Where were the Molecules of Life Made?

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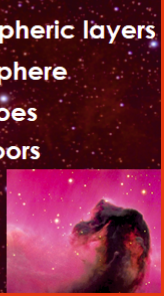
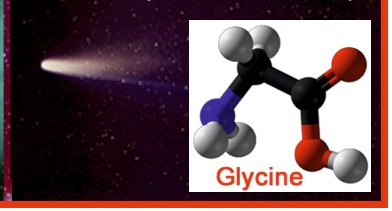
WHERE WERE THE MOLECULES OF LIFE MADE?

- At the boundaries of denser and less dense atmospheric layers
- Lightning strikes in the primordial planetary atmosphere
- In small puddles of water at the foothills of volcanoes
- Alkaline hydrothermal vents on the ancient sea floors
- Via impactors - meteorites, comets and asteroids
- On seashores during the ebb and flow of tides
- ASTROCHEMISTRY: In the Dark Molecular clouds

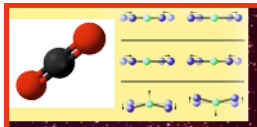


The Stardust Space mission (1999-2006)



Glycine

IR radiotelescopic measurements



Jodrell Bank

Wavenumbers for CO_2, v, cm^{-1} within the range of infra-red

660
2347
3602
3708

Distribution of some common molecules in comets and protostars[a]

Species	Protostars	Comets
	100%	100%
CO	~15	7-20
CO_2	~23	3-6
NH_3	~8	1.5
O_2	<7	<0.5
CH_3OH	~6	~2
HCOOH	~3	~0.05
H_2CO	<3	~3
CH_4	~2	~1
C_2H_6	<0.4	~0.5
OCS	<0.04	0.5

Roush 2001

Measured in percentages relative to H_2O (= 100%)

Amino acid	Murchison Meteorite	Found in proteins on Earth
glycine	✔	✔
Alanine	✔	✔
a-amino-N-butyric acid	✔	
a-aminoisobutyric acid	✔	
valine	✔	✔
norvaline	✔	
isovaline	✔	
proline	✔	✔
pipecolic acid	✔	
aspartic acid	✔	✔
glutamic acid	✔	✔
β-alanine	✔	
β-amino-N-butyric acid	✔	
β-aminoisobutyric acid	✔	
Y-aminobutyric acid	✔	
sarcosine	✔	
N-ethylglycine	✔	
N-methylalanine	✔	

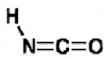
Murchison meteorite

Astrochemistry: the way forward

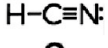
Laboratory based experimental astrochemistry results

MOLECULE IRRADIATED	MOLECULES PRODUCED	WAVENUMBERS (cm^{-1})
The Irradiation of Methyl Cyanide (CH_3CN) Ice at 15 K with 200 keV H+	METHYLENIMINE (H_3CNH_2)	1136
	METHANE (CH_4)	1304
	KETENIMINE $H_2C=C=NH$	2035
	CYANOACETYLENE (HCCCH)	2066
	HYDROGEN CYANIDE (HCN)	2087
	METHYL ISOCYNAIDE ($CH_3N=C$)	2168
	METHYL CYANIDE ($CH_3C=N$)	2252, 2941, 3002
The Irradiation of a Mixture of 1:1 of NH_3:CO_2 Ice at 30 K with 1keV Electrons	AMMONIUM ION (NH_4)	1492
	CYANATE ION (OCN^-)	2165
	CARBON MONOXIDE (CO)	2140
	AMMONIUM CARBAMATE ($NH_4NH_2CO_2$)	622, 830, 1038, 1118, 1399, 1492, 1546, 1625
The Irradiation of a 1:1 Mixture of 1:1 NH_3:CH_3OH Ice at 30 K with 1keV Electrons	METHYL FORMATE (H_3COHCO)	1167
	METHANE (CH_4)	1303
	HYDROXYMETHYL RADICAL (CH_2OH)	1352
	FORMAMIDE ($HCONH_2$)	1384
	FORMIC ACID (HCOOH)	1589
	FORMALDEHYDE (H_2CO)	1722
	FORMYL RADICAL (HCO)	1849
	CARBON MONOXIDE (CO)	2138
	CYANATE ION (OCN^-)	2166
	ISOCYANIC ACID (HNCO)	2258
	CARBON DIOXIDE (CO_2)	2341

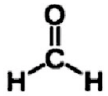
Small Molecules of Life



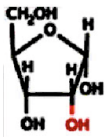
Isocyanic acid



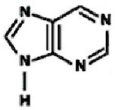
Hydrogen cyanide



Formaldehyde



Ribose sugar



Purine base

Primodine base

With all these organic molecules being delivered on to the surface of the Earth, we have a beginnings of a new chapter of life's emergence on Earth

NoRCEL Network of Researchers on the Chemical Evolution of Life