Bio-inspired Programmable Self-assembly on DNA Templates

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Molecular architecture

- The goal of molecular architecture is to precisely arrange molecules or even atoms in space and to make them operate as intended
- Conventional synthetic approaches for such self-assembling systems are not efficient enough

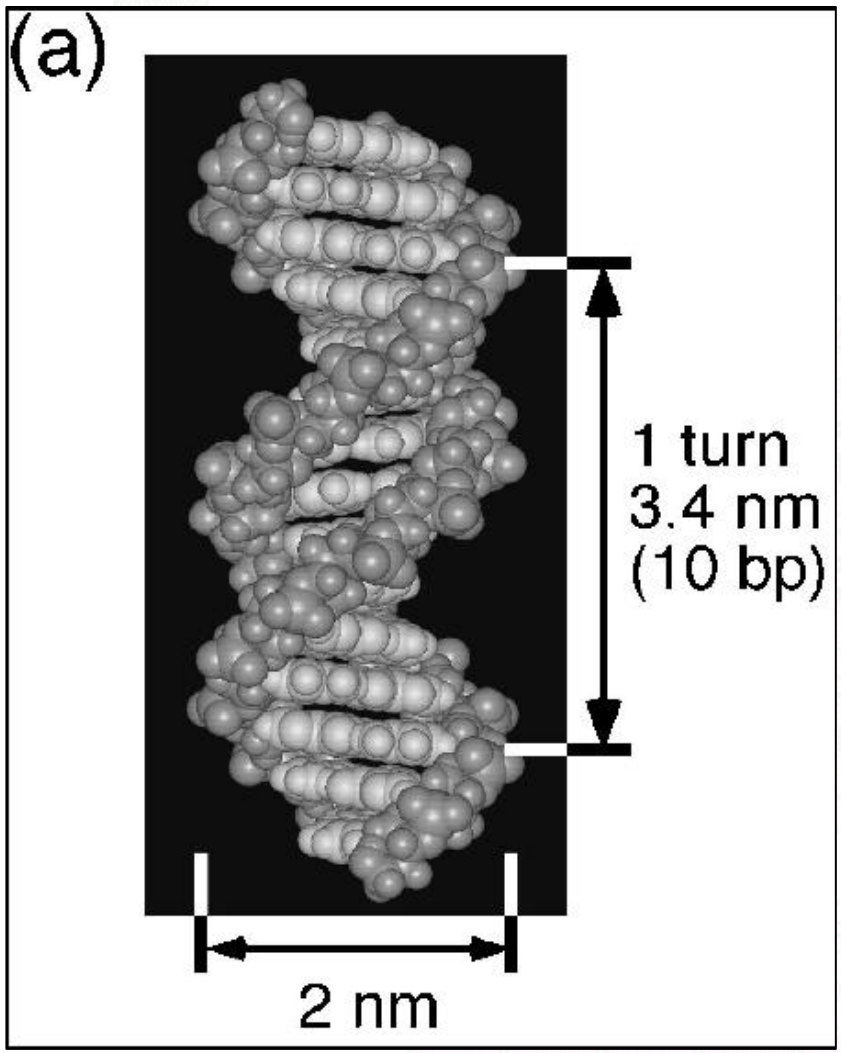
Biomolecules in molecular architecture

- Biomolecules like DNA, proteins and polysaccharides can be generated without dispersion in number, composition, sequence and direction
- These molecules organize with highly selective and specific spatial arrangement

Biomolecules in molecular architecture

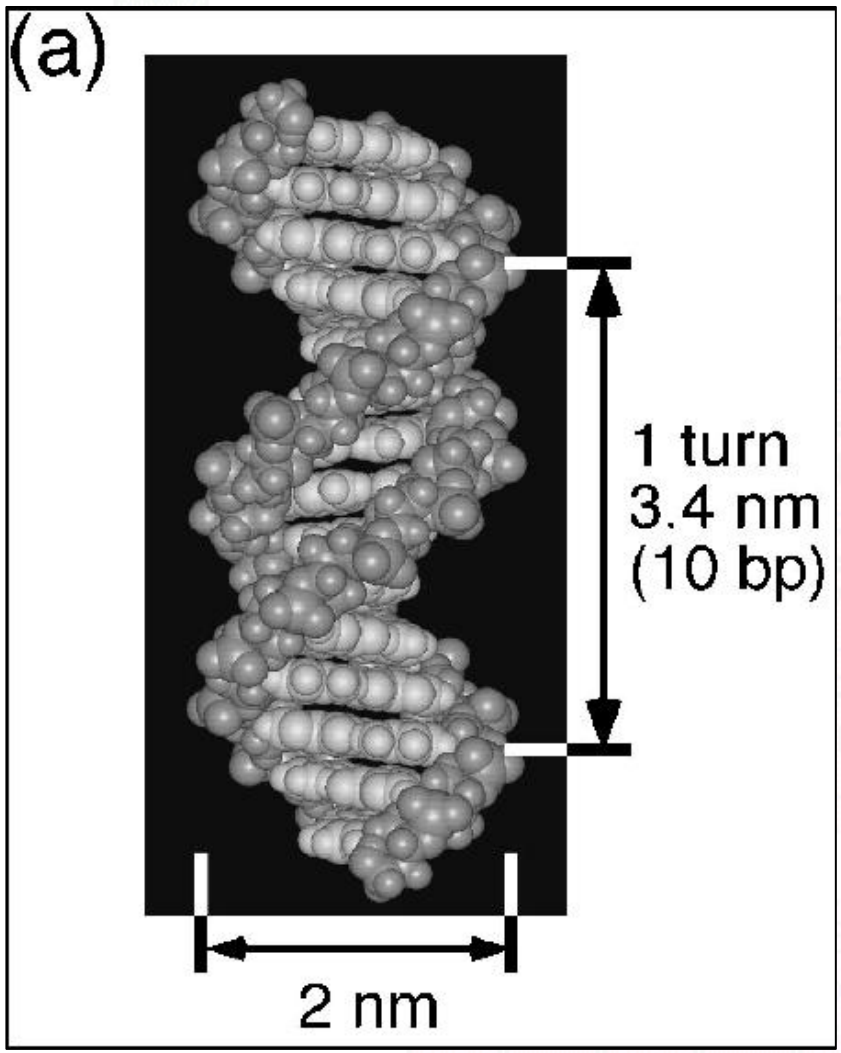
- Therefore, structural motifs of biopolymers have great potential as templates for programmable self-assembly to generate well-defined molecular architectures

B-form DNA



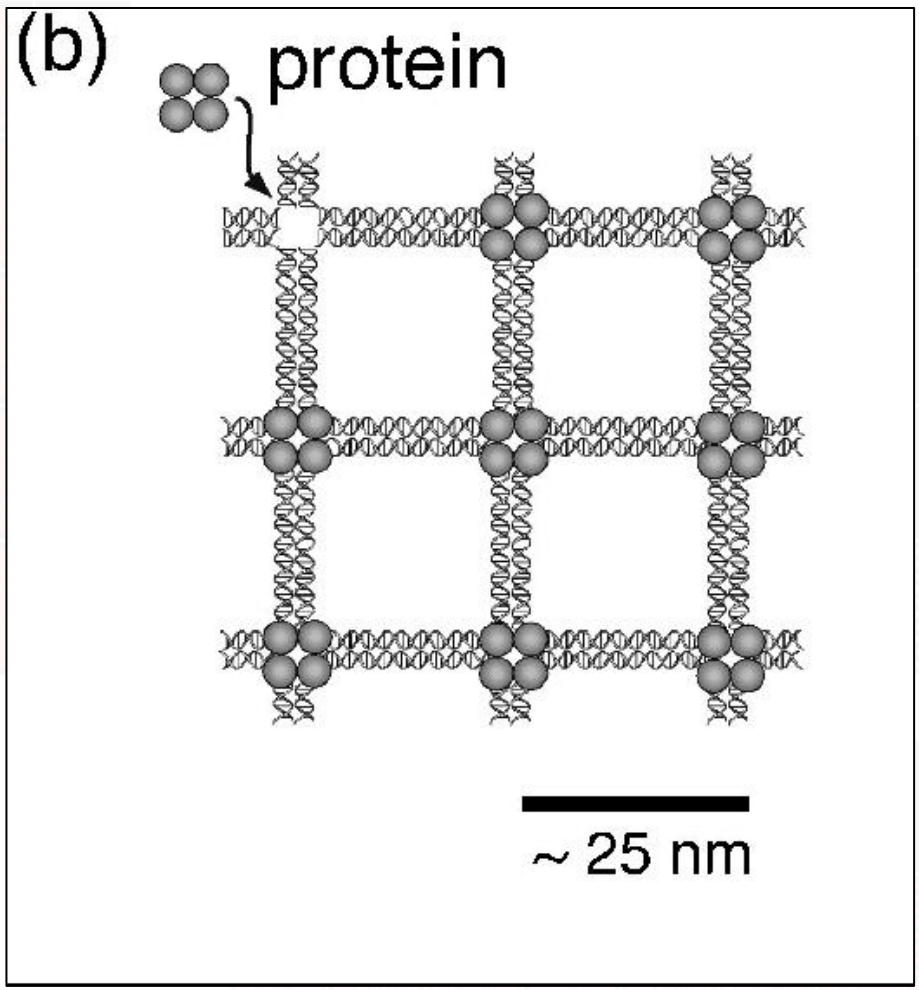
- Chemical synthesis is well established
- DNA synthesizers routinely make oligomers ~100 nucleotides long
- Unnatural nucleotides can be also incorporated

B-form DNA



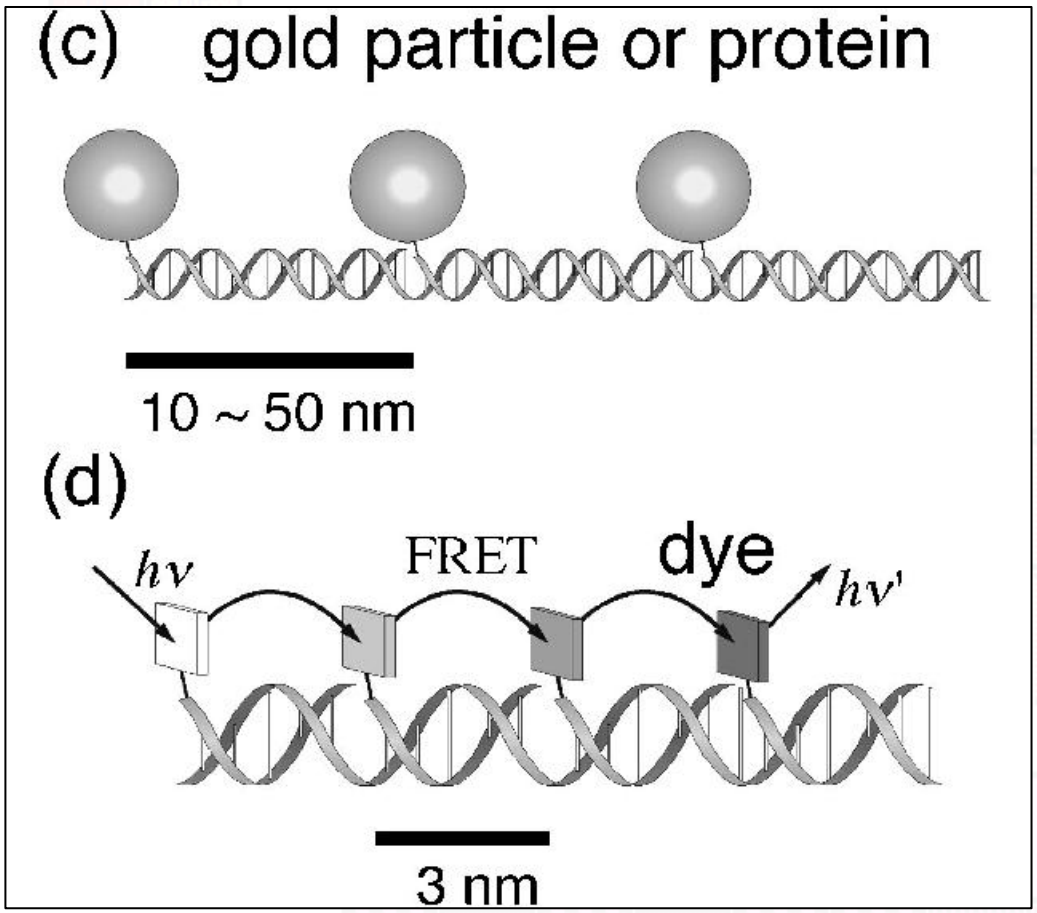
- Watson-Crick base pairing rules to assemble DNA strands into:
  - duplex
  - triplex (?)
  - quadruplex (?)
  - hairpins
  - branched structures

Different workgroups have reported:



b) Specifically patterned protein array made on self-assembled DNA nanostructures (La Bean *et al.*)

Different workgroups have reported:



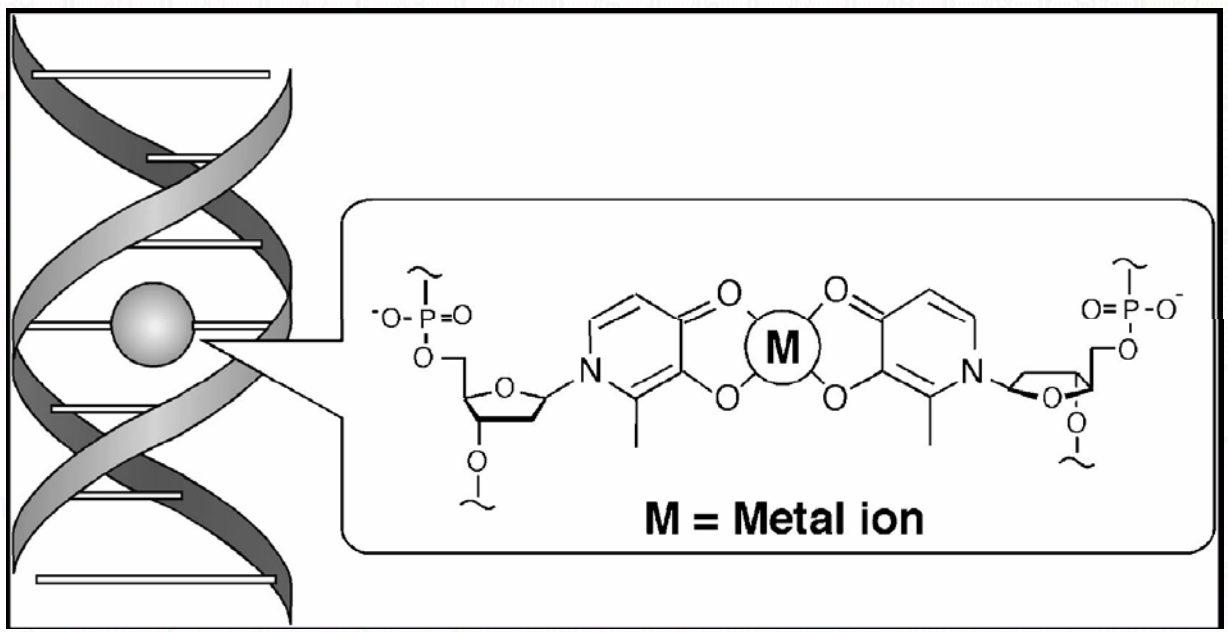
c) Covalent DNA-protein or DNA-gold conjugates (Niemeyer *et al.*)

d) DNA as template for single molecular photonic wires (Kawahara *et al.*)

FRET – Fluorescence Resonance Energy Transfer

Tanaka & Shionoya, 2006

- Metal-assisted base pairing
- Conversion of nucleobases into metal ligands



Tanaka & Shionoya, 2006

- Why?
- Metal complexes show a variety of characteristics features that can not be found in organic compounds alone
  - >new functionalized (nano-)materials that can be used as:
    - Biosensors
    - Nanodevices
    - Catalysts

Tanaka & Shionoya, 2006

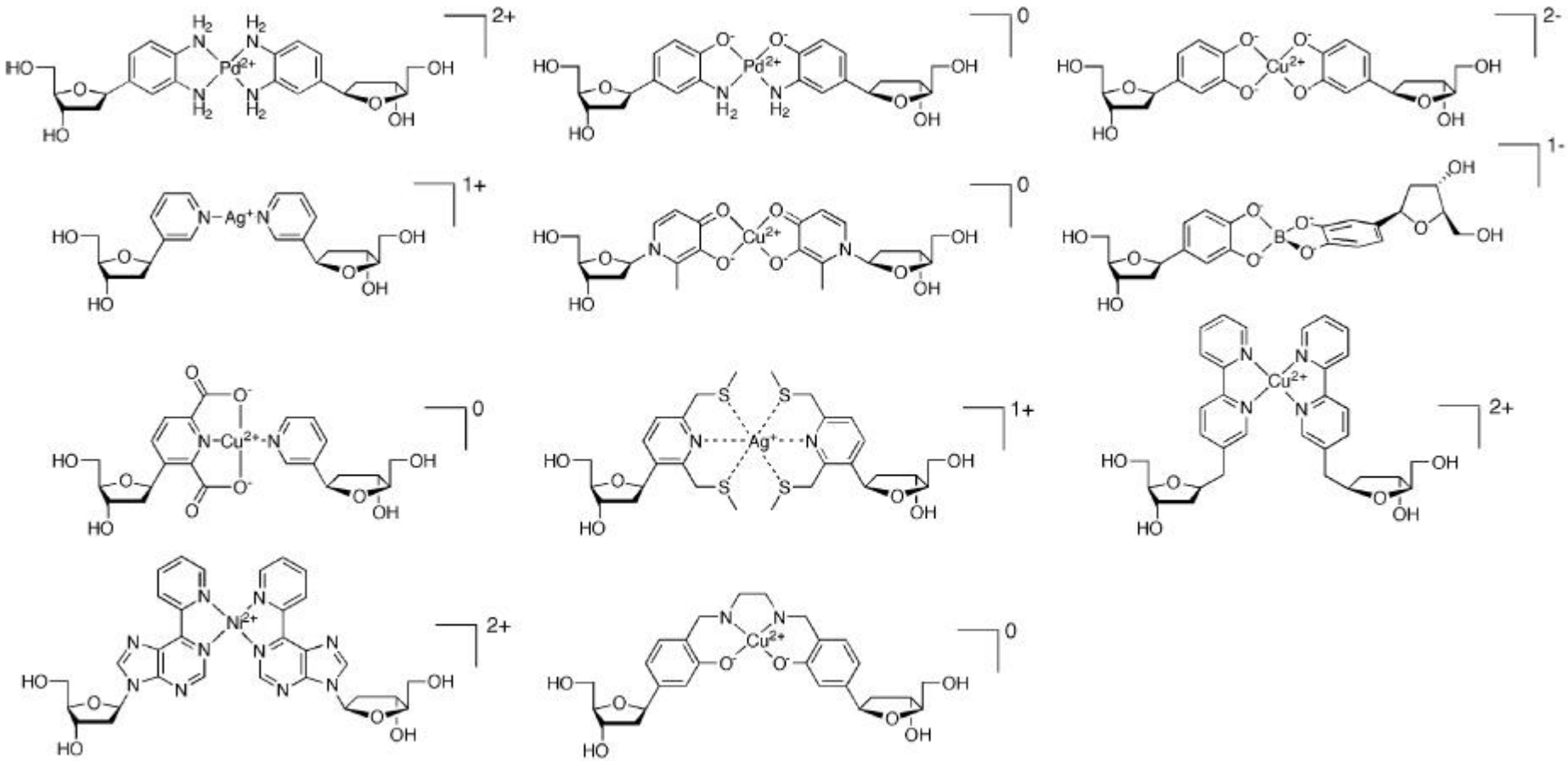


Figure 5. Metal-mediated base pairs.

Tanaka & Shionoya, 2006

- Influence of metal-mediated base pairing on the thermal stability of a DNA double strand:

1. Natural base pair (A-T)

d(5'-CACATTAA**T**GTTGTA–3')
d(3'-GTGTAATT**A**CAACAT–5')

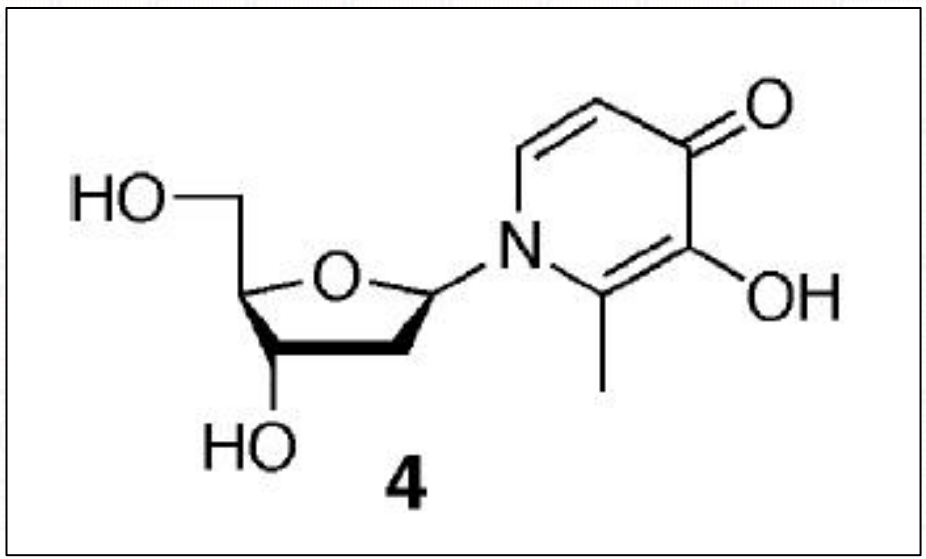
2. H-H base pair

d(5'-CACATTA**H**TGTTGTA-3')
d(3'-GTGTAAT**H**ACAACAT-5')

H – hydroxypyridone

Tanaka & Shionoya, 2006

- Hydroxypyridone base:



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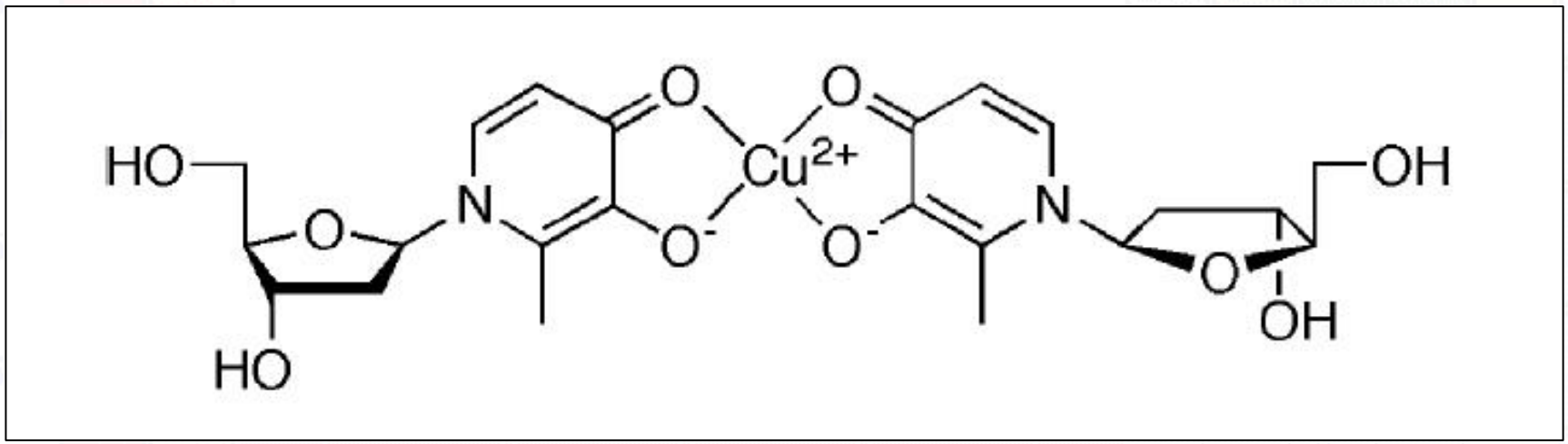
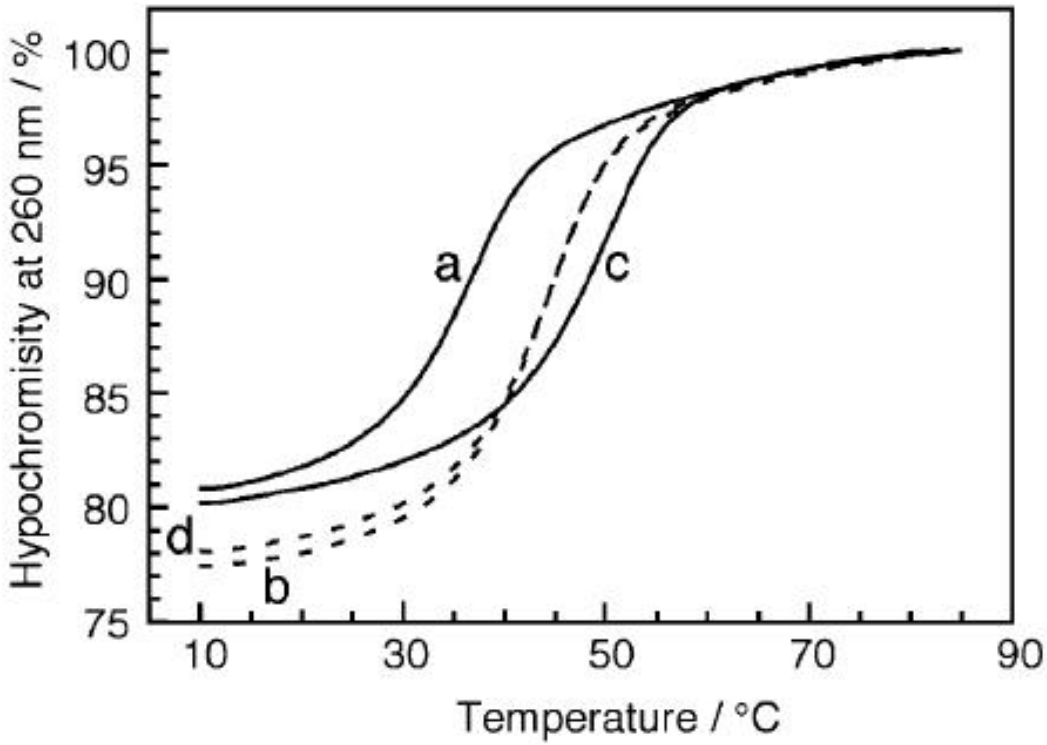
Tanaka & Shionoya, 2006

- H-Cu^{2+}-H base pair:



12 d(5'-CACATTA**H**TGTTGTA-3')
d(3'-GTGTAAT**H**ACAACAT-5')

13 d(5'-CACATTAA**T**GTTGTA-3')
d(3'-GTGTAATT**A**CAACAT-5')



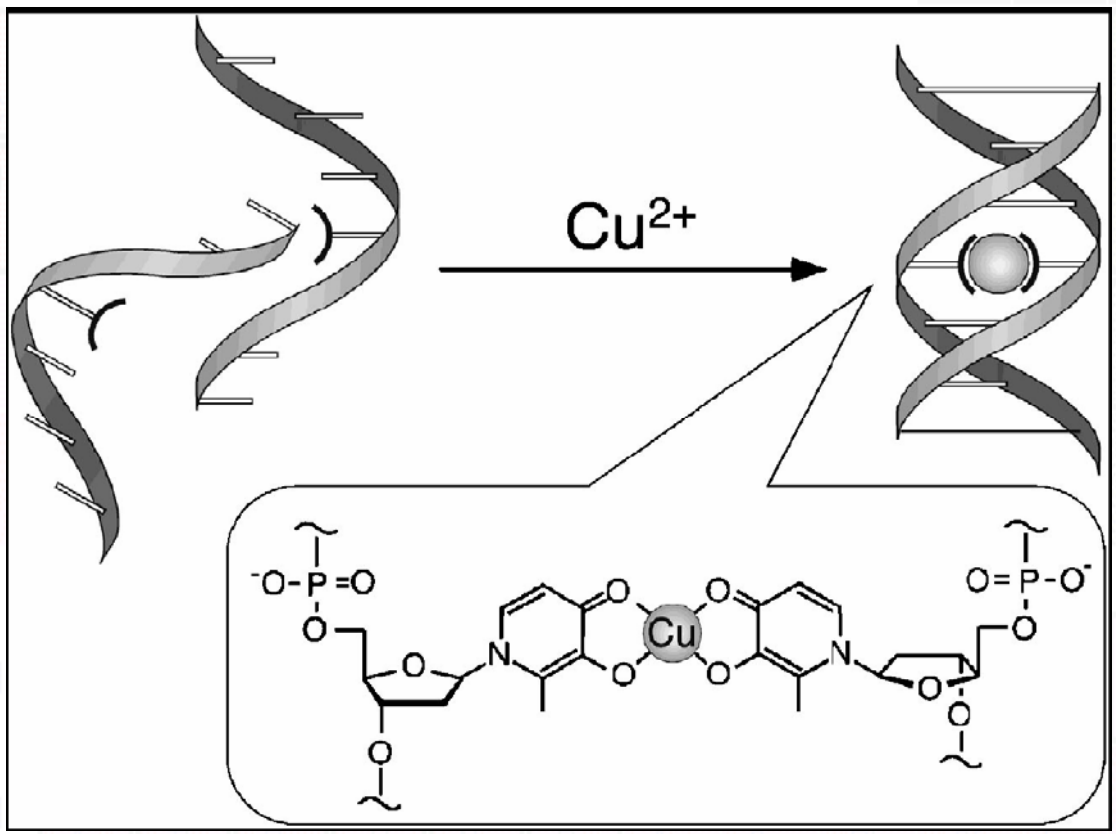
a) In the absence of Cu^{2+} ions, the duplex 12 had T_m of 37 °C

b) The duplex with natural base pairs (13) had T_m of 44.2 °C, Cu^{2+} addition had nearly no influence (d)

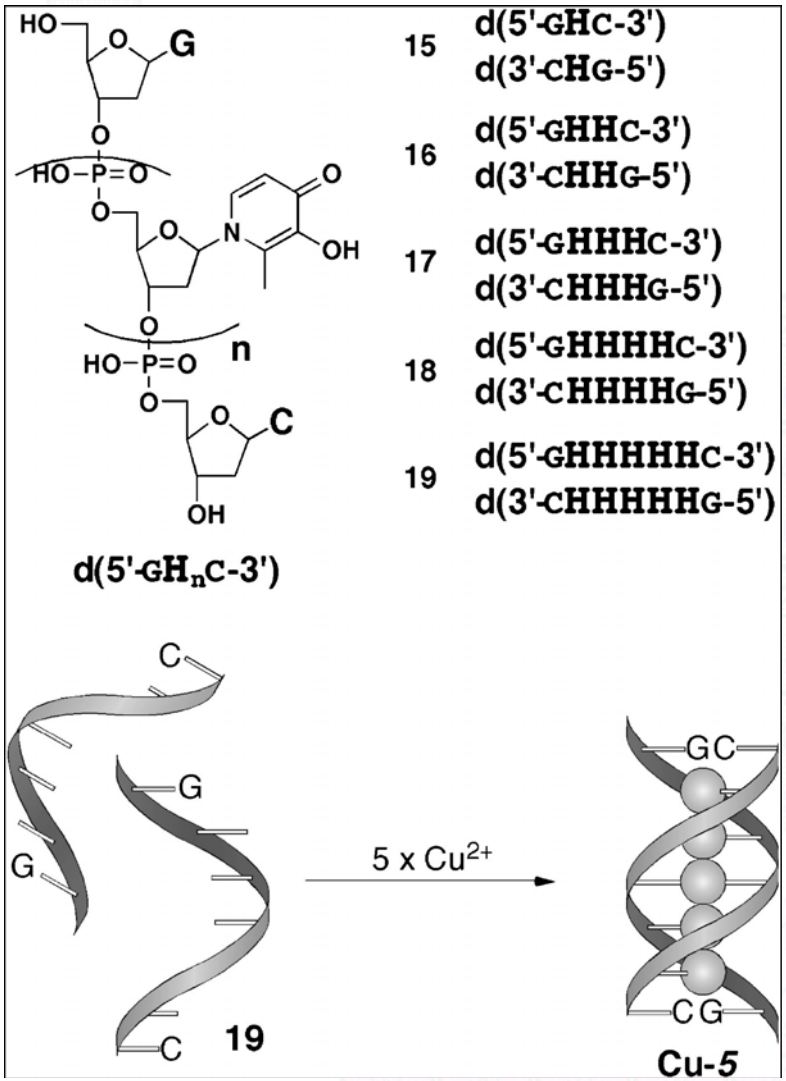
c) In the presence of equimolar Cu^{2+} ions, the duplex 12 had T_m of 50.1 °C

Tanaka & Shionoya, 2006

- H-Cu^{2+}-H base pair stabilized the duplex by 13 ^{o}C



Tanaka & Shionoya, 2006



- Oligonucleotides with mono- to pentanuclear Cu^{2+} complexes stacked within B-form DNA

Tanaka & Shionoya, 2006

- The Cu^{2+} ions couple ferromagnetically with one another through unpaired *d* electrons:
  - > new method to synthesize metal arrays and structures in a discrete and predictable fashion
  - > molecular magnets and wires

References

- Kentaro Tanaka & Mitsuhiko Shionoya. **Bio-inspired Programmable Self-assembly on DNA Templates.** *Chemistry Letters*, 2006, 35(7), 694
- Tanaka *et al.* **Programmable self-assembly of metal ions inside artificial DNA duplexes.** Nature Nanotechnology 1, 190 - 194 (2006)
- Burley, G. A., Gierlich, J., Mofid, M. R., Nir, H., Tal, S., Eichen, Y., Carell, T. *JACS* 2006, 128 (5), 1398-1399.