

Accumulation by temperature gradients

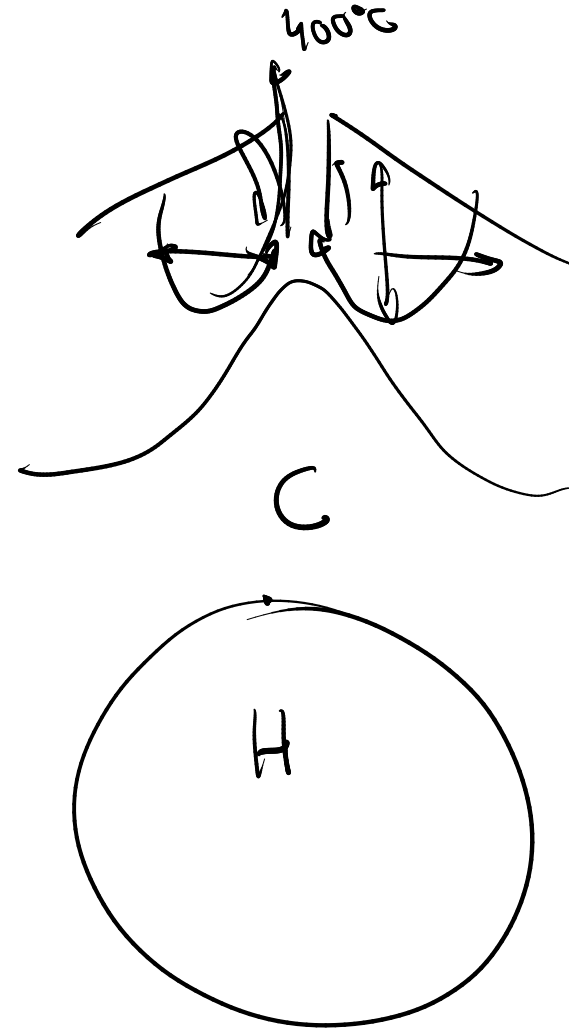
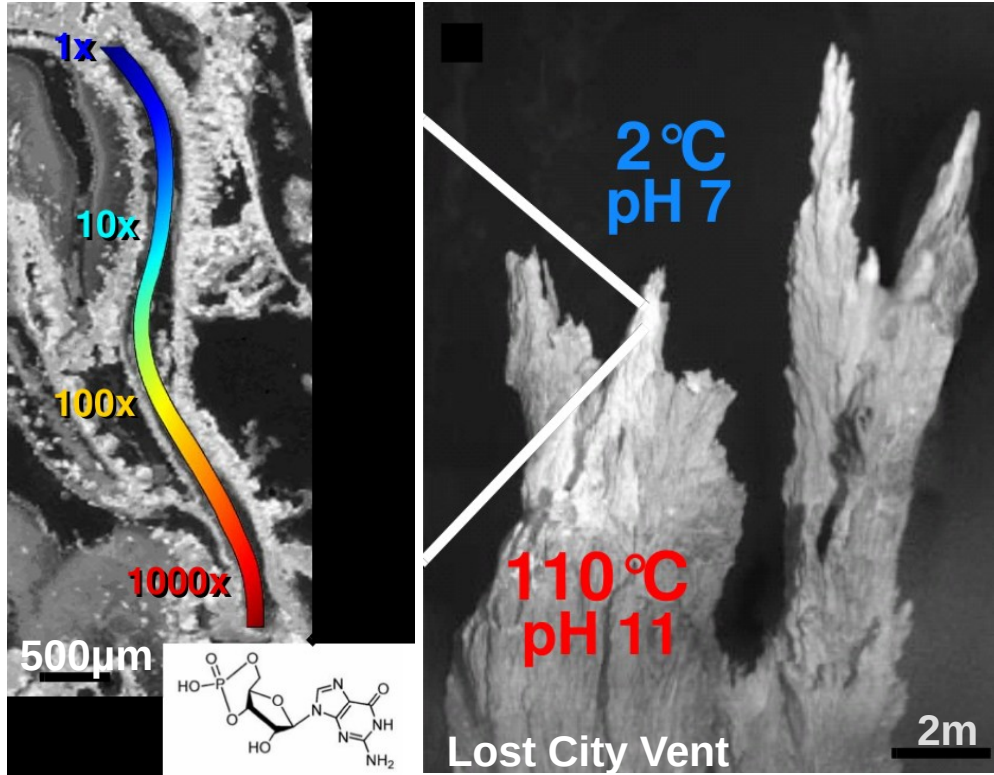
# Hot Vapor Settings



Iceland

# Accumulation by temperature gradients

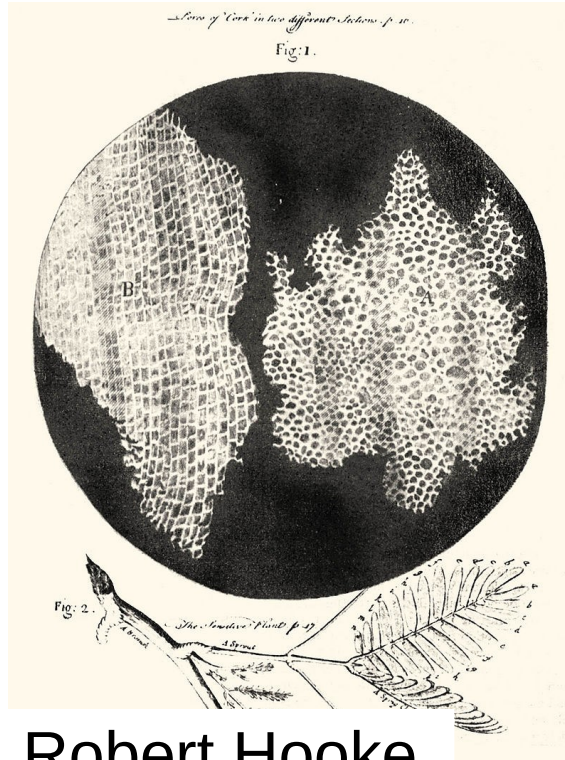
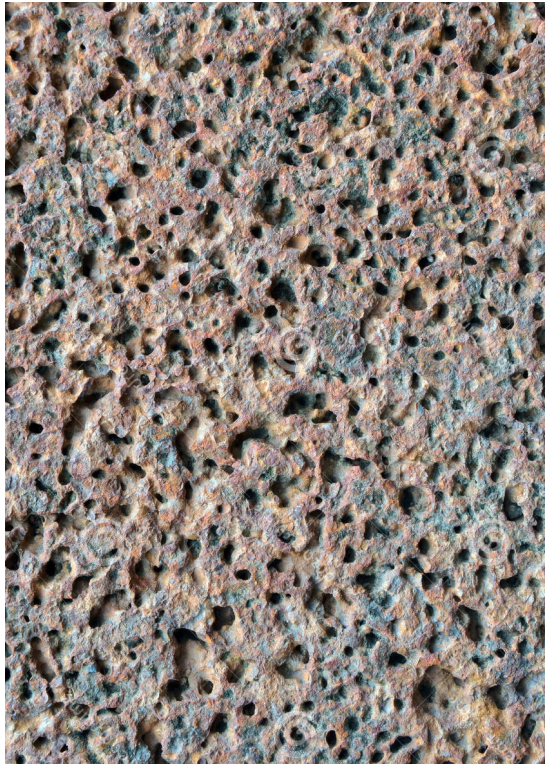
## Hydrothermal Settings





# Accumulation by temperature gradients

## Cells defined by Pores of Rock



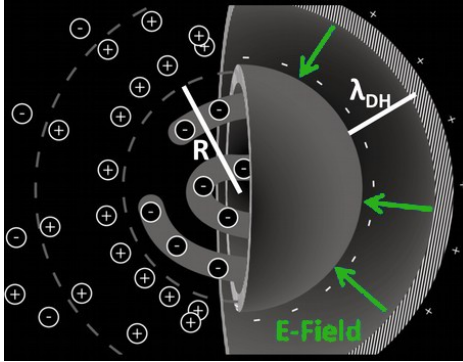
Robert Hooke

# Accumulation by temperature gradients

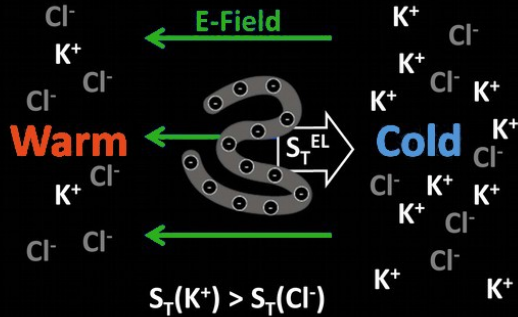
## Thermophoresis



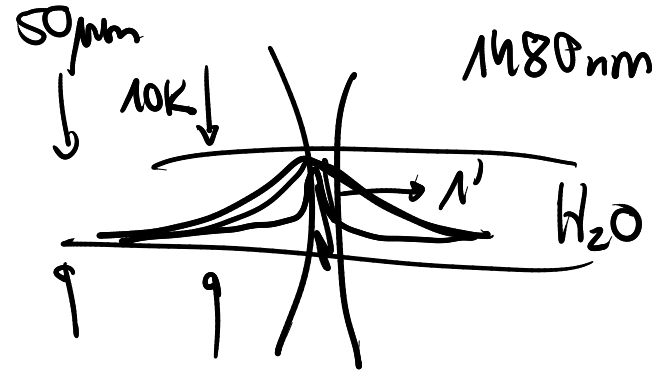
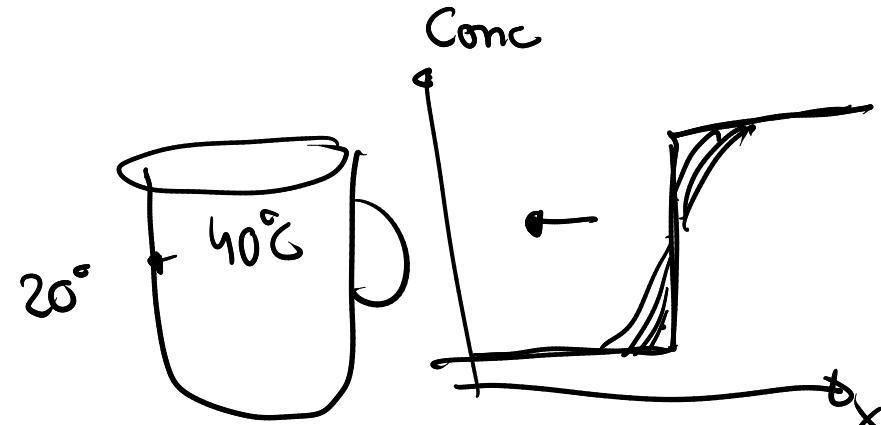
Local E-Field



Global E-Field



Duhr and Braun, PNAS 103, 19678 (2006)  
 Reichl, Herzog, Götze, and Braun, PRL 112, 198101 (2014)



$$S_T^{SCM} \frac{R}{Z_{eff}^2} = \frac{e^2 R / \lambda_{DH}}{16\pi k_B T^2 \epsilon_r \epsilon_0 (1 + R/\lambda_{DH})^2} \times \left( 1 - \frac{\partial \ln \rho(T)}{\partial \ln T} - \frac{\partial \ln \epsilon_r(T)}{\partial \ln T} \left( 1 + \frac{2\lambda_{DH}}{R} \right) \right)$$

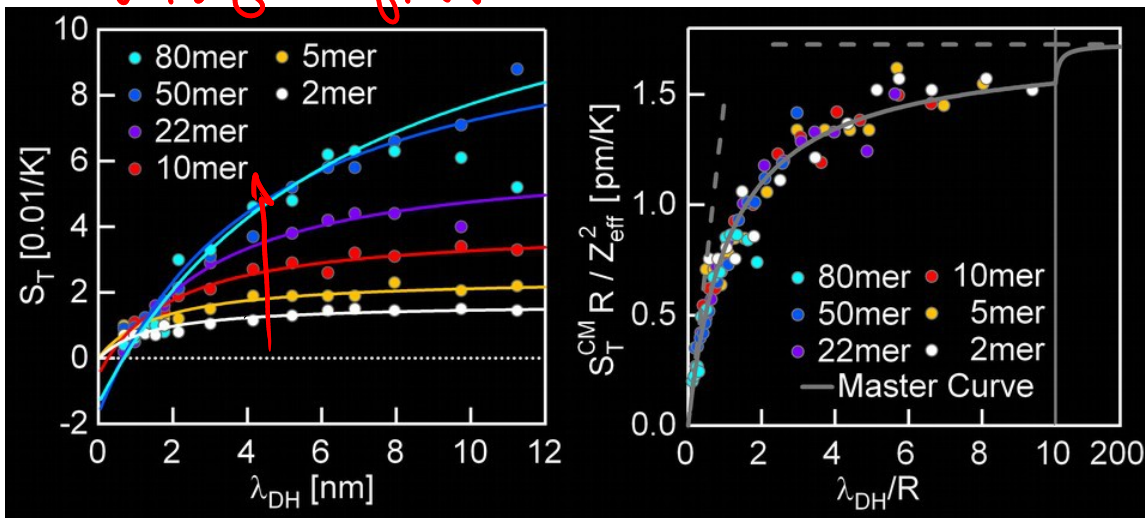
=> NanoTemper

# Accumulation by temperature gradients

## Thermophoresis



↓ Physiological concentration



high salt

low salt

$$S_T^{\text{CM}} \frac{R}{Z_{\text{eff}}^2} = \frac{e^2 R / \lambda_{\text{DH}}}{16\pi k_B T^2 \epsilon_r \epsilon_0 (1 + R / \lambda_{\text{DH}})^2} \times \left( 1 - \frac{\partial \ln \rho(T)}{\partial \ln T} - \frac{\partial \ln \epsilon_r(T)}{\partial \ln T} \left( 1 + \frac{2\lambda_{\text{DH}}}{R} \right) \right)$$

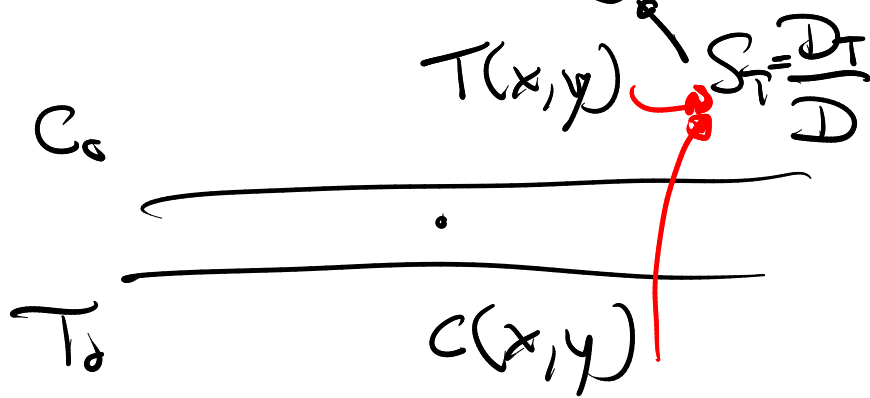
Diff. coeff.      Gradient of T

$$\vec{v} \cdot c = \int_0^{\infty} \frac{\#}{s \cdot A} = -D \nabla c - c D_T \nabla T$$

$\stackrel{=0}{\sim}$

$$c \approx c_0 \exp\left(-\frac{D_T}{D} \Delta T\right)$$

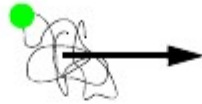
$$c(T) = c_0 \exp\left(-\frac{D_T}{D} (T - T_0)\right)$$



# Accumulation by temperature gradients

## Thermophoresis of DNA

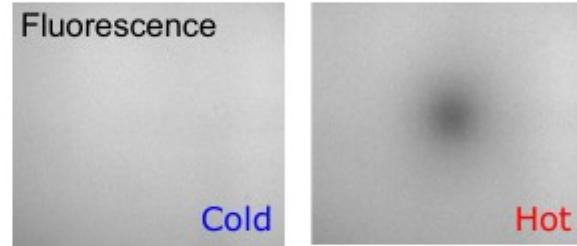
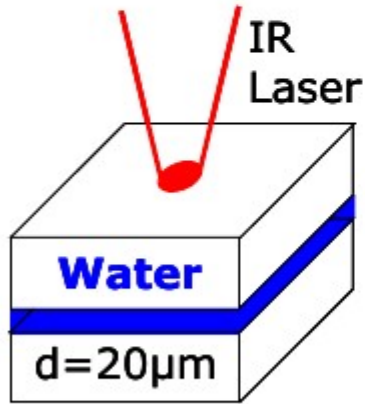
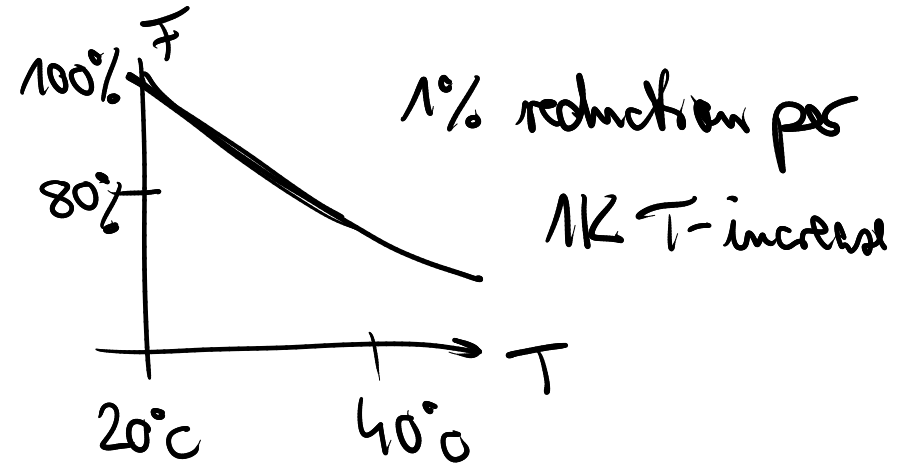
**Warm**



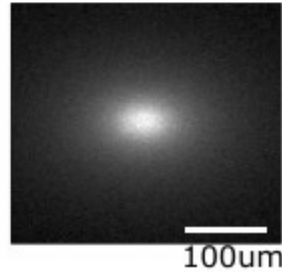
**Cold**

$$v = -D_T \nabla T$$

$$j = -D \nabla c - D_T c \nabla T$$



Temperature Image  
(z-average)

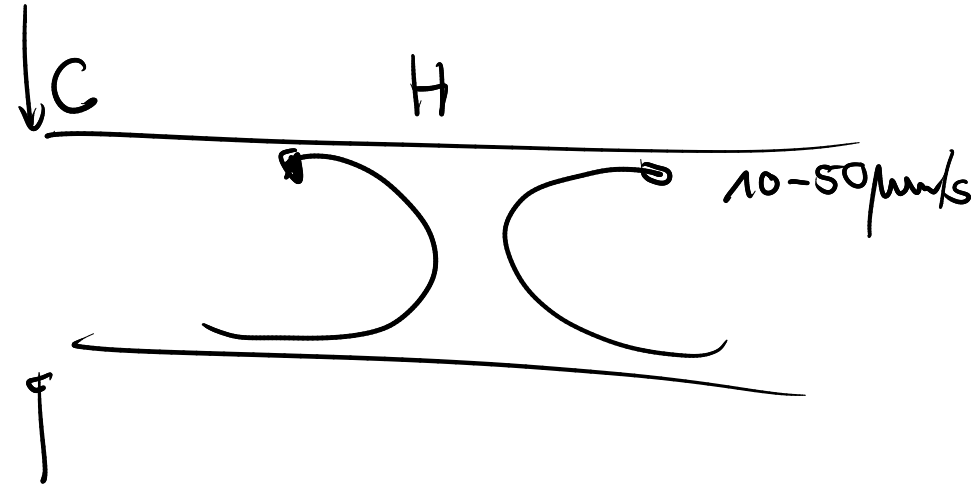
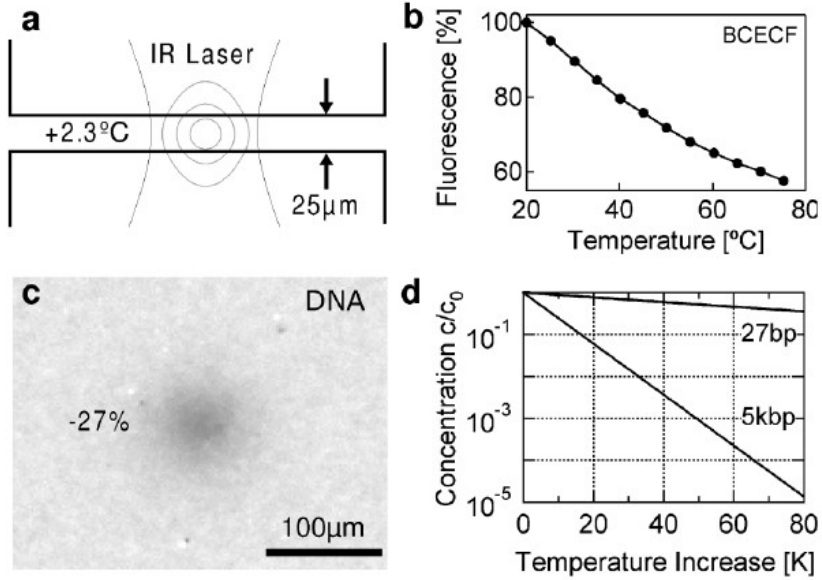


# Trapping of DNA by Thermophoretic Depletion and Convection

Dieter Braun\* and Albert Libchaber

Center for Studies in Physics and Biology, Rockefeller University, New York, New York 10021

(Received 2 May 2002; published 14 October 2002)





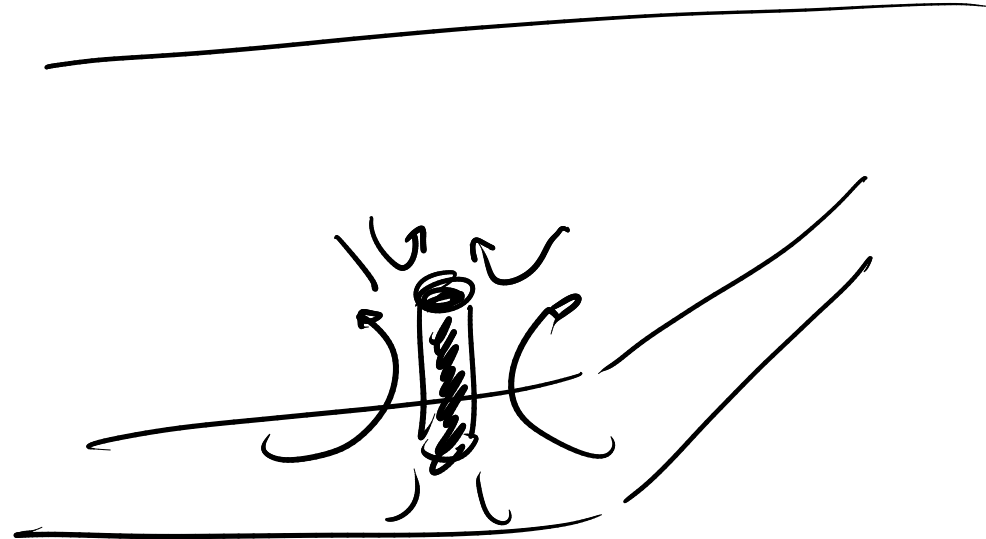
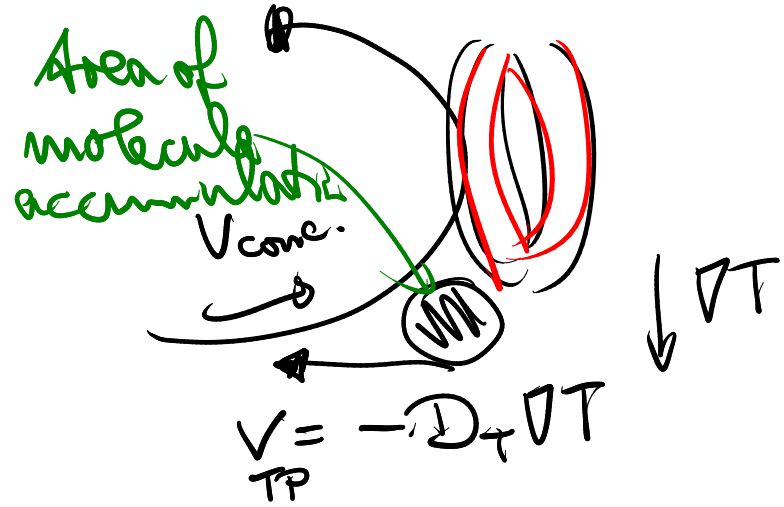
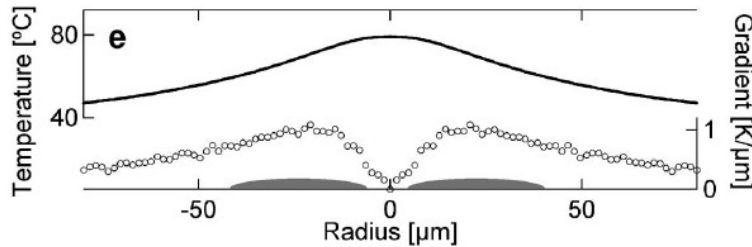
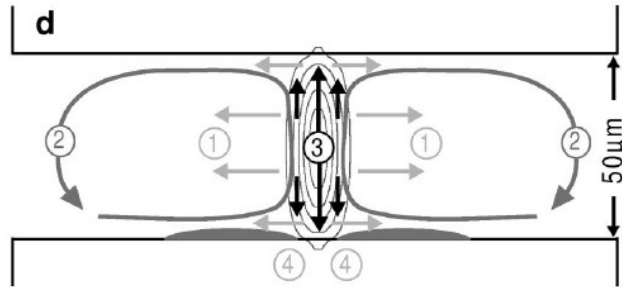
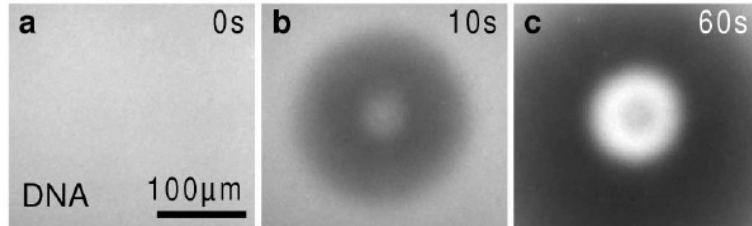
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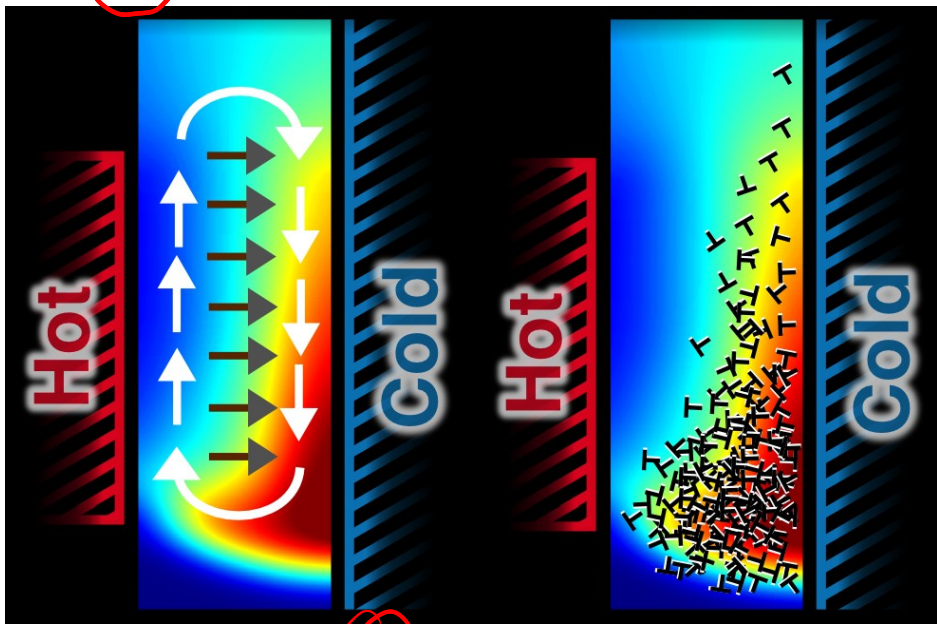




# Accumulation by temperature gradients

## Accumulation by heat flow

$C_0$



Convection  $C$   
Thermophoresis

PRL 2002, PNAS  
2007, NanoLetters  
2009, PRL 2010,  
APL 2015, PCCP  
2016

$$\frac{C}{C_0} = \exp\left(+0.4 \frac{D}{L} \cdot \frac{\Delta T}{T} \cdot \frac{L}{\lambda}\right)$$

10K

W

C

Thermophoresis

$J = -D \nabla C$   
 $= -D \frac{\partial C}{\partial x}$   
 $J = -D \frac{\Delta C}{\Delta x}$

1.5mm

10x

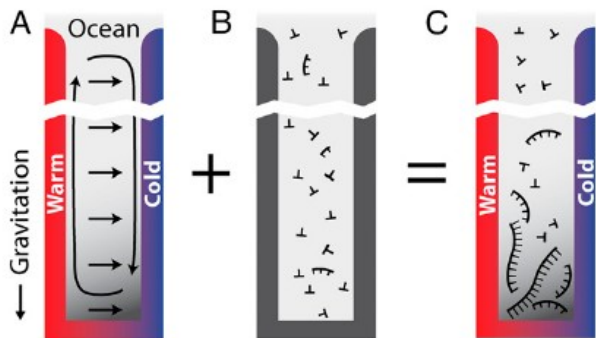
Simulation with Comsol

150  $\mu$ m

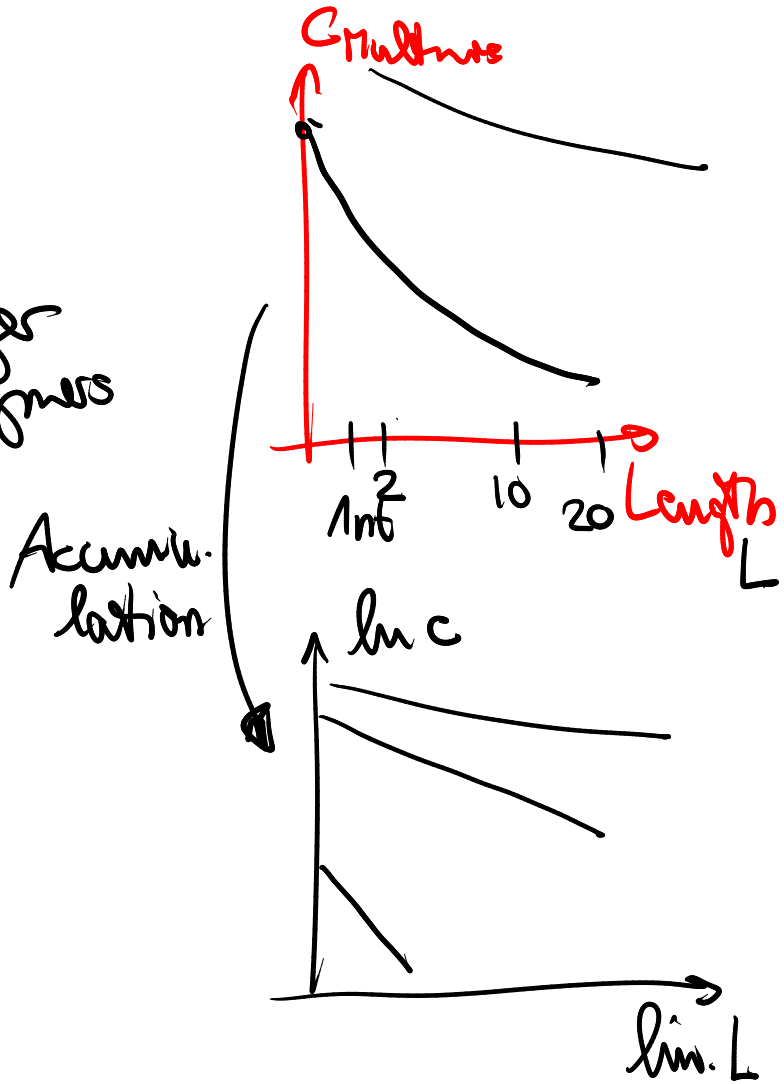
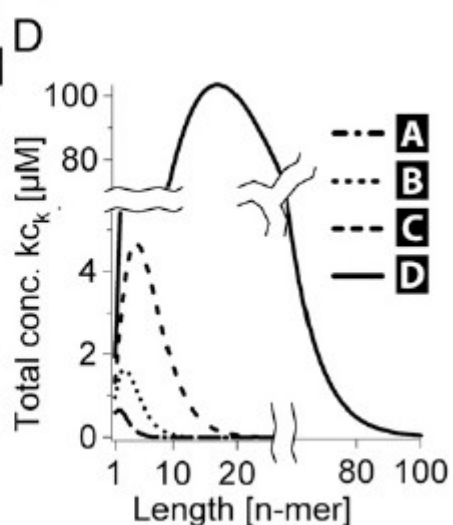
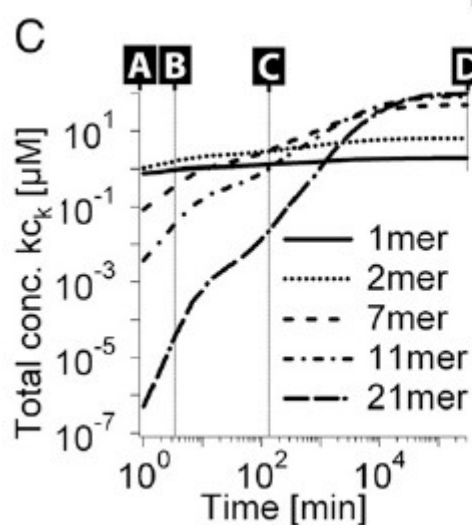
# Accumulation and Polymerization

## Escalation of polymerization in a thermal gradient

Christof B. Mast<sup>a,1</sup>, Severin Schink<sup>b,1</sup>, Ulrich Gerland<sup>b</sup>, and Dieter Braun<sup>a,2</sup>



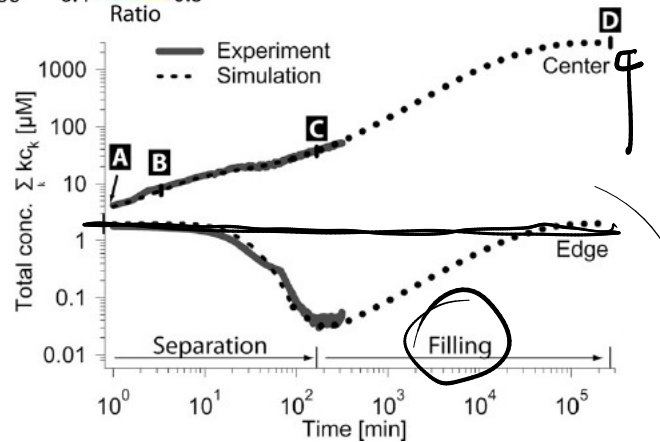
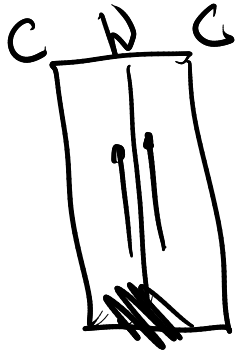
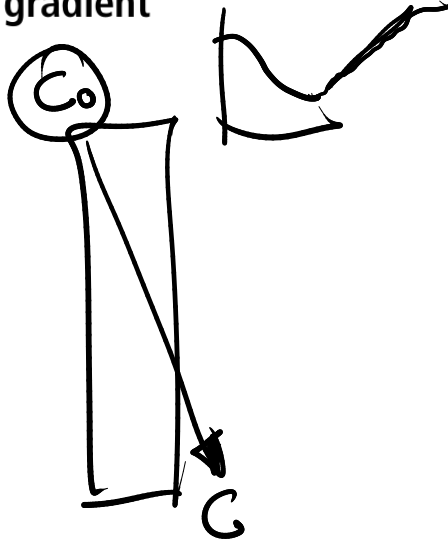
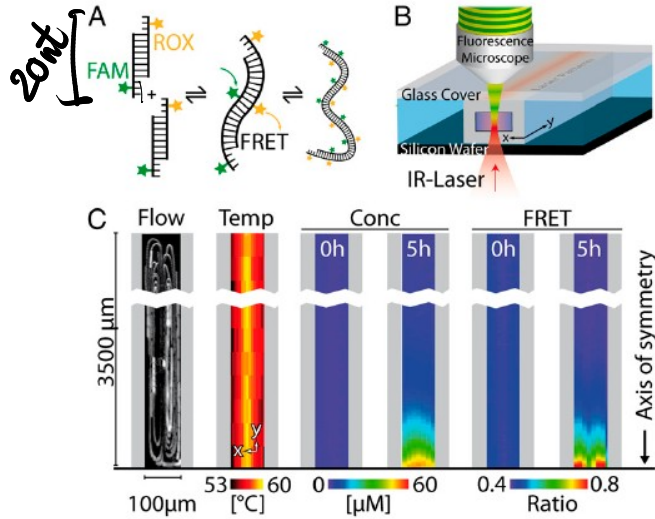
$C$  Monomers  $\rightarrow$  longer Polymers



# Accumulation and Polymerization

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# Accumulation and Polymerization



Christina Dirscherl

*Dpe*

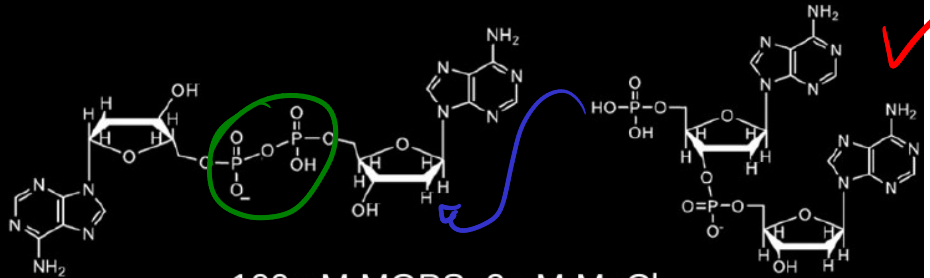


Initial Steady state

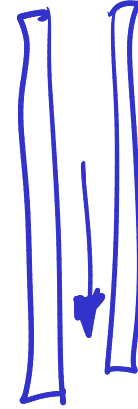
Less Concentration

Pyrophosphate Oligomers

Linear Oligomers



100mM MOPS, 2mM MgCl<sub>2</sub>  
150 / 15 / 1.5mM Amino-ImpdA  
pH 6.5 (NaOH), Time = 24h  
a) Isothermal 8 / 20 / 30°C  
b) Trap with T = 8 - 30°C



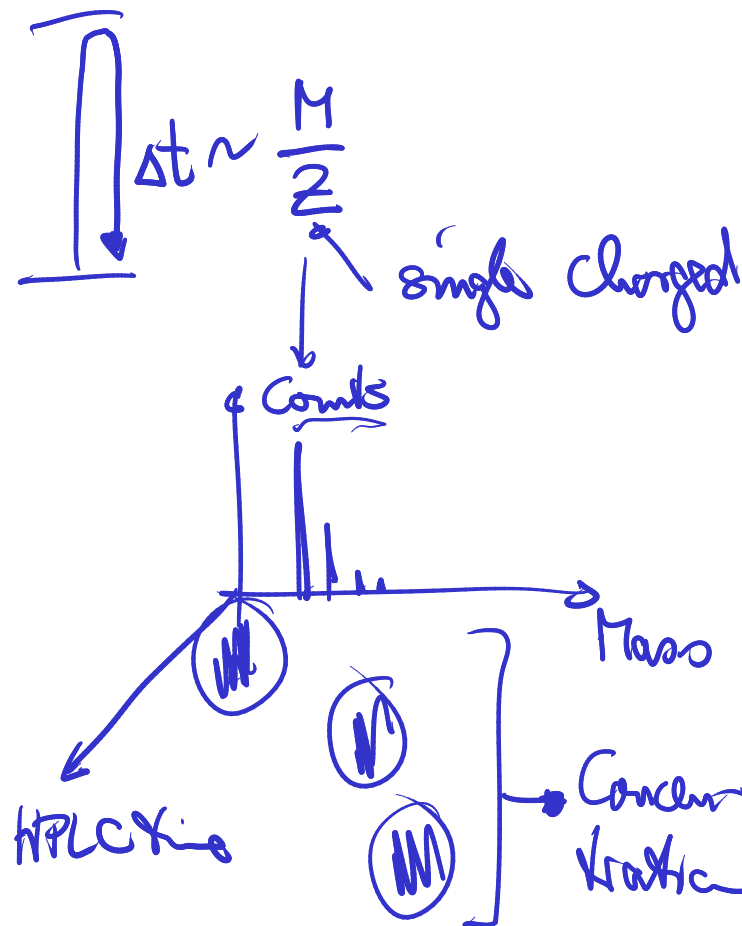
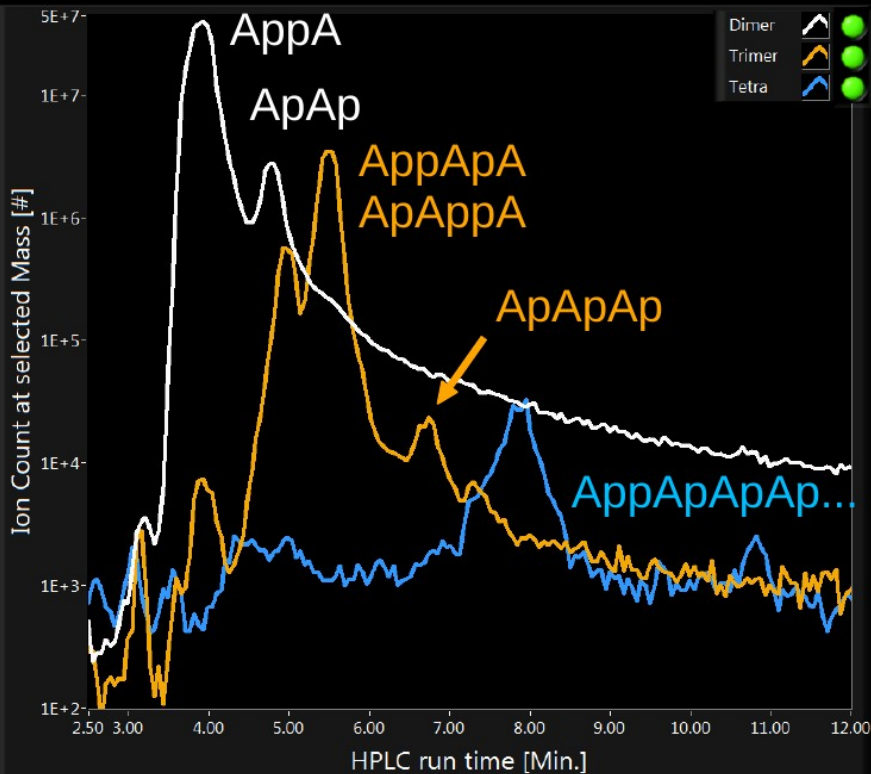
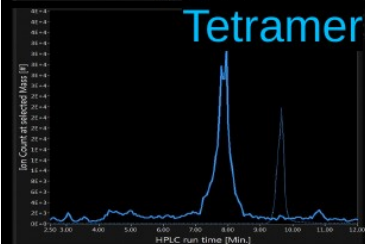
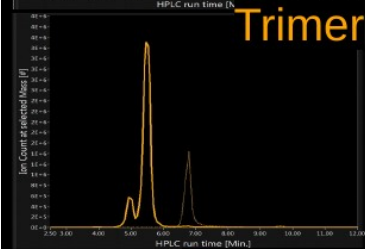
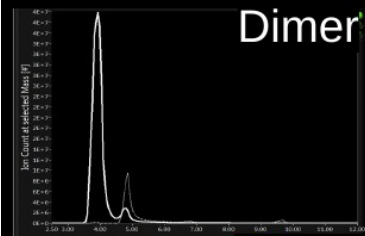


# Accumulation and Polymerization

## Boosting polymerization by thermal trap

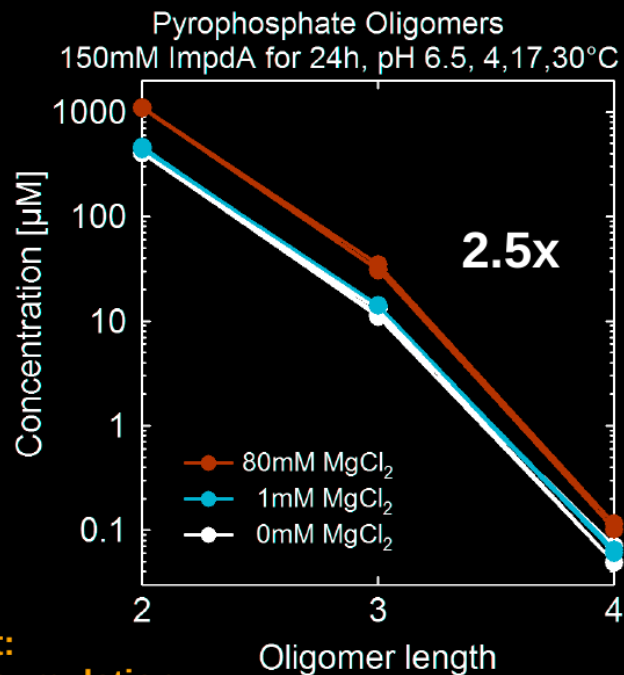
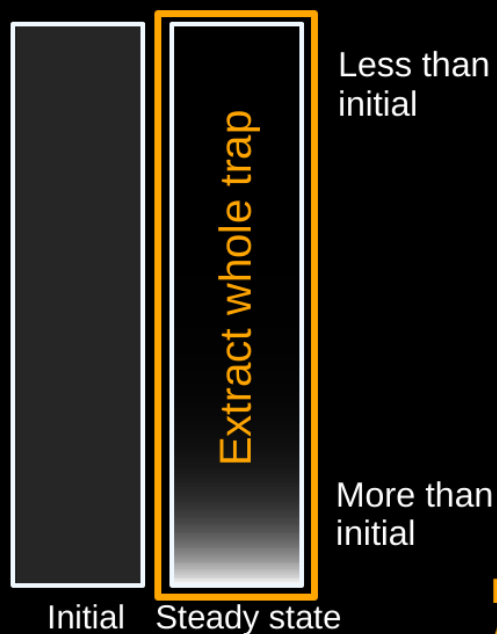
Detection in HPLC-ESI-TOF

Ion pairing reverse phase HPLC  
(H<sub>2</sub>O, Methanol, TEA, HFIP)



# Accumulation and Polymerization

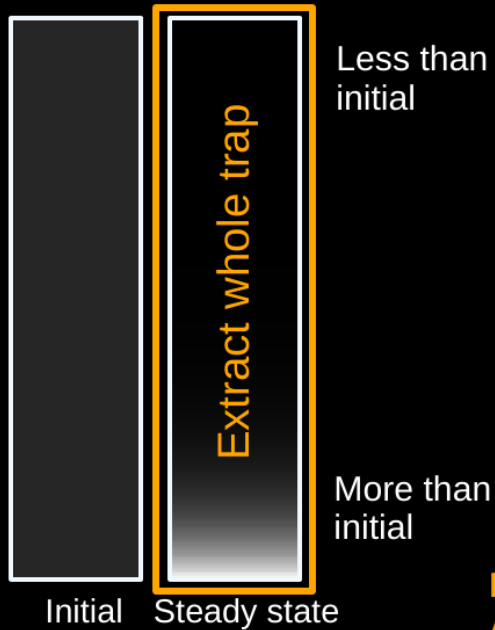
## Boosting polymerization by thermal trap



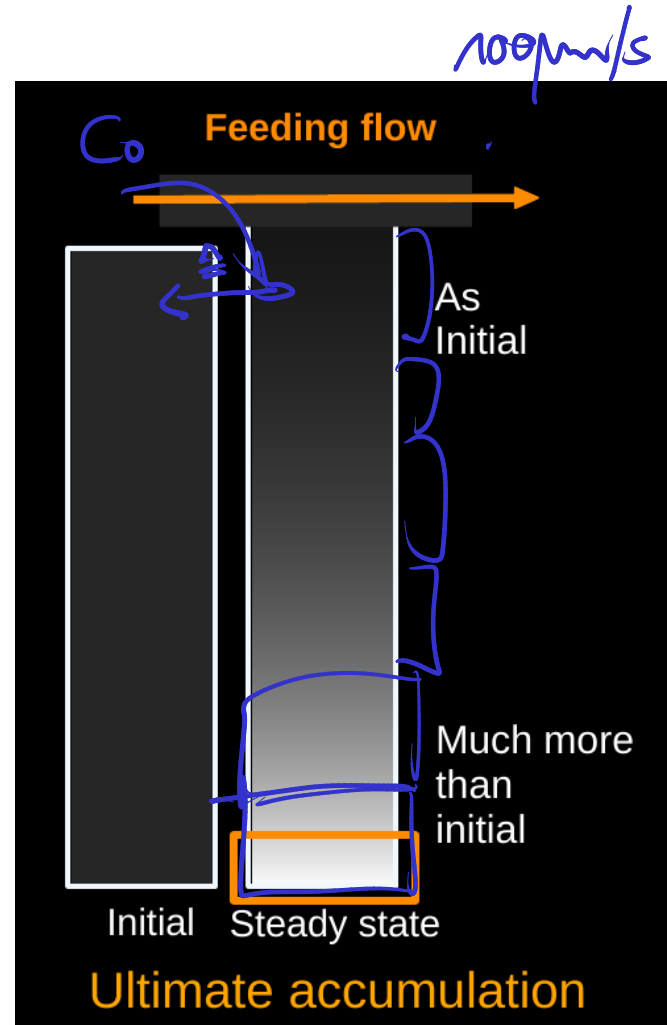
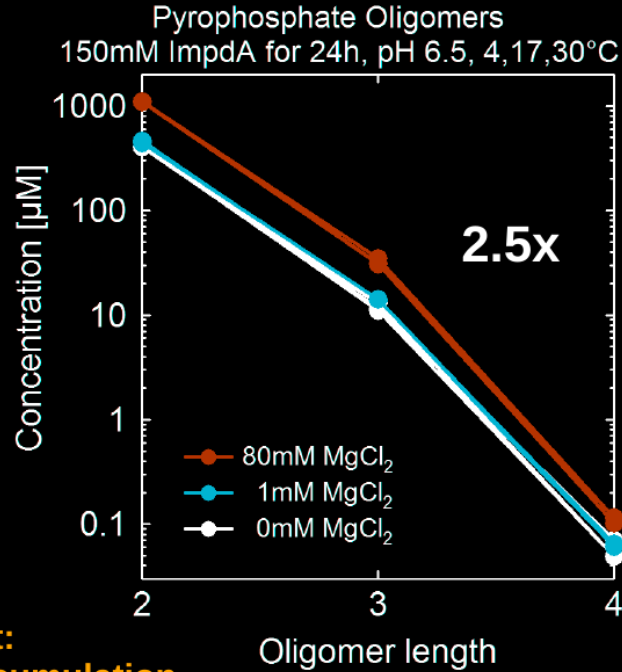
**But:**  
**Accumulation.**  
**of ImpA and Mg**

# Accumulation and Polymerization

## Boosting polymerization by thermal trap



**But:**  
**Accumulation.**  
**of ImpA and Mg**

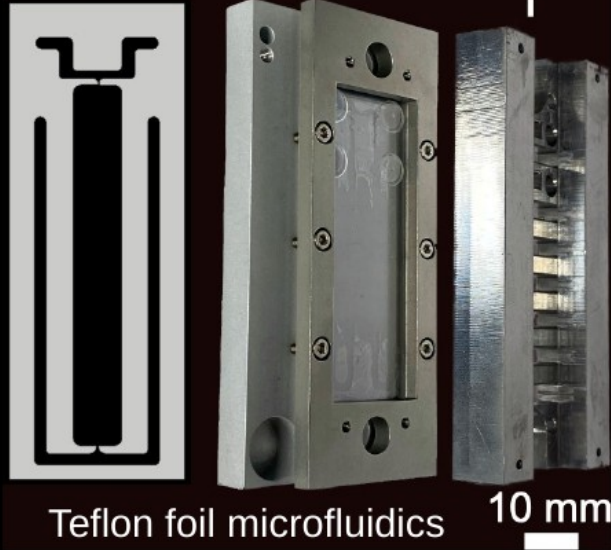


# Accumulation and Polymerization



Christof  
Mast

cooled  
microfluidics    electr.  
heater



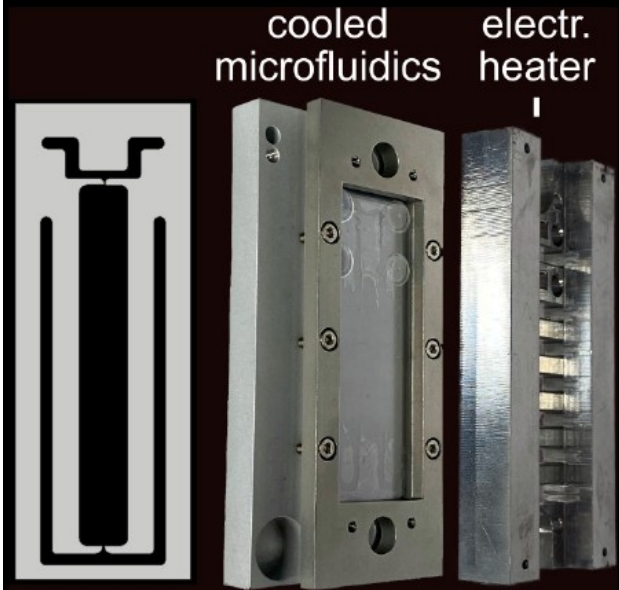
Teflon foil microfluidics  
Thickness 120...500 $\mu$ m  
 $V = 10..50\mu$ l,  $p < 20$ atm



# Accumulation and Polymerization



Christof  
Mast

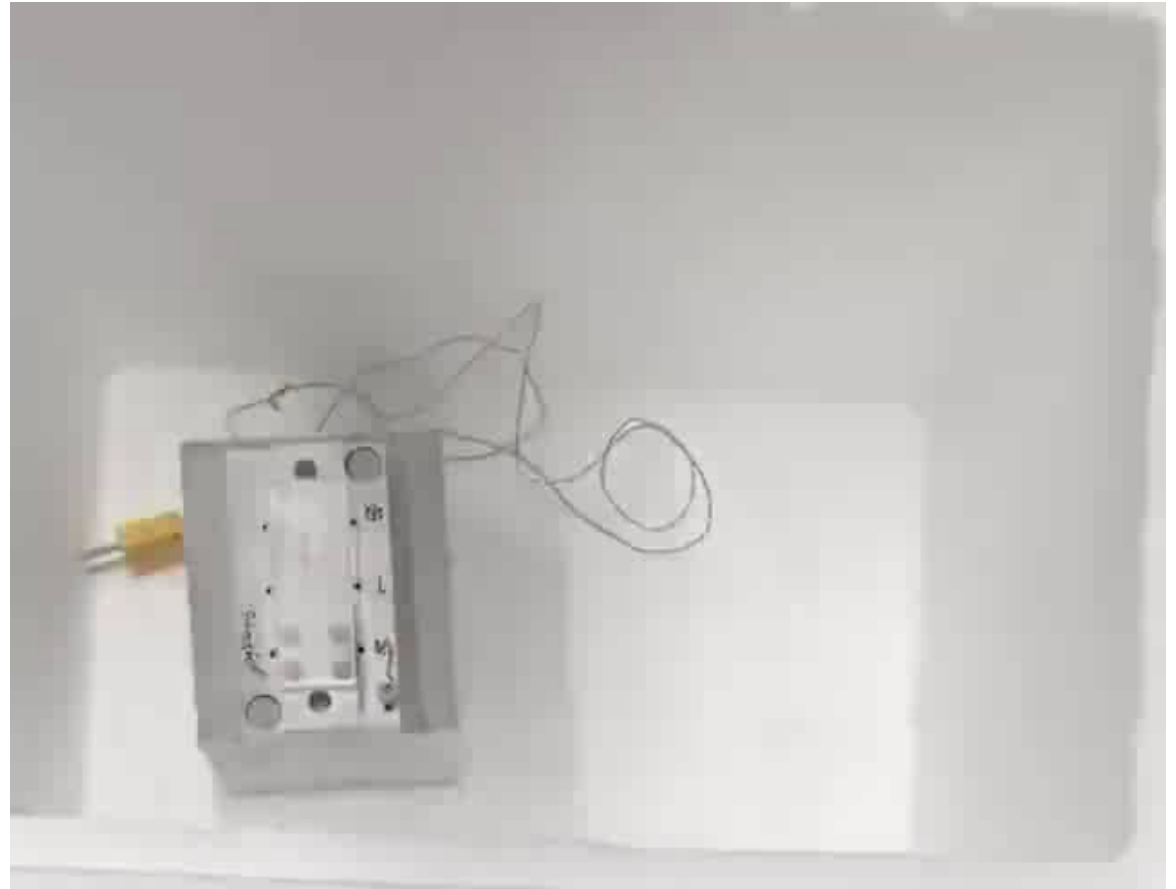


cooled  
microfluidics

electr.  
heater

Teflon foil microfluidics  
Thickness 120...500 $\mu$ m  
 $V = 10..50\mu$ l,  $p < 20$ atm

10 mm



# Accumulation and Polymerization



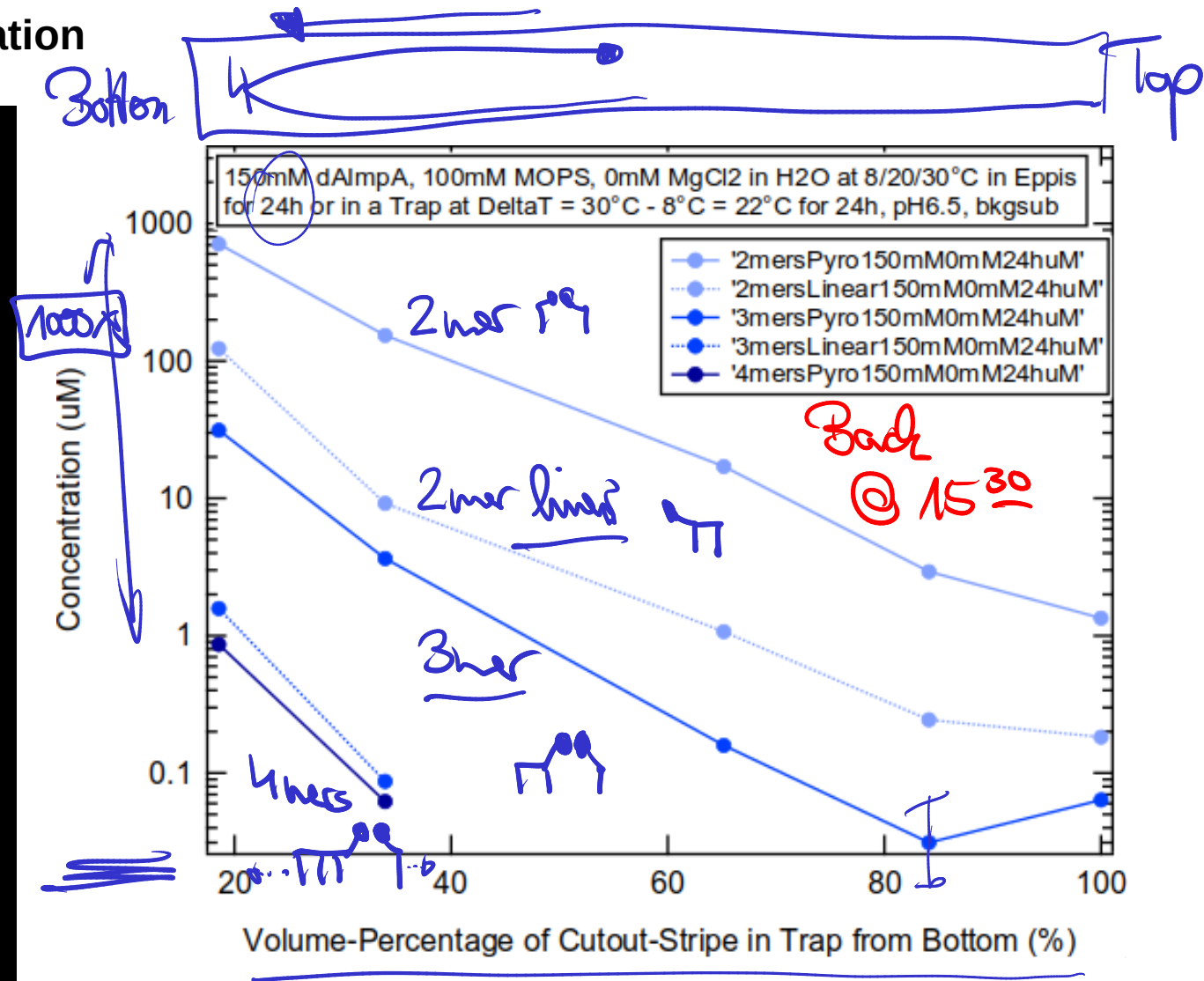
Christof Mast

cooled microfluidics  
electr. heater



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Thickness 120...500 $\mu$ m  
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10 mm



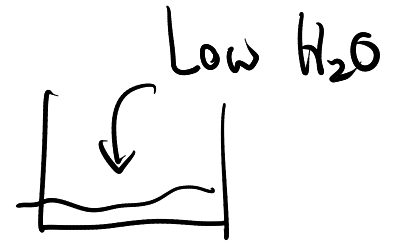
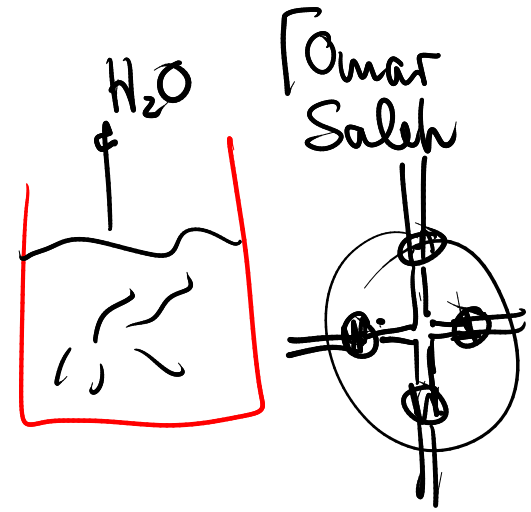
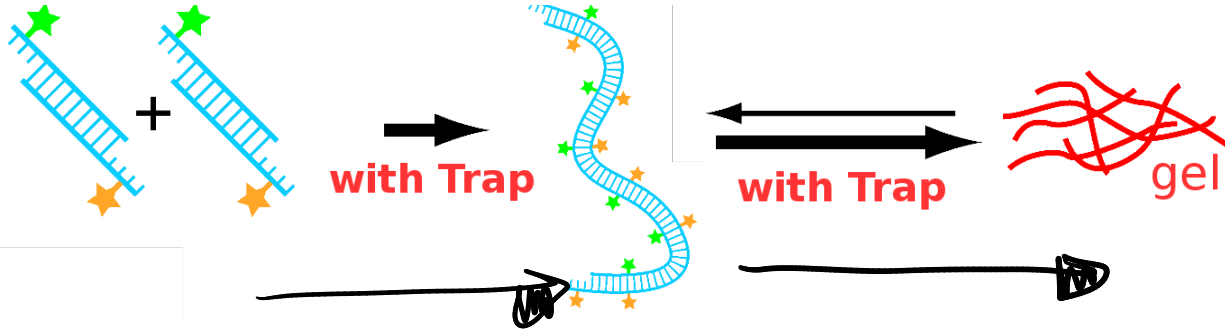
# Accumulation and Polymerization leads to gels

 DNA Hydrogels Hot Paper

International Edition: DOI: 10.1002/anie.201601886  
German Edition: DOI: 10.1002/ange.201601886

## Heat-Flow-Driven Oligonucleotide Gelation Separates Single-Base Differences

Matthias Morasch, Dieter Braun, and Christof B. Mast\*



2D, 3D: Phase transition  
1D: cannot undergo Phase transition



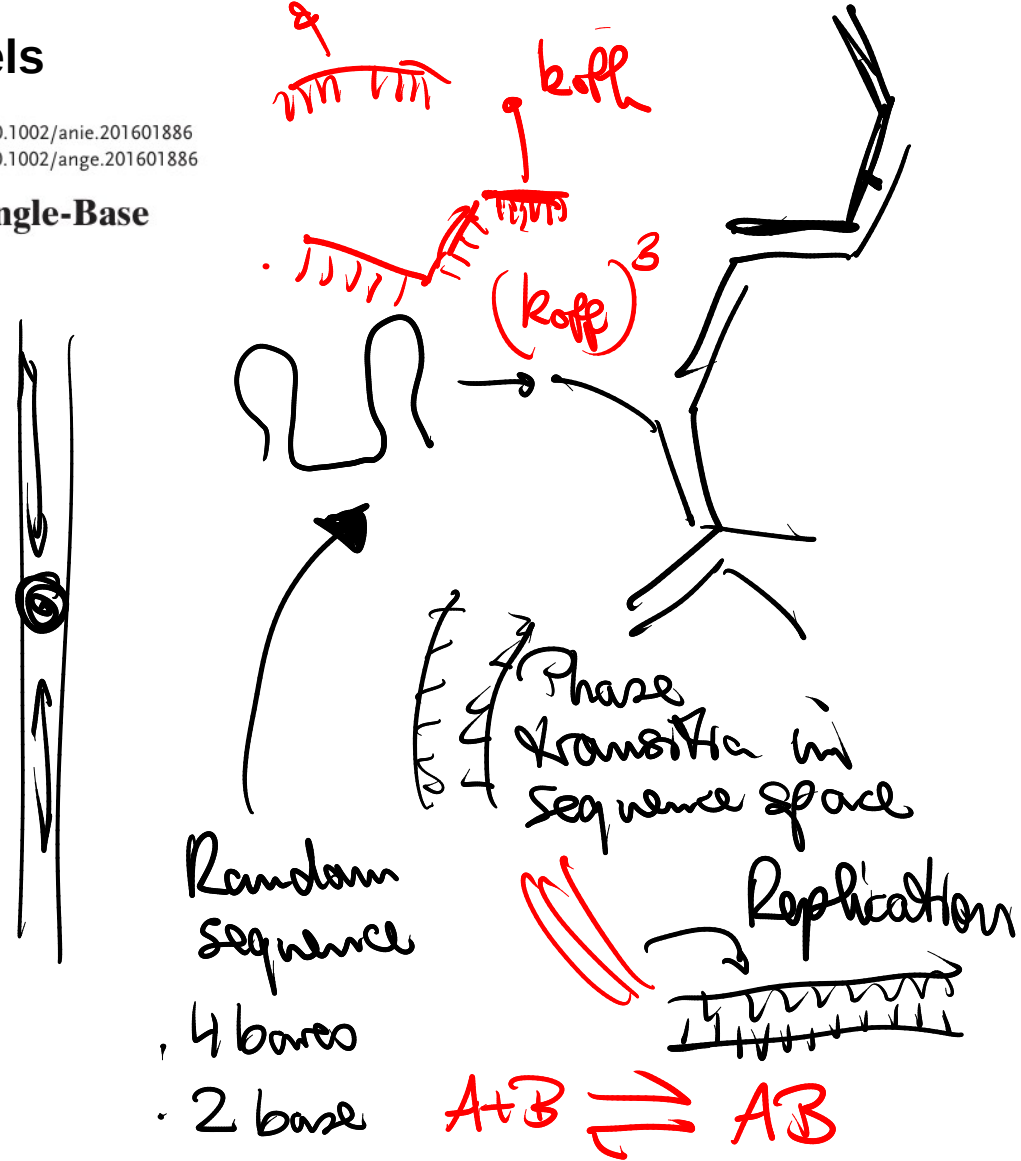
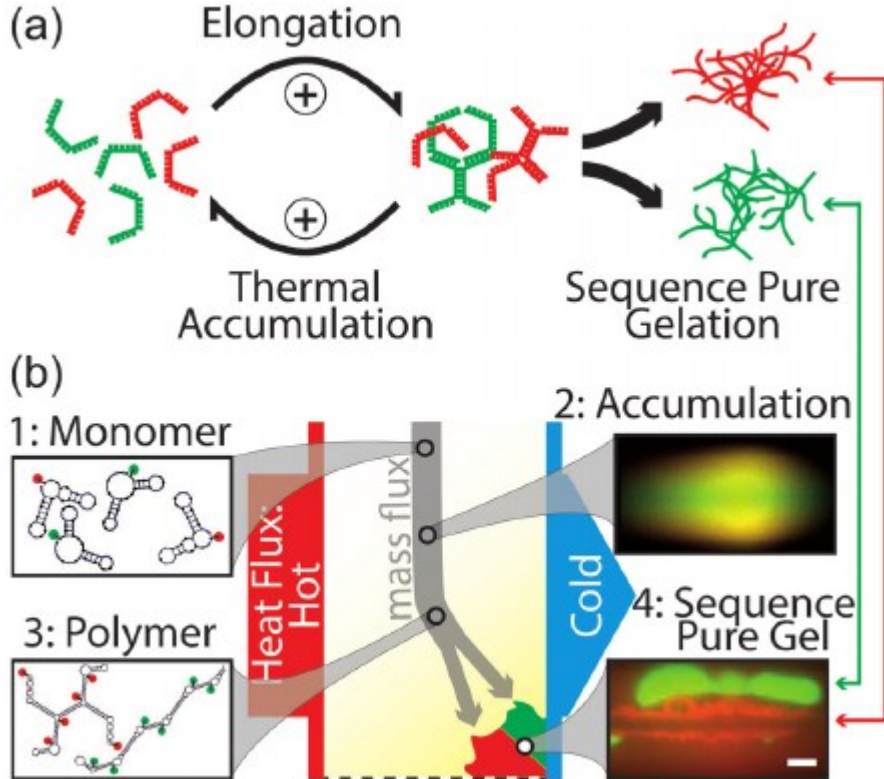
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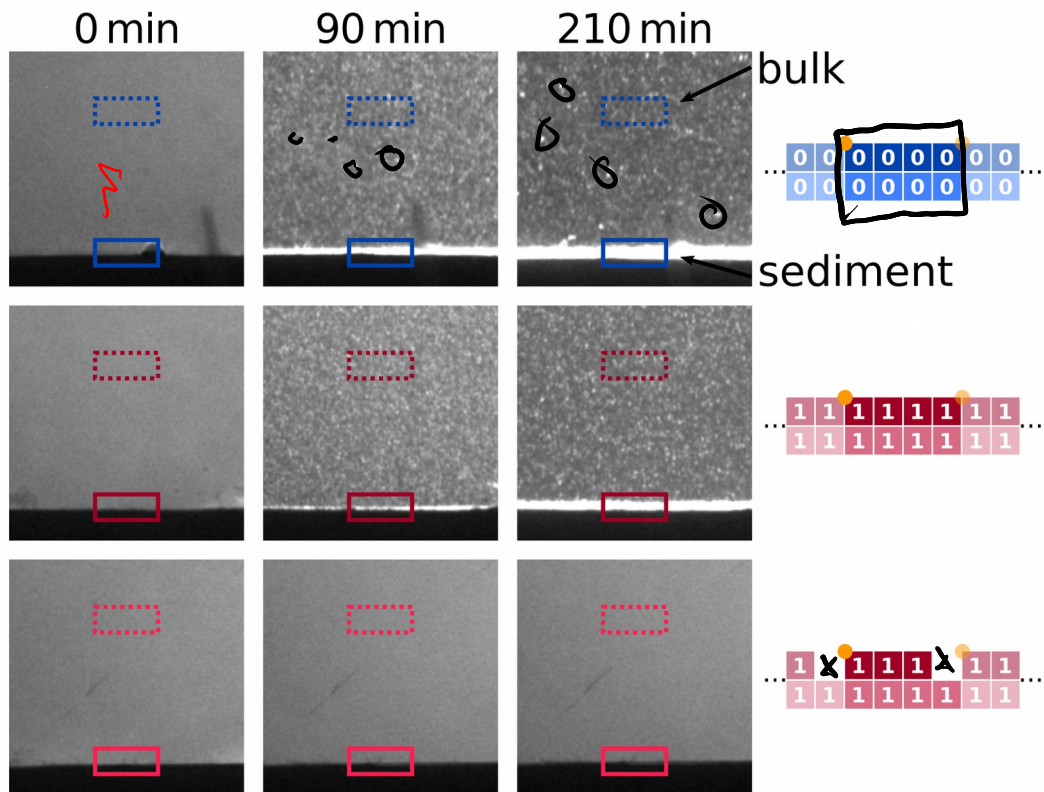
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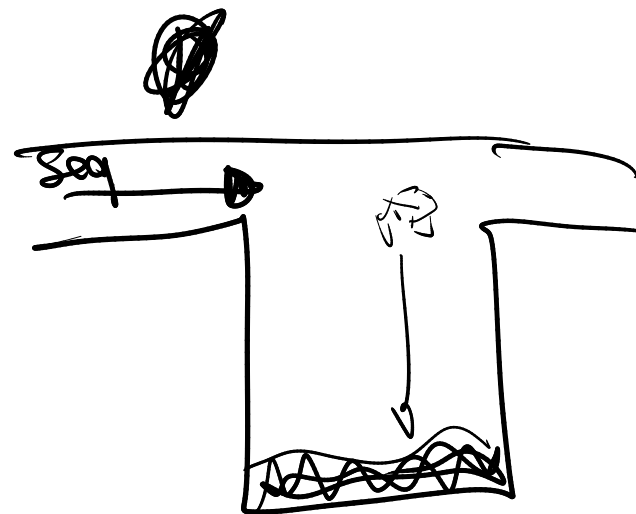


# Gelation and sedimentation

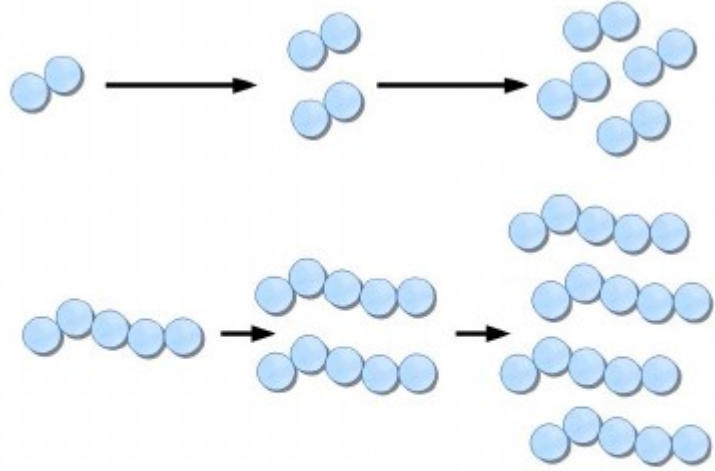
**a**



Conc ↑ → Phase Transition

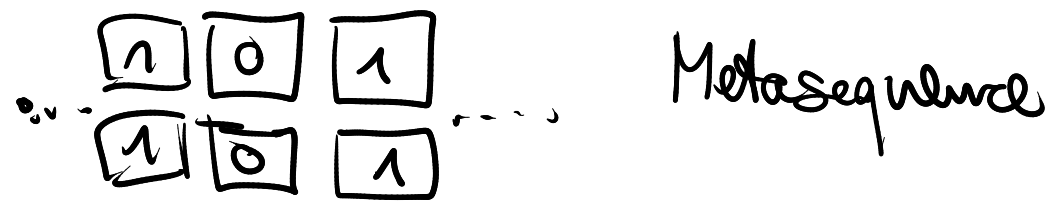
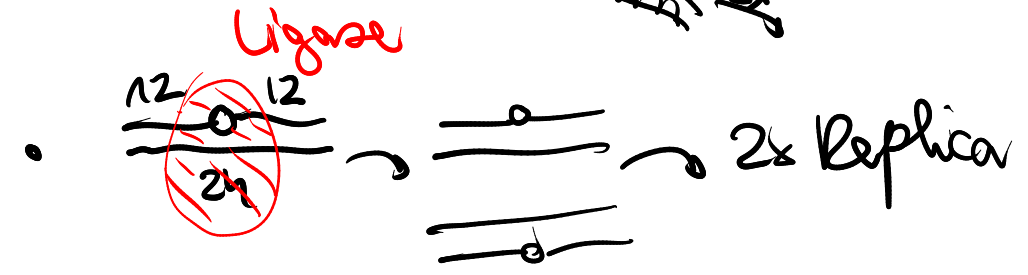
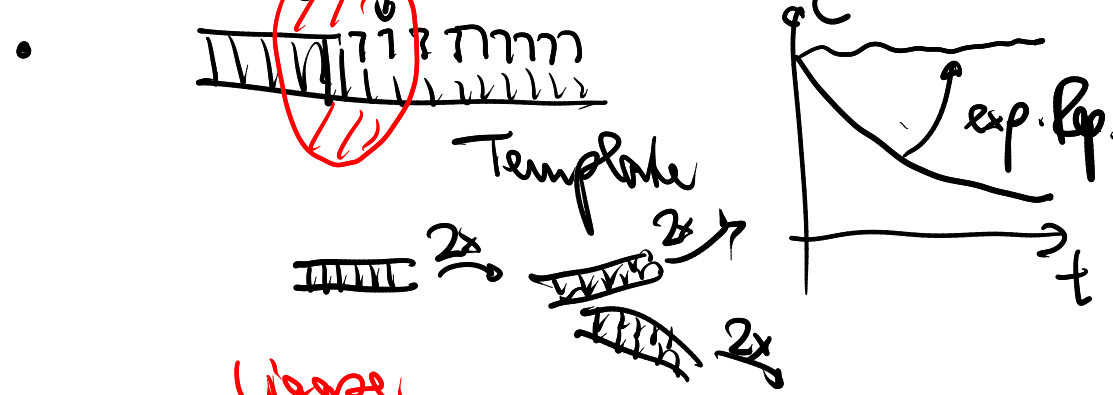


# Replication driven by temperature gradients

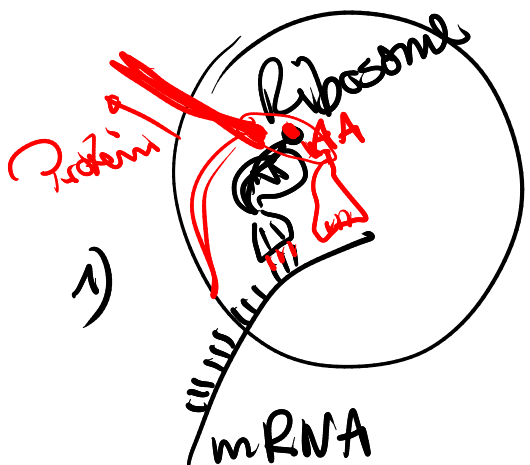
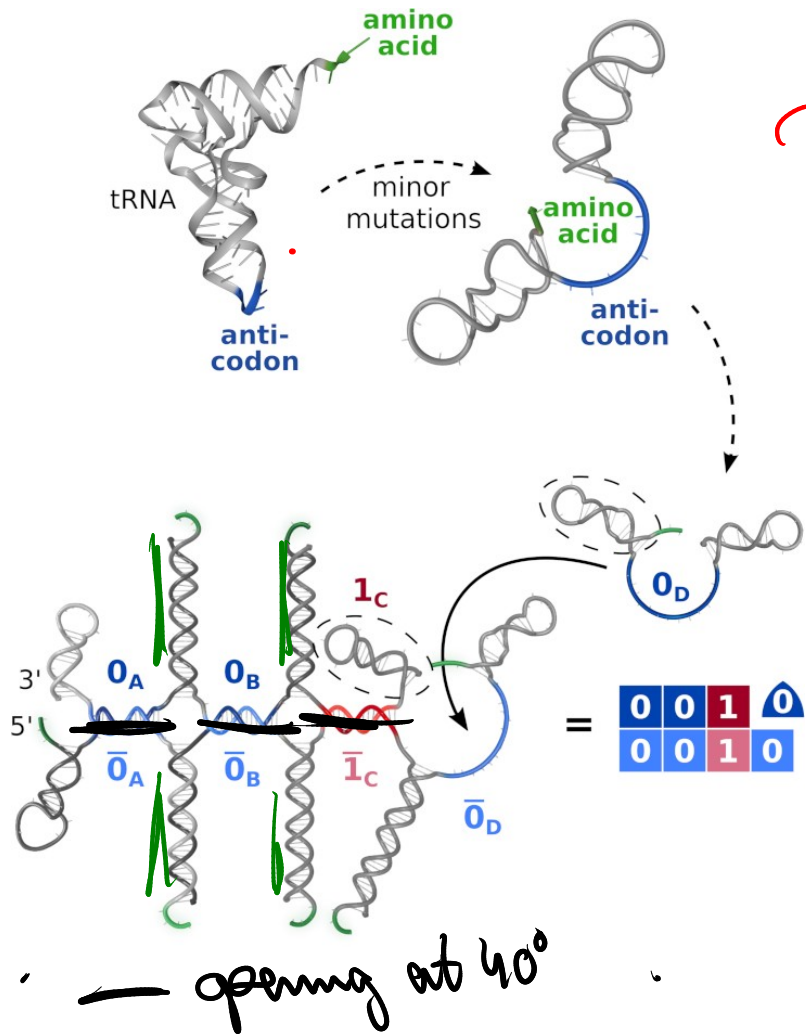


**Replication by Convection**

Base by base  
 Protein  
 50 nt/s (PCR) | 2-AT: 1 nt/h  
 activate Nucleotides



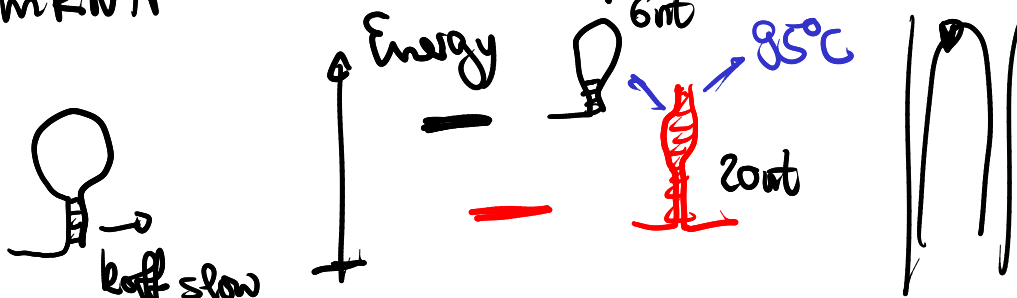
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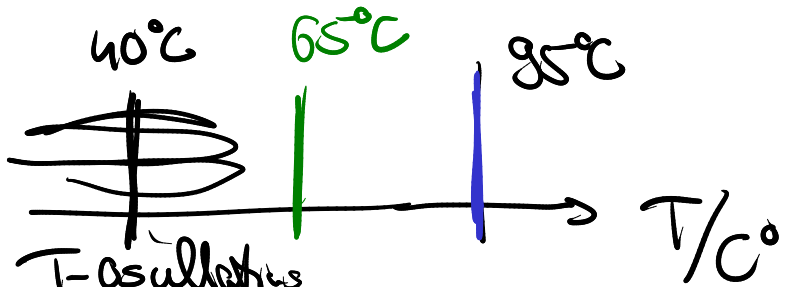
1)

20 tRNA: useful for replication?

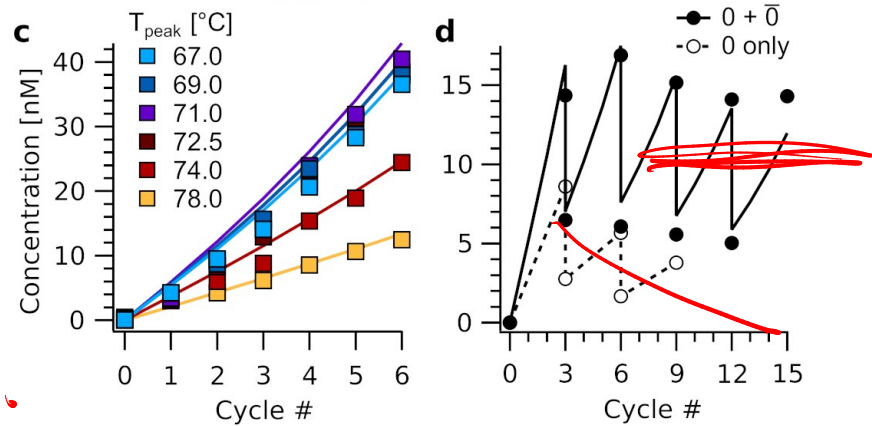
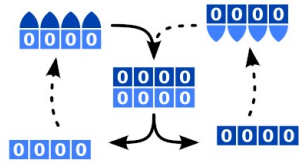
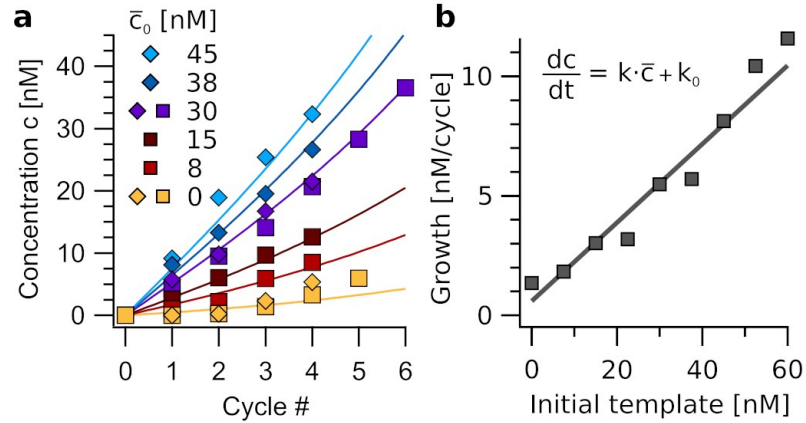
2)



3)

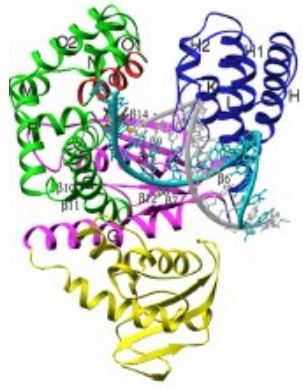


# Replication driven by temperature gradients

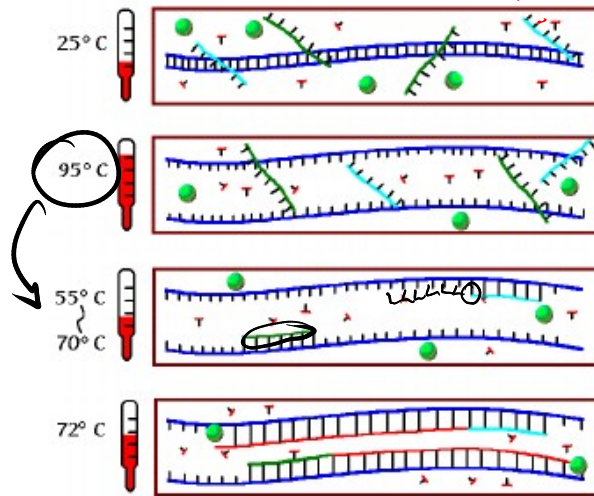


# Replication driven by temperature gradients

## Polymerase Chain Reaction (PCR)



Taq Polymerase



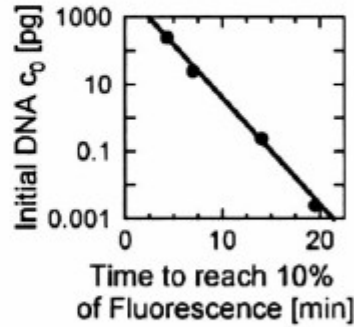
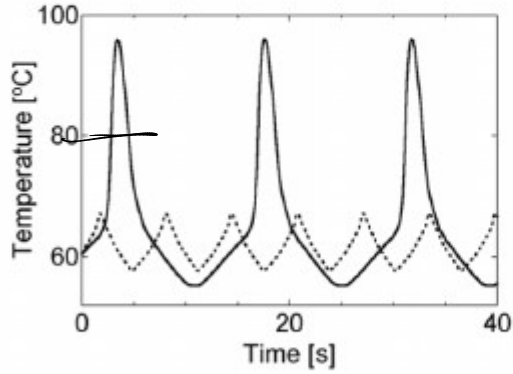
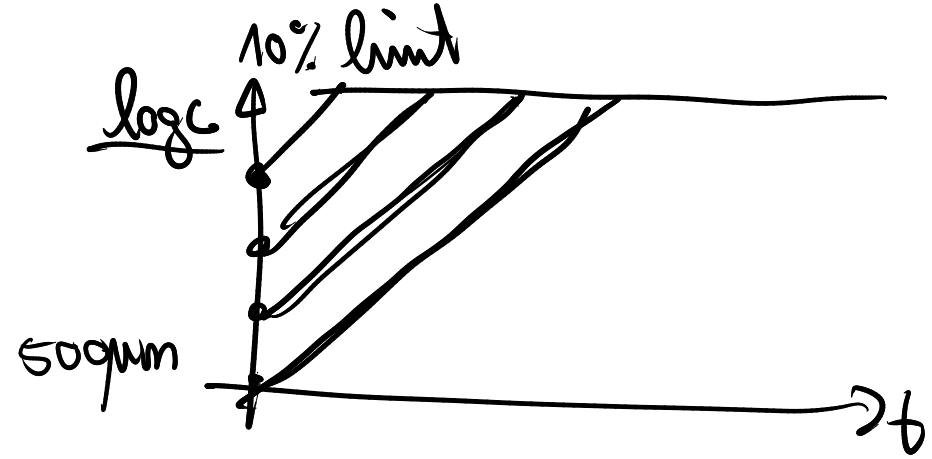
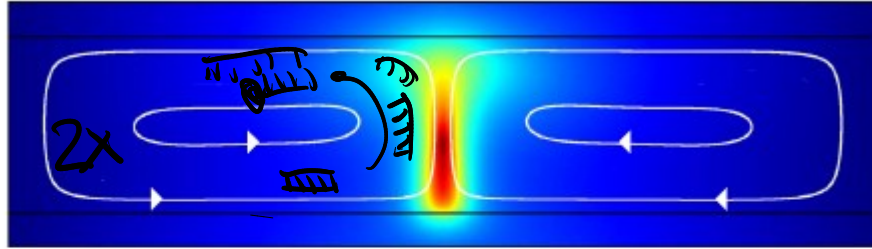
Protein is Thermostable:

- 30 Min @ 85°C
- 50 ut/s



# Replication driven by temperature gradients

## Replication by Convection (PCR)



Length independent Replication  
(80-2000 base pairs)

Braun, Goddard & Libchaber, PRL 91, 158103 (2003)

