shown schematically in Figure 1.

3.5.2 Glycine

The electron impact mass spectrum of the ligand, glycine did not contain the molecular ion peak. However, a prominent base peak was observed at m/z 30, 100 %. This coincides with the loss of COOH. This is shown schematically in Figure 2.

3.5.3 Cd(phe)₂

The expected molecular ion was not observed. This is not unusual because the energy used in electron impact ionization has the possibility of further fragmenting the molecular ion. However, with an expected molecular ion of m/z 388 the fragmentation pattern was observed to follow two routes, T and U. Path T corresponds to the loss of one ligand from the molecular ion with the peak at m/z 276, 1 %. Pathway U agrees with the formation of a ligand as a positive ion with the observed peak at m/z 164, 4 %. The ion loses a benzylic radical leading to the formation of the ion with the peak observed at m/z 73, which is the base peak. Further fragmentation by the lose COO gave a peak at m/z 120, 84.52 %. This fragments producing a tropylium ion at m/z 91, 83.33 %. This is represented schematically in Figure 3.

3.6 In-Vitro Studies

The synthesized compounds were screened for possible anti- bacterial and -fungi activities. The zones of inhibition were obtained against one fungus, three Gram-positive and three Gram-negative bacteria. The Gram-positive bacteria are *Bacillus subtilis*, NCIB 3610; *Staphylococcus aureus*, NCTC 6571 and Methicillin Resistant *Staphylococcus aureus* (MRSA), ATCC 300. The Gram-negative bacteria are *Escherichia coli*, NCTC 8196; *Pseudomonas aeruginosa*, ATCC 19429 and *Proteus vulgaris*, NCIB. While *Candida albicans* NCYC 6 the fungus. The standard used was acriflavine. The results indicated that the compounds exhibited broad spectrum activities against the bacteria and fungi strains and in some cases higher activities compared to the standard. The results obtained are presented in Tables 7 and 8.

The results obtained indicate that the metals are contributory factors in the antimicrobial activities of the complexes. Most of the complexes irrespective of the ligand used, gave similar zones of inhibition. Pointing to the fact that donor atoms and the size of the chelate ring are similar for both ligands.

It is suggested that the lipophilic character of the coordination complexes be increased as this would enhance their ability to permeate the cell walls of the microbes. This may increase the antimicrobial activity of the compounds considerable.

4. Conclusion

The coordination complexes of Mn(II), Co(II), Ni(II), Cu(II), Cd(II) with two amino acids glycine and phenylalanine were synthesized and characterized. The ligands coordinated the metal ions through N and O donor atoms. A square planar geometry was proposed based on the result of the various analyses. A comparative study of the zones of inhibition indicated that chelation may increase the antimicrobial activity of biological ligands such as amino acids. Also the antimicrobial activity of the coordination compounds is also a function of the metal.

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Table 1. Some physical properties of the complexes

Compound	Empirical Formulae	Colour	M.P/D.T (°C)	Yield (%)
Co(gly) ₂	Co(C ₂ H ₄ O ₂ N)	Pink	260(d)	61.6
Cu(gly) ₂	Cu(C ₂ H ₄ O ₂ N)	Turquoise blue	209-211(d)	67.4
Mn(gly) ₂	Mn(C ₂ H ₄ O ₂ N)	White	202-204(d)	74.4
Ni(gly) ₂	Ni(C ₂ H ₄ O ₂ N)	Green	201(d)	60.2
Cd(gly) ₂	Cd(C ₂ H ₄ O ₂ N)	White	201(d)	72.7
Co(phe) ₂	Co(C ₉ H ₁₀ O ₂ N)	Pink	231-232	84.3
Cu(phe) ₂	Cu(C ₉ H ₁₀ O ₂ N)	Blue	191-193	67.2
Mn(phe) ₂	Mn(C ₉ H ₁₀ O ₂ N)	White	244-247	69.6
Ni(phe) ₂	Ni(C ₉ H ₁₀ O ₂ N)	Green	226(d)	72.8
Cd(phe) ₂	Cd(C ₉ H ₁₀ O ₂ N)	White	198(d)	62.4

Table 2. Electronic spectra bands(nm) for the glycinato-complexes (1:2)

Compound	Band I	Band II	Band III	d-d
Glycine	199	211	244	
Cu(gly) ₂	202	235	385, 391	637shld, 667, 820, 832shld
Cd(gly) ₂	196	265	296	-
Co(gly) ₂	205	223	241, 313	484shld, 511, 523shld
Mn(gly) ₂	235	283	313, 373	433, 496shld, 526, 541
Ni(gly) ₂	205	214	241	433, 496shld, 526, 541shld

Shld = shoulder.

Table 3. Electronic spectra bands (nm) for the phenylalanito-complexes and ligand

Compound	Band I	Band II	Band III	Band IV	d-d
Phenylalanine	196	217	232	268	433, 496, 514, 538
Cu(phe) ₂	196	208	223	238	526shld, 541, 565, 595shld
Cd(phe) ₂	199	241	-	-	103, 610, 511, 069
Ni(phe) ₂	-	217	232	262	433, 496, 538, 547shld
Co(phe) ₂	196	220	238	265	433, 484shld, 496, 526shld
Mn(phe)	205	214	232	310	433, 499, 538, 547shld

Shld = shoulder.

Table 4. Relevant Infrared frequencies for the glycinate-complexes and ligand

Band	Glycine (ligand)	Cu(gly) ₂	Cd (gly) ₂ (cm ⁻¹)	Ni(gly) ₂	Co(gly) ₂	Mn(gly) ₂
v _s (NH ₂)	3119br	3252br	3110br	3243br	3267br	3154br
v _{asy.} (COO ⁻)	1615s	1636w	1641s	1646m	1626m	1634m
v _{sy.} (COO ⁻)		1506sh	1458m	-	1406m	1458m
v (M-N)		518s	552sh	555sh	571w	531vs
v (M-O)		665sh	696s	773sh	721w	683sh

Keys: gly = glycine w = weak; m = medium; s = strong; vs = very strong; br = broad; sh = sharp.

Table 5. Relevant Infrared frequencies for the phenylalanito-complexes and ligand

Band	Phe	Cu(phe) ₂	Cd(phe) ₂ (cm ⁻¹)	Ni(phe) ₂	Co(phe) ₂	Mn(phe) ₂
v _s (NH ₂)	3454br	3301sh	3404br	3356, 3282sh	3357br	3380, 3285br
v _{asy} (COO ⁻)	1626m	1616w	1616s	1635s	1635sh	1716m
v _{sy.} (COO ⁻)	1566m	1503s	1414sh	1457s	1457s	1456s
v (M-N)		534sh	524sh	521vs	529vs	520m
v (M-O)		675sh	693s	693s	699m	678m

Keys: phe = *dl*-phenylalanine; w = weak; m = medium; s = strong; vs = very strong; br = broad; sh = sharp.

Table 6. Magnetic moment for some of the complexes

COMPOUND	μ_{eff} (BM)
Cu(phe) ₂	1.93
Co(phe) ₂	2.32
Ni(phe) ₂	1.15
Cd(phe) ₂	0
Mn(phe) ₂	5.29

Table 7. Results of zone of inhibition (mm) for glycinato-complexes

Microorganisms	Gly	Cu(gly) ₂	Cd(gly) ₂	Ni(gly) ₂	Co(gly) ₂	Mn(gly) ₂	C
<i>E. coli</i> (-)	6	15	8	6	6	11	20
<i>P. aeruginosa</i> (-)	6	6	6	6	7	8	6
<i>S. aureus</i> (+)	6	6	8	6	6	8	20
<i>P. vulgaris</i> (-)	6	6	6	6	6	11	15
<i>B. subtilis</i> (+)	6	6	8	6	6	16	6
MRSA(+)	6	6	6	6	6	6	6
<i>C. Albicans</i>	6	6	15	16	20	13	19

Table 8. Results of zone of inhibition (mm) for phenylalanito-complexes

Microorganisms	Phe	Cu(phe) ₂	Cd(phe) ₂	Ni(phe) ₂	Co(phe) ₂	Mn(phe) ₂	C
<i>E. coli</i> (-)	6	14	6	8	6	11	20
<i>P. aeruginosa</i> (-)	6	6	6	8	6	8	6
<i>S. aureus</i> (+)	6	24	6	6	6	8	20
<i>P. vulgaris</i> (-)	6	6	6	6	6	11	15
<i>B. subtilis</i> (+)	6	6	6	8	6	16	6
MRSA(+)	6	6	6	6	6	6	6
<i>C. Albicans</i>	14	6	6	6	6	13	19

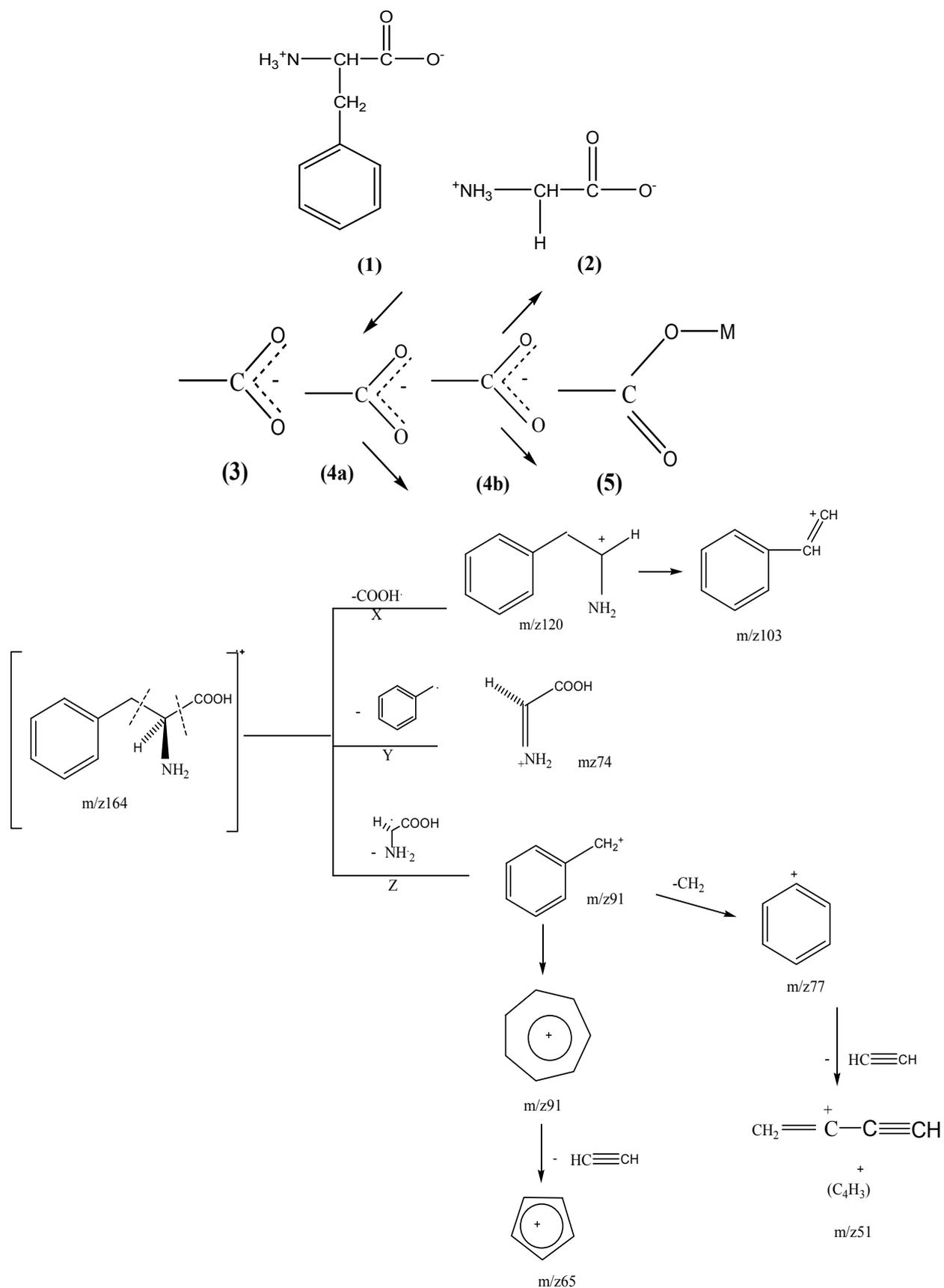


Figure 1. Proposed fragmentation pattern of phenylalanine

