A Prebiotic Surface Catalysed Synthesis of Alkyl Imine Precursors to the Aminoacids, Alanine, Serine and Threonine

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Abstract: - Alkynes such as ethyne and propyne form weak charge-transfer, η^2 -alkynyl complexes with surface catalysts such as Mg.porphin in which the alkynyl group is positively charged and the porphin has a negative charge. The enthalpy changes are -0.018 and -0.002 h, respectively. Addition of ammonia to the complexes allows the formation of Mg.2-amino ethenyl.porphin and Mg.2-amino propenyl.porphin with small enthalpy changes. and subsequent cyclic formation to Mg.1H aziridin-2yl.porphin and Mg. 2-methyl 1H aziridin-3yl.porphin complexes. The former may undergo a prototropic ring opening to form the imino precursor to the amino-acid alanine. Both complexes undergo ring opening with hydroxide anion to give the imine precursors to the amino-acids, serine and threonine. where the activation energies and enthalpy changes are,respectively, 0.072 h and -0.159h, and 0.072 h and -0.167 h.
This mechanism constitutes another method for the formation of reactive, and unstable, imines that could facilitate the formation of aziridine-2ones, which have been predicated as important in amino acid synthesis.
The reactions have been shown to be feasible from the overall enthalpy changes in the ZKE approximation at the HF and MP2 /6-31G* level.

Key-Words: Alkynes, 2-amino ethenyl, 2-amino propenyl, 1H aziridin-2yl and 1H 2-methyl aziridin-3yl complexes of Mg.porphin

1 Introduction

In a presumed mildly reducing prebiotic atmosphere [1,2] imines may be expected to arise from the partial hydrogenation of many nitrile species [3,4,5], and from the dehydration of aldehyde ammonias [6,7]. They have also been widely canvassed as having been formed in the polymerisation of hydrogen cyanide [8], and providing the precursors of some nucleic acid bases [9]. As the partial reduction products of cyanogen they have been implied as a possible source of all the nucleic acid bases [6,10]. Imines are known to react by carbene transfer to form aziridines [11] where a catalyst may produce an enantiomeric enrichment [12,13]. They also occur in biochemistry as intermediates in the enzymatic oxidative deamination of many amino acids [1]. Imines are usually regarded as unstable, reactive and may be difficult to isolate [14], whilst the alkyl imines appear only marginally stable with regard to the corresponding alkyl vinyl amines and alkyl aziridines.

In this paper a mechanism is proposed for the formation of imines from the catalytic ammoniation of alkynes where the alkyne is coordinated to the metal catalyst, Mg.porphin, and has some of the characteristics of an alkyne (a vinylene complex).

2 Problem Formulation

The computations tabulated in this paper used the GAUSSIAN98 [15] commercial package. The standard calculations at the HF and MP2 levels including zero-point energy corrections [16], together with scaling [17], using the same basis set, 6-31G*. are as previously published [6]. Enthalpy changes at the MP2 level not including scaled zero point energies are designated as $\Delta H_{(MP2)}$. The charge transfer complexes are less stable when calculated at the Hartree Fock level [16].
If the combined energy of the products is less than the combined energy of the reactants it may show that the reaction is also likely to be spontaneous at higher

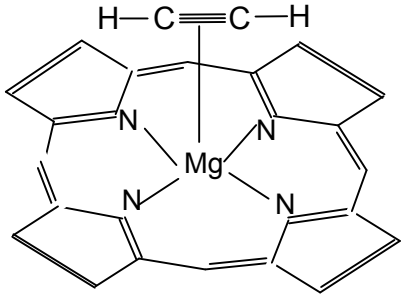
temperatures. This paper uses the atomic unit of energy, the hartree [15].
1h = 627.5095 kcal.mol^{-1}.
1h = 4.3597482 x 10^{-18} J

3 Problem Solution

3.1 Total Energies (hartrees)

Mg.porphin is a powerful catalyst able to form charge transfer complexes with a number of different kinds of molecules [18]. With acetylene the ligand is positively charged (0.08) and the porphin has a negative charge. The acetylene sets as ligand with a linear C-C-H structure as shown.

Mg.porphin + H-C≡C-H → Mg.ethynyl .porphin
(1) (2)



Mg.ethynyl .porphin
(2)

Δ H = -0.01807 h

The data for this molecule and the others involved in the synthesis are given in Table.1.

The total energies and zero point energies for the HF and MP2/6-31G* equilibrium geometries are given in Table 1.

Table 1

MP2 /6-31G* total energies and zero point energies (hartrees) for the respective equilibrium geometries

Molecule	MP2 hartree	ZPE (HF) hartree
Mg.porphin (1)	-1185.12250	0.29262
Mg.ethynyl.porphin (2)	-1262.20848	0.32333
Mg.cis 2-amino ethenyl.porphin (3)	-1318.54885	0.36958
Mg.trans 2-amino ethenyl.porphin (4)	-1318.53002	0.36860
Mg.2-amino ethylidene.porphin. (5)	-1318.50125	0.36526
Mg.1H-aziridin-2-yl.porphin (6)	-1318.55322	0.37028
Mg.N-ethanimine.porphin (7)	-1318.65396	0.36813
ethanimine	-133.49001	0.07392
vinylamine	-133.46732	
aziridine	-133.46025	
2-methyl aziridin-3-one	-246.48876	0.08481
CO	-113.02818	0.00484
H_2	-1.14414	0.01034
OH^-	-75.51314	0.00885

3.2 The overall stoichiometry for the formation of ethanimine.

Although Mg.porphin is here taken as the catalyst for the reaction, the overall stoichiometry of the ammoniation of alkynes can be represented for the case of acetylene as follows,

H-C≡CH + NH_3 → CH_3-CH=NH

Δ H = -0.05767 h

The enthalpy change is negative indicating that there may be energetically favorable routes to the initial formation of the imine.

However, as ethanimine is marginally stable with regard to vinylamine and ethylene imine a mechanism is needed to justify the formation of this reactive molecule.

$$CH_2{=}CH\text{-}NH_2 \rightarrow CH_3\text{-}CH{=}NH$$

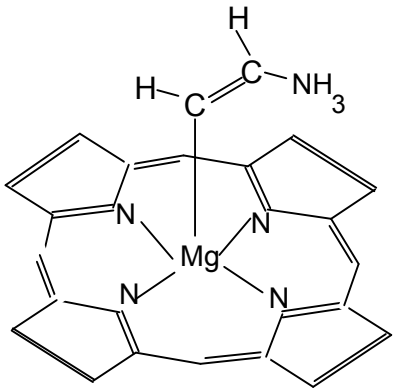
$$\Delta H_{(MP2)} = -0.02269.\ h$$

The intermediates by which this stoichiometric reaction may have occurred are as follows:

3.3 The ammoniation of the Mg.ethynyl. porphin.

The positively charged ligand can react with ammonia to form a cis and a trans complex as follows,

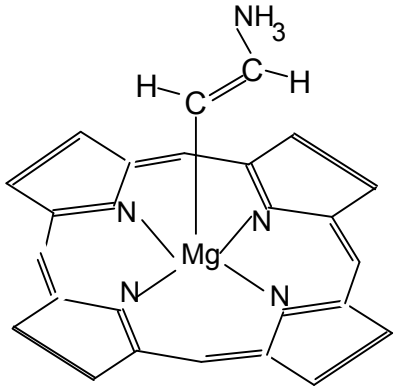
Mg.ethynyl.porphin + NH_3 →
cis Mg.2-amino ethenyl.porphin
(2) (3)



cis Mg.2-amino ethenyl.porphin
(3)

$\Delta H = 0.02676\ h$

Mg.ethynyl.porphin + NH_3 →
trans Mg.2-amino ethenyl.porphin
(2) (4)



trans Mg.2-amino ethenyl.porphin
(4)

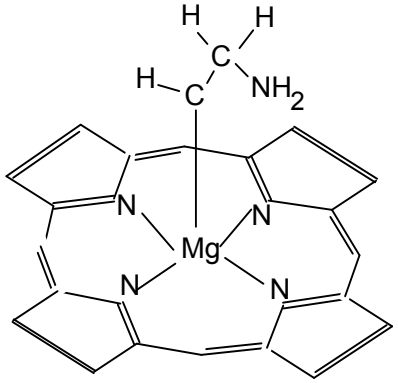
$\Delta H = 0.04471\ h$

The formation of these complexes is the rate determining step in this sequence of reactions. The cis Mg.2-amino ethenyl.porphin complex is the more stable and enables a close proximity of the amine group and the methine carbon atoms of the bound acetylene.

3.4 The formation of Mg.2-amino ethylidene. porphin.

The cis Mg.2-amino ethenyl.porphin may be transformed by a protropic shift to form Mg.2-amino ethylidene.porphin.

cis Mg.2-amino ethenyl.porphin →
Mg.2-amino ethylidene.porphin.
(3) (5)



Mg.2-amino ethylidene.porphin.
(5)

$\Delta H = 0.04375\ h$

The potential energy diagram for the first prototropic shift is shown in Fig.1.

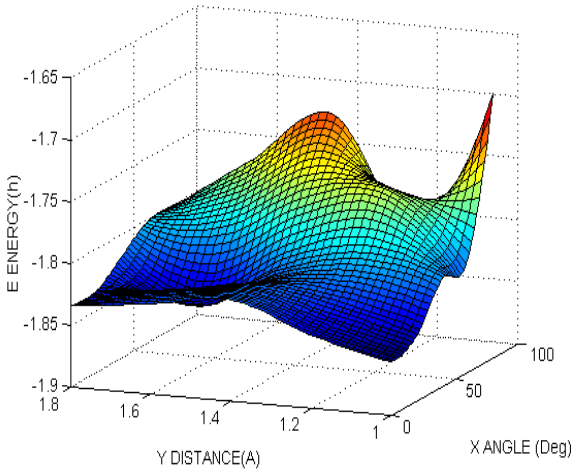


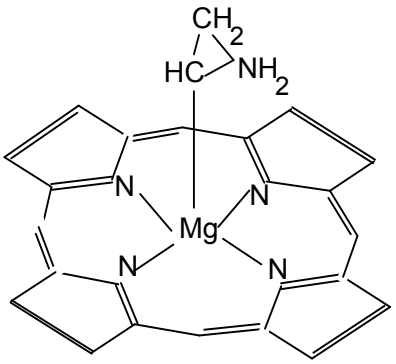
Fig.1. The potential energy surface for the prototropic shift on molecule, cis Mg.2-amino ethenyl.porphin. The X-axis depicts the bending of the angle (110.0 - A) degrees, where A is the angle H-N-C(2). The Y-ordinate represents the stretching of the single H-N bond. The minimum for the cis Mg.2-amino ethenyl.porphin is at, X=0.0 degrees, Y=1.0 A. A saddle point is at are at X=65 degrees, Y=1.7 A. The minimum for the Mg.2-amino ethylidene.porphin is at X=80 degrees, Y=1.8 A.
The energy is -1313+E h.

The activation energy for the amino group to dissociate a proton and to reach the saddle point is given as 0.049 h, whilst the activation energy to open the final aziridine ring is given as 0.041 h..

3.5 The formation of the Mg.1H aziridin-2-yl. porphin

The Mg.2-amino ethylidene.porphin undergoes ring closure to form Mg.1H aziridin-2-yl. porphin.

cis Mg.2-amino ethenyl.porphin →
Mg. 1H aziridin-2-yl. porphin.
(3) (6)



Mg. 1H aziridin-2-yl. porphin.
(6)

The enthalpy change for the ring closure of the cis Mg.2-amino ethenyl.porphin complex is favorable.

$$\Delta H = -0.00374 \text{ h}$$

The complex appears stable with normal bond lengths. An optimised model of the structure is shown in Fig.2.

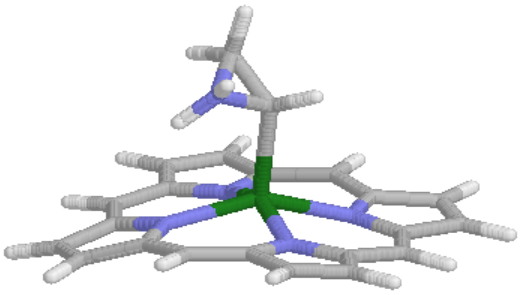


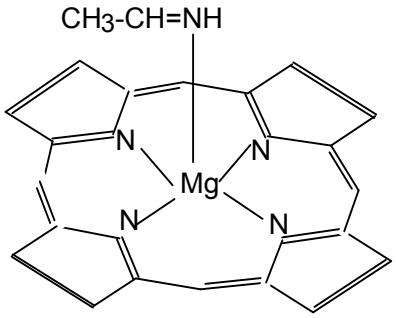
Fig.2. An optimized model of the structure Mg.1H aziridin-2-yl. porphin. (6)

The total energy of the The Mg.2-amino ethylidene.porphin is larger than the energy of the saddle point, so that the activation energy to close the ring is very low, given at the HF level as 0.001 h.whilst the activation energy to open the ring is given as 0.022 h. Therefore, the formation of Mg. 1H aziridin-2-yl. porphin is probably a concerted reaction.

3.6 The formation of the Mg.N-ethanimine. porphin.

A further prototropic shift opens the ring to form the ethanimine ligand. As the nitrogen of the ethanimine ligand carries a formal negative charge compared to the charge on carbon-1 of the ligand it does isomerise to the more stable charge transfer adduct.

Mg.1H aziridin-2-yl. porphin. →
Mg.ethanimine. porphin.
(5) (6)



Mg.N-ethanimine. porphin.
(7)

$\Delta H = -0.10266$ h

The potential energy diagram for the prototropic shift is shown in Fig.3.

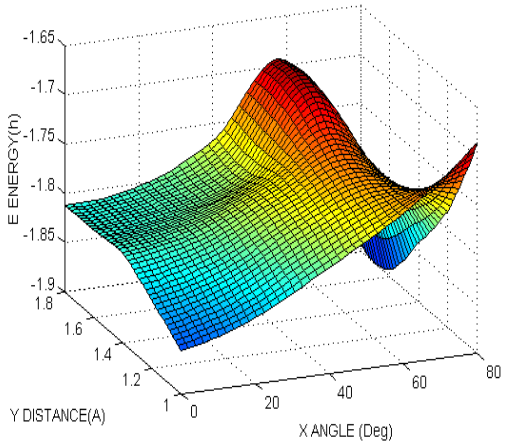


Fig.3. The potential energy surface for the prototropic shift on molecule, Mg.1H aziridin-2-yl. porphin. The X-axis depicts the bending of the (110.0 - A) angle, where A is the angle H-N-C(2). The Y-ordinate depicts the stretching of the H-N bond. The minimum for the Mg.1H aziridin-2-yl. porphin is at, X=0.0 degrees, Y=1.0 A. The minimum for the Mg.ethanimine.porphin is at, X=80.0 degrees, Y=1.8 A. The saddle point is at X=65.0 degrees, Y=1.2 A. The energy is -1313+E h.

The activation energy to open the ring is 0.110 h, whilst the activation energy to close the ring is 0.208 h.

3.7 The formation of the ethanimine.

The final dissociation of the Mg.porphin and ethanimine complex would require heat.

Mg.ethanimine. porphin. →
Mg.porphin + ethanimine
(7)

The enthalpy change is,

$\Delta H = 0.04004$ h

This is the imine precursor to the amino acid alanine.

3.8 The formation of the Mg.aziridin-2-one. porphin.

The Mg.N-ethanimine. porphin has been previously shown to react with excited carbon monoxide to form an aziridin-2-one complex [19] which should be easily dissociable by heat.. Such a complex has been inferred as able to polymerise to protein.

Mg.ethanimine.porphin.CO → Mg.aziridin-2-one. porphin.

$\Delta H = -0.03846$ h

3.9 The overall stoichiometry for the formation of 2-hydroxy ethanimine.

The enthalpy change for the formation of 2-hydroxy ethanimine is as follows,

Mg.porphin + H-C≡C-H + NH_3 + 2 OH^- →

Mg.porphin $^{2-}$ + H_2O + HO-CH_2-CH=NH

$\Delta H = -0.13328$ h

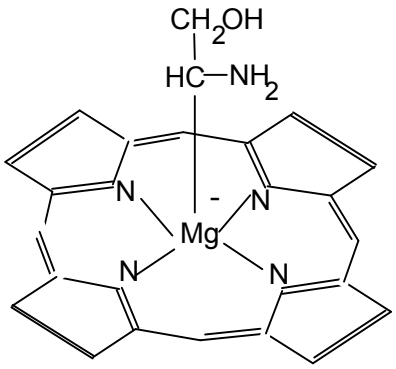
The mechanism by which this may have occurred is depicted in the following sections.

3.10 The formation of the imine precursor to the amino acid serine.

In the presence of hydroxide ion the Mg.1 H aziridin-2-yl. porphin ring may be cleaved to yield the charge transfer complex, Mg.1-amino ethan-2-ol.porphin as shown.

Mg.1H aziridin-2-yl. porphin. + OH^- → Mg.1-amino ethan-2-ol.porphin$^-$

(5) (8)



Mg.1-amino ethan-2-ol.porphin $^-$
(8)

ΔH = -0.15947 h

The data for these molecules is given in Table.2.

Table 2

MP2 /6-31G* total energies and zero point energies (hartrees) for the respective equilibrium geometries

Molecule	MP2 hartree	ZPE (HF) hartree
Mg.1-amino ethan-2-ol.porphin $^-$ (8)	-1394.23111	0.38472
Mg.1H aziridin-2-yl. porphin.$^-$ (9)	-1317.99647	0.35254
Mg.porphin^{2-} (10)	-1185.00997	0.28821
2-hydroxy ethanimine (11)	-208.51089	0.08029
Mg.2-hydroxy ethanimine.porphin (12)	-1393.67885	0.37575
Mg.1-imino ethan-2ol.porphin^{2-} (13)	-1393.47046	0.36474

The initial energy of the reactants is greater than the saddle point for the conversion to the Mg.1-amino ethan-2-ol.porphin. However, the presence of the negatively charged hydroxide ion in the same system as the charge transfer complex produces a lowering of the total energy such that an activation energy is still needed to effect the ring cleavage.
The graph for the potential energy surface for the cleavage is shown in Fig.4.

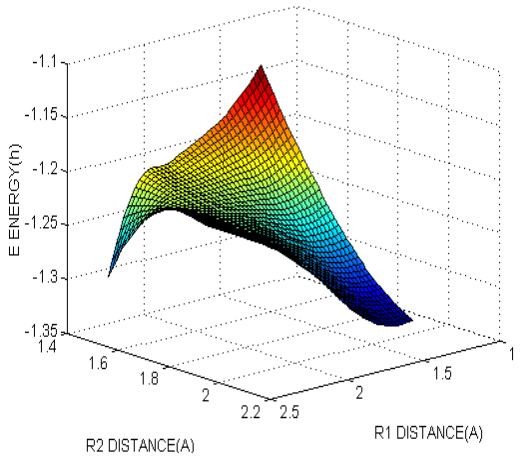


Fig.4. The potential energy surface for the nucleophilic attack of hydroxide anion on molecule, Mg.1H aziridin-2-yl. porphin. The R1-axis depicts the stretching of the CH_2-O bond, whilst the R2 axis depicts the stretching of the CH_2-N bond. The minimum for the Mg.1H aziridin-2-yl. porphin is at, R1=2.4 A, R2=1.5 A. The minimum for the Mg. 1-amino ethan-2-ol.porphin is at R1=1.4 A, R2=2.1 A. The saddle point is at R1=2.2 A, R2=1.7 A. The energy axis is -1389+E h.

From the graph shown, calculated at the HF level of accuracy, the activation energy to open the ring is estimated at, 0.072 h, whilst the energy to close the ring is estimated at, 0.121 h.

3.11 The formation of 2-hydroxy ethanimine

The Mg. 1-amino ethan-2-ol.porphin complex is negatively charged, and may lower its energy by oxidation, photochemical electron ejection, or dissociation. The dissociation requires a small input of energy, as shown,

Mg. 1-amino ethan-2-ol.porphin$^-$ + OH^- $\rightarrow$
(8)
Mg.porphin^{2-} + H_2O + $HO\text{-}CH_2\text{-}CH{=}NH$
(10) (11)

$\Delta H = 0.02125$ h

However, the free 2-hydroxy ethanimine may combine again with neutral Mg.porphin to form a stable charge transfer complex, as shown,

Mg.porphin + $HO\text{-}CH_2\text{-}CH{=}NH$
(1)
$\rightarrow$
Mg.2-hydroxy ethanimine.porphin
(12)

$\Delta H = -0.04293$ h

The overall enthalpy change is favorable,

$\Delta H = -0.02168$ h

3.12 The formation of the imine precursor to the amino acid serine from Mg.1-imino ethan-2ol. porphin$^-$.

In the presence of hydroxide ion a proton may be eliminated from the $-NH_2$ group of Mg.1H aziridin-2-yl.porphin, as shown,

Mg.1H aziridin-2-yl. porphin. + OH^- $\rightarrow$
(8)

Mg.1H aziridin-2-yl. porphin.$^-$ + H_2O
(9)

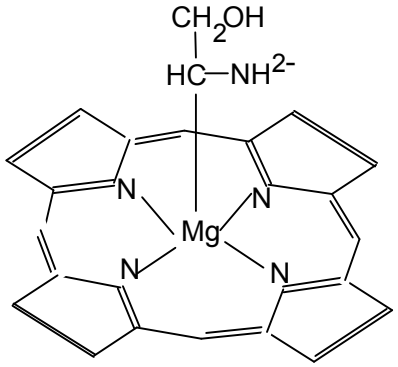
The enthalpy change is favourable,

$\Delta H = -0.15273$ h

It is also of interest to calculate the considerable stability of the doubly negatively charged complex that is possible if further reaction of Mg.1H aziridin-2-yl. porphin.$^-$ with hydroxide anion opens the ring or leads to dissociation of the complex, according to the equation,

Mg.1H aziridin-2-yl. porphin.$^-$ + OH^- $\rightarrow$
Mg.1-imino ethan-2ol.porphin^{2-}

(13)



Mg.1-imino ethan-2ol.porphin^{2-}
(13)

The enthalpy change is unfavourable,

$\Delta H = 0.04243$ h

In this case the energy of the reactants, Mg.1H aziridin-2-yl. porphin$^-$ and hydroxide anion, is below the energy of the saddle point, and the activation energy to open the ring is much greater. The potential energy surface is given in Fig.5.

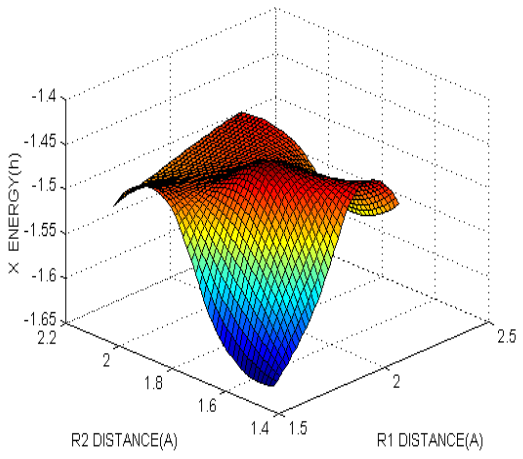


Fig.5. The potential energy surface for the nucleophilic attack of hydroxide anion on molecule, Mg.1H aziridin-2-yl. porphin $^-$. The R1-axis depicts the stretching of the CH_2-O bond, whilst the R2 axis depicts the stretching of the CH_2-N bond. The minimum for the Mg.1H aziridin-2-yl. porphin^{2-} is at, R1=2.2 A, R2=1.7 A. The minimum for the Mg. 1-imino ethan-2-ol.porphin^{2-} is at R1=1.6 A, R2=2.1 A. The saddle point for the transition is at R1=2.1 A, R2=1.9 A. The dissociated complex is at R1=1.6 A, R2=1.5 A. The energy is -1388+E h.

The activation energy to open the ring was estimated from the graph at the HF level of accuracy as, 0.134 h, whilst the activation to close the ring was 0.069 h. Almost the same activation energy, 0.146 h, led to the dissociation of the complex to a van der Waals complex. As the enthalpy change is positive and the complex may easily dissociate, this is probably not a preferred route to the imine.

3.13 The overall stoichiometry for the formation of 2-hydroxy propanimine.

The enthalpy change for the formation of 2-hydroxy propanimine is as follows,

Mg.porphin + CH_3-C≡C-H + NH_3 + 2 OH^- →

Mg.porphin $^{2-}$ + H_2O + CH_3-CH(OH)-CH=NH

Δ H = -0.13159 h

The mechanism by which this may have occurred is depicted in the following sections.

3.14 The formation of the imine precursor to the amino acid threonine from Mg.2-methyl 1H aziridin-3yl.porphin complex.

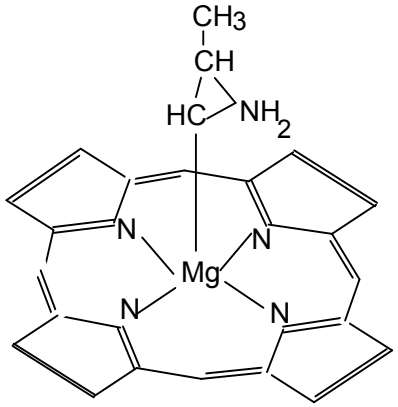
Propyne also forms a very weak charge transfer complex with the catalyst Mg.porphin, as shown,

Mg.porphin + propyne → Mg.propyne.porphin

Δ H = -0.00209 h

It also forms a similar stable Mg.2-methyl 1H aziridin-3yl.porphin complex acccording to the equation,

Mg.porphin + CH_3-C≡CH + NH_3 →
Mg.2-methyl 1H aziridin-3yl.porphin
(1) (14)



Mg.2-methyl 1H aziridin-3yl.porphin
(14)

Δ H = 0.00257 h

The energies for these compounds are given in Table 3.

Table 3

MP2 /6-31G* total energies and zero point energies (hartrees) for the respective equilibrium geometries

Molecule	MP2 hartree	ZPE (HF) hartree
Mg.2-methyl 1H-aziridin-3-yl.porphin (14)	-1357.73015	0.40040
Mg.1-amino-propan-2-ol.porphin$^-$ (15)	1433.41073	0.40892
propyne	-116.24181	0.06010
2-hydroxy propanimine (16)	-247.68362	0.11027
Mg.2-hydroxy propanimine.porphin		

(17)

-1432.84498 0.40475

However, this is not expected to yield the imine precursor to 2-amino-butyric acid as this is rare in nature and the charge on carbon-2 (-0.027) is less than for the corresponding carbon-3 on the Mg.1H aziridin-2yl.porphin complex (-0.20) described here. The potential energy diagram for the prototropic shift is shown in Fig.6

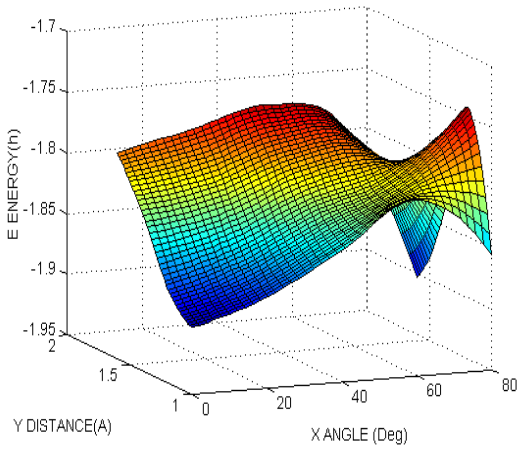


Fig.6. The potential energy surface for the prototropic shift on molecule, Mg.2-methyl 1H aziridin-3yl.porphin complex. The X-axis depicts the bending of the (110.0 -A) angle, where A is the angle H-N-C(2). The Y-ordinate depicts the stretching of the H-N bond. The minimum for the Mg.2-methyl 1H aziridin-3-yl. porphin is at, X=0.0 degrees, Y=1.0 A. The minimum for the Mg.propanimine.porphin is at, X=80.0 degrees, Y=1.8 A. The saddle point is at X=65.0 degrees, Y=1.3 A. The minimum for the Mg.1-amino propene.porphin complex is at X=80.0 degrees, Y=1.0 A. The saddle point for the amino compound is at X=65.0 degrees, Y=1.0. The energy is -1428+E h.

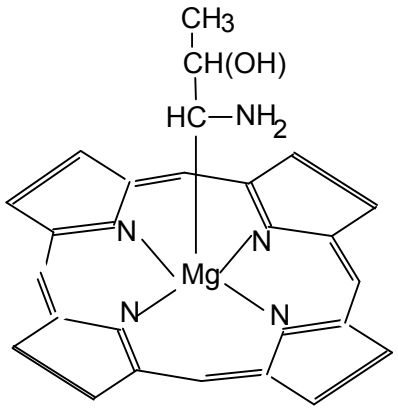
The diagram indicates that the activation energy to form the imine precursor to 2-amino butyric acid, 0.106 h is greater than the activation energy to form the 1-amino propene, 0.092 h.

3.15 The formation of the imine precursor to the amino acid threonine from Mg.2-methyl 1 H aziridin-3yl.porphin complex in the presence of hydroxide ion.

In the presence of hydroxide anion nucleophilic attack at carbon-2 may open the ring according to the equation,

Mg.2-methyl 1H aziridin-3yl.porphin + OH^- → Mg.1-amino-propan-2-ol.porphin$^-$

(15)



Mg.1-amino-propan-2-ol.porphin$^-$

(15)

ΔH = -016744 h

The potential energy diagram is given in Fig.7 .

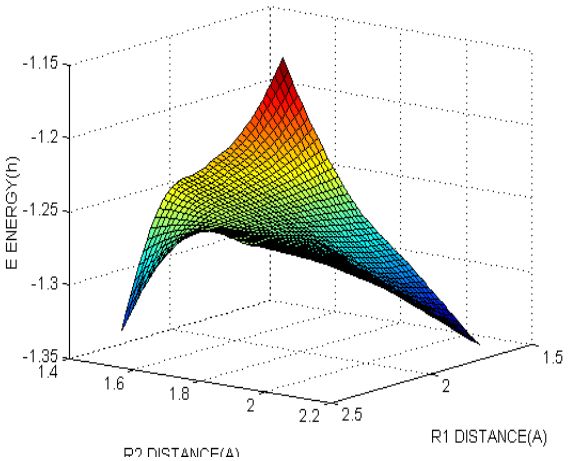


Fig.7. The potential energy surface for the nucleophilic attack of hydroxide anion on molecule, Mg.2-methyl 1H aziridin-3yl.porphin. The R1-axis depicts the stretching of the CH_2-O bond, whilst the R2 axis depicts the stretching of the CH_2-N bond. The

minimum for the Mg.2-methyl aziridin-3-yl. porphin is at, R1=2.4 A, R2=1.5 A. The minimum for the Mg. 1-amino propan-2-ol.porphin$^-$ is at R1=1.6, R2=2.1 A. The saddle point is at, R1=2.3, R2=1.7 A. The energy is -1428+E h.

Again the initial energy of the reactants is greater than the energy of the saddle point, but the presence of the hydroxide ion in the system lowers the total energy so that an activation energy is still observable. From the graph the activation energy to open the ring is given as 0.072 h, whilst the activation energy to close the ring is, 0.122 h.

3.16 The formation of 2-hydroxy propanimine

Similarly to the Mg. 1-amino ethan-2-ol.porphin, the Mg. 1-amino propan-2-ol.porphin complex is negatively charged, and may lower its energy by oxidation, photochemical electron ejection, or dissociation. The dissociation requires a small input of energy, as shown,

Mg. 1-amino propan-2-ol.porphin$^-$ + OH^- $\rightarrow$
(15)
$Mg.porphin^{2-}$ + H_2O + $HO\text{-}CH(CH_3)\text{-}CH{=}NH$
(10) (16)

$$\Delta H = 0.03106 \text{ h}$$

However, again, the free 2-hydroxy propanimine may combine again with neutral Mg.porphin to form a stable charge transfer complex, as shown,

Mg.porphin + $HO\text{-}CH(CH_3)\text{-}CH{=}NH$
(16)
$\rightarrow$
Mg.2-hydroxy propanimine.porphin
(17)

$$\Delta H = -0.03721 \text{ h}$$

The overall enthalpy change is favourable,

$$\Delta H = -0.00393 \text{ h}$$

4. Conclusion

The reaction of acetylene with ammonia has been described as giving initially vinylamine as the first product [20], although this does not appear as stable as ethanimine. The mechanism described here involving a surface catalysed ammoniation of alkynes appears possible according to the laws of thermodynamics and kinetics, and may allow more control over the reaction. However, it still seems apparent that a variety of products will be produced.. Hydrolysis of the corresponding aziridin-2-ones should give the protein poly-alanine in this case. Hydroxide opening of the ring should give the imine precursor to the protein poly-serine. Propyne forms a similar stable Mg.3-methyl 1H aziridin-2yl.porphin complex but it is shown that it is not expected to give the imine precursor to lead to 2-amino-butyric acid. Presumably, all long chain alkyl 2-amino carboxylic acids would be limited for the same considerations as shown here. However, the Mg.2-methyl 1H aziridin-3yl.porphin complex should be opened by hydroxide ion to give the imine precursor to the amino-acid threonine.

The imine, ethanimine, is also readily available in prebiotic chemistry from the partial reduction of methyl cyanide, found in the interstellar medium. Precursor imines to all of the the amino acids do seem readily available from simple gaseous atmospheric molecules, as shown here for the amino acids, alanine, serine and threonine.
Further work at a higher accuracy may alter the values given here.

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