

# Reaction networks and autocatalysis

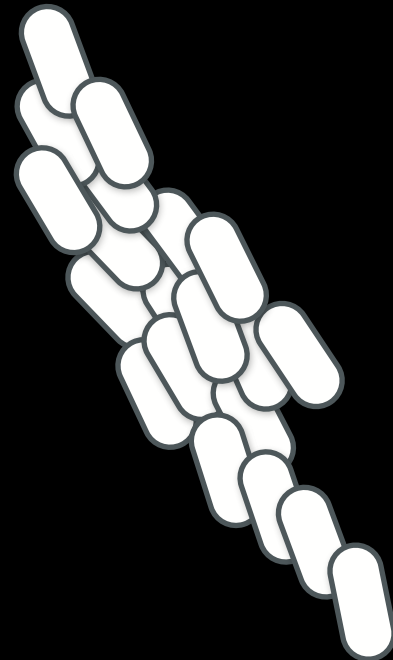
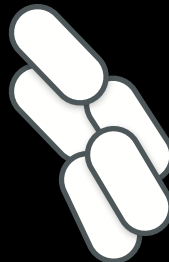
Nathaniel Virgo



# Autocatalysis

- Chemical self production:
  - the ability of a set of chemical species to make more of that same set, by undergoing a series of chemical reactions

# Life makes life



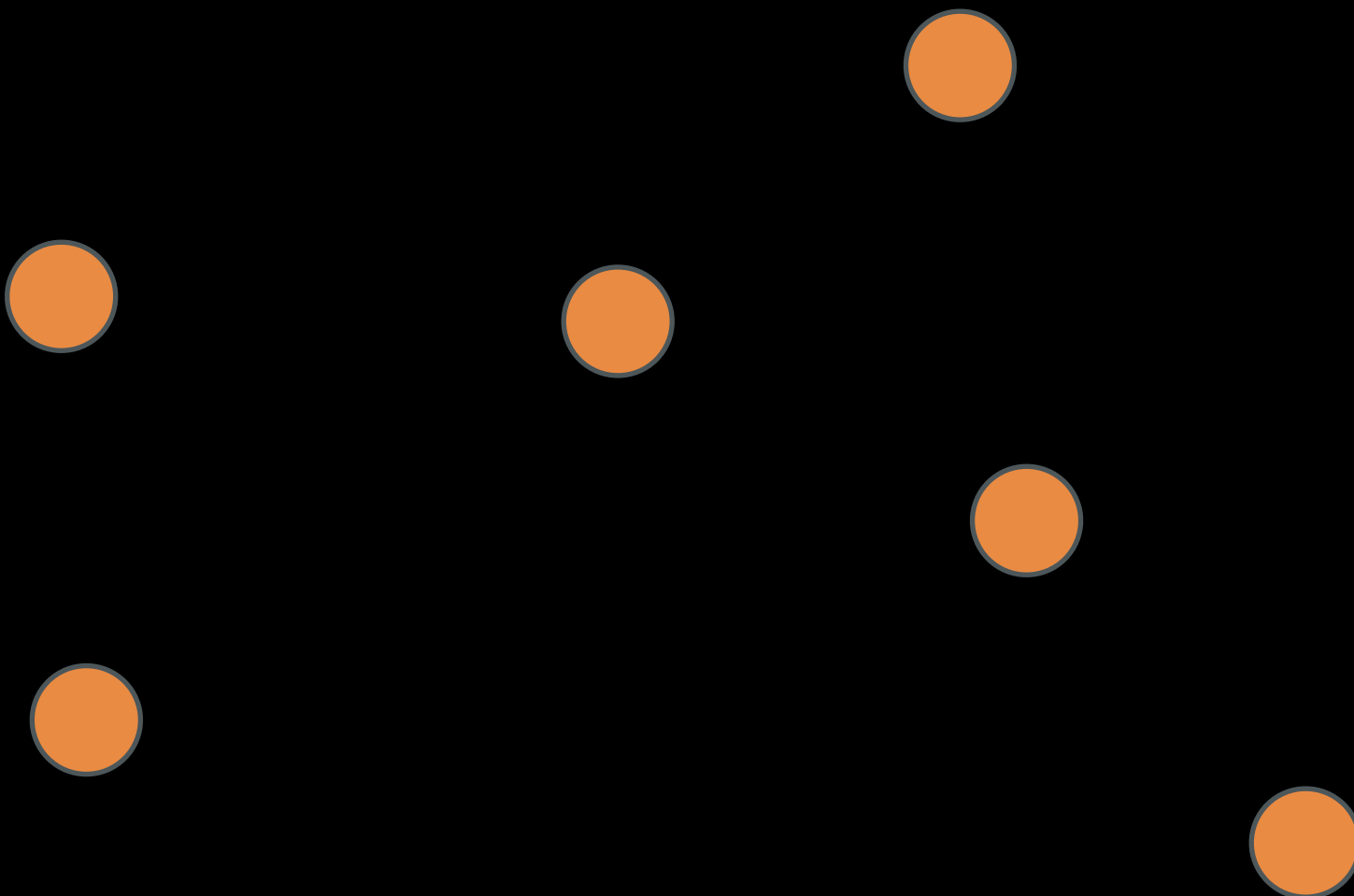
# Chemical reactions



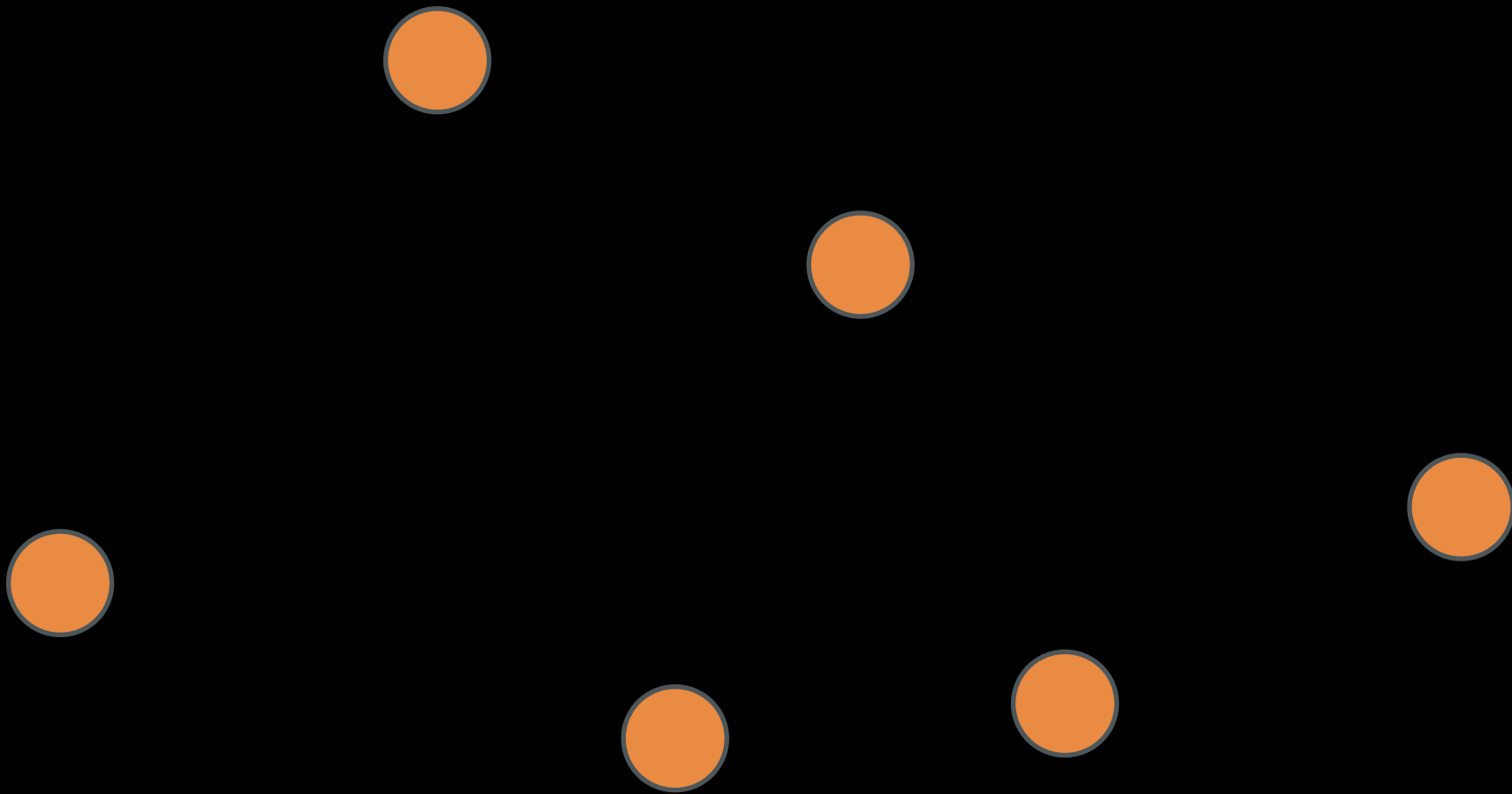
# Chemical reactions



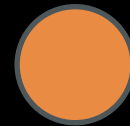
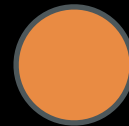
# Chemical reactions



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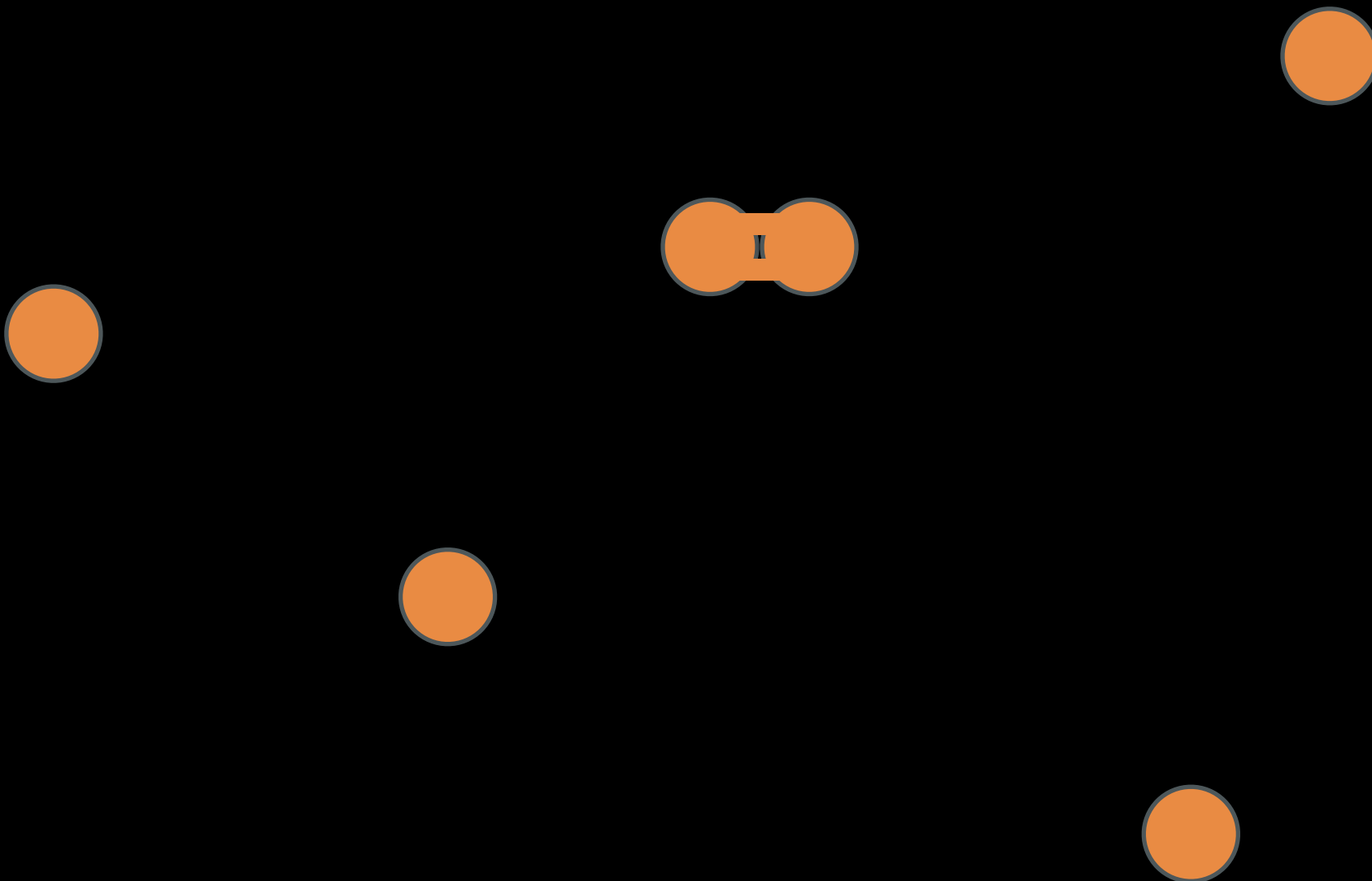


# Chemical reactions





# Chemical reactions



# Chemical reactions

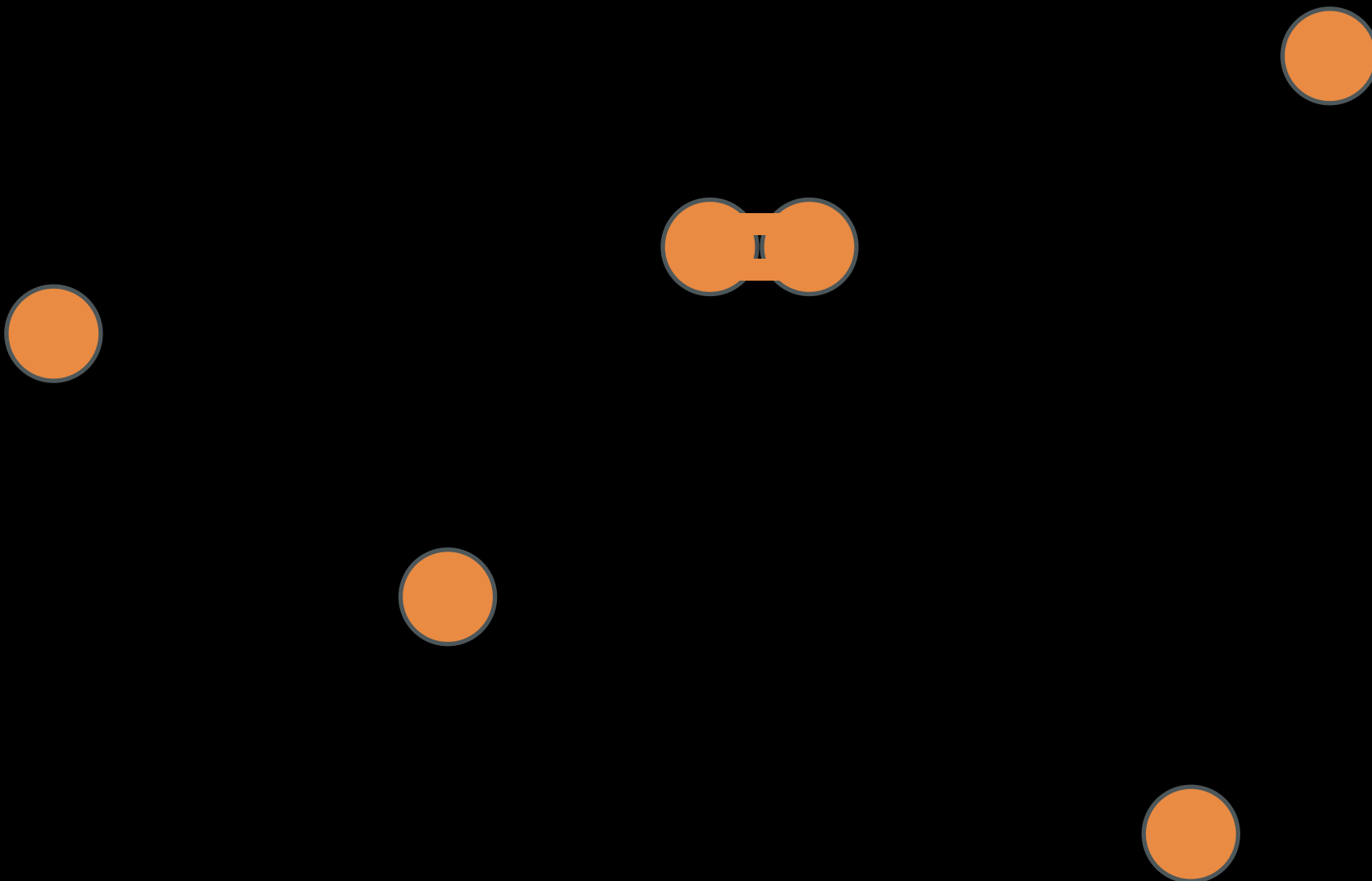


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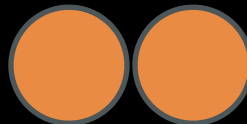
B



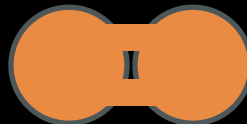
# Chemical reactions



# Chemical reactions



# Chemical reactions



# Chemical reactions



# Chemical reactions



reactants

product

# Chemical reactions



reactants

product

reactions generally happen faster  
the higher the concentration  
of reactants



# Catalysis



e.g.



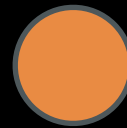
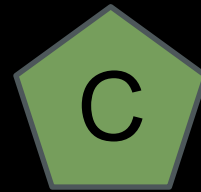
# Catalysis as a reaction network



*net reaction*



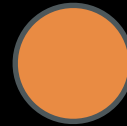
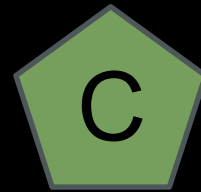
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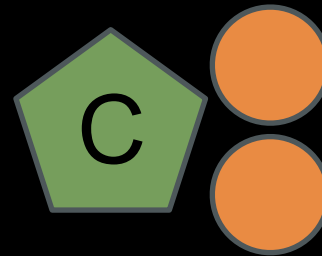
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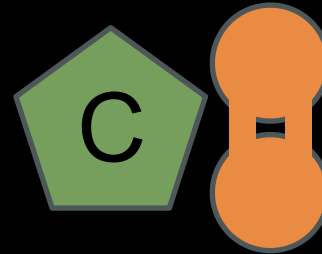
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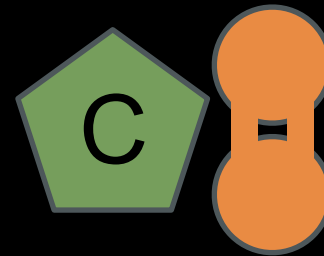
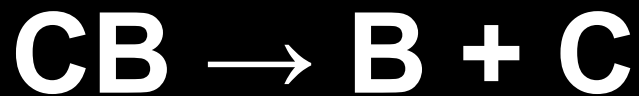
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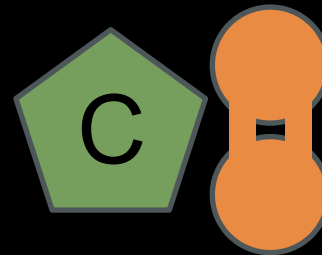
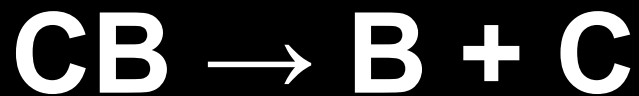
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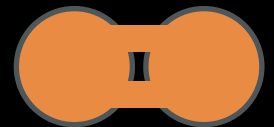
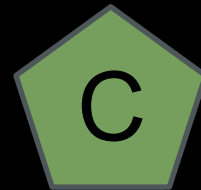
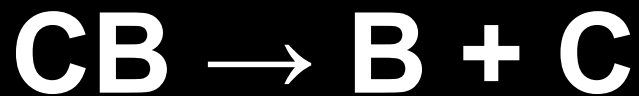


*net reaction*





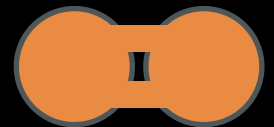
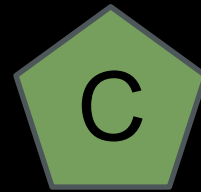
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*net reaction*



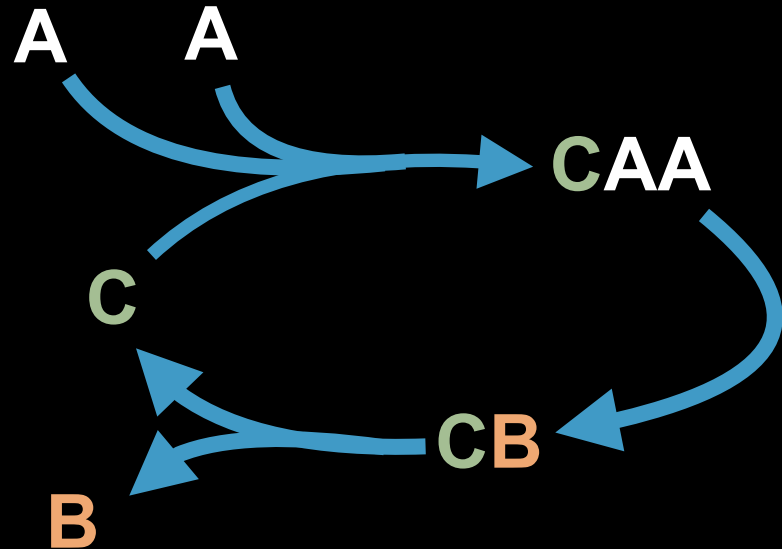
# Catalysis as a reaction network



*net reaction*



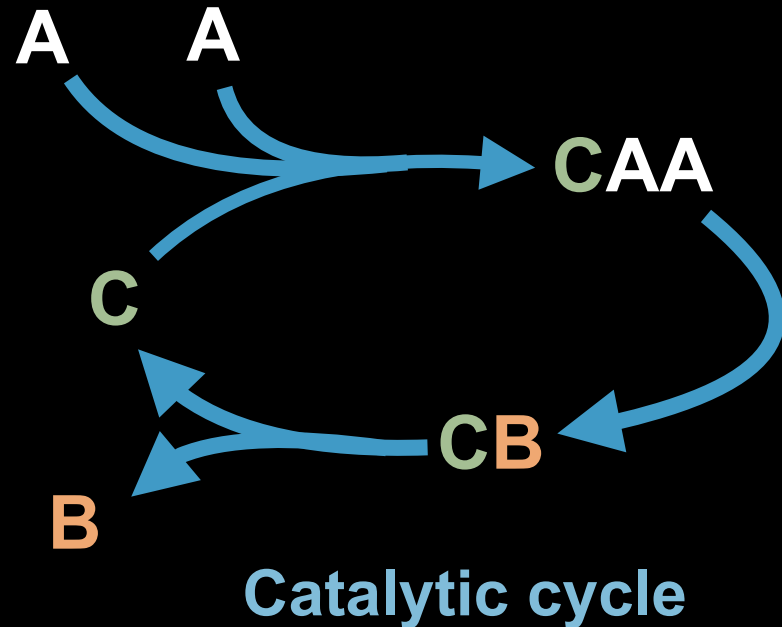
# Catalysis as a reaction network



*net reaction*



# Catalysis as a reaction network



*net reaction*



# Catalyst

broad definition: something that gets returned after a sequence of reactions

# Autocatalyst

broad definition: something that acts as a catalyst for its own production

# Autocatalytic reaction networks

Reaction network:  
multiple chemical  
reactions that interact.

Our first example is  
called the *formose  
reaction* (formaldehyde  
/ aldose)  
(Butlerov, 1861)

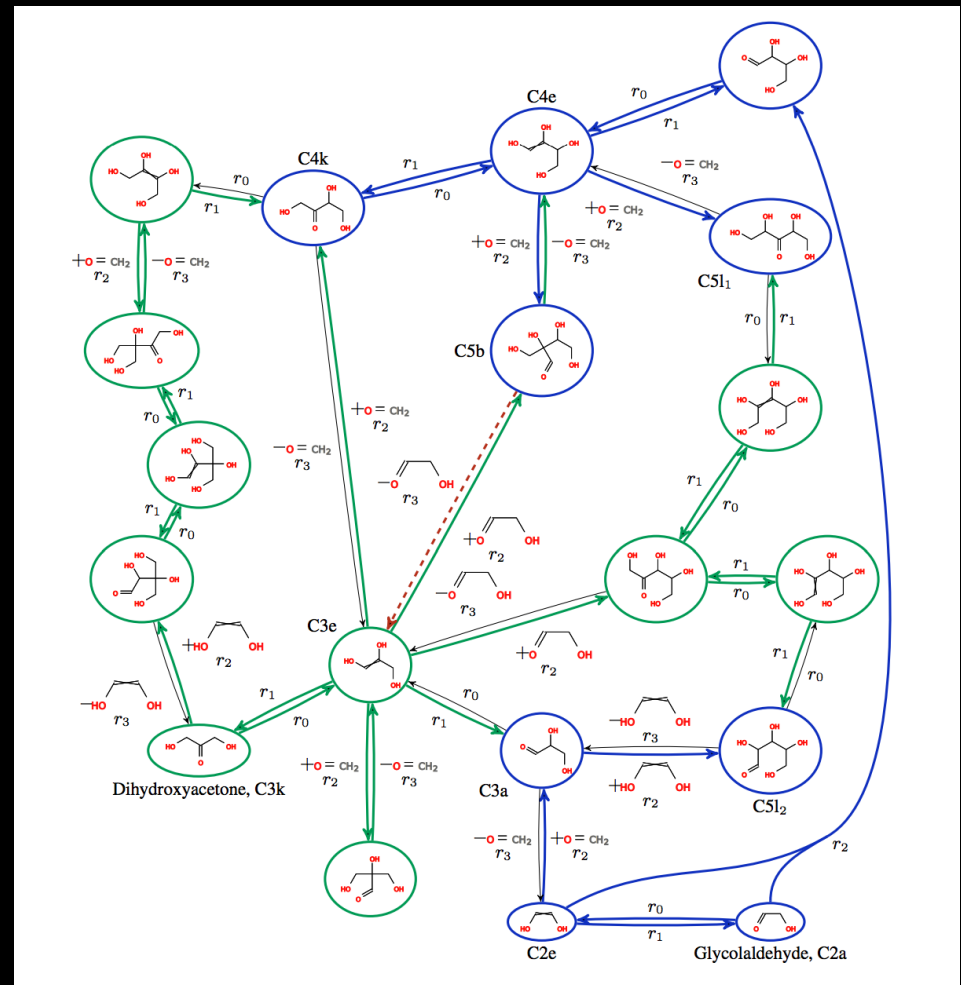
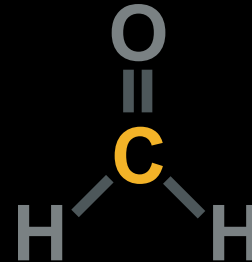
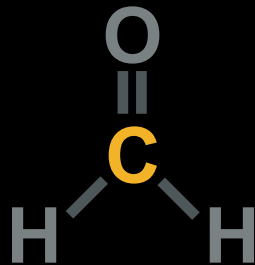
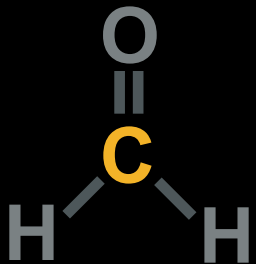
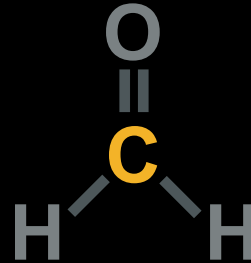
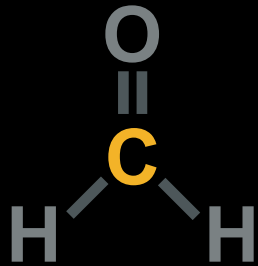
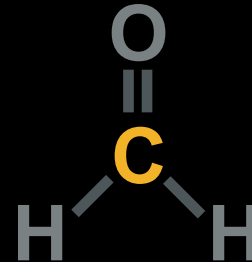
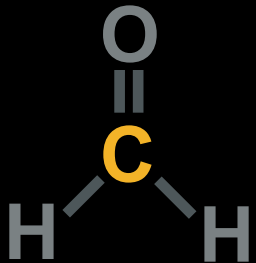
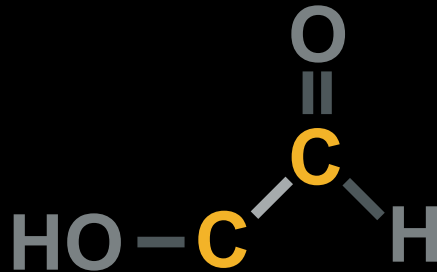
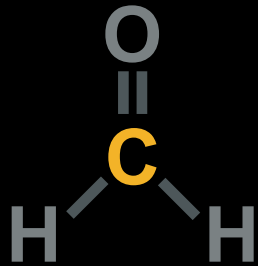


image: Andersen et al., 2013

# Formose reaction (highly simplified!)

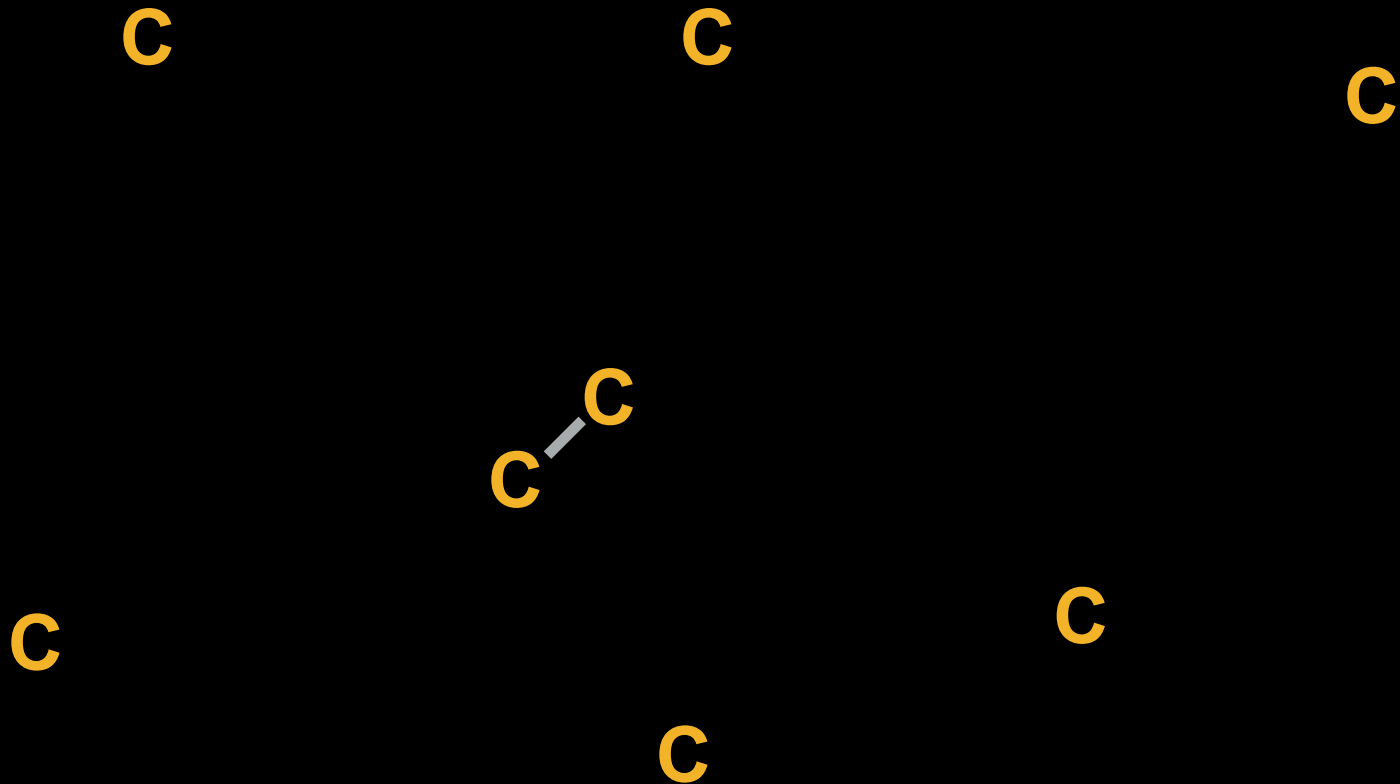


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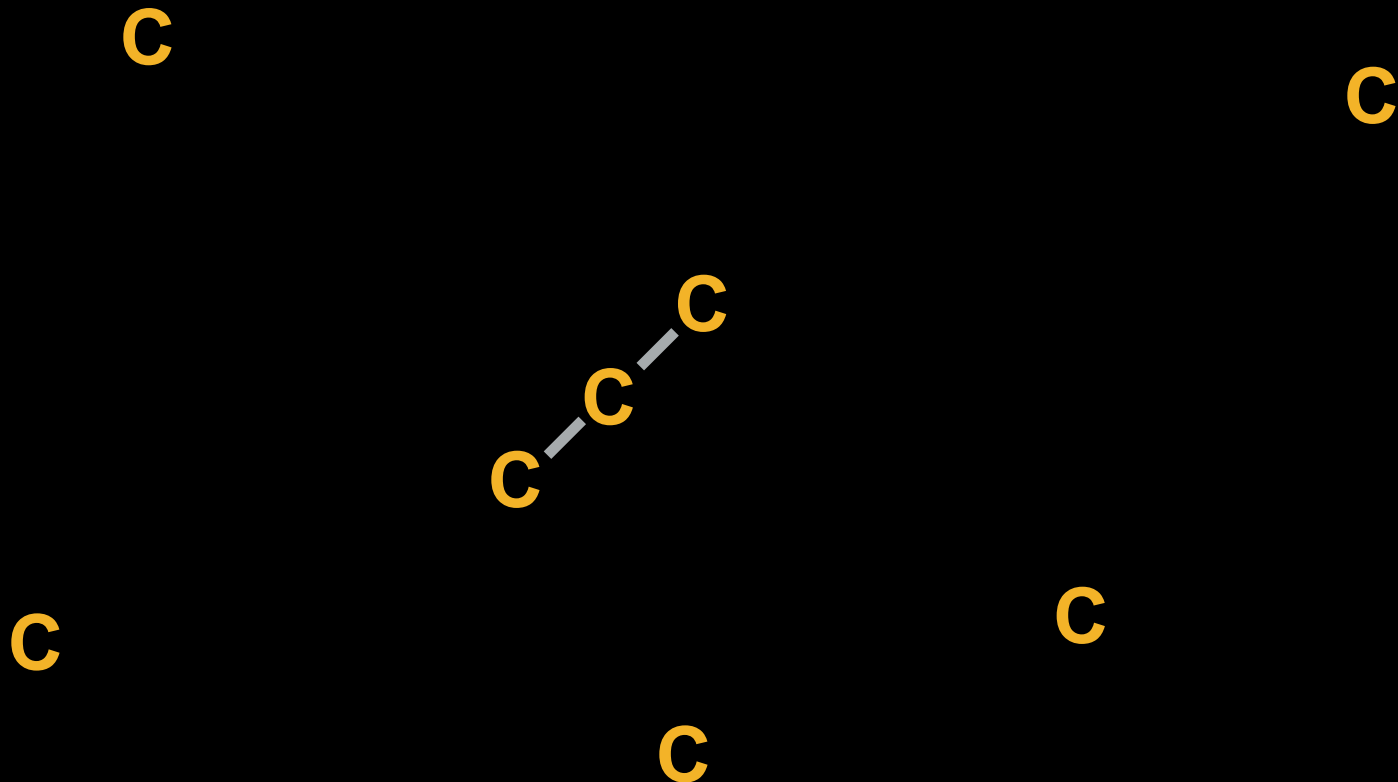




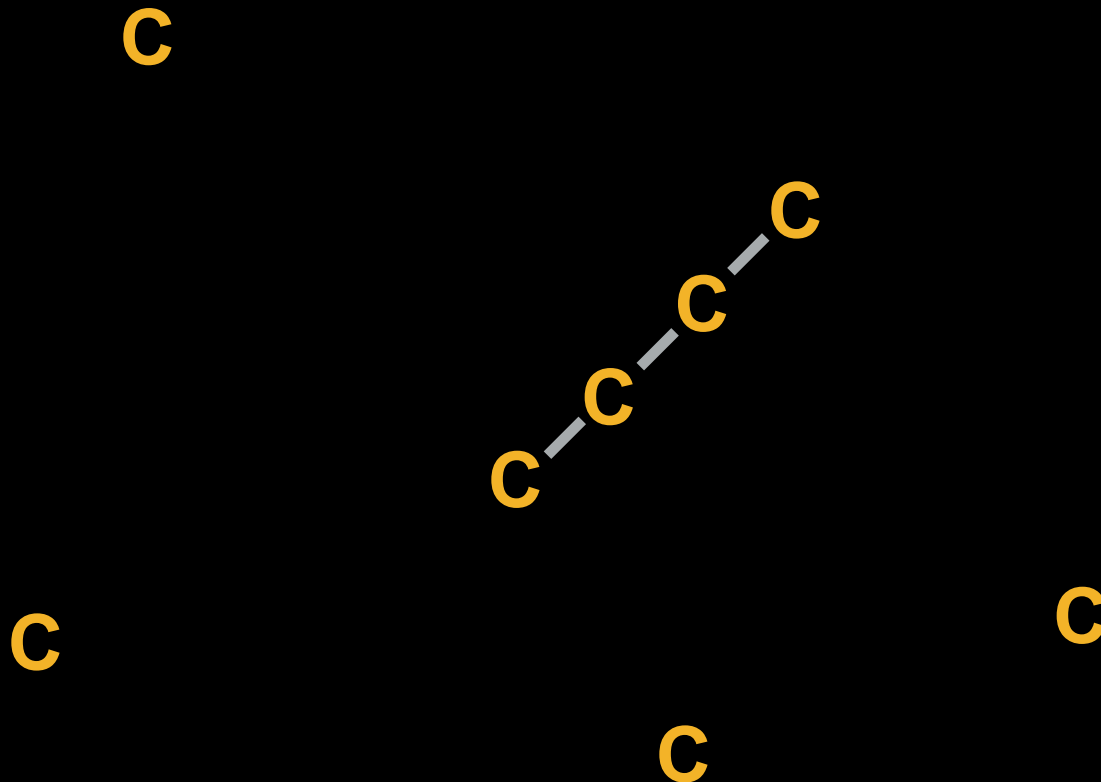
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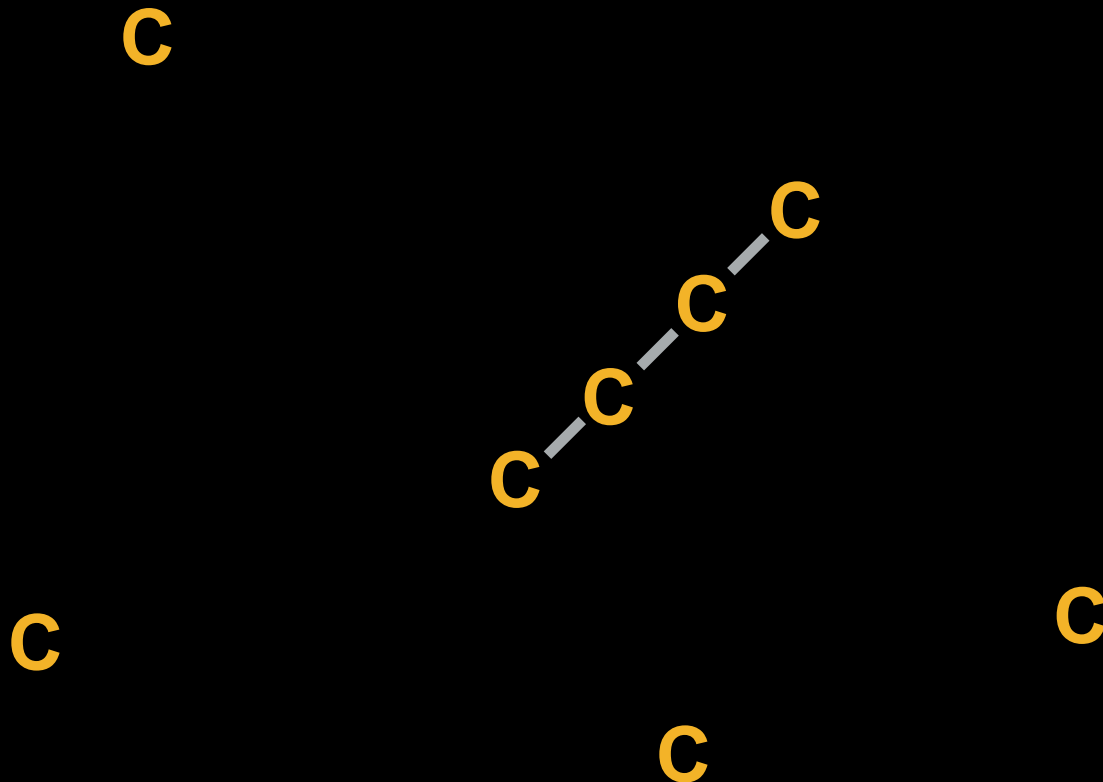
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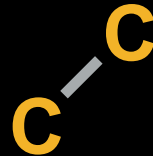
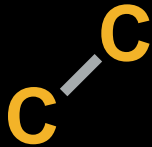


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C



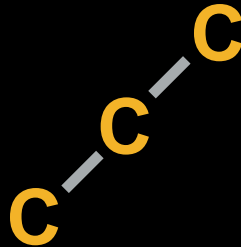
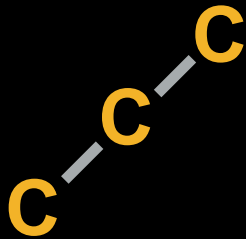
C

C

C

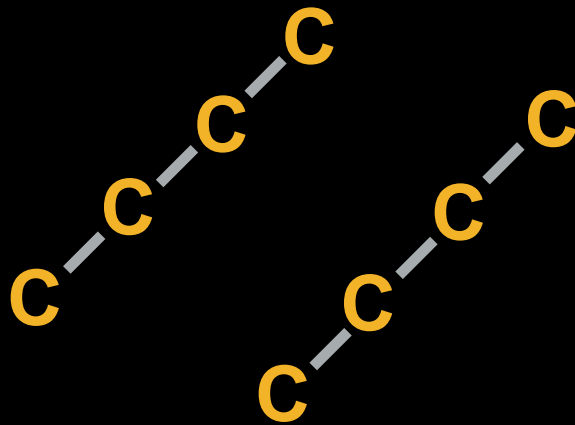
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C

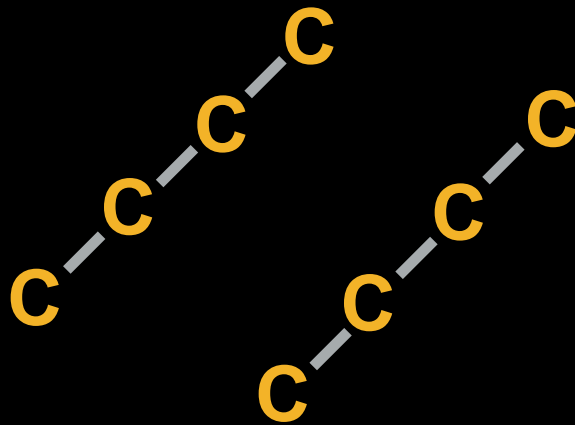


C

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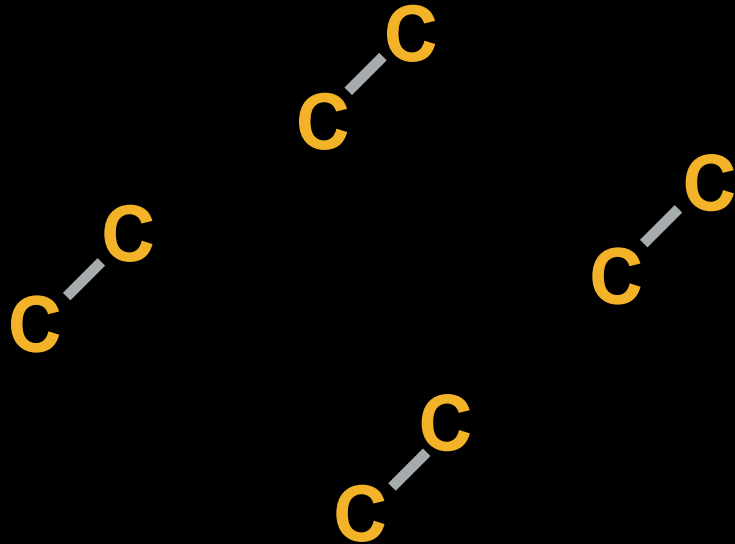


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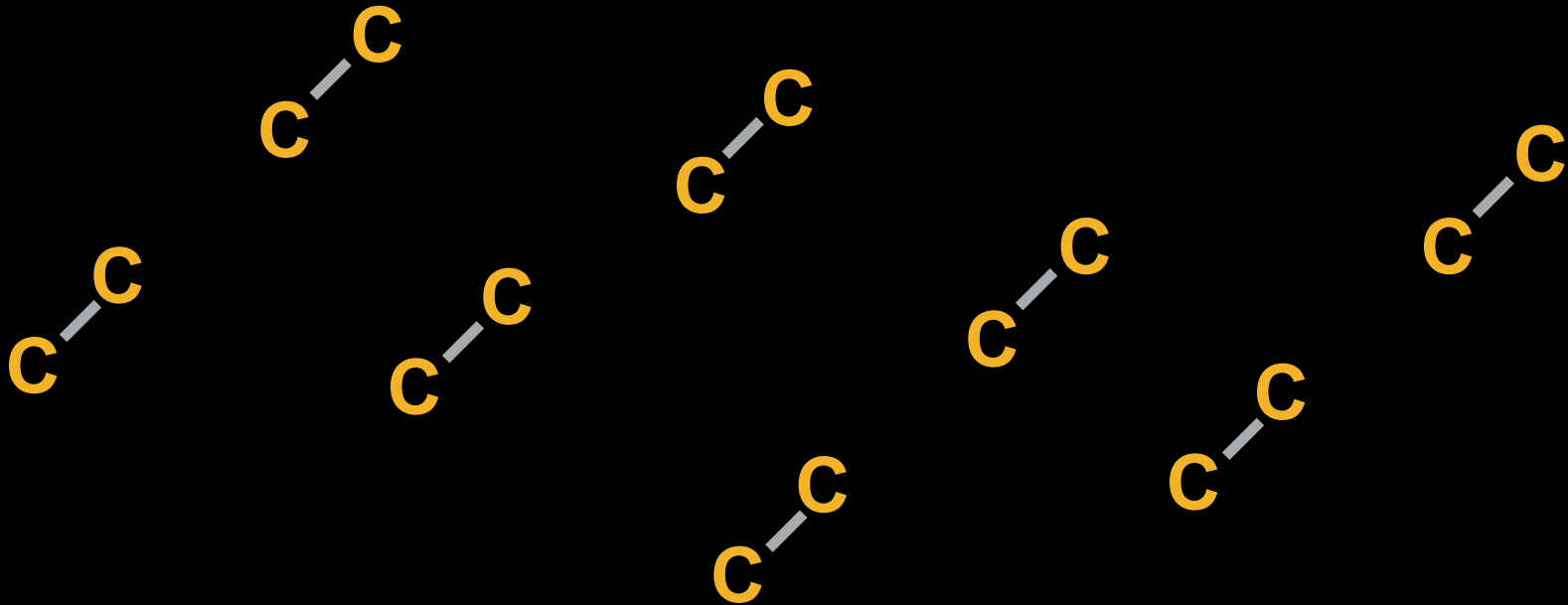




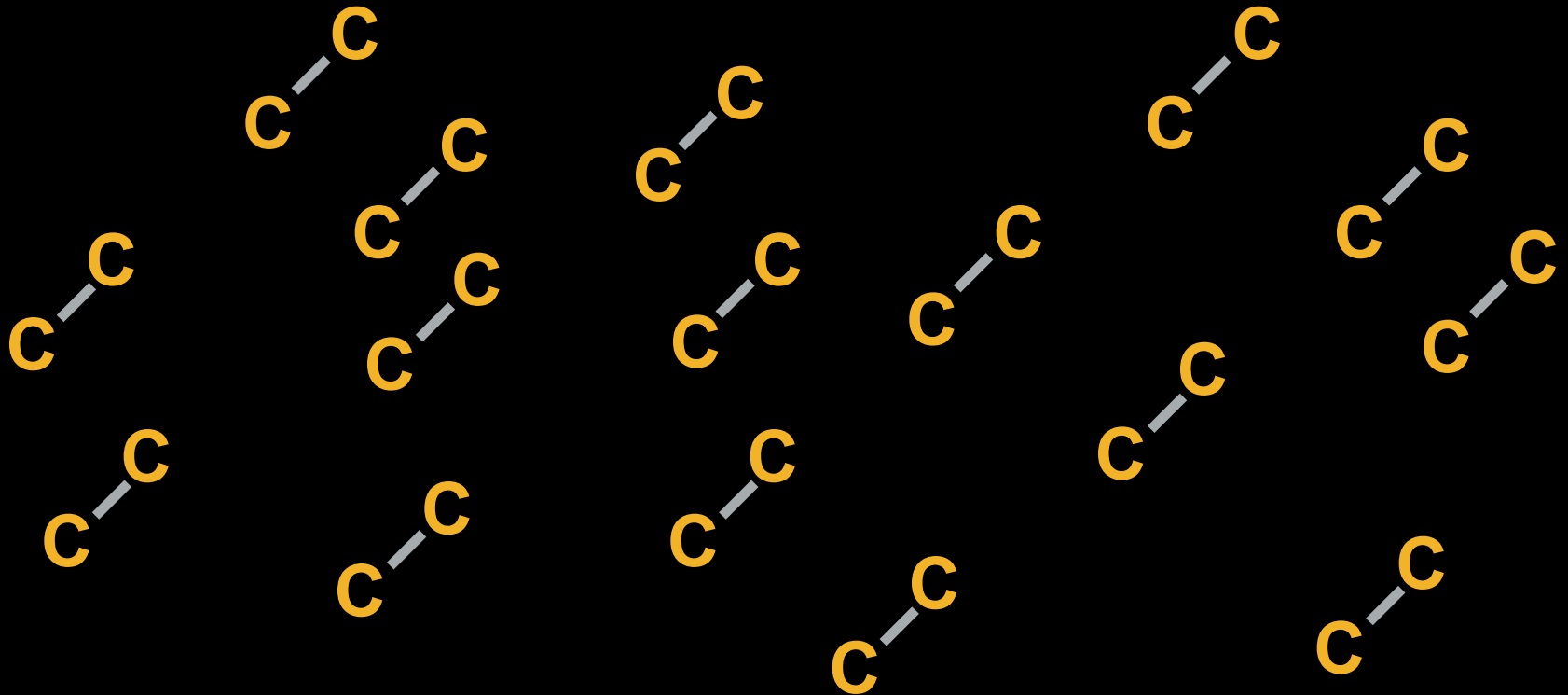
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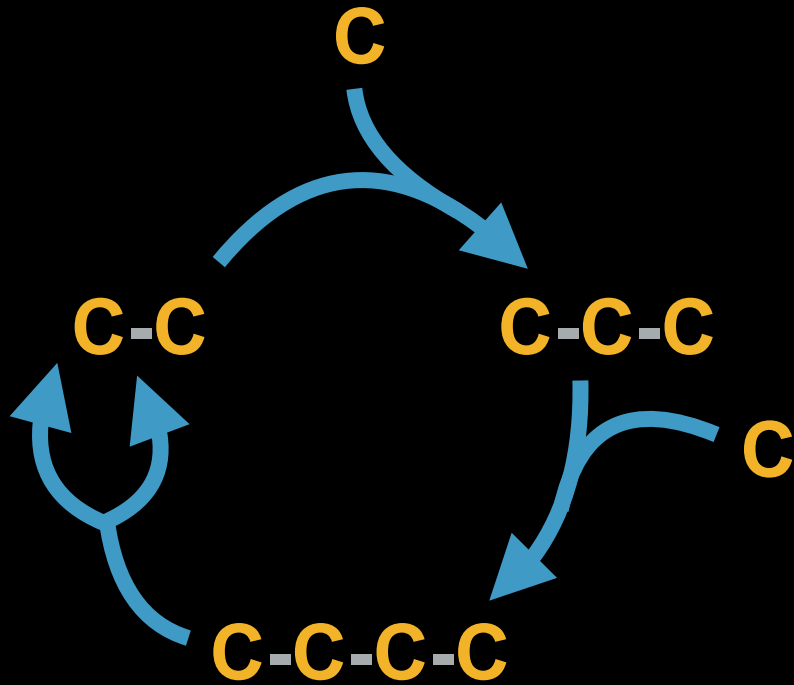
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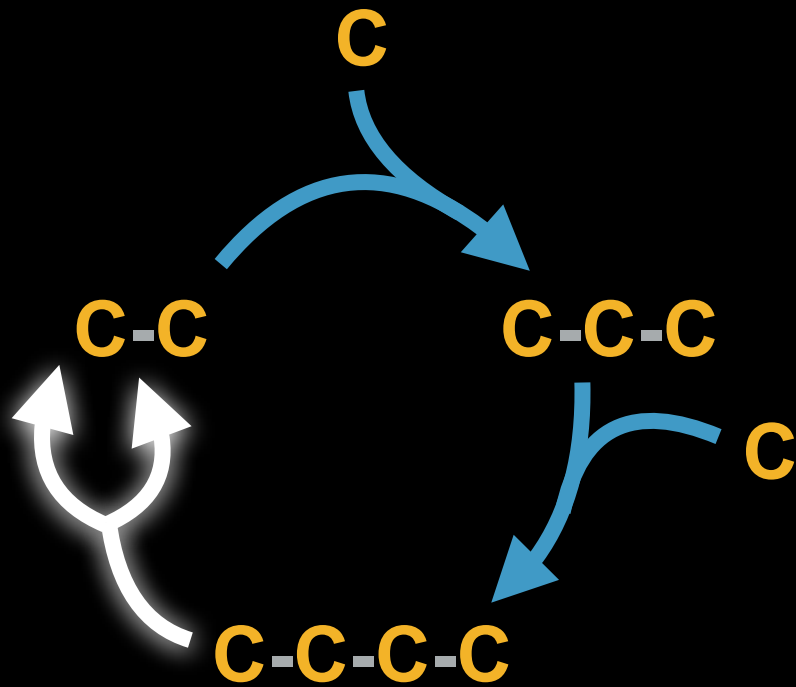
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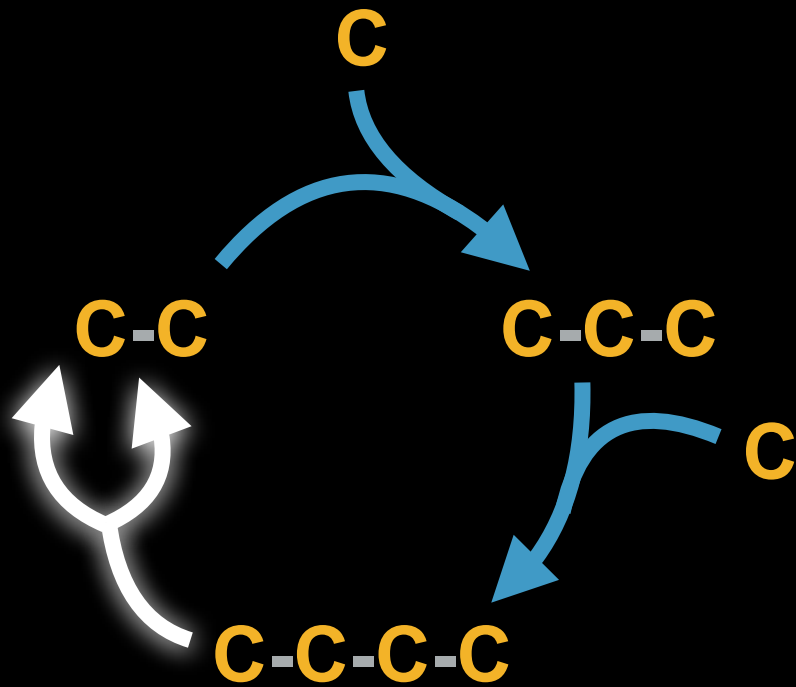


# Formose reaction (highly simplified!)



"branching step"

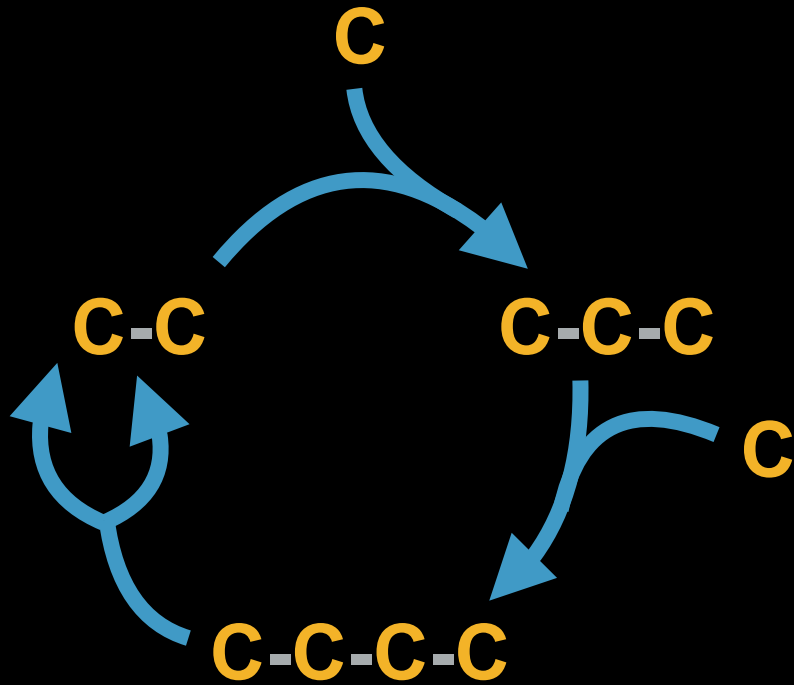
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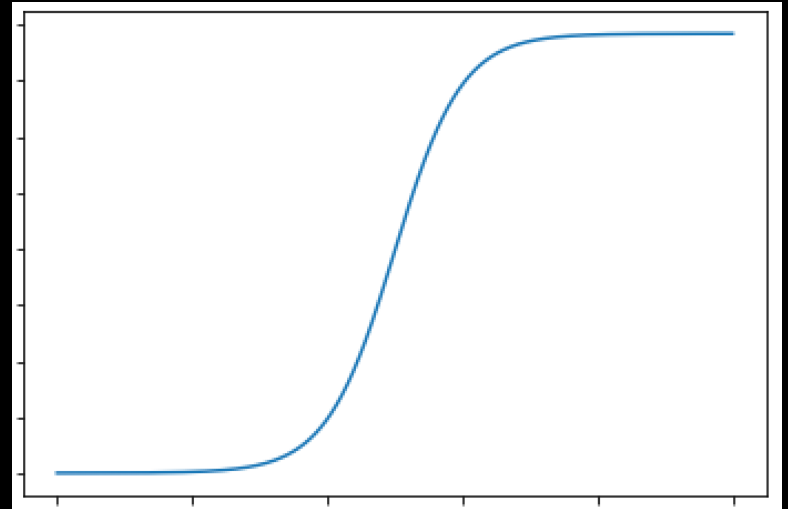
"branching step"

**Autocatalytic cycle**

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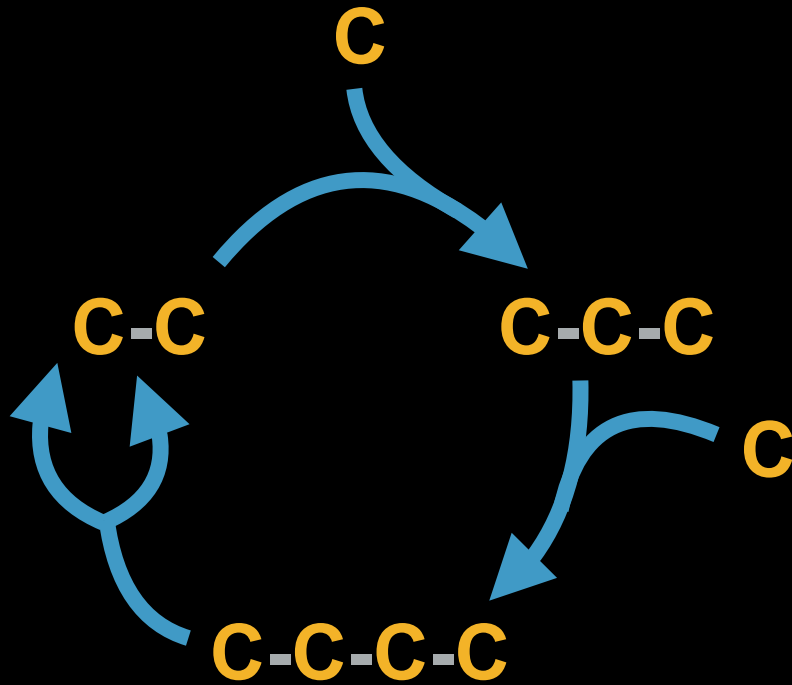


sugar concentration

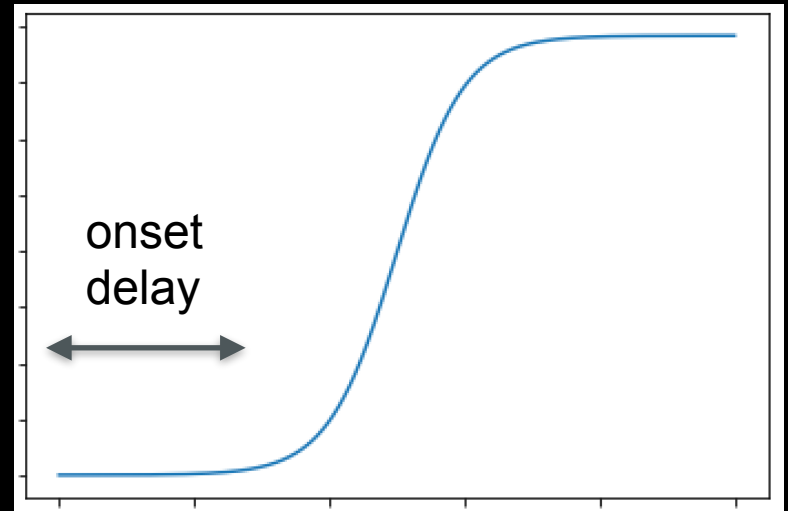


time

# Formose reaction (highly simplified!)



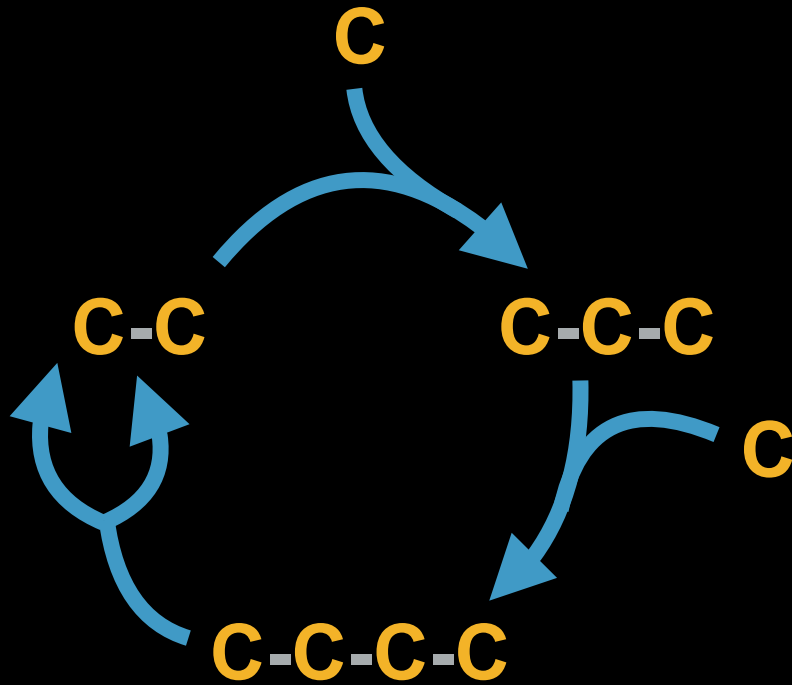
sugar concentration



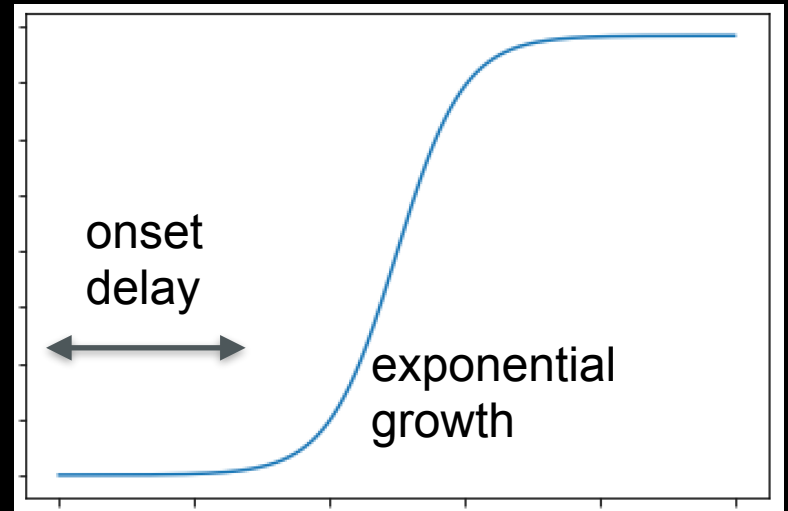
time



# Formose reaction (highly simplified!)

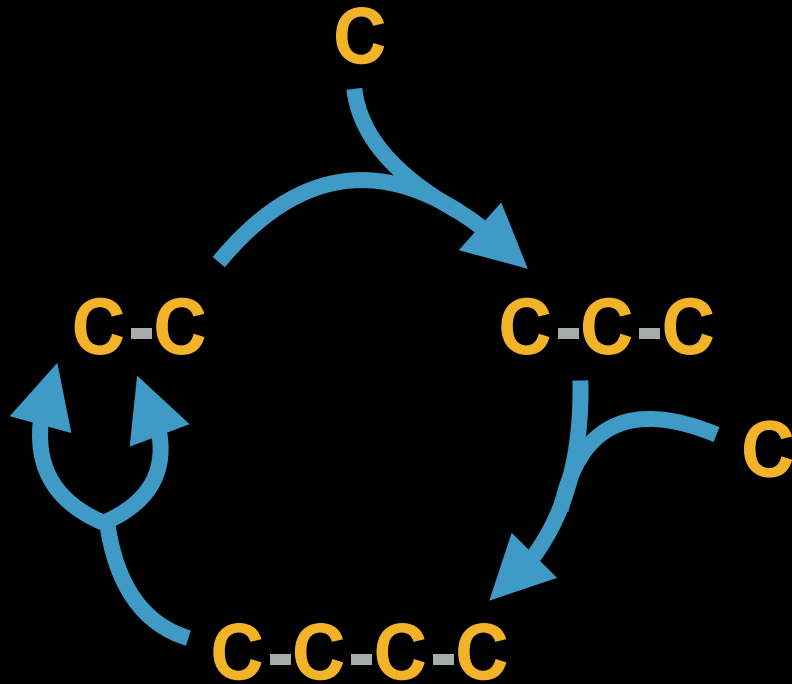


sugar concentration

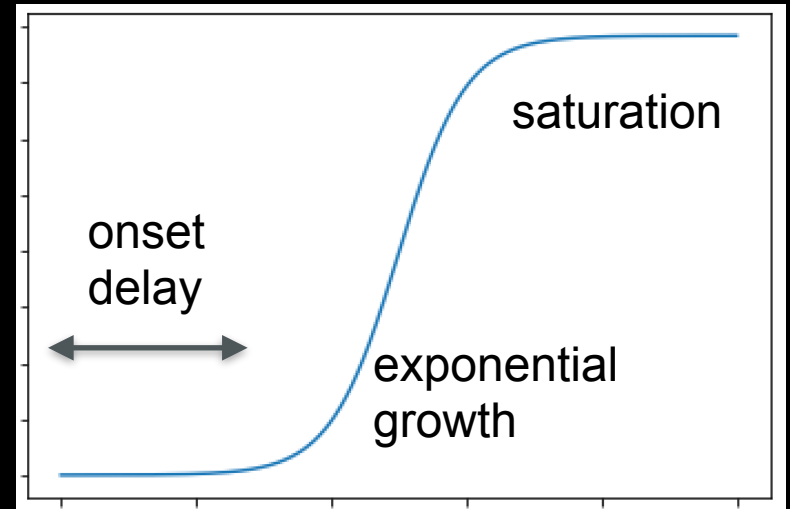


time

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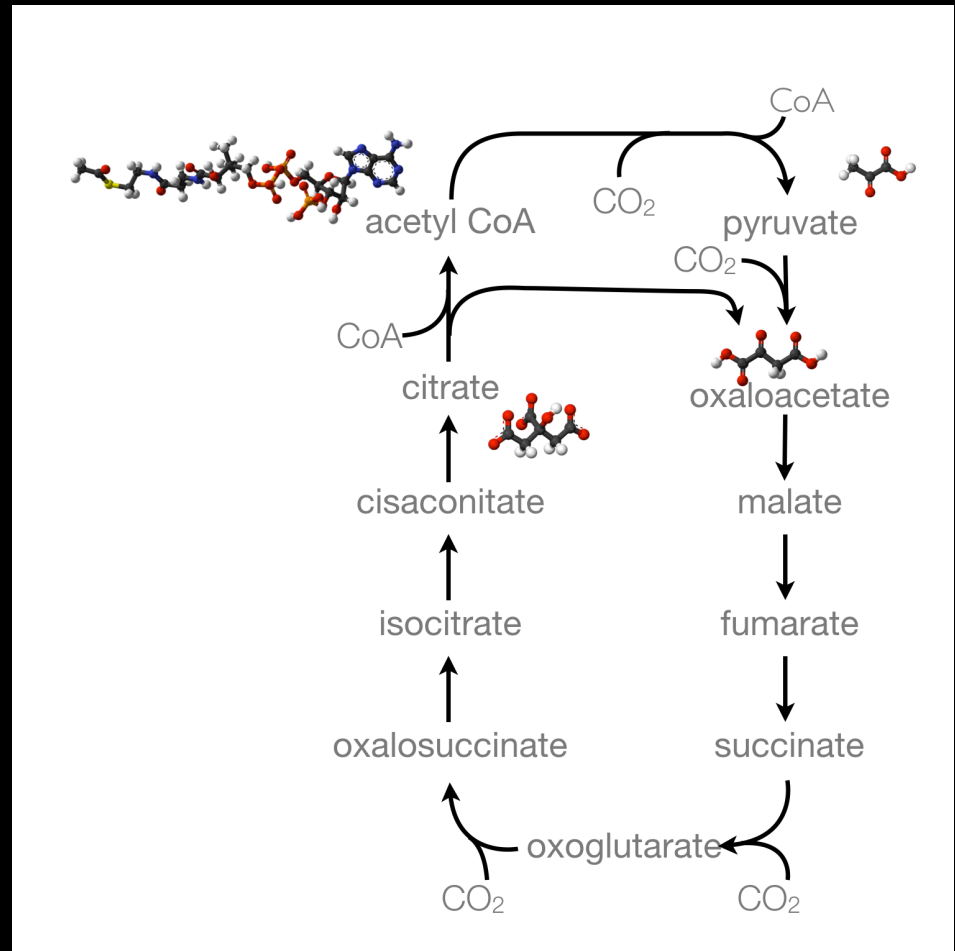
sugar concentration



time

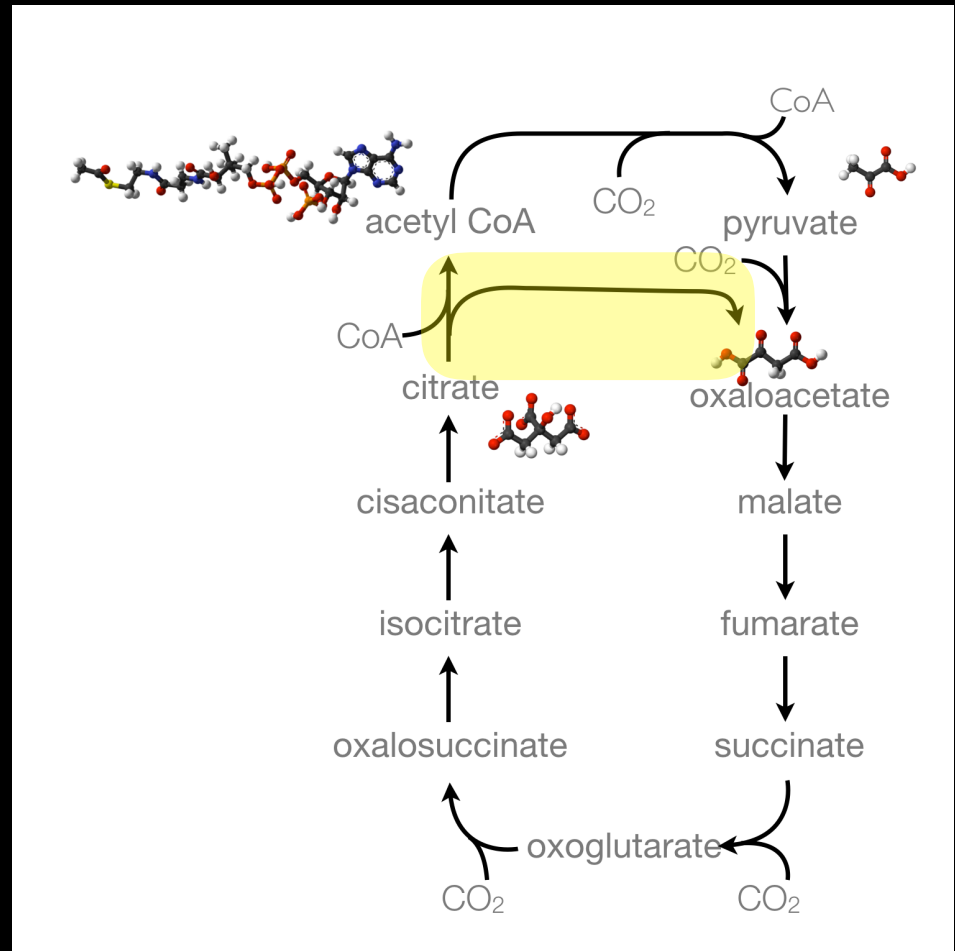
# Experimental autocatalysis

- Reverse citric acid cycle
- Key part of metabolism of many organisms
- but unlike formose, many steps are 'difficult' reactions, requiring specific catalysts

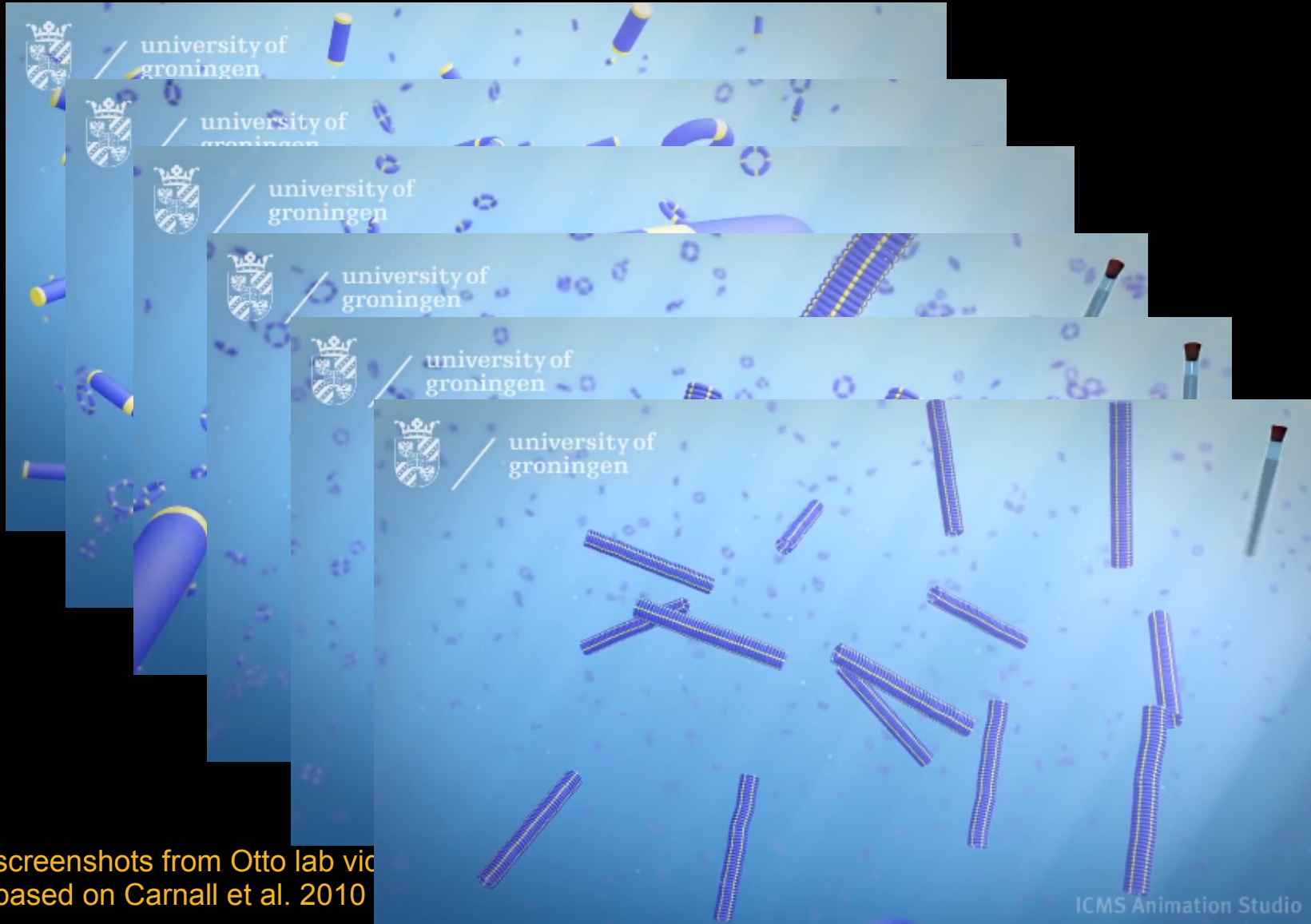


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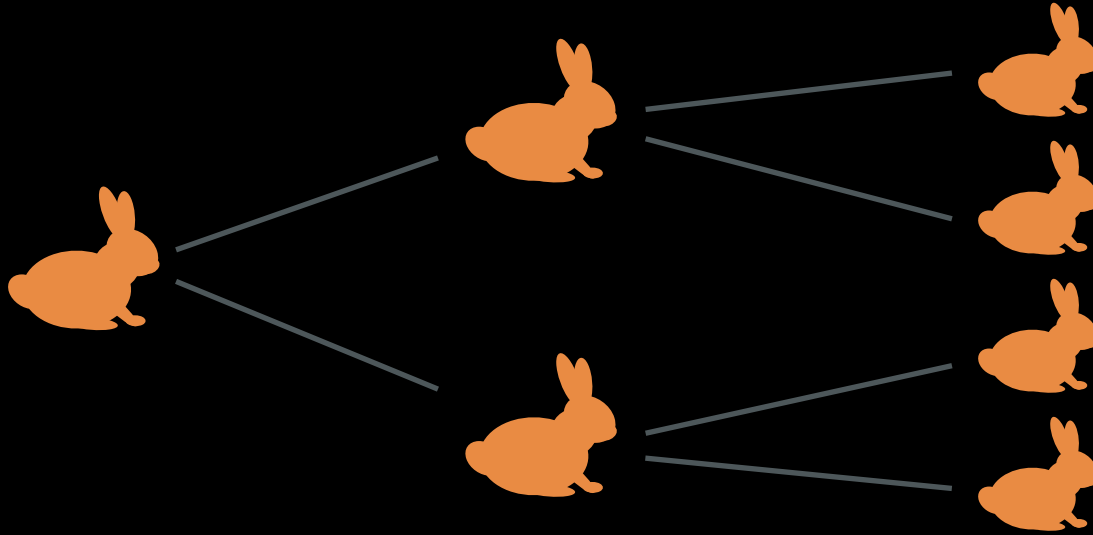


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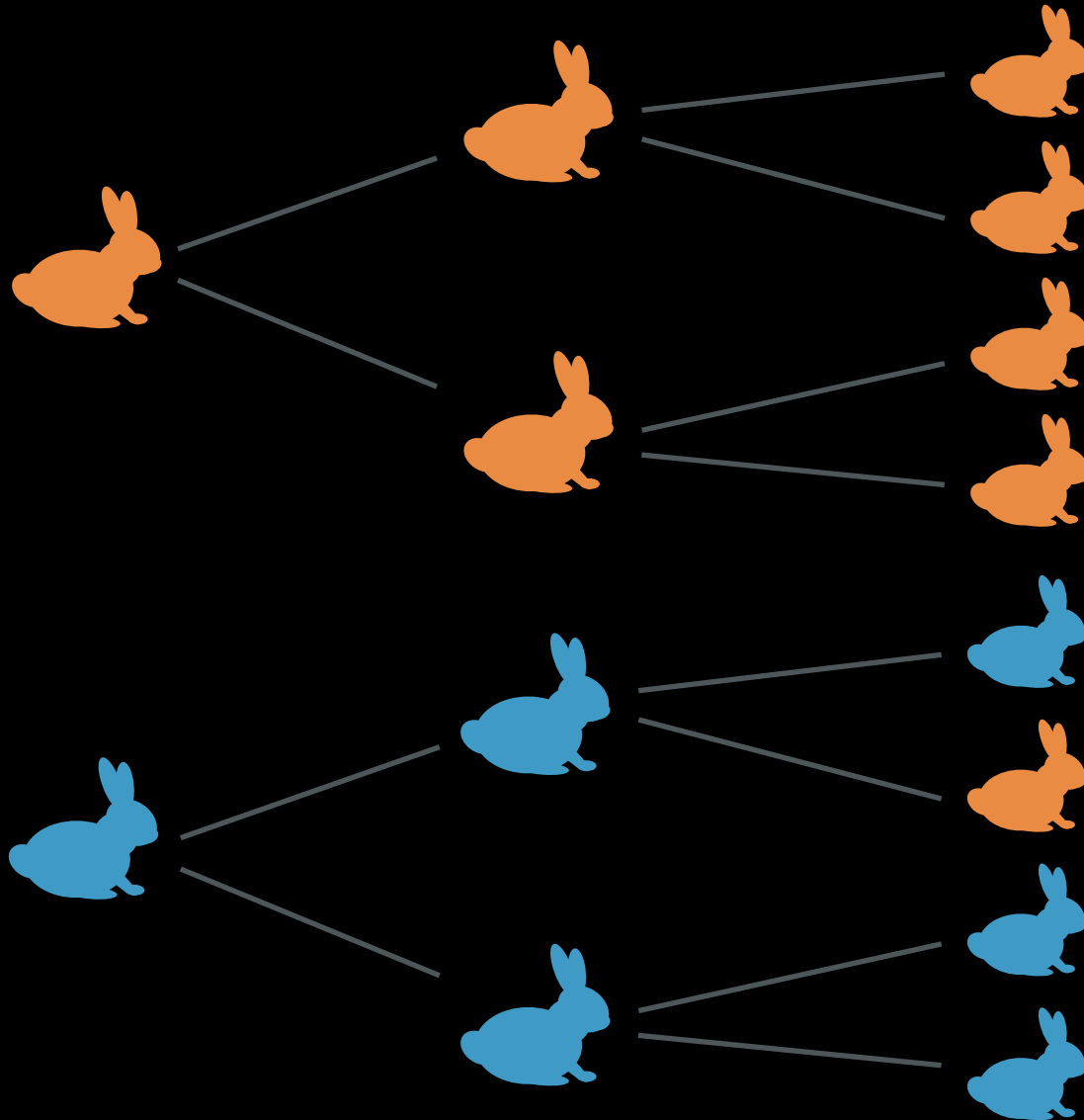


screenshots from Otto lab vid  
based on Carnall et al. 2010

# Autocatalysis vs replication



# Autocatalysis vs replication



# Template replicators

B

B

A

B

A

**ABAA**

B

A



# Template replicators

B

A

BBAB  
ABAA

A

# Template replicators

B

A

BBAB  
ABAA

A

# Template replicators

B

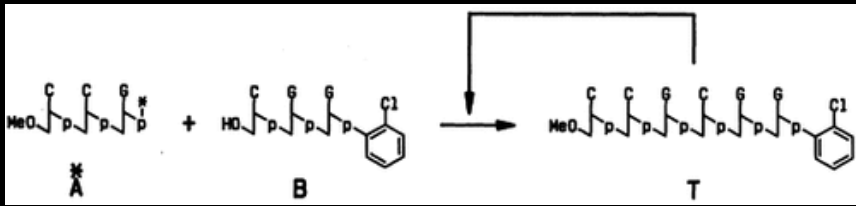
A

**BBAB**

**ABAA**

A

# Template replicators



von Kiedrowski (1986)

modified RNA trimers as monomers

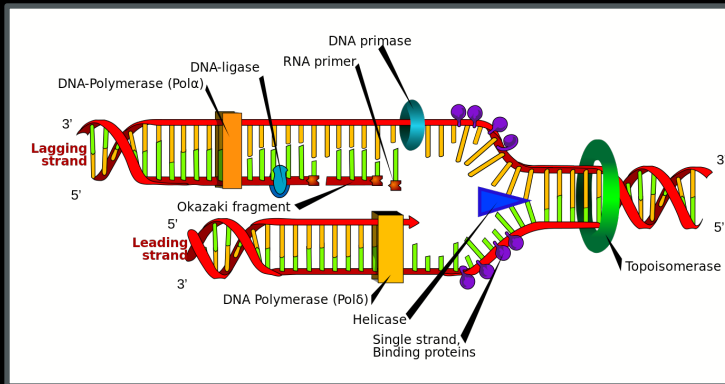
Main problem: the monomers have to be quite complicated to avoid “side reactions”



Virgo et al. (2011)

acrylic shapes with magnets on air-hockey table

# Eigen's paradox (Eigen 1971)



complicated molecular  
machinery

high fidelity  
replication

evolution by  
natural selection

# Possibilities for pre-biotic heredity

- Template replication

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- Template replication
- Replicase-like RNAzyme that can copy itself
  - similar issue: the molecule has to be quite complex (but it's a promising area of active study)

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- Template replication
- Replicase-like RNAzyme that can copy itself
  - similar issue: the molecule has to be quite complex (but it's a promising area of active study)
- “Compositional heredity” - no heteropolymers, information stored in composition of protocell instead (Segre et al., Vasas et al.)



# Summary and open questions

- Autocatalysis is chemical self-production
- Reaction networks are a useful tool to understand it
- Replication with heredity is more difficult than autocatalysis
- Open questions:
  - How can biomolecules be produced abiotically?
  - Did the first autocatalytic cycles resemble biochemistry, or were they completely different?
  - How did evolution by natural selection first arise?

# References (page 1/2)

## **modern computational research into reaction network modelling**

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## **Eigen's paradox (see also Wikipedia)**

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## **The 'air hockey table' template replicators**

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von Kiedrowski, G. (1986). A self-replicating hexadeoxynucleotide. Angewandte Chemie International Edition in English, 25(10), 932-935.

**Thank you!**