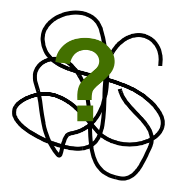
# Mikroskopische Temperaturgradienten in der Biophysik und dem Ursprung des Lebens?

1. Optisches Heizen
2. Konvektive DNA Replikation (cPCR)
3. Thermophorese von DNA
4. Akkumulation durch Thermophorese
5. Thermischer Lebensursprung?

Dieter Braun, Emmy-Noether Gruppe, LMU München
Angewandte Physik, LS Gaub, www.dieterb.de

# Biophysik offener Systeme

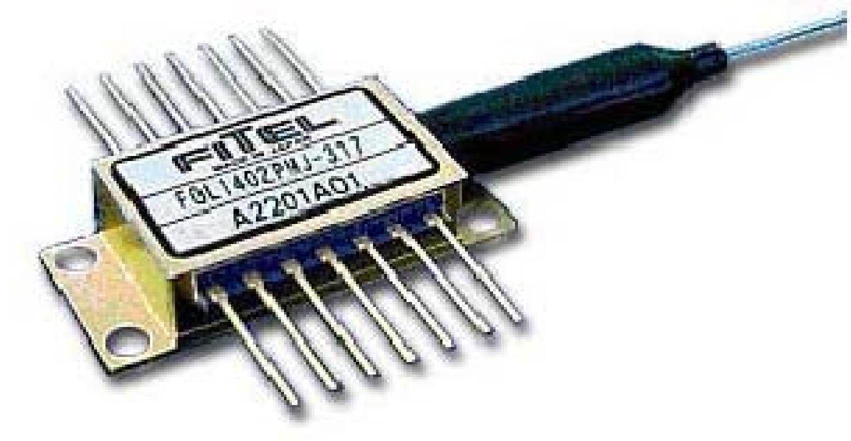
Temperaturgradient

Warm ←  → Kalt

0.1mm

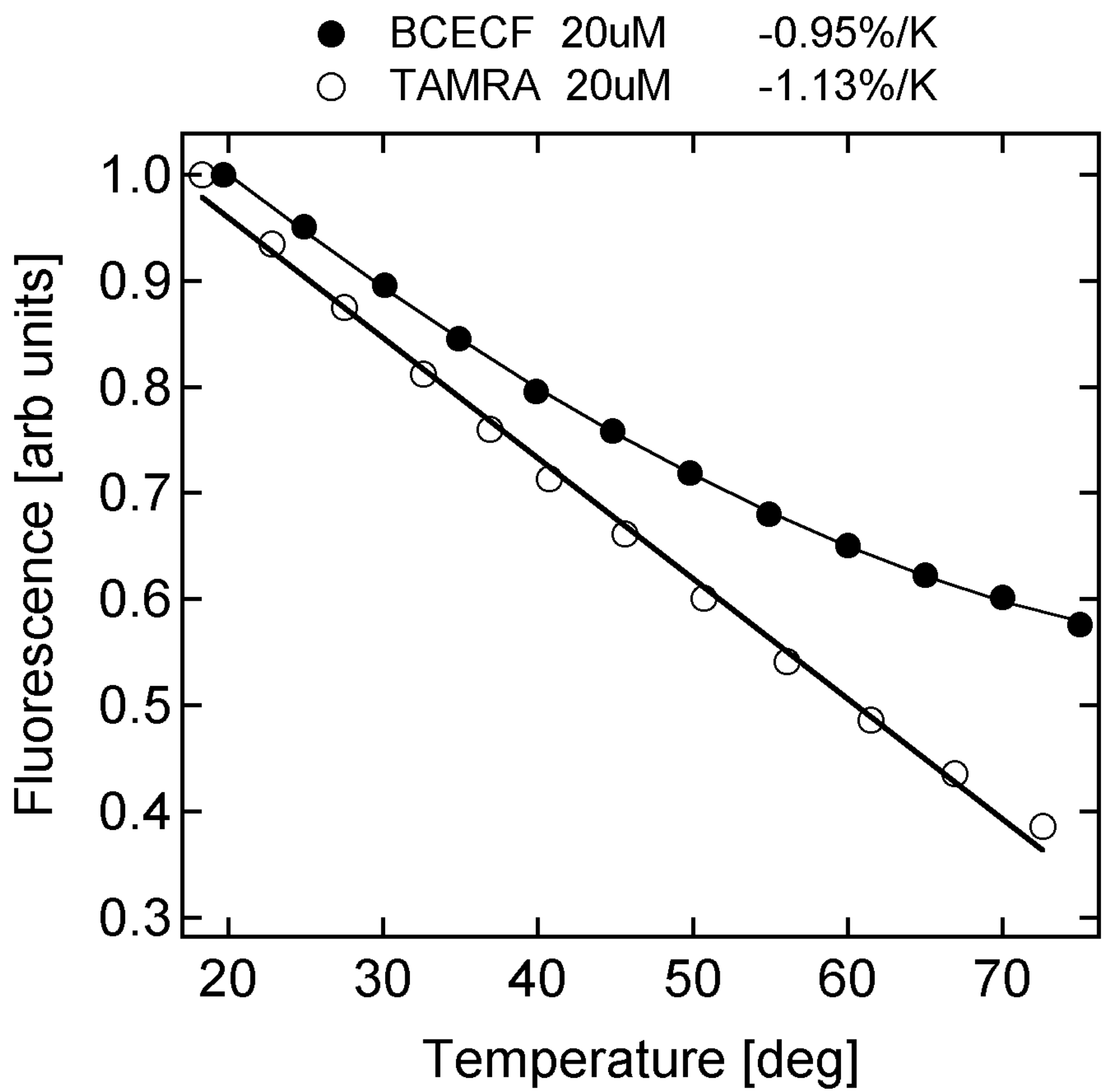
# 1. Optisches Heizen

*Infrarot-Laser*

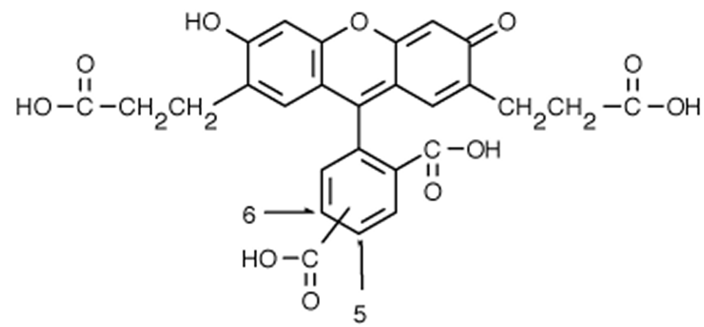



1480nm
fasergekoppelt

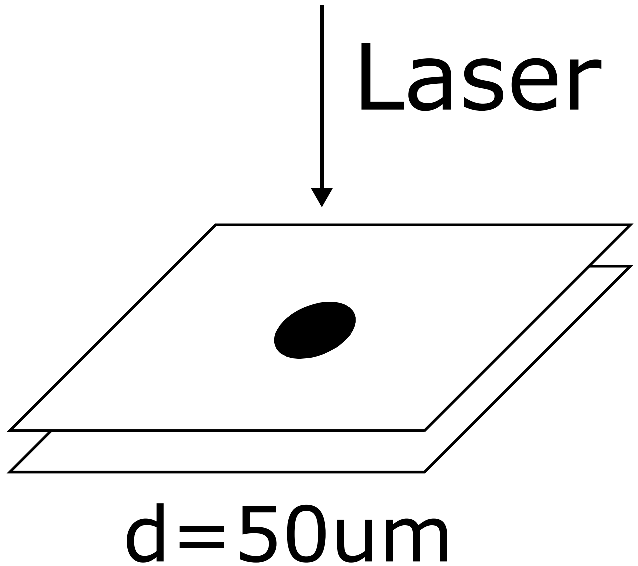
# 1. Optisches Heizen



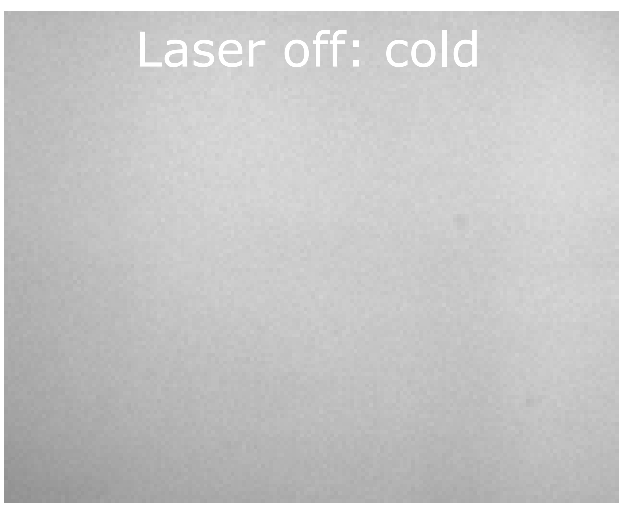

## Optisches Thermometer



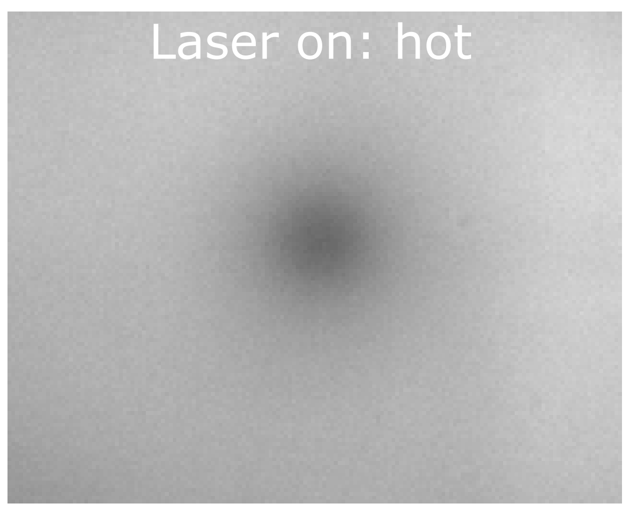
# 1. Optisches Heizen



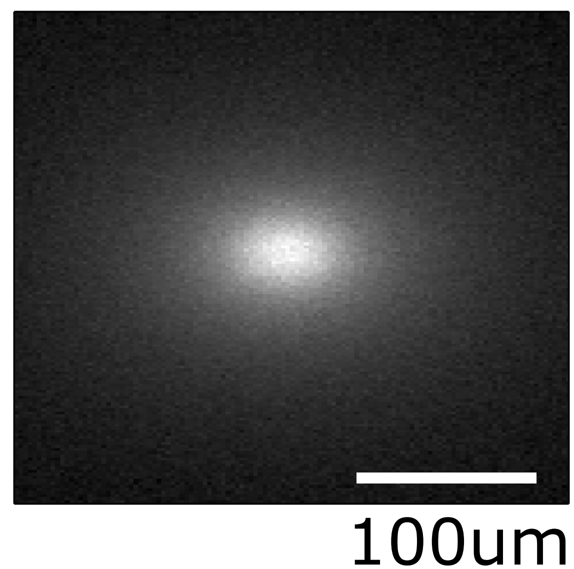

Fluoreszenz kalt



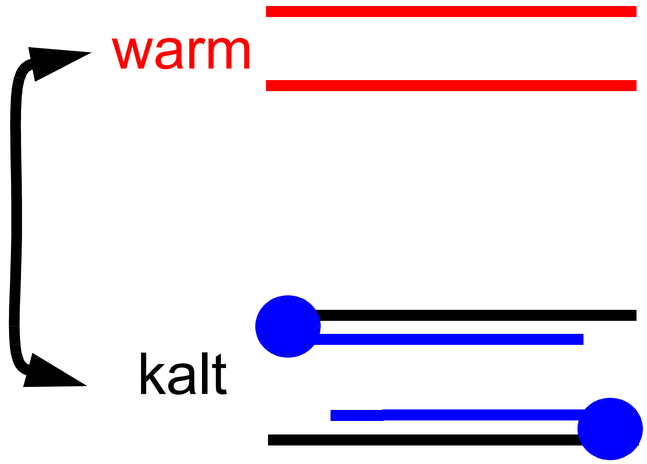

Fluoreszenz warm

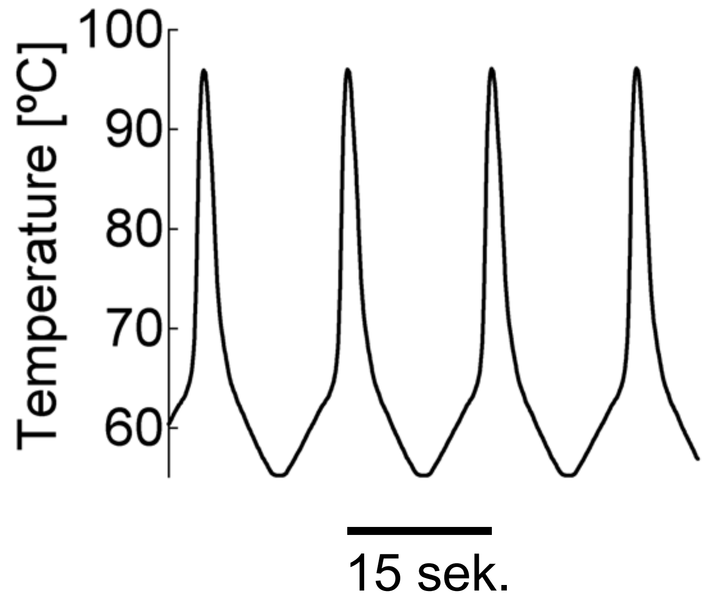



Temperaturbild



# 2. Konvektive DNA Replikation (cPCR)



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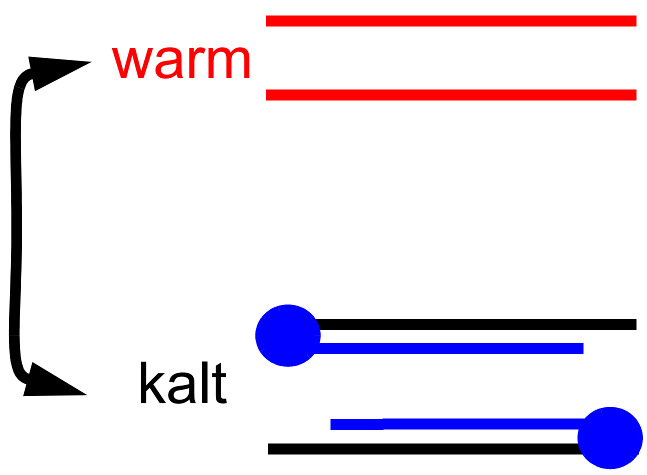


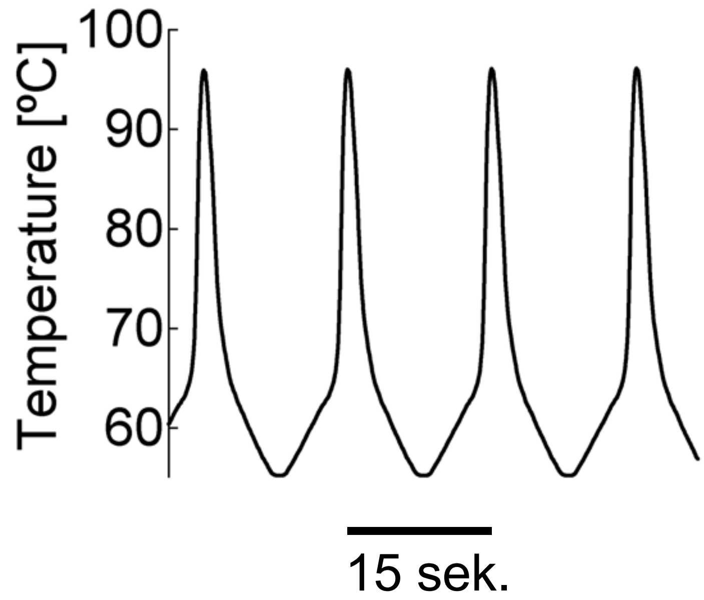


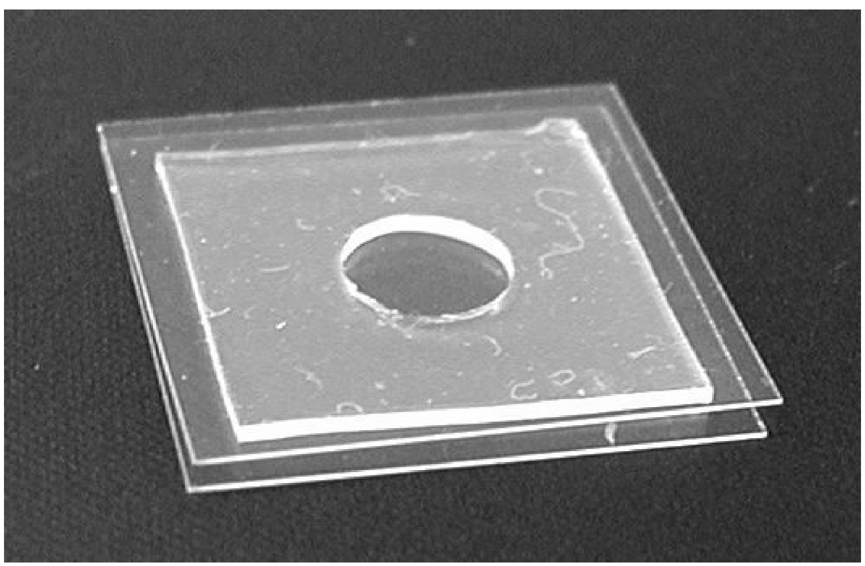

Convection
Movie

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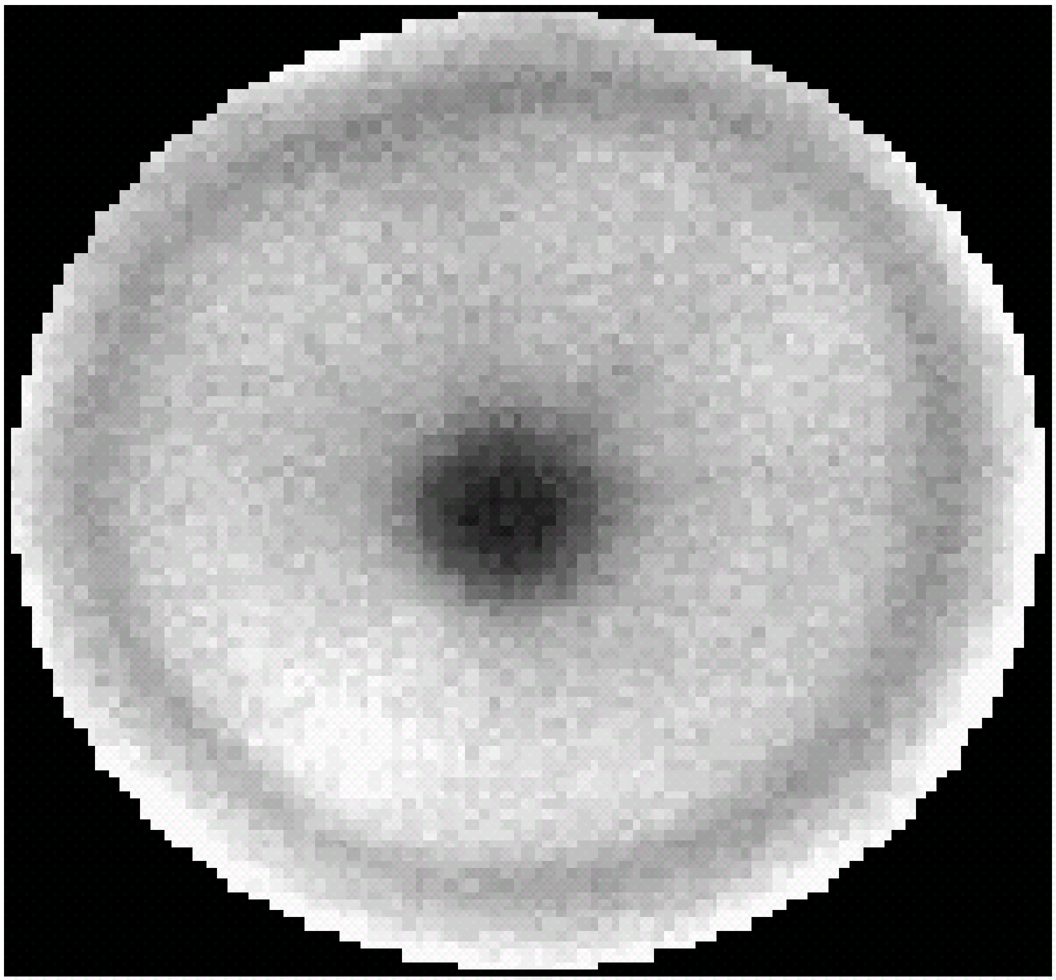
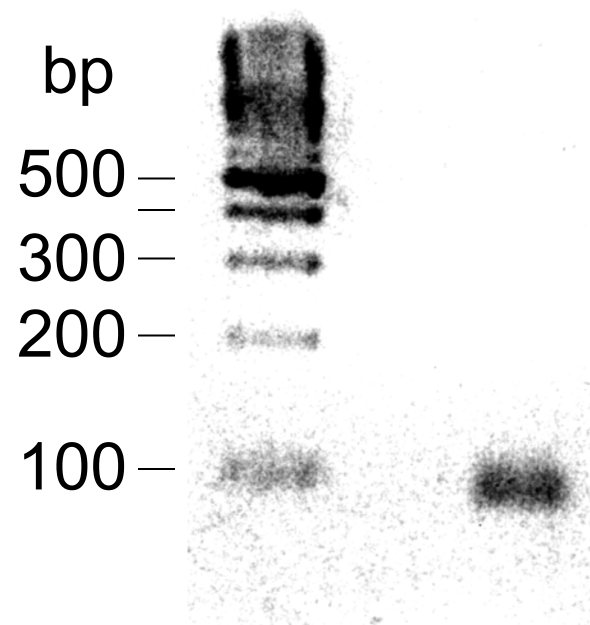


Amplifikation 100.000x
in 25 Minuten




PRL 91:158103 (2003)

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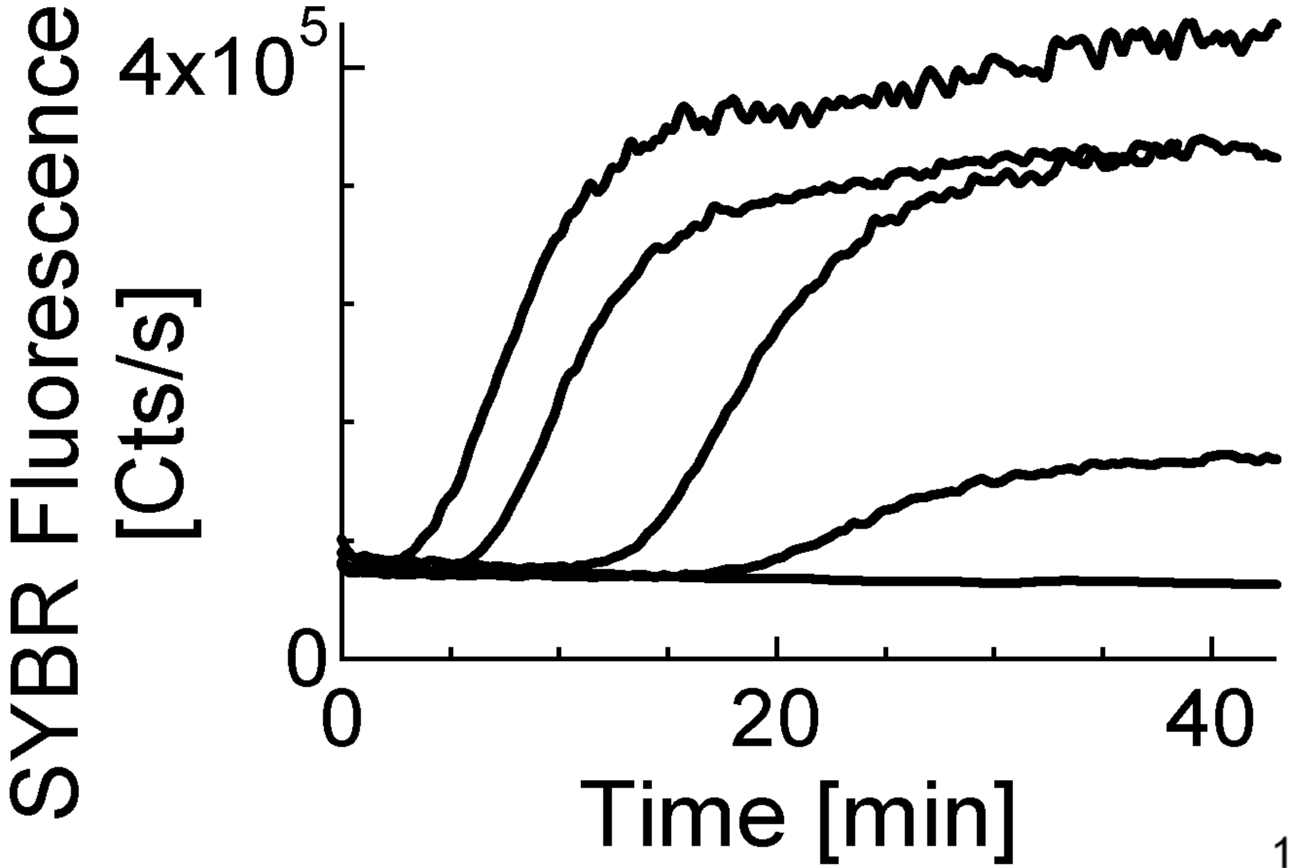
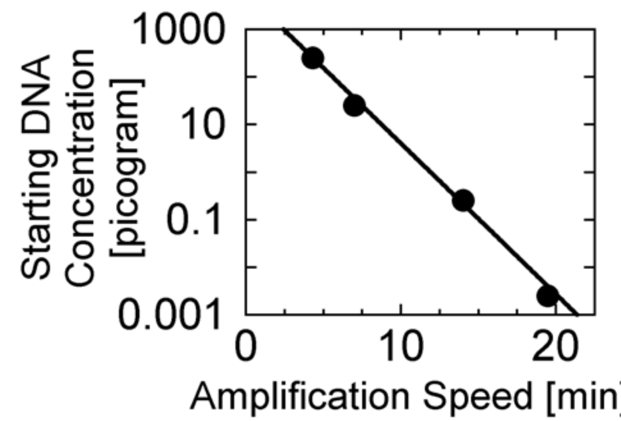
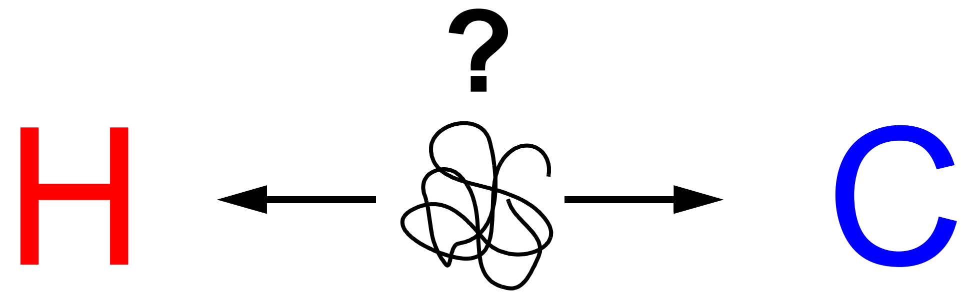


# 3. Thermophorese von DNA




Movie 200er

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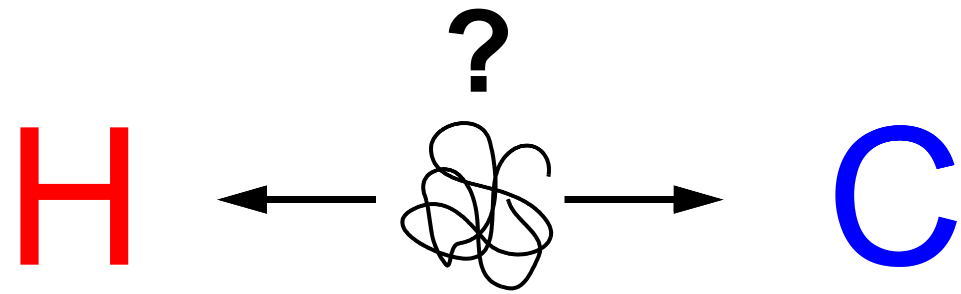
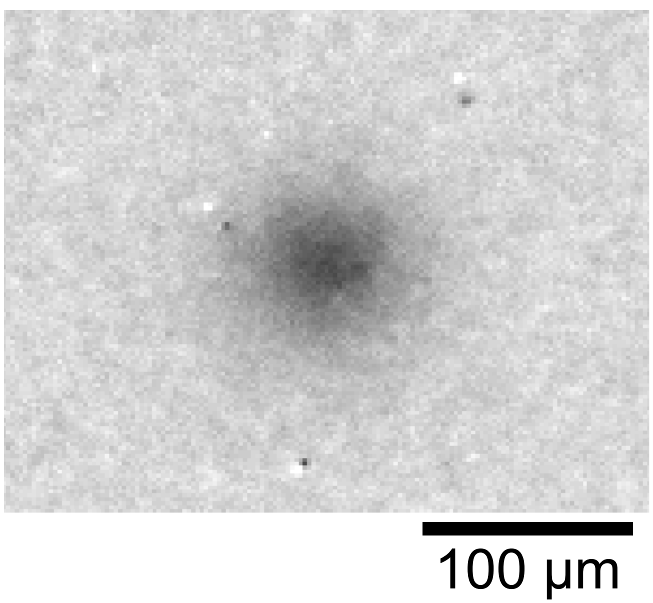
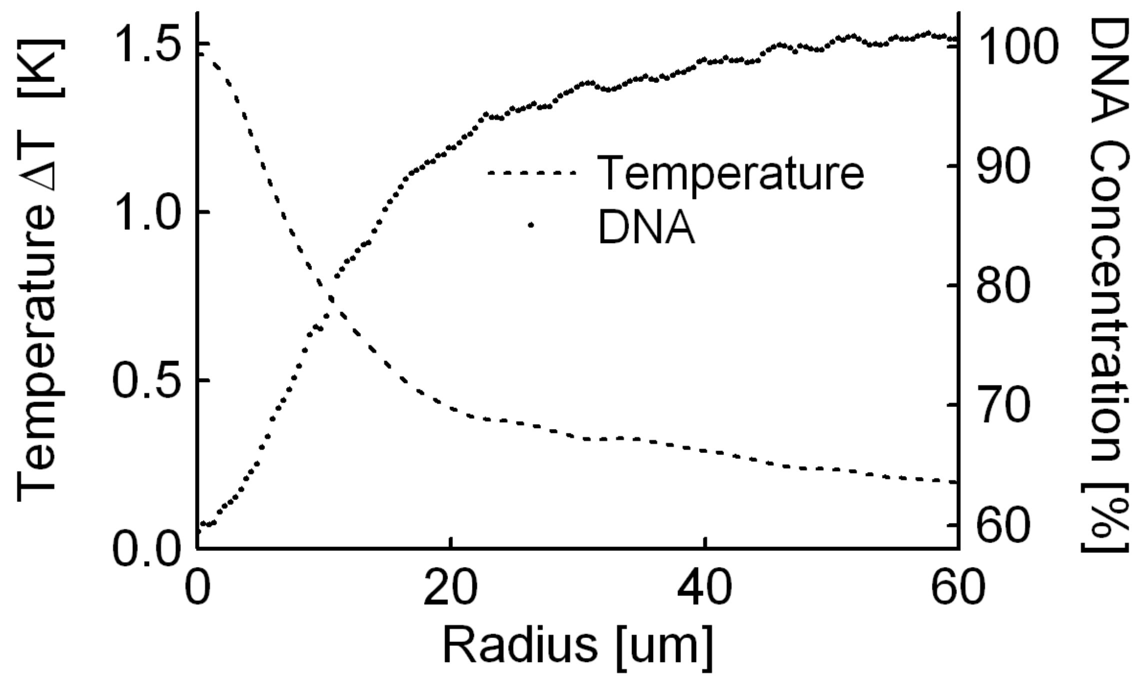



*Onsager-Relation:*

$$j = -D\nabla c - D_T c(1-c)\nabla T = 0 \longrightarrow \frac{c}{c_0} = e^{-\frac{D_T}{D}(T-T_0)}$$

DNA, 5000 base pairs



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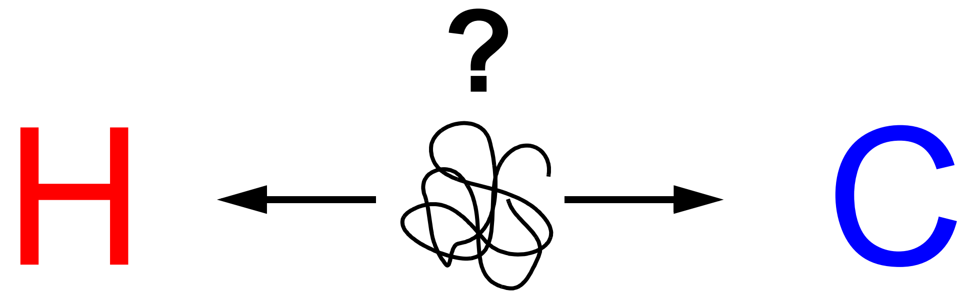


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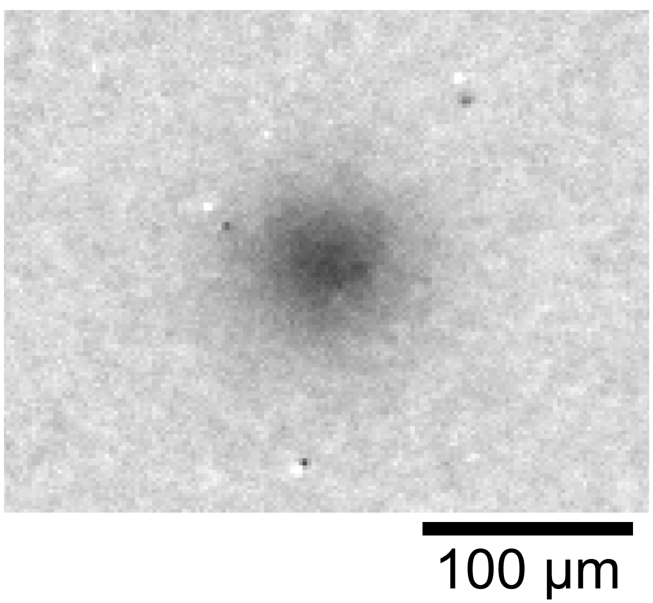
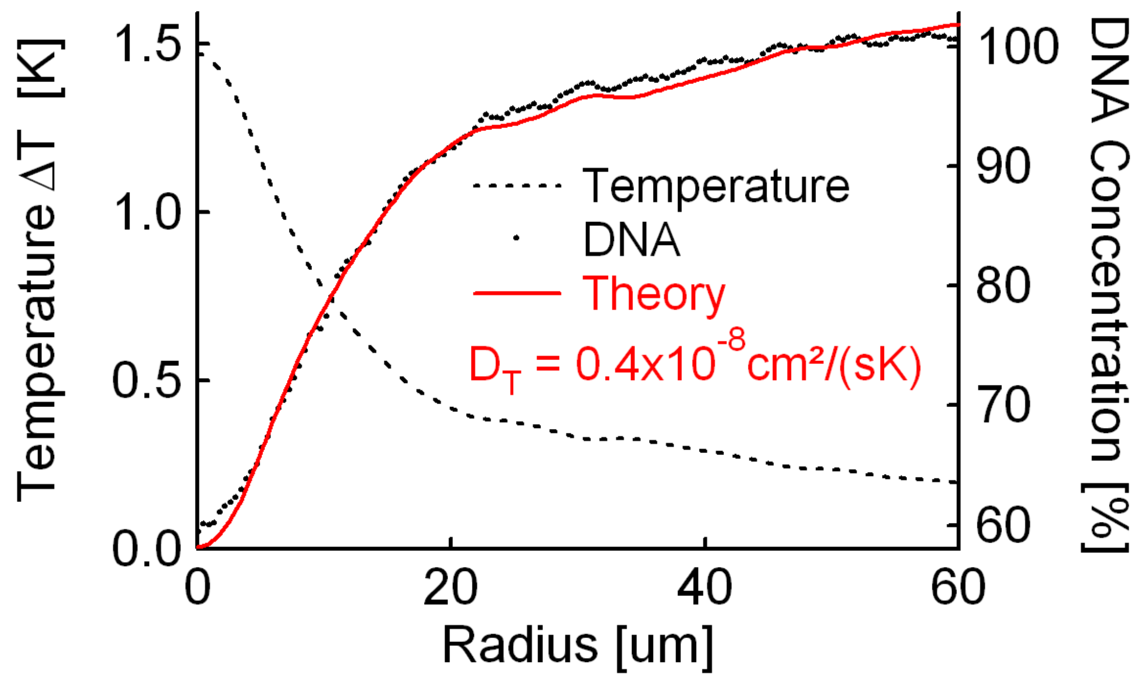


# 3. Thermophorese von DNA

*Aus Gradient der ionischen, freien Grenzflächen-Energie*

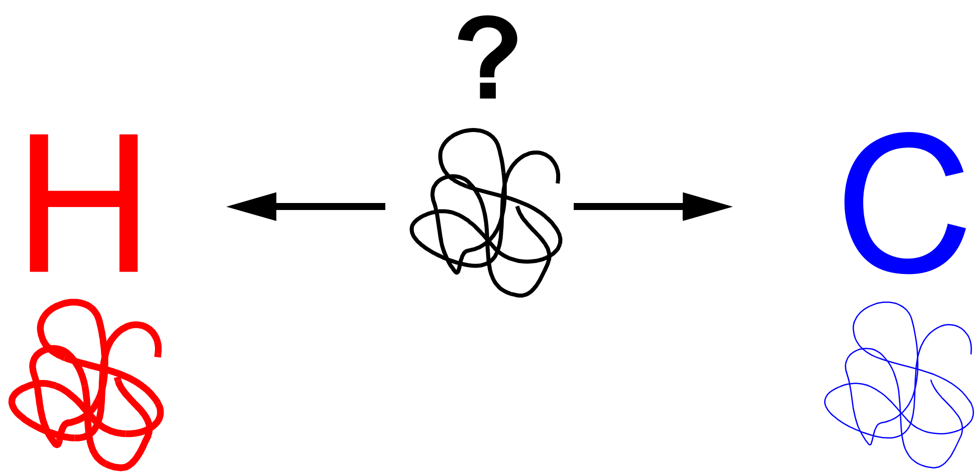
Debye Hückel Length $\lambda_{DH} = \sqrt{(\varepsilon k_B T)/[2 c_S e^2]}$

Interfacial Free Energy $\gamma = -\varepsilon \psi_S^2 / 8\pi\lambda_{DH}$

Drift velocity (Ruckenstein) $v = -l \nabla\gamma / \eta$

$$\frac{D_T}{D} = \frac{3\pi l_B Z_{eff}^2}{4 T a^3} \lambda_{DH}^2$$

*(Piazza 2002)*




Oberflächenenergie groß

Oberflächenenergie klein

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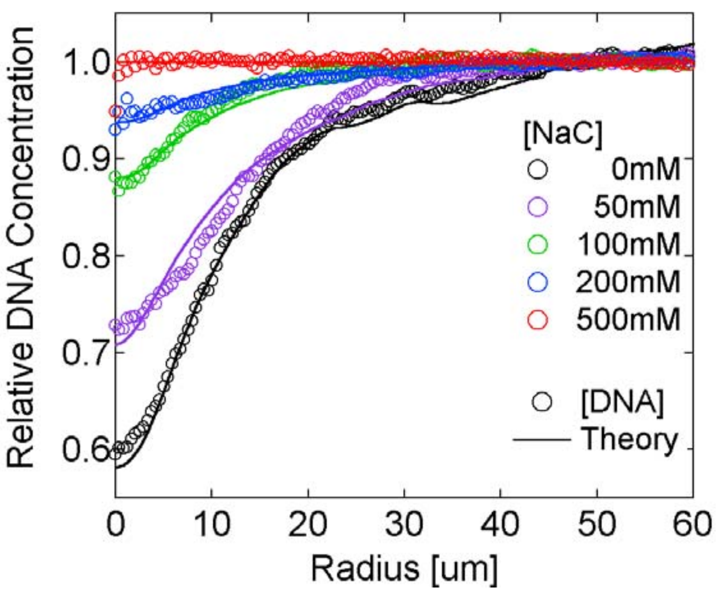
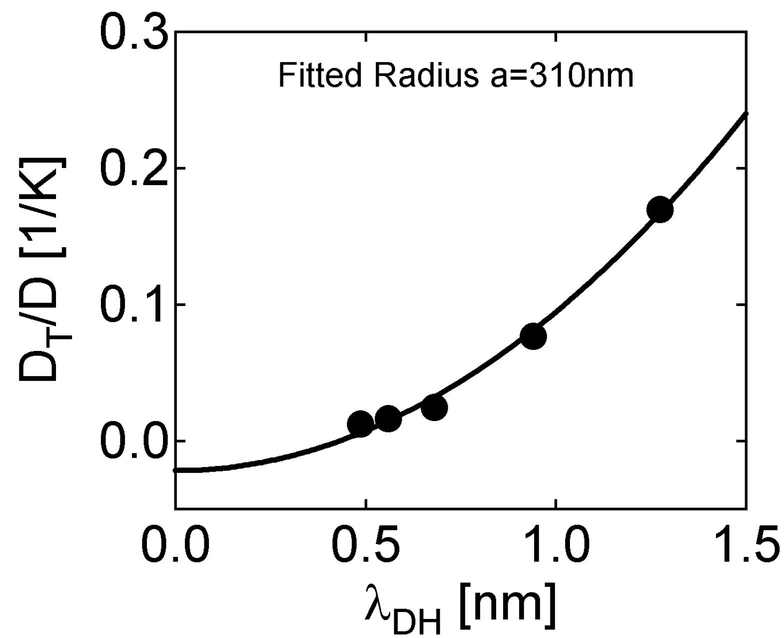
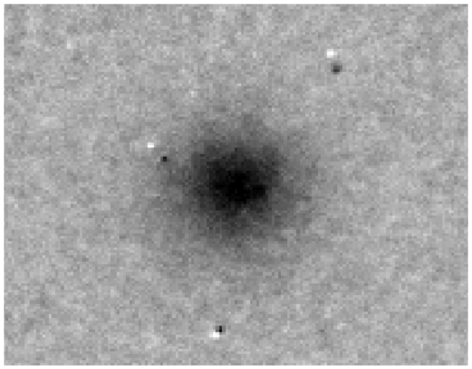


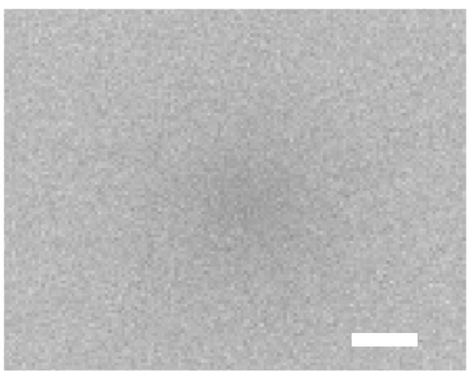



# 3. Thermophorese von DNA

5000bp DNA



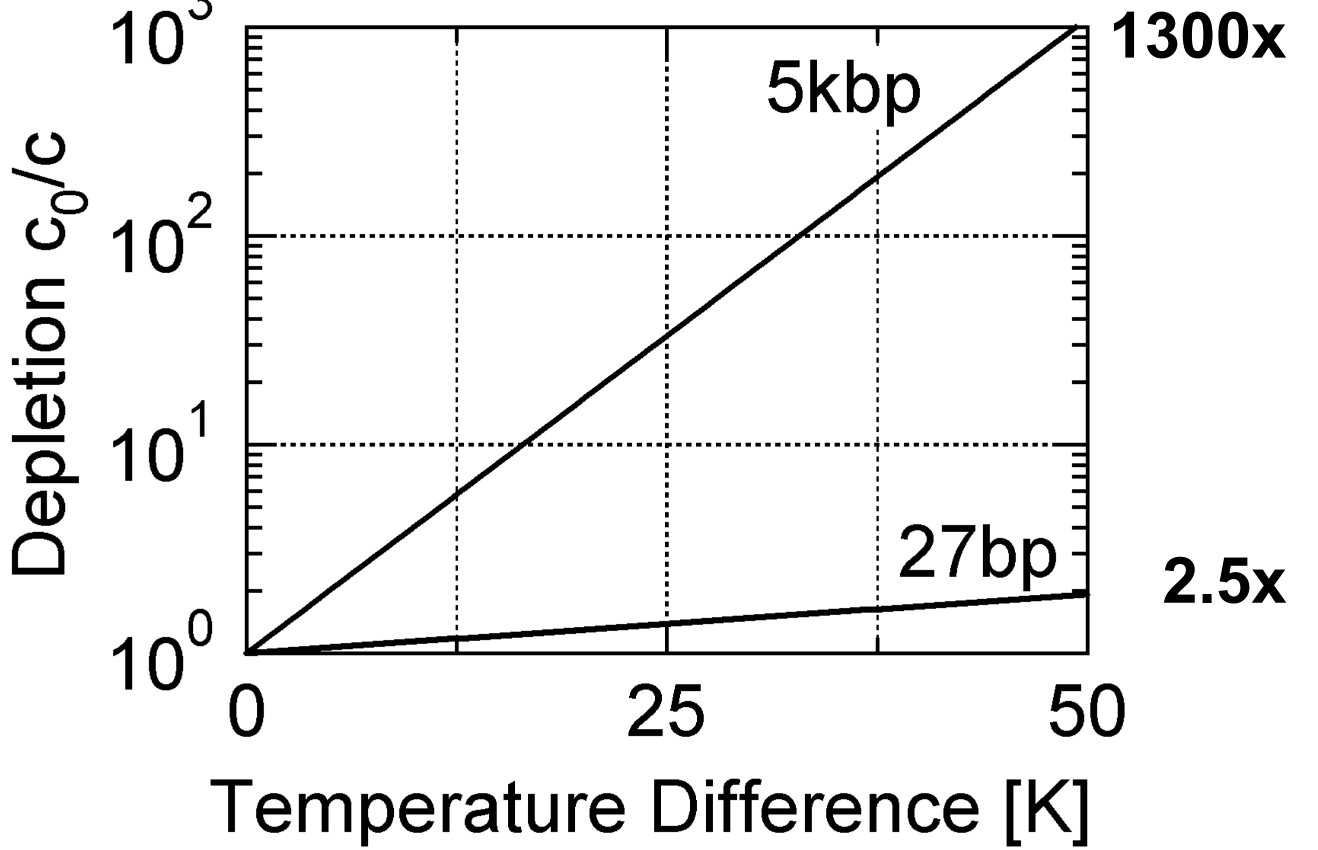
27bp DNA



50μm

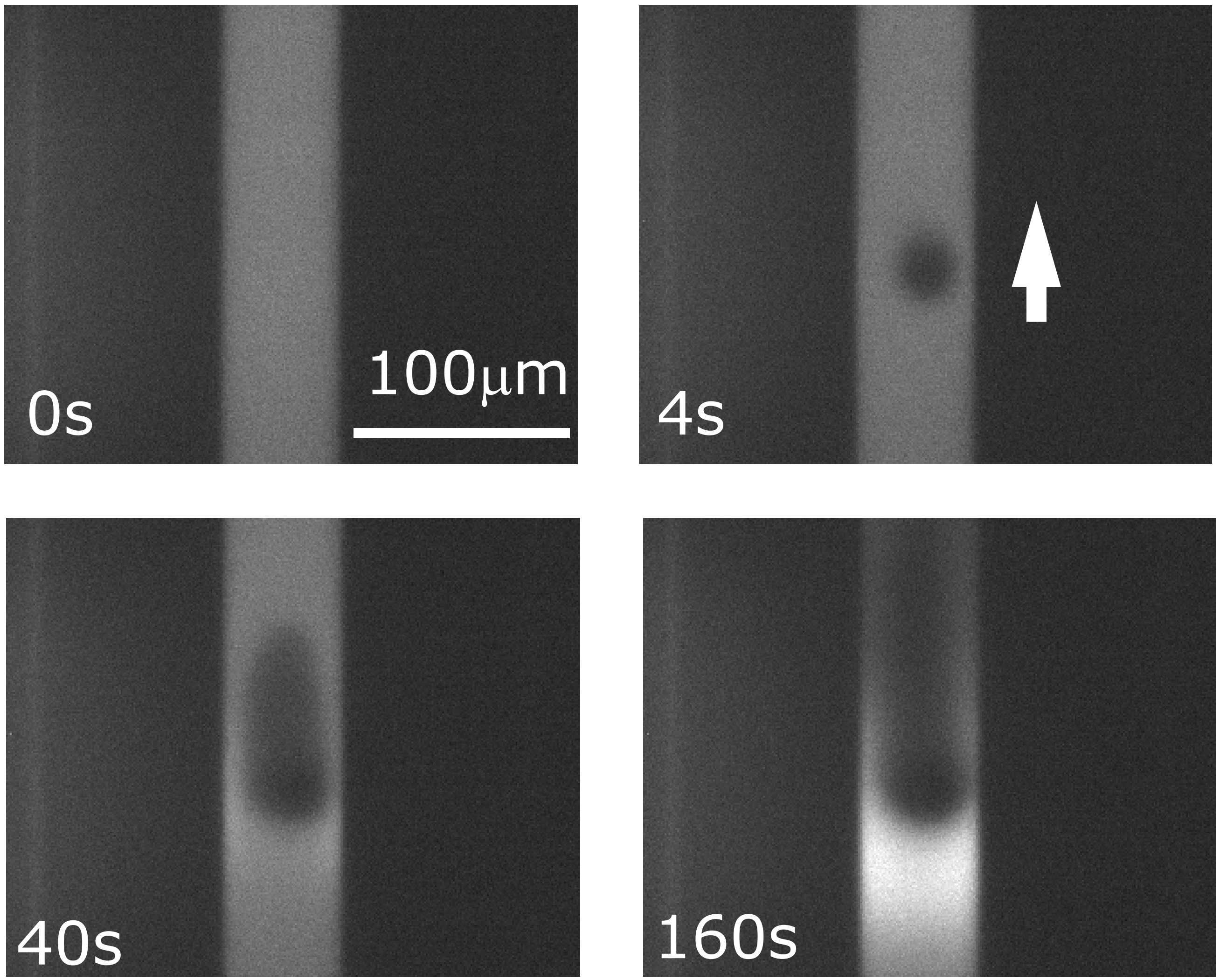
$$\frac{c_0}{c} = e^{\frac{D_T}{D}(T - T_0)}$$

**Depletion**



# 4. Akkumulation durch Thermophorese

Akkumulation, wenn Thermophorese
gegen den Fluß gerichtet ist



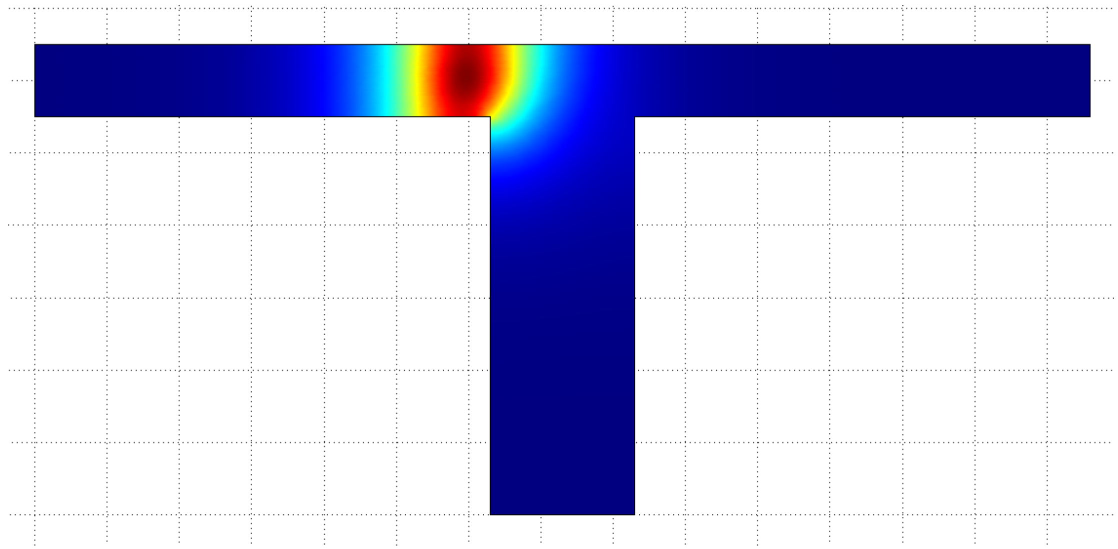
# 4. Akkumulation durch Thermophorese

50000bp DNA

Lambda Movie

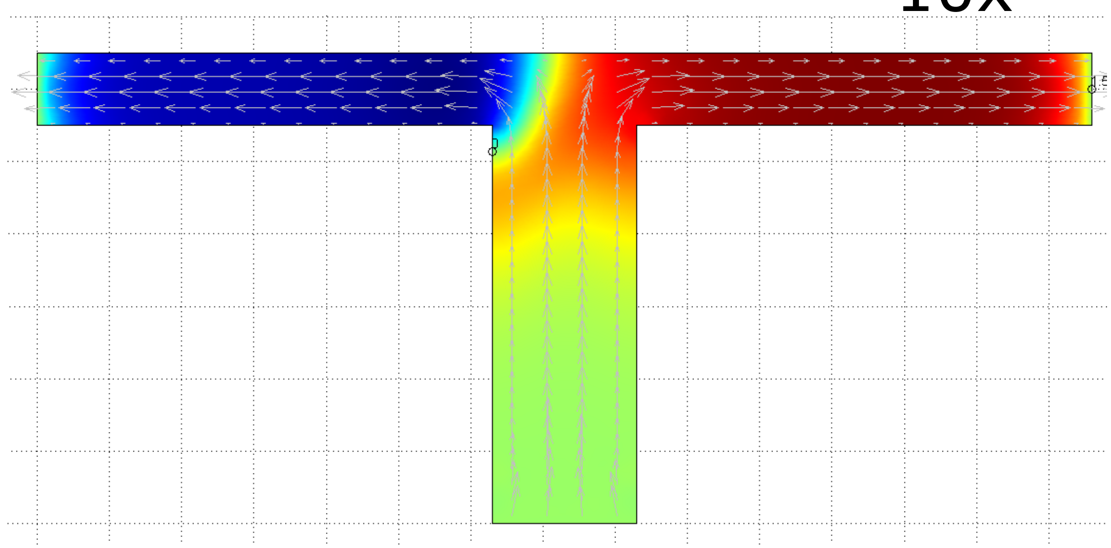
# 4. Akkumulation durch Thermophorese

Temperature



10x

DNA



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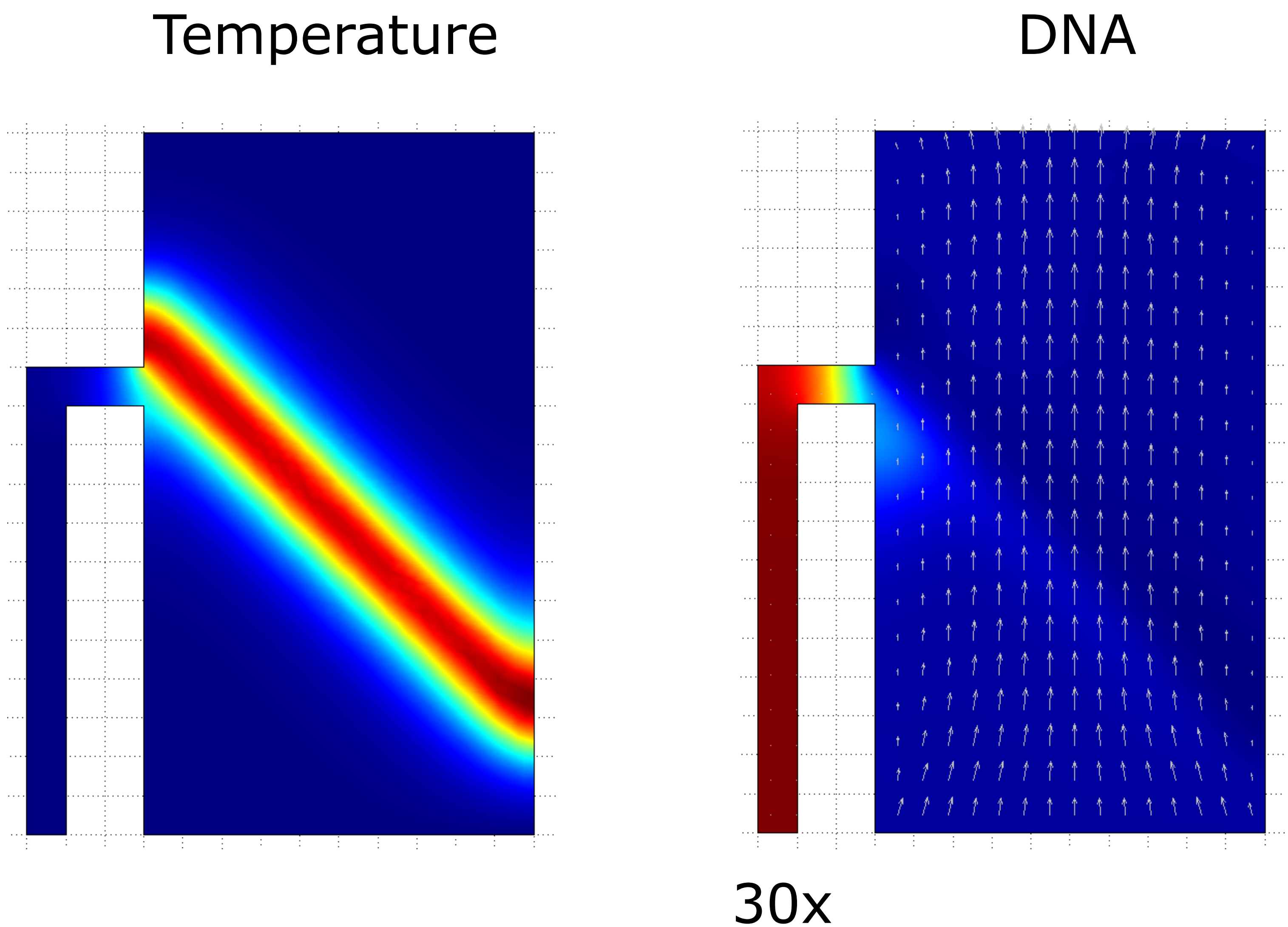
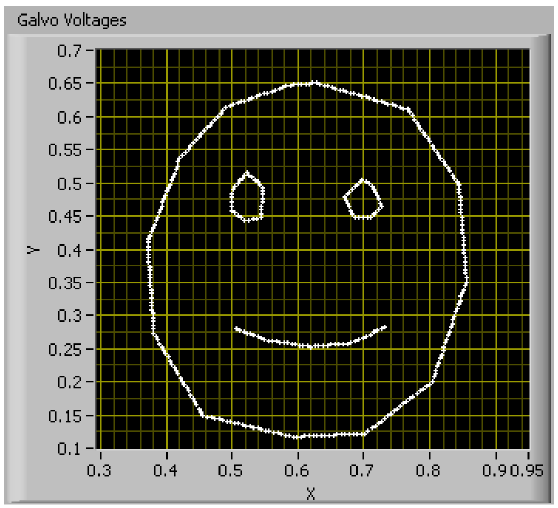
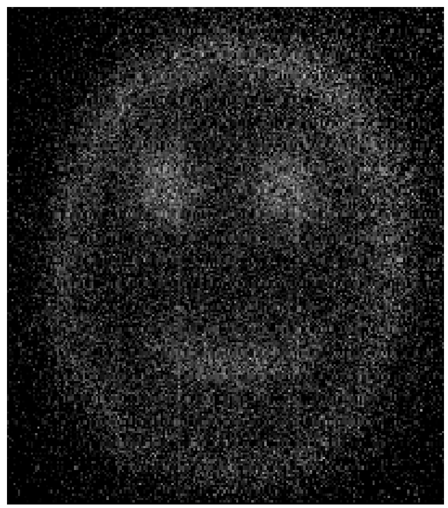


# 4. Akkumulation durch Thermophorese

Laser Scanner




Temperatur



DNA

# 4. Akkumulation durch Thermophorese

Horizontal
in channel

# 4. Akkumulation durch Thermophorese

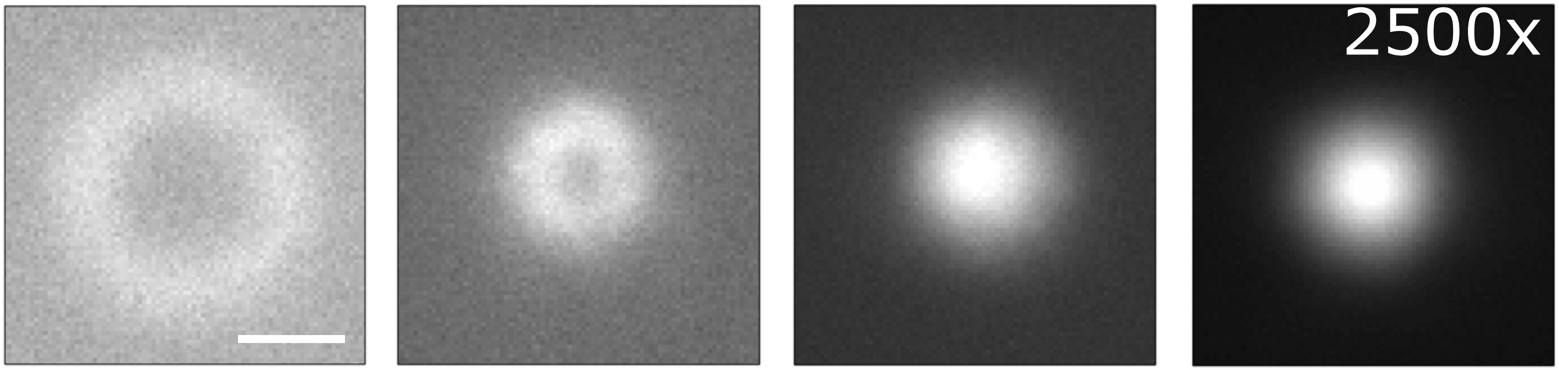
200nm

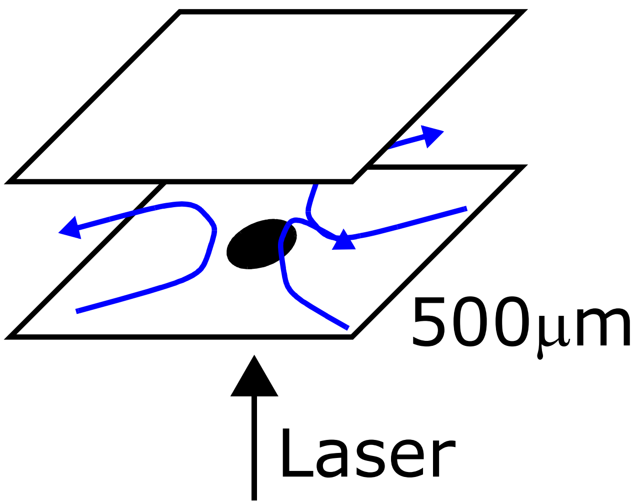
in channel

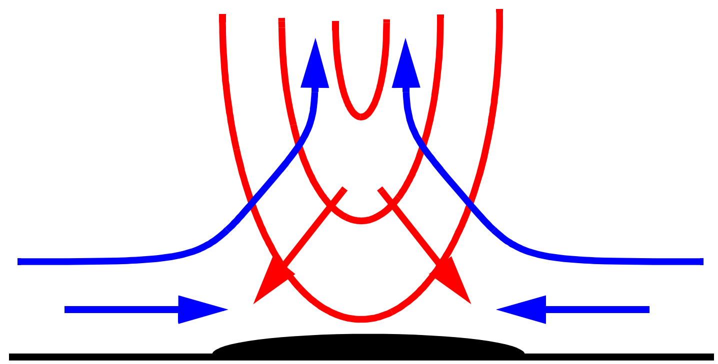
200nm

in convection

# 4. Akkumulation durch Thermophorese



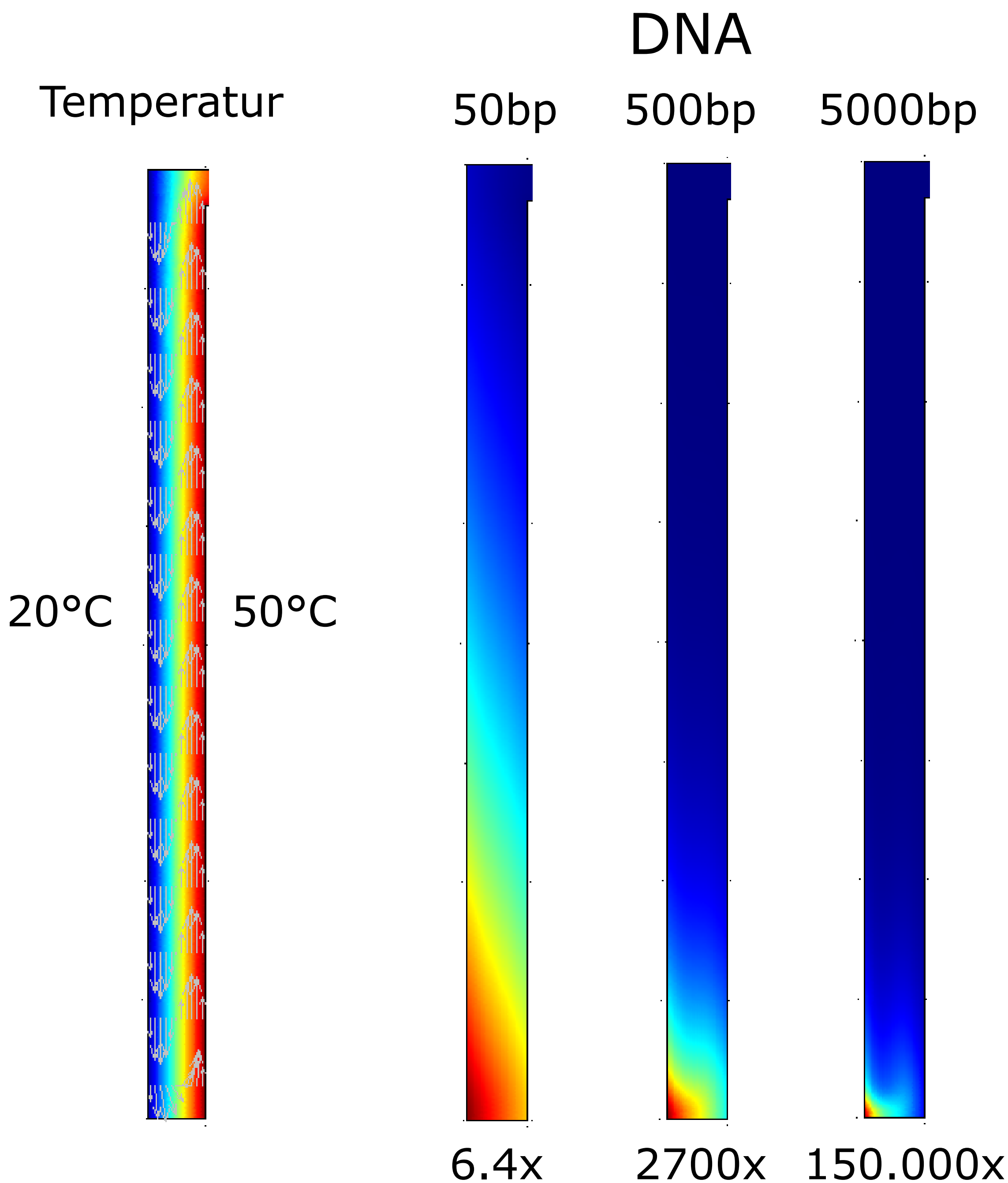



Wärme -zieht Konvektion an
-stößt DNA ab

PRL 89:188103 (2002)

# 4. Akkumulation durch Thermophorese



# 5. Thermischer Lebensursprung?

Wir können durch Konvektion + Thermophorese zwei Kernprobleme der molekularen Evolution recht einfach lösen:

1. Akkumulation. Thermophorese und Konvektion führt zu nach unten gerichteter Akkumulation von genetischen Polymeren.

2. Replikation. Die Replikation durch Binden, Ligation und Trennen kann in einer laminaren Konvektion einfach und effizient gelöst werden.

Welcher Ort ist dafür am plausibelsten?

# 5. Thermischer Lebensursprung?

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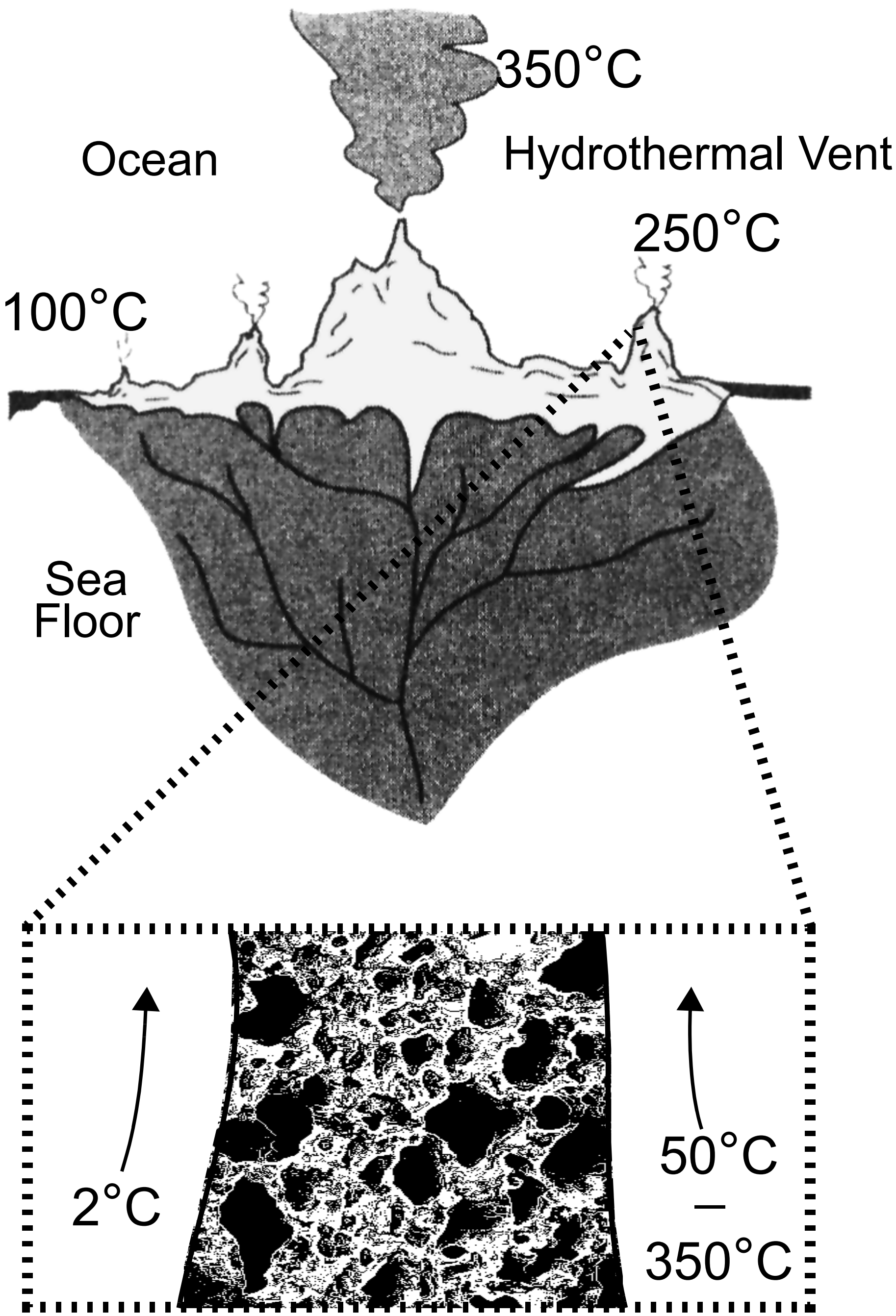
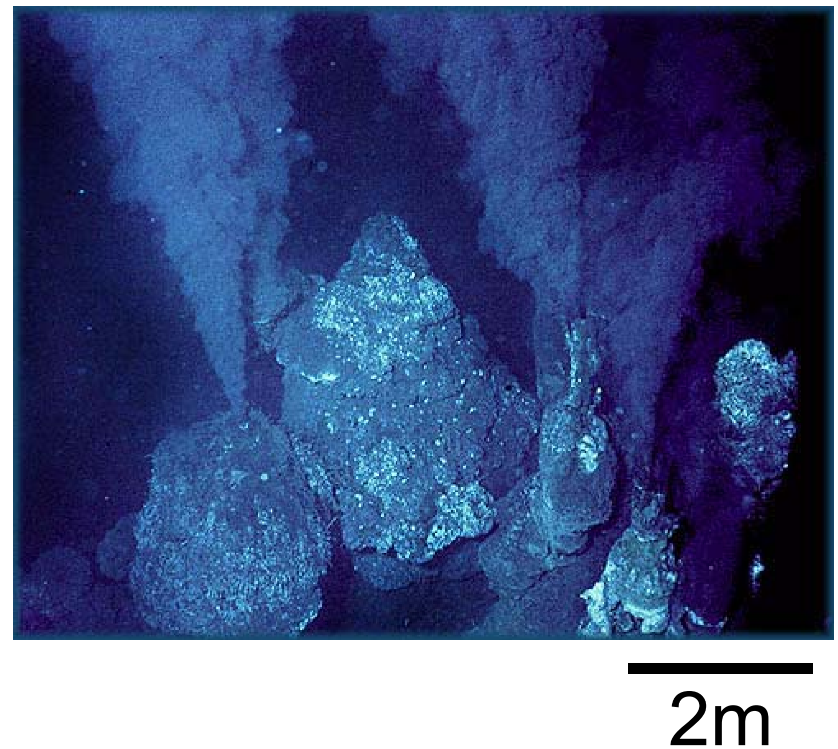



Hydrothermale Quellen

Trieben thermische Kräfte die ersten Lebewesen an?

# 5. Thermischer Lebensursprung?

**TABLE 3.1.**
Chemical composition of typical 350°C black-smoker fluid compared to seawater

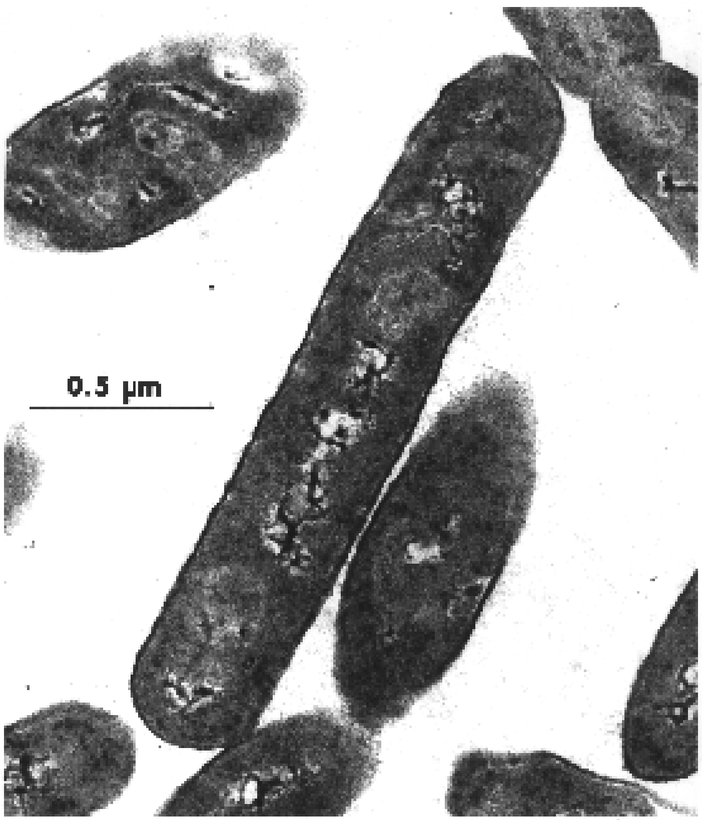
| *Element* | *Hydrothermal Fluid* | *Seawater* | *Units* | *Enrichment Factor (minimum)* |
|---|---|---|---|---|
| $H_2S$ | 3–12 | 0 | mM kg$^{-1}$ | ∞ |
| $H_2$ | 0.05–1 | 0 | mM kg$^{-1}$ | ∞ |
| $CH_4$ | 25–100 | 0 | μM kg$^{-1}$ | ∞ |
| Mn | 360–1140 | 0 | μM kg$^{-1}$ | ∞ |
| Fe | 750–6500 | 0 | μM kg$^{-1}$ | ∞ |
| Be | 10–40 | 0 | nM kg$^{-1}$ | ∞ |
| Zn | 40–100 | 0.01 | μM kg$^{-1}$ | 4000 |
| Cu | 10–40 | 0.007 | μM kg$^{-1}$ | 1500 |
| Ag | 25–40 | 0.02 | nM kg$^{-1}$ | 1250 |
| Pb | 10–360 | 0.01 | nM kg$^{-1}$ | 1000 |
| Co | 20–220 | 0.03 | nM kg$^{-1}$ | 650 |
| Si | 15–20 | 0.05 | mM kg$^{-1}$ | 300 |
| Al | 5–20 | 0.02 | μM kg$^{-1}$ | 250 |
| Ba | 10–40 | 0.15 | μM kg$^{-1}$ | 66 |
| Cs | 100–200 | 2 | nM kg$^{-1}$ | 50 |
| Li | 410–1320 | 25 | μM kg$^{-1}$ | 16 |
| Rb | 10–30 | 1 | μM kg$^{-1}$ | 10 |
| $CO_2$ | 5–15 | 2 | mM kg$^{-1}$ | 2.5 |
| Ca | 10–55 | 10 | mM kg$^{-1}$ | 1 |
| Sr | 90 | 85 | μM kg$^{-1}$ | 1 |
| B | 450–560 | 415 | μM kg$^{-1}$ | 1 |
| As | 30–450 | 30 | nM kg$^{-1}$ | 1 |
| Se | 1–75 | 2 | nM kg$^{-1}$ | 0.5 |
| P | 0.5 | 2 | μM kg$^{-1}$ | 0.25 |
| Mg | 0 | 50 | mM kg$^{-1}$ | 0 |
| $SO_4$ | 0–1 | 30 | mM kg$^{-1}$ | 0 |
| Alk | (−0.1)-(−1) | 2 | mM kg$^{-1}$ | 0 |

From summary data in Elderfield and Schultz (1996), but with numbers rounded and ranked by degree of enrichment above seawater.

# 5. Thermischer Lebensursprung?

## Leben in Steinporen

Archaea




Prof. Stetter, Regensburg

"Die unsichtbare Mehrheit"

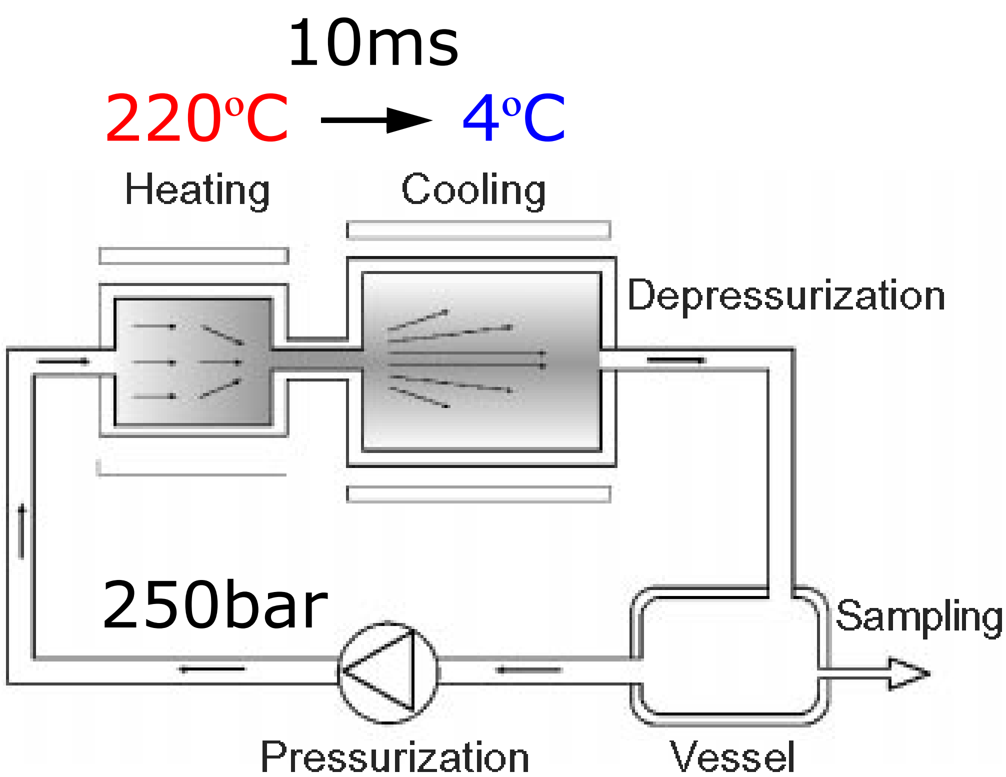
(Whitman, PNAS, 95:6578, 1998)

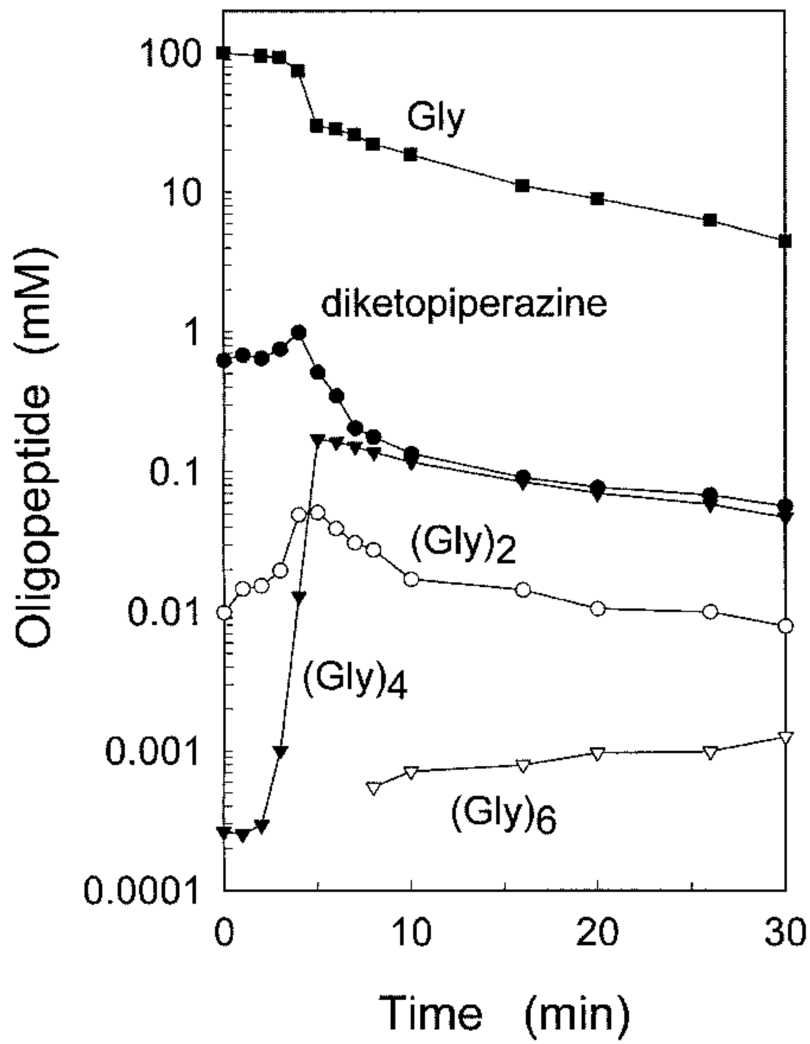
Table 5. Number of prokaryotes in the world

| Environment | No. of prokaryotic cells, $\times 10^{28}$ |
|---|---|
| Aquatic habitats | 12 |
| Oceanic subsurface | 355 |
| Soil | 26 |
| Terrestrial subsurface | 25–250 |
| Total | 415–640 |

# 5. Thermischer Lebensursprung?

## Peptid-Polymerisation durch schnelles Kühlen

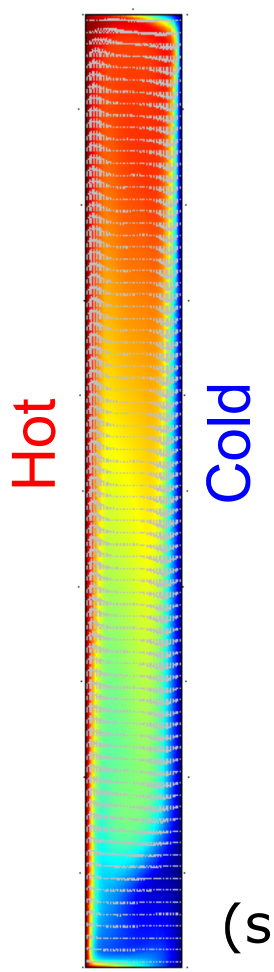



Koichiro Matsuno et.al. Science 283:831 (1999)

# 5. Thermischer Lebensursprung?

## Peptid-Polymerisation durch schnelle Konvektion?



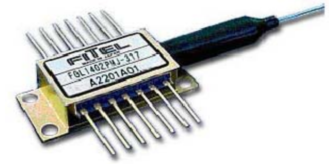

(simuliert)

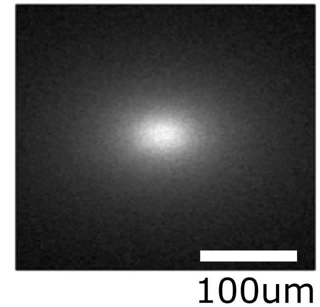
*Theorie: Konvektion bei 20Hz*
*Kühlzeiten 50ms*

*Mikroskopische Druckkammer*
*für 250 °C und 700 bar*

# Biophysik offener Systeme

1. Optisches Heizen



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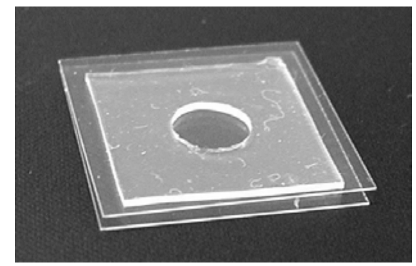
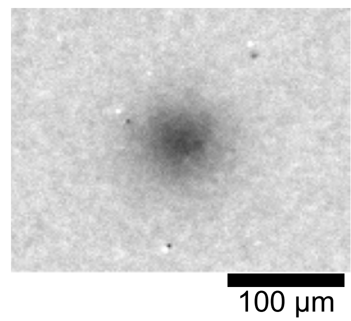
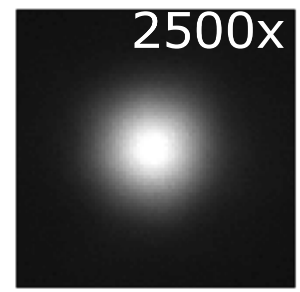


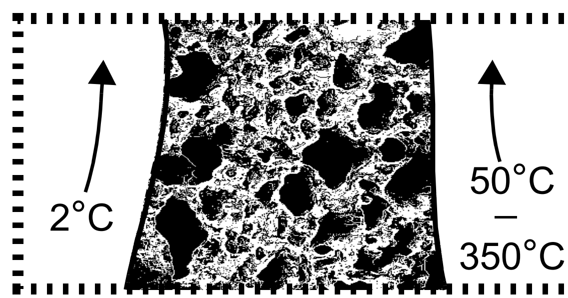
3. Thermophorese von DNA




4. Akkumulation durch Thermophorese




5. Thermischer Lebensursprung?




Dieter Braun, Emmy-Noether Gruppe, LMU München
Angewandte Physik, LS Gaub, www.dieterb.de