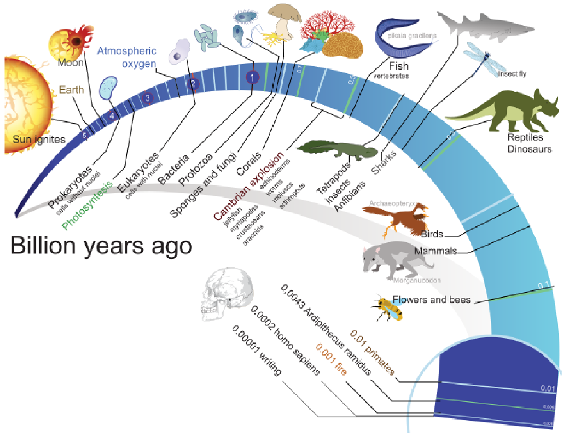
# Topic 2
# The primordial soup

WS 2016
*The molecular origins of life*

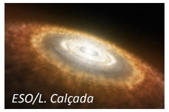
Zibi Pianowski

## When life originated on Earth?




*If life arose relatively quickly on Earth ... then it could be common in the universe."*

## When life originated on Earth?





**Hadean Eon** (4600 Ma - 4000 Ma)

- 4600 Ma – Earth formation
- 4500 Ma – Theia collides Earth → Moon
  *Earth's axis of rotation stabilized, which allowed abiogenesis*
- 4460 Ma – oldest known lunar rock - Lunar sample 67215, *Apollo 15*
- 4404 Ma – the oldest known material of terrestrial origin – zircon mineral (Australia) – isotopic composition of oxygen suggests presence of water on the Earth's surface
- 4374 Ma – the oldest consistently dated zircon

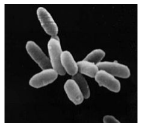
**Archean Eon** (4000 Ma – 2500 Ma)

*1 Ma = 1 million years*

- 4031 Ma – formation of the Acastia Gneiss
  - the oldest known intact crustal fragment on Earth
- 4100 Ma - 3800 Ma – Late Heavy Bombardment (LHB)
- 3800 Ma – greenstone belt (Greenland) – isotope frequency consistent with presence of life

## When life originated on Earth?

- 4100 Ma – „remains of biotic life" found in zirconites (Australia)
- 3900 Ma – 2500 Ma – cells remaining procaryotes appear
  *first chemoautotrophes: oxidize inorganic material to get energy, $CO_2$ – carbon source*
- 3700 Ma – oldest evidences for life – biogenic graphite in Isua greenstone belt (Greenland)
- c.a. 3500 Ma – lifetime of the Last Universal Common Ancestor (LUCA)
  *split between bacteria and archaea*
- 3480 Ma – oldest fossils – microbial mat (bacteria and archaea) fossils – sandstone, Australia
- 3000 Ma – photosynthesizing cyanobacteria evolved – water used as reducing agent
  → production of oxygen → oxidation of iron into iron ore ($FeO_x$) *(banded iron)*
- 2500 Ma - free oxygen in atmosphere → Great Oxygenation Event („Oxygen catastrophe")
  *extinction of most anaerobic organisms*



*Archaea (Halobacteria)*
*extremophiles*

*cyanobacteria*

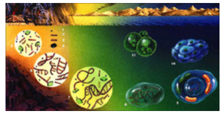
## The origin of life on Earth

- 384-322 BC – Aristotle – *abiogenesis*: spontaneous generation of life forms from unanimated matter (flies from old meat, mice from dirty hay)
- 1665 AC – Robert Hooke (microscope) – discovery of bacteria – considered a proof for spontaneous generation (bacteria division was not observed by then)
- 1668 – Francisco Redi – *biogenesis*: every life comes from another life
- 1861 – Louis Pasteur – bacteria do not grow in sterilized nutrient-rich medium, unless inoculated from outside; abiogenesis under current conditions regarded as impossible and therefore disproven

*Panspermia* – idea that life came to Earth from elsewhere in the Universe (e.g. Extremophilic organisms hibernated and traveling inside meteorites) – Anaxagoras (400ts BC), Berzelius, Kelvin, von Helmholtz, Arrhenius...;
*Pseudo-panspermia* – biorelevant molecules delivered from outside of Earth (meteorites)

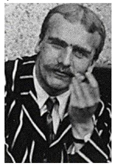
## *The origin of biorelevant molecules on Earth*

Alexander Oparin
(USSR, 1894-1980)



„atmospheric oxygen prevents the synthesis of certain organic compounds that are necessary building blocks for the evolution of life"

John B. S. Haldane
(UK, India, 1892-1964)



*1.The early Earth had a chemically reducing atmosphere.*
*2.This atmosphere, exposed to energy in various forms, produced simple organic compounds ("monomers").*
*3.These compounds accumulated in a "soup" that may have concentrated at various locations (shorelines, oceanic vents etc.).*
*4.By further transformation, more complex organic polymers - and ultimately life - developed in the soup.*

„Primordial soup"

„Biopoeiesis" – prebiotic oceans as „hot diluted soup" under anoxic conditions: e.g. $CO_2$, $NH_3$, $H_2O$

„Life arose through the slow evolution of chemical systems of increasing complexity"

## *Basic classes of biomolecules*

- Aminoacids
- Lipids
- Carbohydrates (sugars)
- Nucleotides
- Nucleosides (sugar+nucleotide)

## *Vital chemical reactions*

Aminoacid polymerization → ribosome

nucleotide polymerization → DNA/RNA polymerases

## *Experimental prebiotic organic chemistry*

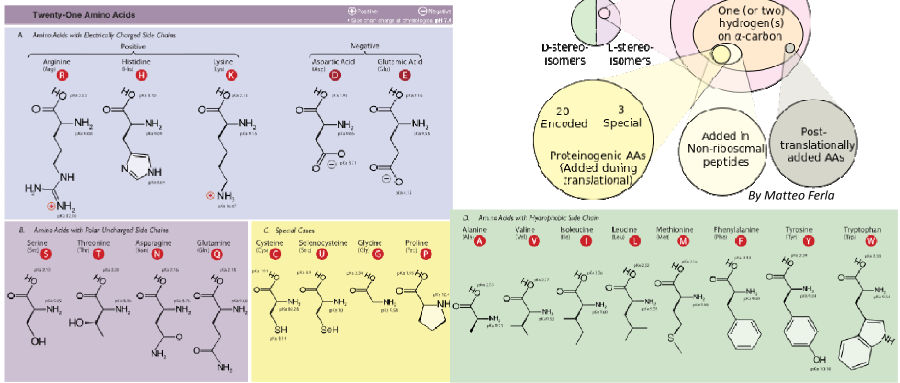
- Prebiotic chemistry deals with reactive substances (like HCN) often at concentrations much higher than probable in prebiotic environments
- Prebiotic experiments usually performed with very small number of pure substrates
- Early protometabolic processes might have used a broader set of organic compounds than the one contemporary biochemistry

- No evidences/fossils from that early Earth → we try to SPECULATIVELY fit different examples of chemical reactivity into an EXPECTED OUTCOME which we know as contemporary biochemistry

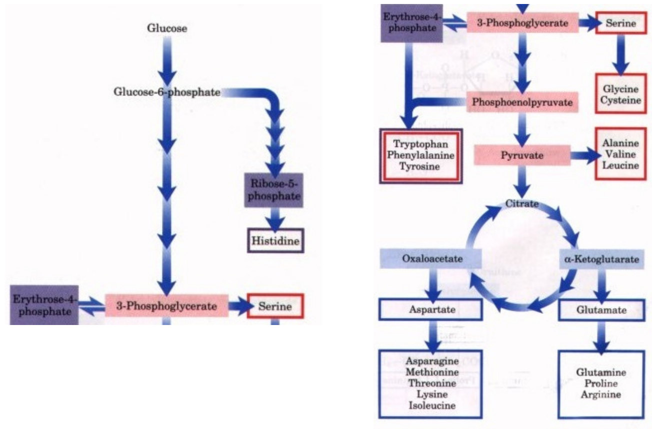
- Most of the discussed transformations are performed by highly specific and evolved enzymes at high speed and efficiency – prebiotic chemistry is supposed to be much slower and less efficient, but more robust and diverse

## *Proteinogenic aminoacids*

*genetically encoded*




## *Biosynthesis of biogenic aminoacids*



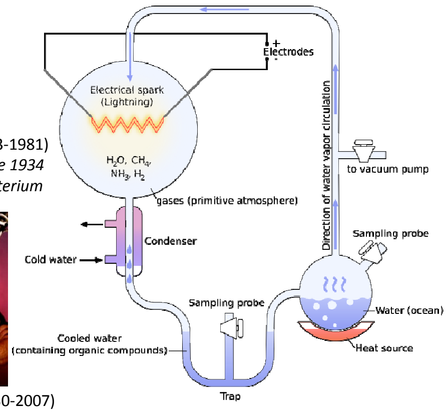

## *Atmosphere composition for young terrestrial planets*

| | Reduced | Neutral | Oxic |
|---|---|---|---|
| Carbon (C) | $CH_4$ | $CO$, $CO_2$ | $CO_2$ |
| Nitrogen (N) | $NH_3$ | $N_2$ | $N_2$ |
| Oxygen (O) | $H_2O$ | $H_2O$, $CO$, $CO_2$ | $O_2$ |
| Hydrogen (H) | $H_2$, $CH_4$, $NH_3$, $H_2O$ | $H_2O$ | $H_2O$ |

## *Miller-Urey experiment - 1952*

Harold Urey (1893-1981)
*UCSD, Nobel prize 1934*
*Discovery of deuterium*

Stanley Miller (1930-2007)
*UCSD San Diego, CA, USA*



## Products of the Miller-Urey experiment

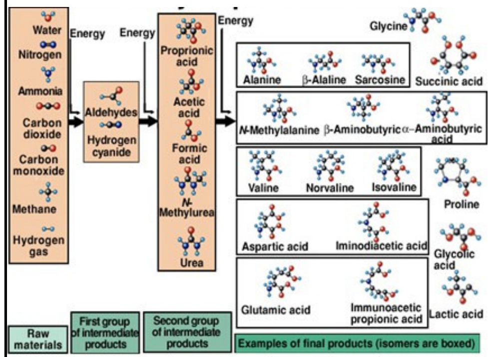
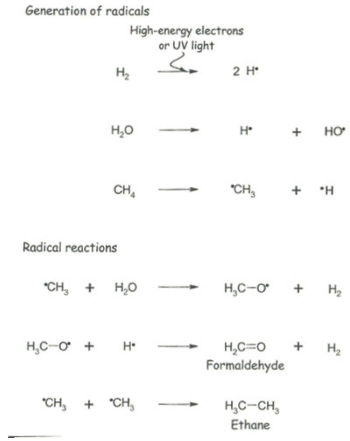
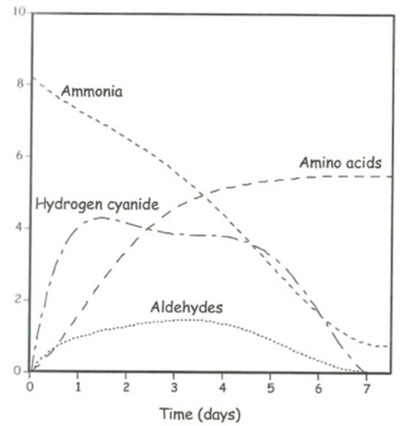



TABLE 4.2
**Typical Miller-Urey reaction products formed under reducing conditions**

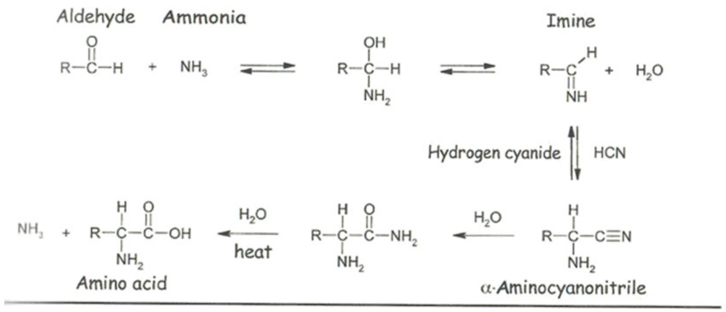
| Compound | Yield (% total fixed carbon) | Compound | Yield (% total fixed carbon) |
|---|---|---|---|
| Formic acid | 4.0 | Succinic acid | 0.27 |
| Glycine | 2.1 | Sarcosine | 0.25 |
| Glycolic acid | 1.9 | Iminoacetic propionic acid | 0.13 |
| Alanine | 1.7 | *N*-methylalanine | 0.07 |
| Lactic acid | 1.6 | Glutamic acid | 0.05 |
| β-Alanine | 0.76 | *N*-methylurea | 0.05 |
| Propionic acid | 0.66 | Urea | 0.03 |
| Acetic acid | 0.51 | Aspartic acid | 0.02 |
| Iminodiacetic acid | 0.37 | α-Aminoisobutyric acid | 0.01 |
| α-Hydroxybutyric acid | 0.34 | | |
| α-Amino-*n*-butyric acid | 0.34 | Total | 15 |

Cysteine and methionine also present, when $H_2S$ is added to the reaction mixture

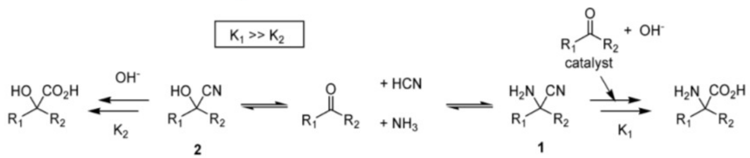



## Strecker reaction




**Scheme 1. Synthesis of α-Amino Acids through the Strecker Reaction**



## α-Aminoacid production in the Miller-Urey experiment

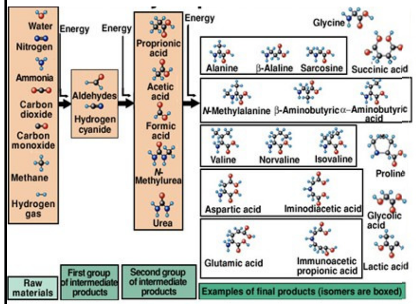



**TABLE 4.3**
**Yields of the α-amino acids in the Miller-Urey experiment**

| Amino acid | Yield (μM) | Amino Acid | Yield (μM) |
|---|---|---|---|
| **Glycine** | 440 | Norleucine | 6 |
| **Alanine** | 790 | **Isoleucine** | 5 |
| α-Aminobutyric acid | 270 | **Serine** | 5 |
| Norvaline | 61 | Alloisoleucine | 5 |
| **Aspartate** | 34 | Isovaline | 5 |
| α-Aminoisobutyric acid | 30 | **Proline** | 2 |
| **Valine** | 20 | **Threonine** | 1 |
| **Leucine** | 11 | Allothreonine | 1 |
| **Glutamate** | 8 | *Tert*-Leucine | 0.02 |

*Note:* Proteogenic amino acids in bold type.

## Modifications of the Miller-Urey experiment

| Researcher(s) | Year | Reactants | Energy source | Results | Probability |
|---|---|---|---|---|---|
| Miller | 1953 | $CH_4$, $NH_3$, $H_2O$, $H_2$ | Electric discharge | Simple amino acids, organic compounds | unlikely |
| Abelson | 1956 | CO, $CO_2$, $N_2$, $NH_3$, $H_2$, H2O | Electric discharge | Simple amino acids, HCN | unlikely |
| Groth and Weyssenhoff | 1957 | $CH_4$, $NH_3$, $H_2O$ | Ultraviolet light (1470–1294 ?) | Simple amino acids (low yields) | under special conditions |
| Bahadur, et al. | 1958 | Formaldehyde, molybdenum oxide | Sunlight (photosynthesis) | Simple amino acids | possible |
| Pavolvskaya and Pasynskii | 1959 | Formaldehyde, nitrates | High pressure Hg lamp (photolysis) | Simple amino acids | possible |
| Palm and Calvin | 1962 | $CH_4$, $NH_3$, $H_2O$ | Electron irradiation | Glycine, alanine, aspartic acid | under special conditions |
| Harada and Fox | 1964 | $CH_4$, $NH_3$, $H_2O$ | Thermal energy (900–1200° C) | 14 of the "essential" amino acids of proteins | under special conditions |
| Oró | 1968 | $CH_4$, $NH_3$, $H_2O$ | Plasma jet | Simple amino acids | unlikely |
| Bar-Nun et al. | 1970 | $CH_4$, $NH_3$, $H_2O$ | Shock wave | Simple amino acids | under special conditions |
| Sagan and Khare | 1971 | $CH_4$, $C_2H_6$, $NH_3$, $H_2O$, H2S | Ultraviolet light (>2000 ?) | Simple amino acids (low yields) | under special conditions |

## Modifications of the Miller-Urey experiment

| | | | | | |
|---|---|---|---|---|---|
| Yoshino et al. | 1971 | $H_2$, CO, $NH_3$, montmorillonite | Temperature of 700°C | Glycine, alanine, glutamic acid, serine, aspartic acid, leucine, lysine, arginine | unlikely |
| Lawless and Boynton | 1973 | $CH_4$, $NH_3$, $H_2O$ | Thermal energy | Glycine, alanine, aspartic acid, ?-alanine, N-methyl-?-alanine, ?-amino-n-butyric acid. | under special conditions |
| Yanagawa et al. | 1980 | Various sugars, hydroxylamine, inorganic salts, | Temperature of 105°C | Glycine, alanine, serine, aspartic acid, glutamic acid | under special conditions |
| Kobayashi et al. | 1992 | CO, $N_2$, $H_2O$ | Proton irradiation | Glycine, alanine, aspartic acid, ?-alanine, glutamic acid, threonine, ?-aminobutyric acid, serine | possible |
| Hanic, et al. | 1998 | $CO_2$, $N_2$, $H_2O$ | Electric discharge | Several amino acids | possible |

## Aminoacid production under hydrothermal conditions

$Ni(OH)_2$/KCN/CO in alkaline aqueous conditions (80-120$^0$C) → α-amino and α-hydroxyacids

Huber, C.; Wächtershäuser, G. *Science* **2006**, *314*, 630–632

$Ca(OH)_2$/$NiSO_4$/KCN/CO in alkaline (pH 9.1-12.9) aqueous conditions (145-280$^0$C) → α-amino and α-hydroxyacids (higher yields): glycine, alanine, serine, glycolate, lactate, glycerate

Huber, C.; Eisenreich, H.; Wächtershäuser, G. *Tetrahedron Lett.* **2010**, *51*, 1069-1071

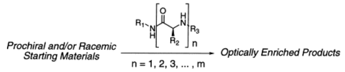
## Extraterrestrial origin of biomolecules

Murchison meteorite
*chondrite*

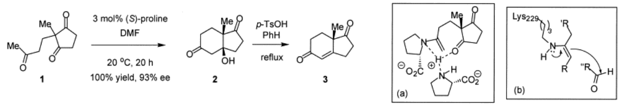
**Table 1. Soluble Organic Compounds in the Murchison Meteorite[a]**

| class of compounds | parts per million | n[b] |
|---|---|---|
| aliphatic hydrocarbons | >35 | 140 |
| aromatic hydrocarbons | 15–28 | 87 |
| polar hydrocarbons | <120 | 10[d] |
| carboxylic acids | >300 | 48[d] |
| amino acids | 60 | 75[d] |
| imino acids | nd[c] | 10 |
| hydroxy acids | 15 | 7 |
| dicarboxylic acids | >30 | 17[d] |
| dicarboximides | >50 | 2 |
| pyridinecarboxylic acids | >7 | 7 |
| sulfonic acids | 67 | 4 |
| phosphonic acids | 2 | 4 |
| *N*-heterocycles | 7 | 31 |
| amines | 13 | 20[d] |
| amides | nd[c] | 27 |
| polyols | 30 | 19 |

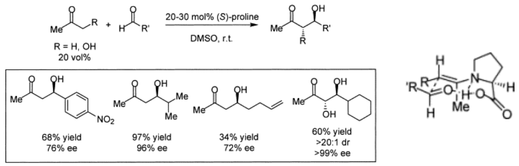
## Catalytic properties of aminoacids - organocatalysis




### Robinson annulation



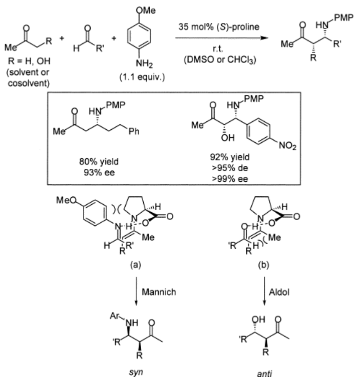

### aldol reaction



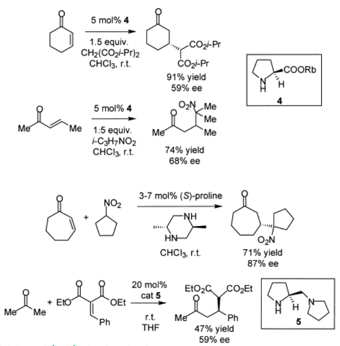

Jarvo, E. R., Miller, S. J. *Tetrahedron* **2002**, *58(13)*, 2481-2495.

## Catalytic properties of aminoacids - organocatalysis

### Mannich reaction



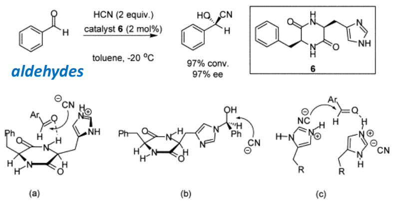

### Michael addition

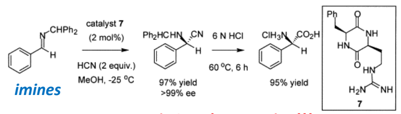



Jarvo, E. R., Miller, S. J. *Tetrahedron* **2002**, *58(13)*, 2481-2495.

## Catalytic properties of aminoacids - organocatalysis

### Hydrocyanation



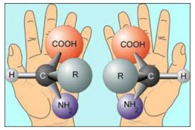

**assymetric Strecker reaction!!!**

Jarvo, E. R., Miller, S. J. *Tetrahedron* **2002**, *58(13)*, 2481-2495.

## *The origins of homochirality*

Currently known biopolymers are homochiral

Structural propensity and catalytic activity strongly depends on the enantopurity
→ Homochirality must have been involved early in the process of life formation
→ Chiral monomers could be only partially enantioenriched




General cause of homochirality:
the initial symmetry breaking + subsequent assymetry amplification:

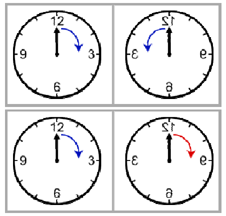
- ***The pairity violation***
- ***Stochastic symmetry disturbances***

Electroweak interactions and the pairity violation principle cause *L*-aminoacids and *D*-sugars to be SLIGHTLY MORE STABLE than their enantiomers

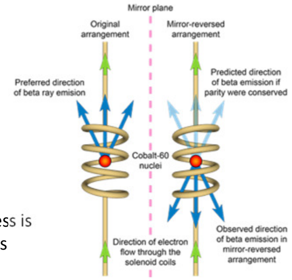
## *The pairity violation – Wu experiment*

Mirror image of the world does not behave exactelly like the world itself
because **TIME GOES UNIDIRECTIONALLY**

*In a mirror, time will not go BACKWARDS!*

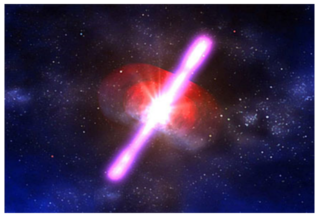



Chien-Shiung Wu (1956) –
experiment on $^{60}Co$ decay



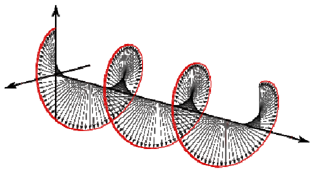

Differentiation in left and right handedness is inherent property of weak interactions

## *The origins of homochirality*

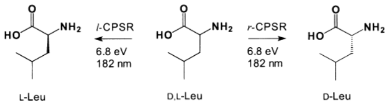


K. Wiersema et al., *Nature* **509** 201, 2014

Circularly polarized light (CPL) from gamma ray bursts



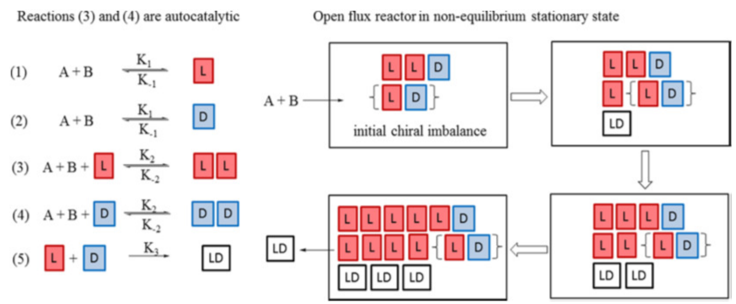
Small enantiomeric excess can be obtained by enantioselective degradation of aminoacids with CPL




*Up to 2.6% ee*

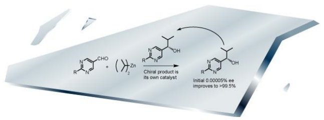
*Meierhenrich, U. J.; Nahon, L.; Alcaraz, C.; Bredehoft, J. H.; Hoffmann, S. V.; Barbier, B.; Brack, A. Angew. Chem., Int. Ed. 2005, 44, 5630*

## *Stochastic induction of assymetry – Frank model*



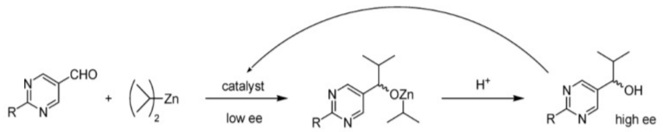

If a chiral dissipative structure catalyzes its own formation and inhibits formation of the opposite enantiomer, any stochastic symmetry breaking in the system will be amplified

## *autocatalytic Soai reaction – extreme chirality amplification*



*Organometallic reaction*
***- NOT prebiotic***

Scheme 9. Soai Autocatalytic Reaction

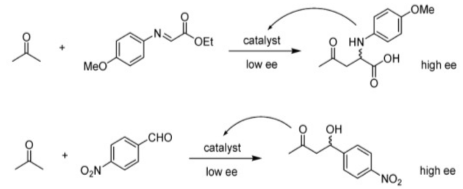



***CPL***
***Aminoacids***
***$^{12}C/^{13}C$-enantiomers!***

*Extremelly sensitive*
*chirality detector*

## *autocatalytic organic reactions*

Scheme 10. Mannich and Aldol Autocatalytic Reactions[a]




*Meaningful transformations for the prebiotic syntheses of aminoacids and sugars*

## *Organocatalysis – the origin of homochirality*

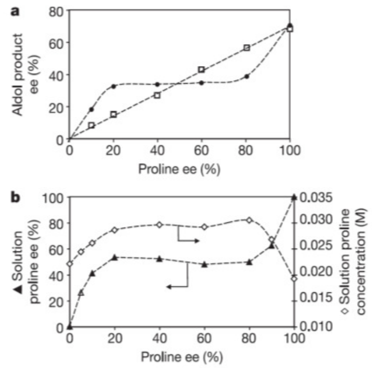
**Table 1. Enantiomeric concentration amplification of phenylalanine after two crystallizations from water**

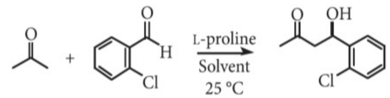
| Component | Initial ee, % | Final ee, % |
|---|---|---|
| D | 10 | 90.0 ± 3.7 |
| | 5 | 91.7 ± 1.5 |
| | 1 | 87.2 ± 2.0 |
| L | 10 | 88.3 ± 1.1 |
| | 5 | 88.6 ± 0.9 |
| | 1 | 90.9 ± 0.3 |

**Solutions with as little as 1% enantiomeric excess (ee) of D- or L-phenylalanine are amplified to 90% ee (a 95/5 ratio) by two successive evaporations to precipitate the racemate. Such a process on the prebiotic earth could lead to a mechanism by which meteoritic chiral α-alkyl amino acids could form solutions with high ee values that were needed for the beginning of biology.**

*Breslow, R., Levine, M. Proc. Natl. Acad. Sci. USA* **2006,** *103(35)*, 12979-12980

## *Chirality amplification in biphasic systems*




Reaction and solution behaviour as a function of the overall proline enantiomeric excess.

a, Product enantiomeric excess versus proline enantiomeric excess for the aldol reaction of equation

b, Solution proline enantiomeric excess (left axis, triangles) and solution proline concentration (right axis, diamonds) as a function of the overall enantiomeric excess for proline at 0.1 M

*Klussmann, M., et al. Nature* **2006,** *441*, 621-623

## Chirality amplification in biphasic systems

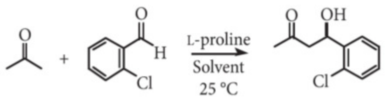
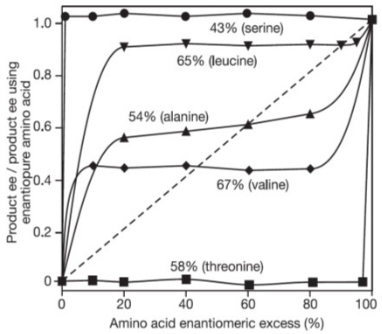


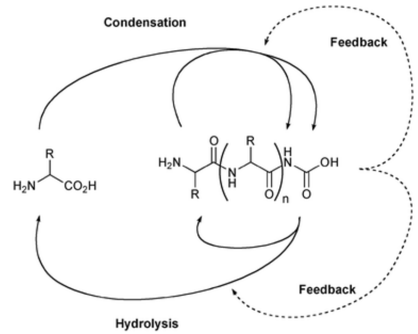

**Table 1** | **Solution enantiomeric excess at the eutectic point in water at 25 °C for selected amino acids**

| Amino acid | ee of solution at eutectic (%) | Amino acid | ee of solution at eutectic (%) |
|---|---|---|---|
| Threonine | 0 | Methionine | 85 |
| Valine | 46 | Leucine | 87 |
| Alanine | 60 | Histidine | 93 |
| Phenylalanine | 83 | Serine | >99 |

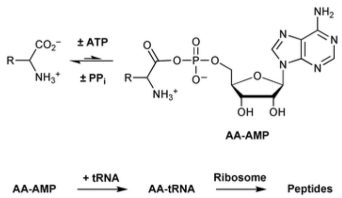


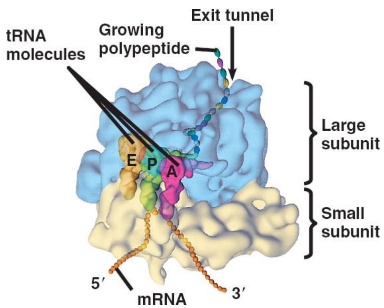

*Klussmann, M., et al. Nature* **2006**, *441*, 621-623

## Condensation of aminoacids into peptides

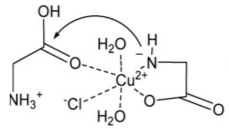


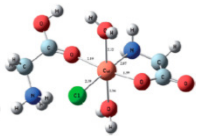

## Biochemical condensation of aminoacids into peptides




## Salt-induced peptide formation (SPIF)





SIPF copper complex geometry with two glycine ligands, optimized by ab initio Hartree–Fock calculations.
Rode, B. M.; Fitz, D.; Jakschitz, T. Chem. *Biodiversity* **2007**, *4*,2674.

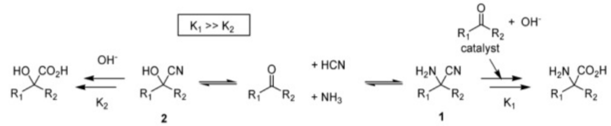
## Prebiotically relevant peptide condensation agents

| Entry | Activating agent | Hydrolysis/ hydration product | $\Delta G^{o\prime}$/ kJ mol$^{-1}$ |
|---|---|---|---|
| 1 | $NH_2CONH_2$ | $CO_2 + NH_3$ | $-16^a$ |
| 2 | COS (g) | $CO_2 + H_2S$ | $-17^a$ |
| 3 | Pyrophosphate | Phosphate | $-19^b$ |
| 4 | CO (g) | $HCO_2H$ | $-16^a$ |
| 5 | HNCO | $CO_2 + NH_3$ | $-54^a$ |
| 6 | HCN | $HCO_2H + NH_3$ | $-75^a$ |
| 7 | RCN | $RCO_2H + NH_3$ | $-80^c$ |
| 8 | $NH_2CN$ | Isourea | $-83^d$ |
| 9 | HNCNH | Isourea | $-97^d$ |
| 10 | HCCH (g) | $CH_3CHO$ | $-112^a$ |

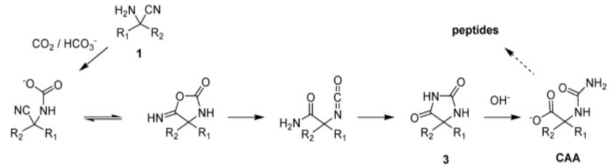
Danger, G.; Plasson, R.; Pascal, R. *Chem. Soc. Rev.* **2012**, *41*, 5416.

## Condensation of aminoacids into peptides

**Scheme 1. Synthesis of α-Amino Acids through the Strecker Reaction**



**Scheme 2. Bücherer–Bergs Hydrolysis of α-Aminonitriles**



## Carbonyl sulfide – condensing agent

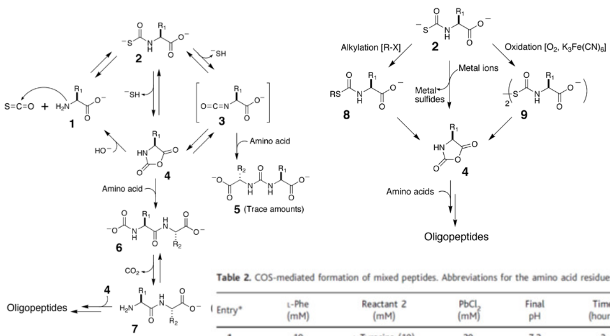


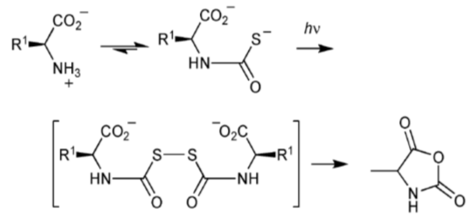
**Table 2.** COS-mediated formation of mixed peptides. Abbreviations for the amino acid residues: A, Ala; F, Phe; L, Leu; S, Ser; Y, Tyr.

| Entry* | L-Phe (mM) | Reactant 2 (mM) | $PbCl_2$ (mM) | Final pH | Time (hours) | Observed dipeptides† | Observed tripeptides† |
|---|---|---|---|---|---|---|---|
| 1 | 10 | L-Tyrosine (10) | 20 | 7.2 | 3 | FF, YY, (YF), (FY) | YYY, (YYF), (YFF), FFF |
| 2 | 25 | L-Leucine (25) | 50 | 7.1 | 3 | FF, LL, (FL) | (LLF), (LFF), FFF |
| 3 | 25 | L-Alanine (25) | 50 | 5.9 | 3 | FF, (AF) | (AAF), (AFF), FFF |
| 4 | 25 | L-Serine (25) | 50 | 6.3 | 3 | SS, FF, SF, FS | SSS, (SFF), FFF |

*Each experiment was initiated by admitting ~20 ml of COS gas to an argon-purged reaction vessel containing 2 ml of the reaction mixture indicated dissolved in 500 mM $Me_3N$ buffer, at an initial pH of 9.1. Peptide products were identified by LCMS after quenching the reaction at 3 hours. †Peptides for which product masses were observed but primary amino acid sequences which were not determined are indicated in parentheses.

Leman, L.; Orgel, L.; Ghadiri, M. R. *Science* **2004**, *306*, 283-286.

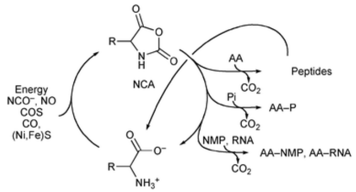
## Carbonyl sulfide – photochemical activation



A slow formation of NCAs from free amino acids and COS in the absence of oxidizing or alkylating agents has been reported and studied through theoretical chemistry investigations. However, it seems unlikely that COS (DGo0 = 16.9 kJ mol1)37 could be able to generate NCA (DGo0 E 60 kJ mol1)20 in spite of its cyclic structure.

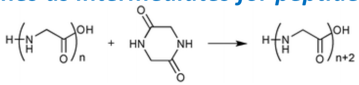
A photochemical activation of thiocarbamate that could take place in a way similar to that of thioacetate in aqueous solution may provide an explanation to this observation. This potential photochemical reaction may also constitute an efficient pathway for the prebiotic formation of NCAs.

## Carbonyl sulfide – photochemical activation

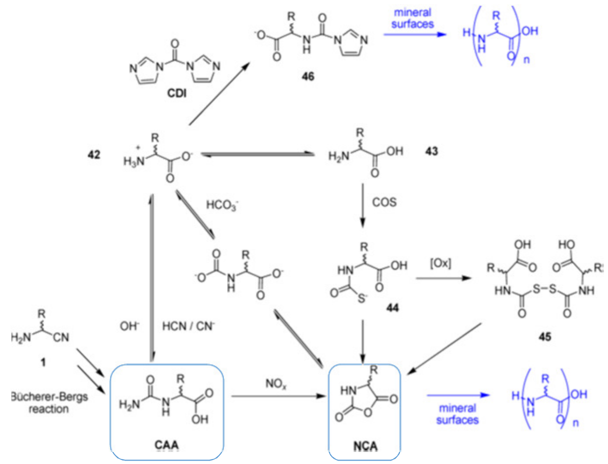



Pathways for the formation of NCAs and
further reactions including polymerization and interactions
with inorganic phosphate (Pi), nucleotides (NMP), and RNA.

## Diketopiperazines as intermediates for peptide condensation



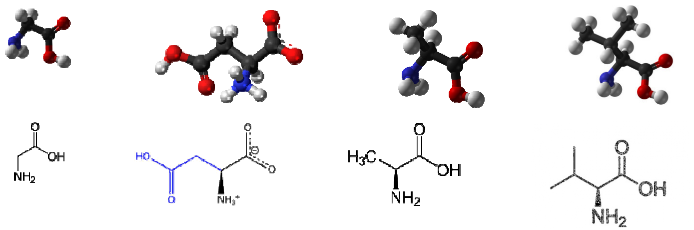
## Condensation of aminoacids into peptides




## Basic aminoacids for primitive genetic code?

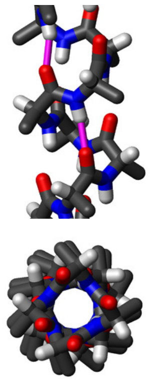
Primordial genetic code might have involved only 4 „GNC" codons:

- *GGC for glycine*
- *GCC for alanine*
- *GAC for aspartic acid*
- *GUC for valine*

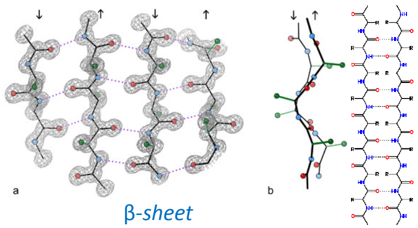


Later, the ‚GNC' code probably evolved into ‚SNS' code (S = G/C, N = A, U, G, C) – 16 codons encoding 10 basic aminoacids (Gly, Ala, Asp, Val, Glu, Leu, Pro, His, Glu, Arg)

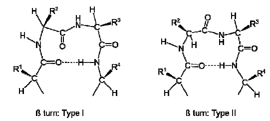
## GADV-protein world



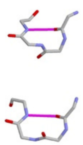
*α-helix (Ala)*



*β-sheet (Val)*



*β-turn (coil) (Gly)*



*hydrophilic and hydrophobic structures*

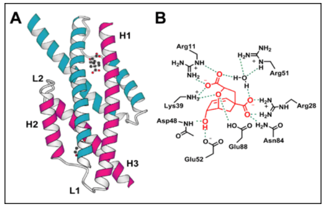
*globular structures*

*catalytic activity (Asp)*

## *Reduced aminoacid alphabet*

9-aminoacid alphabet is sufficient to construct functional enzymes

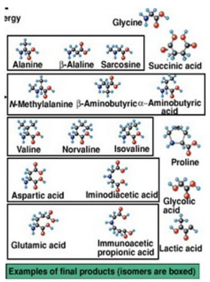
Aminoacids: Asp, Glu, Asn, Lys, Phe, Ile, Leu, Met, Arg



**AroQ structure and active site.** *A*, the homodimeric EcCM is shown with a transition state analog inhibitor bound at its active sites; the two identical polypeptide chains are colored *blue* and *pink* for clarity. *B*, proposed interactions between residues in the evolved active site of the simplified enzyme and the transition state analog inhibitor, compound **1** (*red*), based on the x-ray structure of EcCM. Residues Gln$^{88}$ and Ser$^{84}$ in EcCM are substituted with Glu$^{88}$ and Asn$^{84}$ in the 9-amino acid enzyme. Residue numbers are referenced to EcCM.

Walter, K. U., Vamvaca, K., Hilvert, D. *J. Biol. Chem.* **2005**, *280*,37742-37749.

## *Aminoacids - Summary*




Prebiotic generation plausible – variants of the Miller-Urey experiment
Strecker-type of chemistry likely

Aminoacids are good catalysts, can perform various chemical transformations

The origin of homochirality in the Universe caused by the pairity violation and stochastic fluctuations

Chirality amplification possible in numerous chemical reactions

Aminoacids can catalyse their own formation with chirality amplification and undergo physical enantioenrichment processes

Condensation of aminoacids into peptides plausible under prebiotic conditions using condensing agents

Simple peptides can exhibit broad structural variety,
catalytically active enzymes can be constructed with reduced aminoacid alphabet