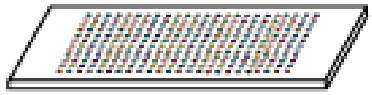
POKRAČOVÁNÍ 22.10.08/předn.3

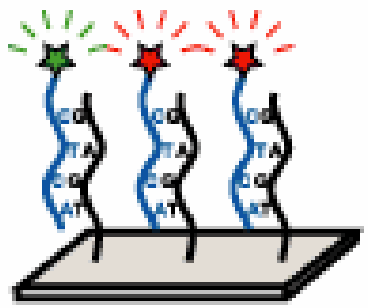
Progress in genomics affects electroanalysis

Many areas of science are influenced by the **fast development of the genomics** and by the **success of the Human Genome Project.**

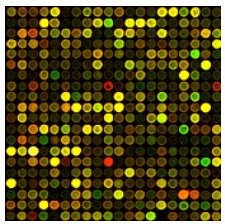


Classical sequencing of individual human genomes with $3x10^9$ base pairs is too **difficult.**

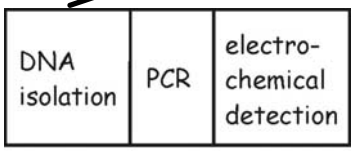
Sequencing by DNA hybridization is gaining importance



Relatively expensive DNA hybridization **ARRAYS** with **optical detection** are **currently applied** in research labs
It is believed that **electrochemistry** can complement the optical detection providing **new LESS EXPENSIVE hybridization detection for decentralized DNA analysis in many areas of practical life**



LOW DENSITY CHIPS

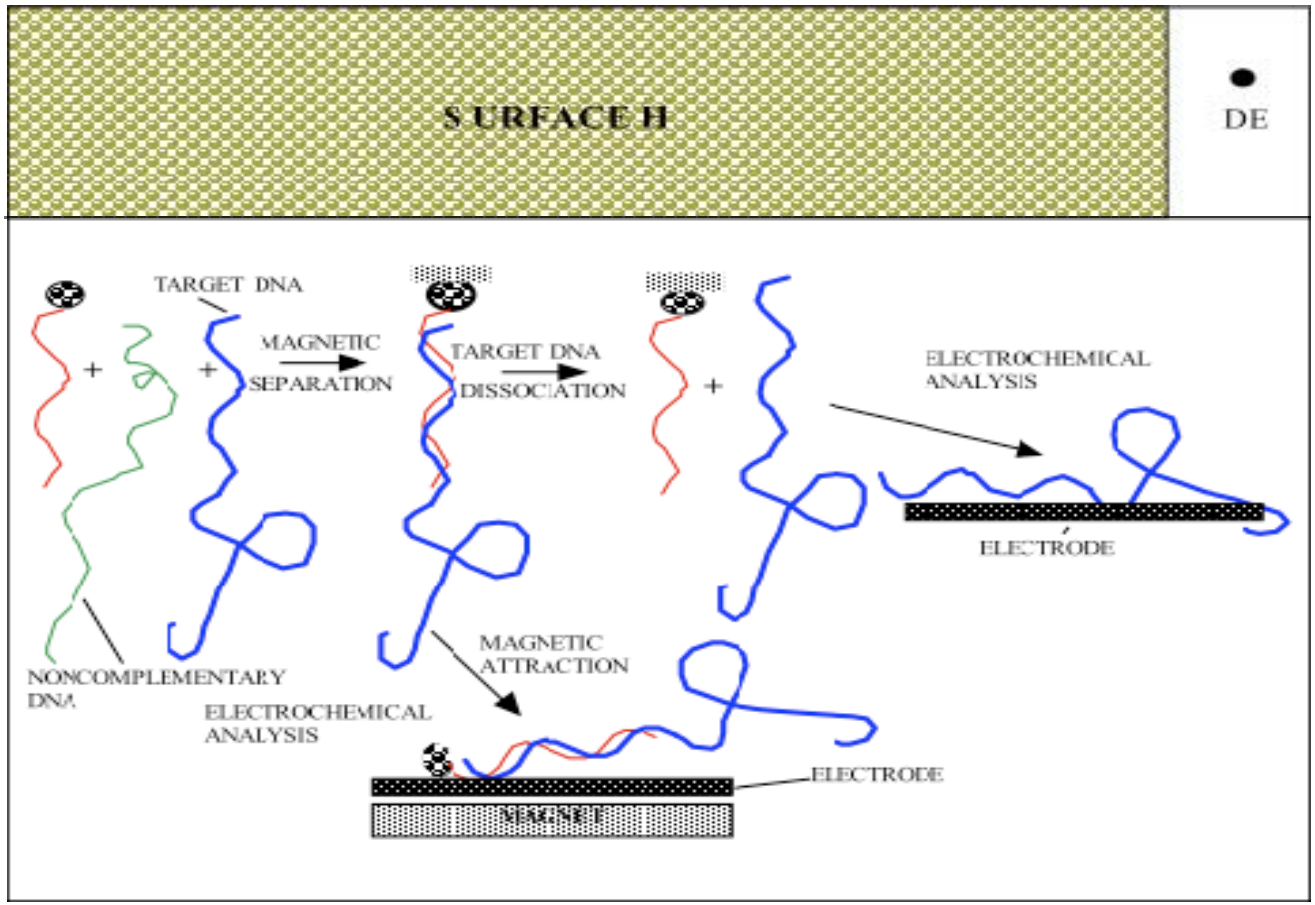


LAB-ON-A-CHIP

Double-surface technique

Few years ago we proposed a new technique in which (in difference to previous techniques) **DNA hybridization is separated from electrochemical detection. Optimum properties of the hybridization surface (H) and the detection electrode (DE) are not identical**. We used **magnetic beads** optimized for hybridization **as surface H** and chose **optimum DE for the given electrode process.**

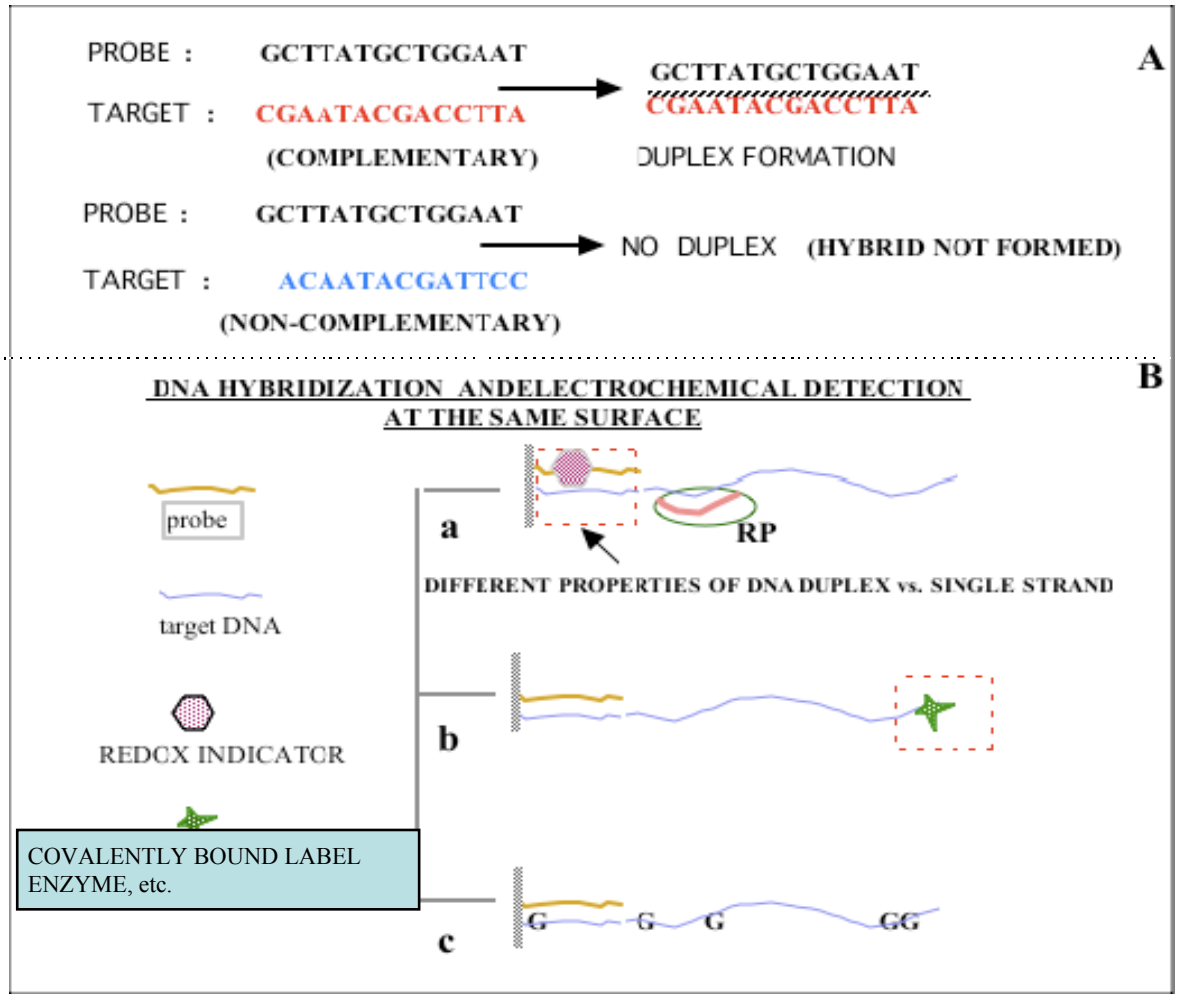
With single-surface techniques analysis of long DNA target molecules and in large excess of noncomplementary DNA may be difficult

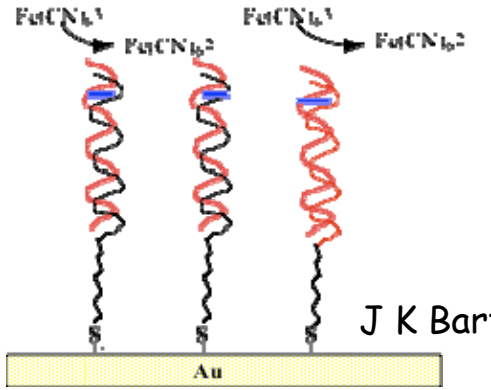


With spherical magnetic beads non-specific binding of NAs is minimized. 20 microL of the bead suspension gives 3 to 7 cm^2 area. Beads can be incorporated into microfluidic systems and chips

Electrochemical sensors/detectors for DNA hybridization

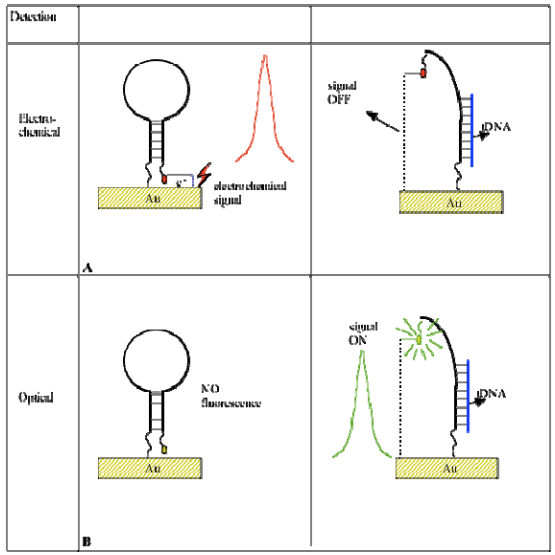
Single-Surface Technologies:





J K Barton

Surface-attached molecular beacons



A Heeger

In the **last decade** nucleic acid electrochemistry was oriented predominantly to **DNA sensors** for (a) DNA **hybridization** and (b) DNA **damage**.
This trend has been **accompanied not only by interesting discoveries** but also by a number of poor **papers lacking the necessary control experiments**, claiming sequence detection **without PCR amplification** but using **synthetic oligos as target DNA**, **etc.**

Electrochemical sensors for DNA hybridization

At present **both single- and double-surface techniques** can be used for **DNA sequencing of longer oligonucleotides and PCR products**.

Electrochemical detection of **point mutations** is also possible.

Optimization of the procedures are now necessary to develop commercially successful devices.

Challenges:

1) **Sequencing eukaryotic DNA without amplification** (by PCR). Great **sensitivity and specificity** of the analysis is required

2) Development of electrochemical **sensors for DNA-protein protein-protein interactions for proteomics and biomedicine**

The results of the DNA electrochemistry studies and development of the electrochemical DNA hybridization sensors in the last decade suggest that these sensors can complement DNA sensors with optical detection

How and when the DNA electrochemistry begun?

Science in Czechoslovakia after the IInd World War

After February 1948 life in Czechoslovakia was increasingly affected by the stalinist ideology and heavily controlled by the Party and Government.

Many scientists and scholars were fired from Universities but some of them got employment in the Institutes of the Czechoslovak Academy of Sciences established in 1952. This was possible particularly at the Institutes whose Directors were influential Party members but serious scientists.

PRAHA/PRAGUE

Institute of Organic Chemistry and Biochemistry/

Director: F. Šorm

Chemistry and Biochemistry of Proteins and Nucleic Acids

B. Keil, B. Meloun, O. Mikes, J. Doskocil, D. Grunberger, A. Holy, I. Rychlík, J. Ríman, J. Sponar, V. Paces, Z. Sormová, S. Zadrazil

For many years Czech scientists were efficiently isolated from the West
In this respect the situation in Brno was much worse than in Prague

Institute of Biophysics, Brno

Director: F. Hercík

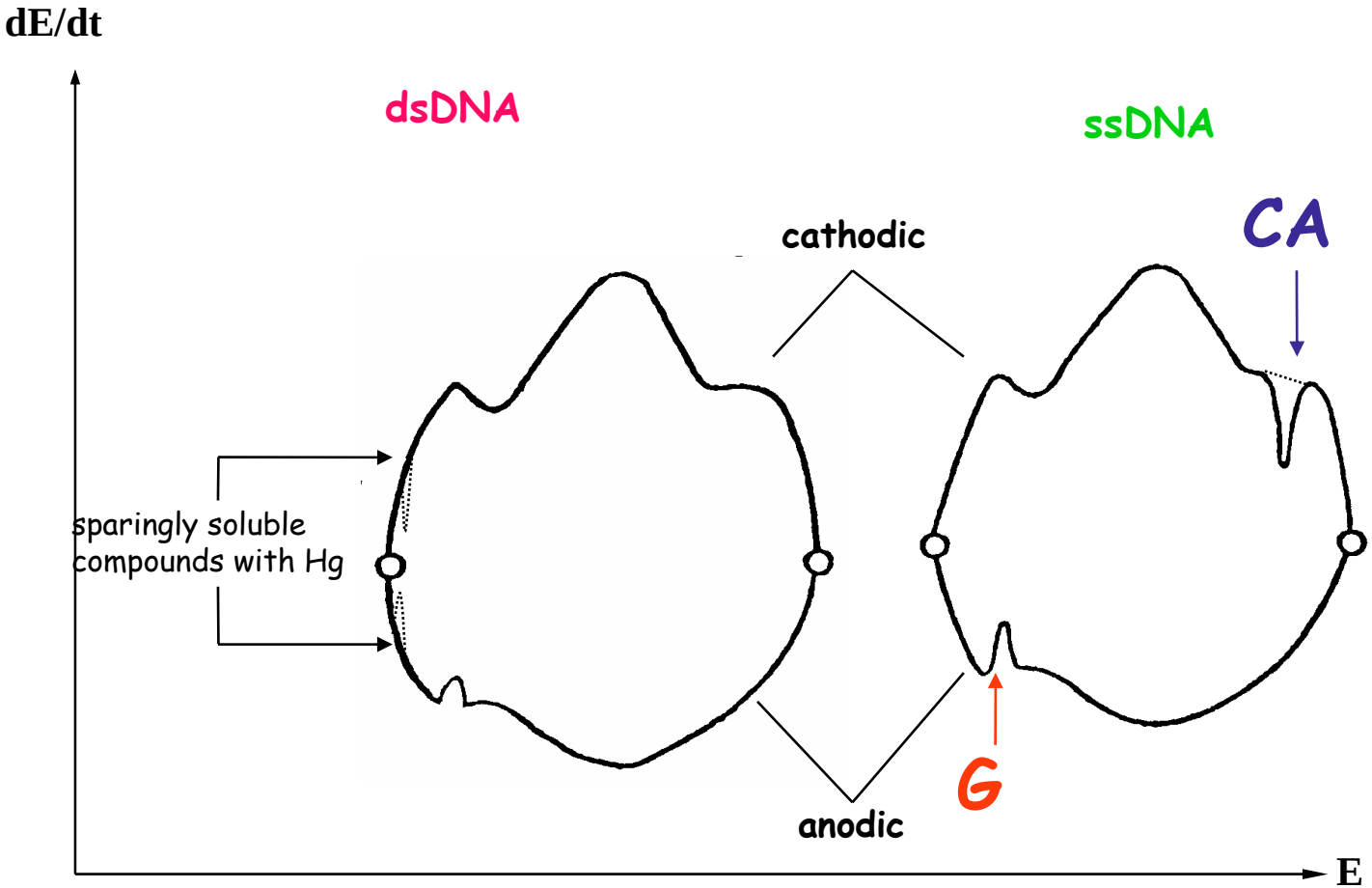
Founded in 1955 for radiobiological research it gradually turned into an institute devoted mainly to DNA

For a long time we received 50 - 100 US $ for materials/chemicals per year and Department. The orders of materials from the West had to be planned 1-2 years ahead

Taking part in meetings in western countries was difficult not only because of currency problems

OSCILLOGRAPHIC POLAROGRAPHY

At controlled alternating current (constant current chronopotentiometry)



LITERATURE in 1958: Adenine is polarographically reducible at strongly acid pH while other NA bases as well as DNA are inactive

J.N.Davidson and E.Chargraff: *The Nucleic Acids*, Vol. 1, Academic Press, New York 1955

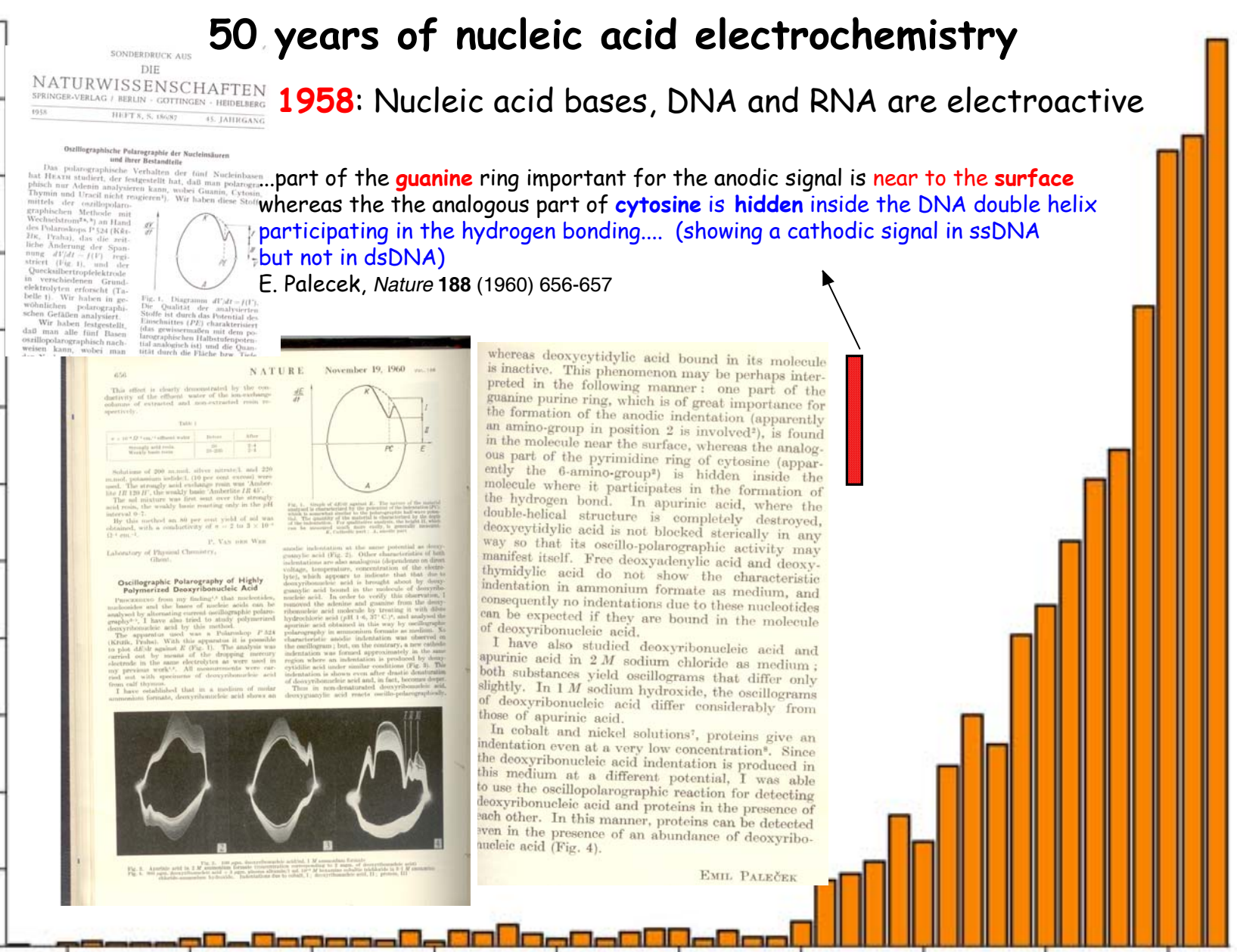
Palecek E.: Oszillographiche *Polarographie der Nucleinsauren und ihrer Bestandteile*; **Naturwiss**. 45 (**1958**), 186
Palecek E.: Oscillographic *polarography of highly polymerized deoxyribonucleic acid*; **Nature** 188 (**1960**), 656

50 years of nucleic acid electrochemistry

1958: Nucleic acid bases, DNA and RNA are electroactive

...part of the **guanine** ring important for the anodic signal is near to the **surface** whereas the the analogous part of **cytosine** is **hidden** inside the DNA double helix participating in the hydrogen bonding.... (showing a cathodic signal in ssDNA but not in dsDNA)

E. Palecek, *Nature* **188** (1960) 656-657



SONDERDRUCK AUS
DIE
NATURWISSENSCHAFTEN
SPRINGER-VERLAG / BERLIN · GÖTTINGEN · HEIDELBERG
1958 HEFT 8, S. 186/87 45. JAHRGANG

Oszillographische Polarographie der Nucleinsäuren und ihrer Bestandteile

NATURE November 19, 1960

Oscillographic Polarography of Highly Polymerized Deoxyribonucleic Acid

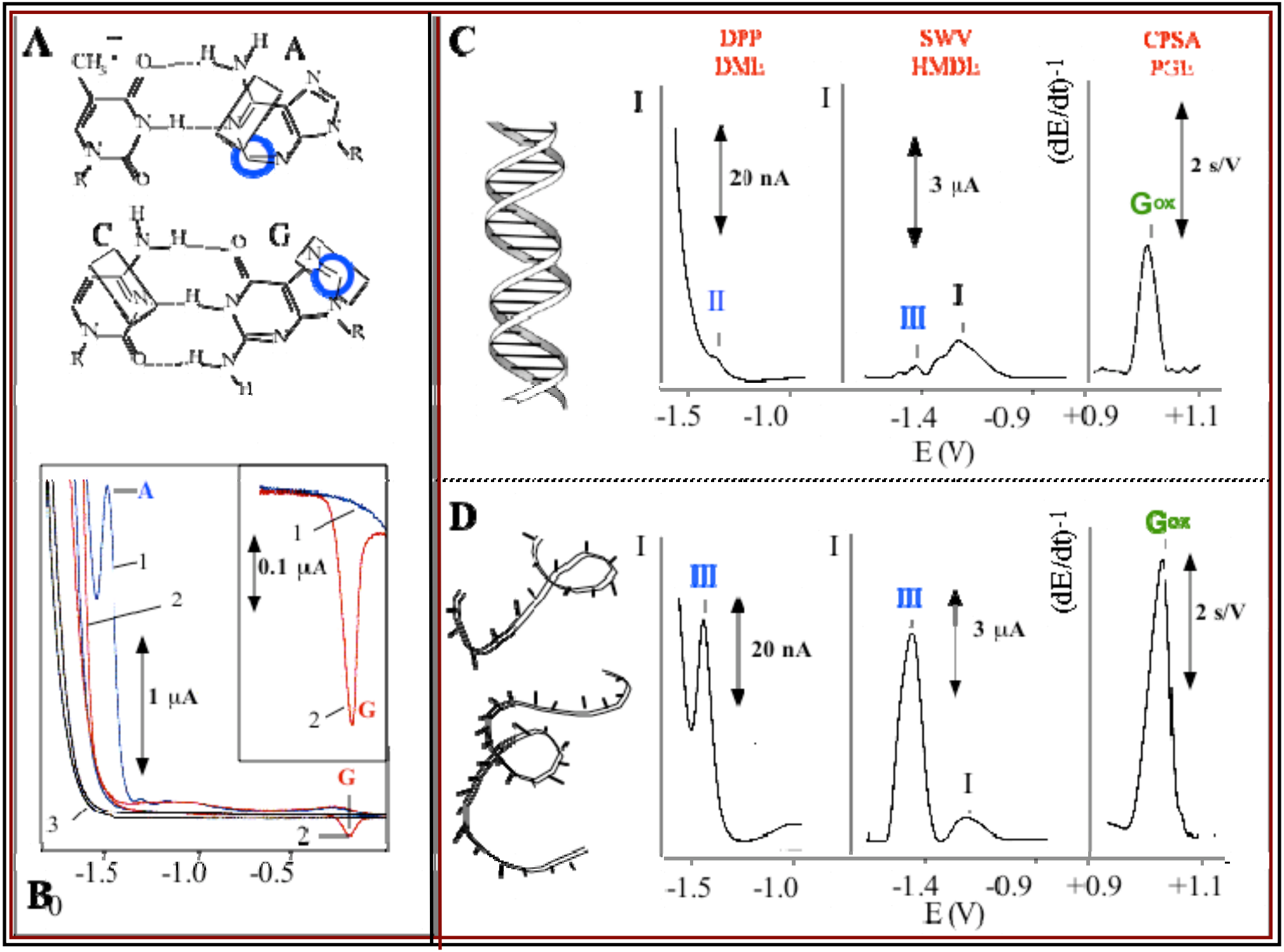
whereas deoxycytidylic acid bound in its molecule is inactive. This phenomenon may be perhaps interpreted in the following manner: one part of the guanine purine ring, which is of great importance for the formation of the anodic indentation (apparently an amino-group in position 2 is involved[2]), is found in the molecule near the surface, whereas the analogous part of the pyrimidine ring of cytosine (apparently the 6-amino-group[2]) is hidden inside the molecule where it participates in the formation of the hydrogen bond. In apurinic acid, where the double-helical structure is completely destroyed, deoxycytidylic acid is not blocked sterically in any way so that its oscillo-polarographic activity may manifest itself. Free deoxyadenylic acid and deoxythymidylic acid do not show the characteristic indentation in ammonium formate as medium, and consequently no indentations due to these nucleotides can be expected if they are bound in the molecule of deoxyribonucleic acid.

I have also studied deoxyribonucleic acid and apurinic acid in 2 *M* sodium chloride as medium; both substances yield oscillograms that differ only slightly. In 1 *M* sodium hydroxide, the oscillograms of deoxyribonucleic acid differ considerably from those of apurinic acid.

In cobalt and nickel solutions[7], proteins give an indentation even at a very low concentration[8]. Since the deoxyribonucleic acid indentation is produced in this medium at a different potential, I was able to use the oscillopolarographic reaction for detecting deoxyribonucleic acid and proteins in the presence of each other. In this manner, proteins can be detected even in the presence of an abundance of deoxyribonucleic acid (Fig. 4).

EMIL PALEČEK

E. Palecek, Fifty years of nucleic acid electrochemistry, **Electroanalysis 2009**, in press


A
A
C
G
B0
A
1
2
3
1 µA
0.1 µA
G
-1.5
-1.0
-0.5
C
DPP
DME
SWV
HMDE
CPSA
PGE
I
20 nA
II
3 µA
III
I
(dE/dt)-1
2 s/V
Gox
-1.5
-1.0
-1.4
-0.9
+0.9
+1.1
E (V)
D
I
III
20 nA
III
3 µA
I
(dE/dt)-1
Gox
2 s/V
-1.5
-1.0
-1.4
-0.9
+0.9
+1.1
E (V)

J. Heyrovsky invented **POLAROGRAPHY** in 1922.
After 37 years he was awarded a Nobel Prize

In difference to most of the electrochemists I met in the 1960's and 1970's, J Heyrovsky was interested in nucleic acids and he greatly stimulated my polarographic studies of DNA

J Heyrovsky S Ochoa A Kornberg

Nobel Prizes 1959

J. Heyrovský

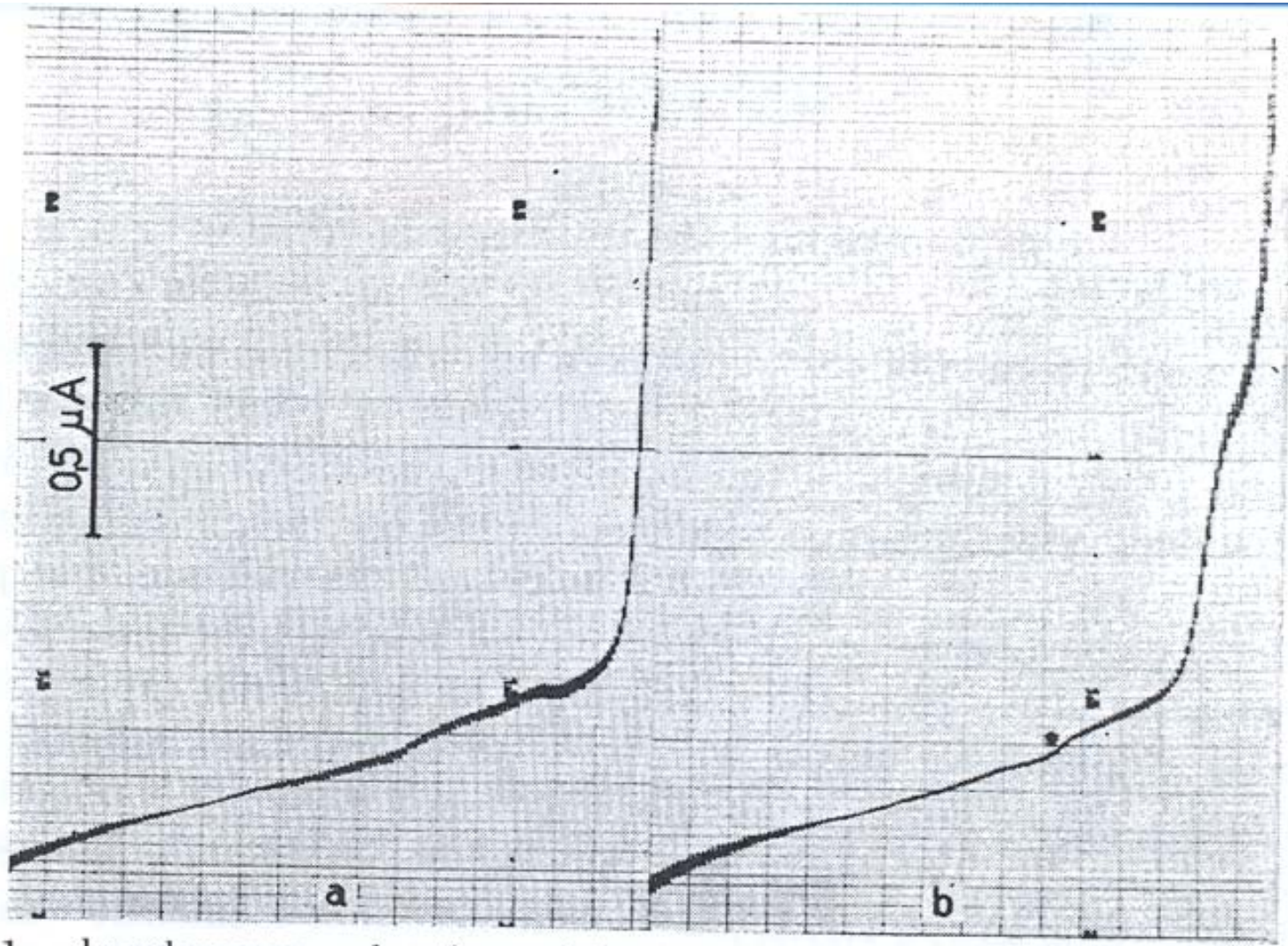


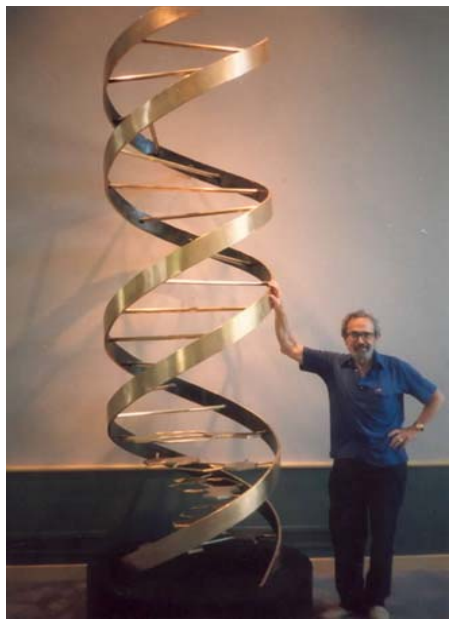
Fig. 1. dc polarograms of native and denatured calf thymus DNA: (*a*) native DNA at a concentration of 500 μg/ml in 0.5*M* ammonium formate with 0.1*M* sodium phosphate (pH 7.0); (*b*) denatured DNA at a concentration of 500 μg/ml in 0.5*M* ammonium formate with 0.1*M* sodium phosphate (pH 7.0). DNA was denatured by heat at the concentration of 666 μg/ml in 0.007*M* NaCl with 0.7 m*M* citrate. Both curves start at 0.0 V, 100 mV/scale unit, capillary I, saturated calomel electrode.

In 1960 when I published my NATURE paper on electrochemistry of DNA I obtained invitations from 3 emminent US scientists:
J. Marmur - Harvard Univ.
L. Grossman - Brandeis Univ.
J. Fresco - Princeton Univ.
To work in their laboratories as a postdoc

In 1960 new techniques were sought to study DNA Denaturation and Renaturation. To those working with DNA Oscillographic Polarography (OP) appeared as a very attractive tool. Invented by J. Heyrovsky, it was fast and simple, showing large differences between the signals of native and denatured DNA. The instrument for OP was produced only in Czechoslovakia.

I accepted the invitation by Julius Marmur but for more than two years I was not allowed to leave Czechoslovakia. In the meantime JM moved from Harvard to Brandeis Univ. By the end of November 1962 I finally got my exit visa and with Heyrovsky Letter of Reccommendation in my pocket I went to the plane just 24 hours before expiration of my US visa. Before my departure I sent my OP instrument by air to Boston. It arrived after 9 months completely broken. I nstead of OP I had to use ultracentrifuges and microbiological methods.

Julius Marmur discovered DNA Renaturation/Hybridization and proposed (in JMB) a new method of DNA isolation which was widely applied. His paper was quoted > 9000x.



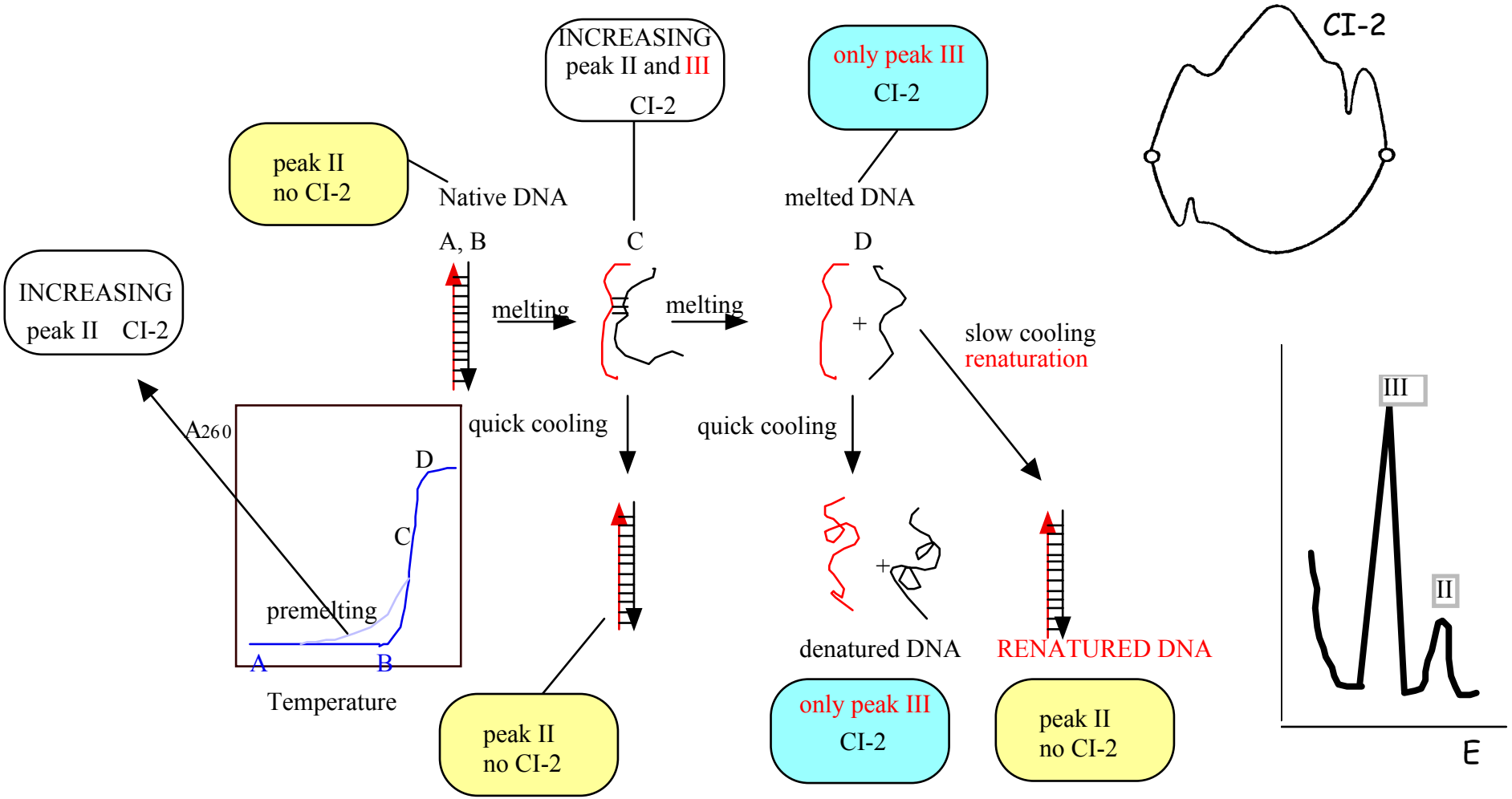
J M at the 40th Anniversary of the Discovery of the DNA Double Helix

At the end of my stay at Brandeis I did some OP experiments which I finished in Brno nd published in J. Mol. Biol. in 1965 and 1966.

Reprinted from COLD SPRING HARBOR SYMPOSIA ON QUANTITATIVE BIOLOGY
Volume XXVIII, 1963
Printed in U.S.A.

Specificity of the Complementary RNA Formed by *Bacillus subtilis* Infected with Bacteriophage SP8

J. MARMUR*, C. M. GREENSPAN, E. PALECEK, F. M. KAHAN†, J. LEVINE, and M. MANDEL‡
Graduate Department of Biochemistry, Brandeis University, Waltham, Massachusetts


CI-2
INCREASING
peak II and III
CI-2
only peak III
CI-2
peak II
no CI-2
Native DNA
melted DNA
A, B
C
D
INCREASING
peak II CI-2
melting
melting
slow cooling
renaturation
quick cooling
quick cooling
A260
D
C
premelting
A
B
Temperature
denatured DNA
RENATURED DNA
peak II
no CI-2
only peak III
CI-2
peak II
no CI-2
III
II
E

DNA Premelting and Polymorphy of the DNA Double Helix

Before my departure to the US I observed Changes in the polarographic behavior of DNA far below the denaturation temperature. These changes were later called DNA Premelting

J. Mol. Biol.
20 (1966) 263-281

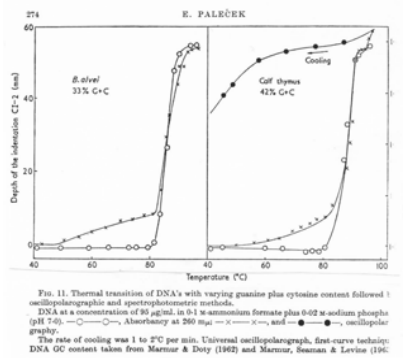


FIG. 11. Thermal transition of DNA's with varying guanine plus cytosine content followed by oscillopolarographic and spectrophotometric methods.
DNA at a concentration of 80 μg/ml. in 0·1 M-ammonium formate plus 0·02 M-sodium phosphate (pH 7·0). —○—○—, Absorbancy at 260 mμ; —×—×—, and —●—●—, oscillopolarography.
The rate of cooling was 1 to 2°C per min. Universal oscillopolarograph, first-curve technique. DNA GC content taken from Marmur & Doty (1962) and Marmur, Seaman & Levine (196

B. sublilis and B. brevis DNAs have the same G+C content and different nucleotide sequence

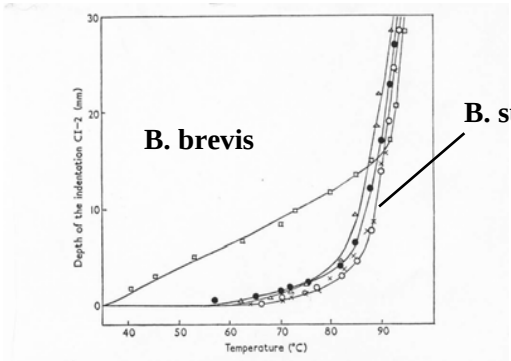
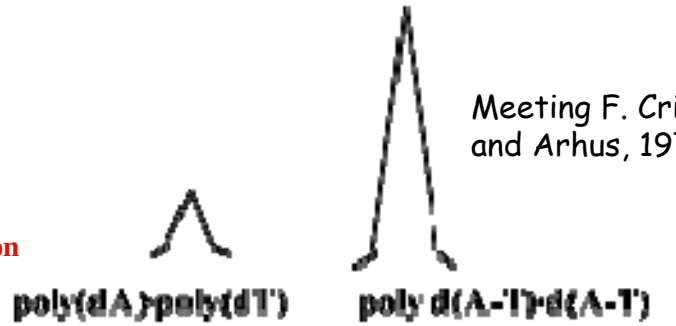


FIG. 12. Thermal transition of DNA's isolated from bacteria of the genus *Bacillus*. DNA at a concentration of 100 μg/ml. in 0·25 M-ammonium formate plus 0·025 M-sodium phosphate (pH 7·0).
—●—●—, *B. subtilis* 168; —×—×—, *B. natto*; —○—○—, *B. subtilis* var. *niger*; —△—△—, *B. subtilis* var. *aterrimus*; —□—□—, *B. brevis* (ATCC 9999).
P 524 polaroscope, dropping mercury electron polarized with repeated cycles of A.C. The measurements were carried out in the laboratory of Prof. J. Marmur, Department of Biochemistry, Brandeis University, Waltham, Mass., U.S.A.

POLAROGRAPHIC BEHAVIOR OF dsDNA
At roomand premeltig temperaturse depended on DNA nucleotide SEQUENCE



Meeting F. Crick in Copenhagen and Arhus, 1977 (B. Clark)

What the people said

Before 1980
No doubt that this electrochemistry must produce artifacts because we know well that the DNA double helix has a unique structure INDEPENDENT of the nucleotide SEQUENCE

After 1980
Is not it strange that such an obscure technique can recognize POLYMORPHY OF THE DNA DOUBLE HELIX?

1976

Reprinted from:
PROGRESS IN NUCLEIC ACID RESEARCH AND MOLECULAR BIOLOGY, VOL. 18
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ACADEMIC PRESS, INC
New York San Francisco London

Premelting Changes in DNA Conformation

E. PALEČEK

6. POLYMORPHY OF DNA SECONDARY STRUCTURE

On the basis of the preceding discussion, a schematic picture of the structure of natural linear DNA in solution under physiological conditions (e.g., at 36°C, moderate ionic strength, and pH 7) can be drawn. We can assume that the double-helical structure of the very long (A + T)-rich regions differs from the structure of the major part of the molecule and that some of the (A + T)-rich segments are open (Fig. 20). An open ds-structure can be assumed in the region of chain termini and/or in the vicinity of ss-breaks and other anomalies in the DNA primary structure. The exact changes in the open ds-regions will depend on the nucleotide sequence as well as on the chemical nature of the anomaly. Most of the molecule will exhibit an average Watson–Crick B-structure with local deviations given by the nucleotide sequence. Elevating the temperature in the premelting region (Fig. 20) is likely to lead to the opening of other regions and, eventually, to expansion of the existing distorted ds-regions and to further structural changes. Thus the course of the conformational changes as a function of temperature (premelting) will be determined by the distribution of the nucleotide sequences and anomalies in the primary structure, and may have an almost continuous character.

Consequently, even if we do not consider "breathing," not only the architecture of a DNA double-helical molecule, but also its mechanics or dynamics can be taken into account.

To determine whether, e.g., only the (A + T)-rich molecule ends will be open at a certain temperature or also long A + T regions in the center of the molecule, further experimental research with better-defined samples of viral and synthetic nucleic acids will be necessary. Further work will undoubtedly provide new information on the details of the local arrangement of nucleotide residues in the double helix, as well as on DNA conformational motility. Thus a more accurate picture of DNA structure will emerge, whose characteristic feature will be polymorphy of the double helix, in contrast to the classical, highly regular DNA structure models.

December 3, 1976

Professor Emil Palecek
Institute of Biophysics
Czechoslovak Academy of Sciences
Brno 12, Kralovopolska 135
Czechoslovakia

Dear Professor Palecek,

I do apologise for taking so long to reply to your letter of September 29 and the very interesting review you sent with it. Unfortunately I myself will not be able to attend the Symposium you plan for September, 1977 and my Cambridge colleague Aaron Klug tells me that he too is unable to be present. Had you considered the possibility of asking Dr. Hank Sobell? He has just published in PNAS an account of the other (base-paired) kink and has ideas about premelting conformations. I have no idea whether he would be able to come but should you wish to invite him his address is: Department of Chemistry, The University of Rochester, River Station, Rochester, New York 14627.

Yours sincerely,

Francis Crick

F. H. C. Crick
Ferkauf Foundation Visiting Professor

FHCC:lt

Post Office Box 1809, San Diego, California 92112 • Telephone (714) 453-4100

RENATURATION OF RNA AS DETECTED BY DPP
Time dependence

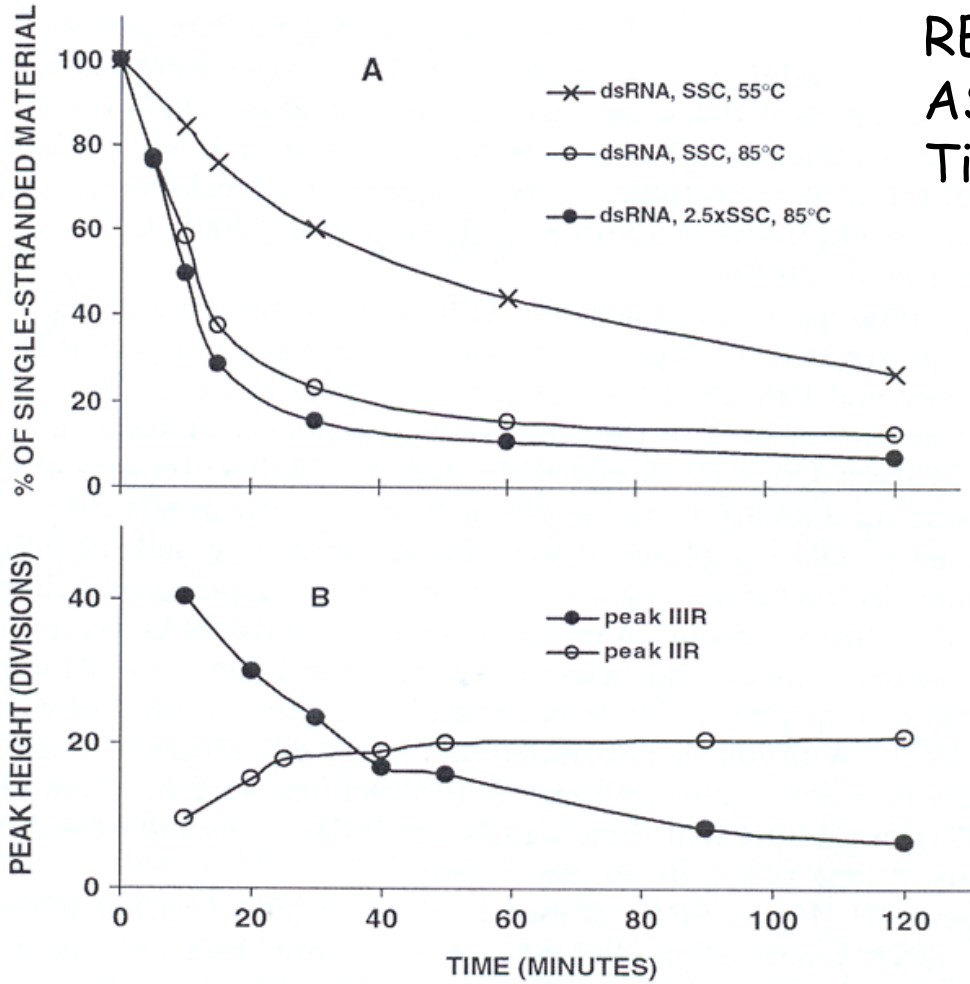


Fig. 10. Time-course of renaturation of phage f2 dsRNA. (A) Thermally denatured ssRNA was incubated (●—●) at 85°C in 2.5 × sodium saline citrate (SSC) or (o—o) at 85°C in SSC, and (x—x) at 55°C. Samples were withdrawn in time intervals given in the graph and quickly cooled. DPP measurements were performed at room temperature at a RNA concentration of 3.2 μg/mL in 0.3 M ammonium formate with 0.2 M sodium acetate, pH 5.6; PAR 174. (B) (o—o) peak IIR. (●—●) peak IIIR. ssRNA (108 μg/mL) in 0.01 × SSC was heated for 6 min at 100°C. Then it was placed into a thermostated polarographic vessel with the same volume of 0.6 M ammonium formate with 0.2 M sodium phosphate, pH 7, preheated to 58°C. The pulse polarograms were measured at 58°C in times given in the graph. Southern–Harwell A 3100, amplifier sensitivity 1/8. Adapted from Palecek and Doskocil (1974). Copyright 1974, with permission from Academic Press.

Firsts in Electrochemistry of Nucleic Acids during the initial three decades

1958 DNA and RNA and all free bases are electrotractive
1960-61 assignment of DNA electrochemical signals to bases, relation between the **DNA structure** and electrochemical responses
1961 adsorption (ac impedance) studies of DNA (IR Miller, Rehovot)
1962-66 DNA premelting, denaturation, renaturation/hybridization detected electrochemically, traces of single stranded DNA determined in native dsDNA. Nucleotide sequence affects dsDNA responses
1965 Association of bases at the electrode surface (V. Vetterl)
1966 application of pulse polarography to DNA studies
1967 detection of DNA damage
1967-68 Weak interactions of low m.w. compounds with DNA (P.J. Hilsson, M.J. Simons, Harrow, UK and H. Berg, Jena)
1974 DNA is unwound at the electrode surface under certain conditions (EP and H.W. Nürnberg, Jülich, independently)
1976 Evidence for polymorphy of the DNA double-helical structure

For two decades only mercury electrodes were used in NA electrochemistry

1978 Solid (carbon) electrodes introduced in nucleic acid research (V. Brabec and G. Dryhurst, Norman)
1980 Determination of bases at nanomolar concentrations by cathodic stripping
1981-83 Electroactive markers covalently bound to DNA
1986-88 DNA-modified electrodes

Results obtained at: IBP, Brno or elsewhere (author's name is given); the results which have been utilized in the DNA sensor development are in **blue**

Elektrochemie nukleových kyselin
není omezena jen na sensory.
Může se zabývat např.

- strukturními přechody DNA
(a) v roztoku
(b) na elektrodě

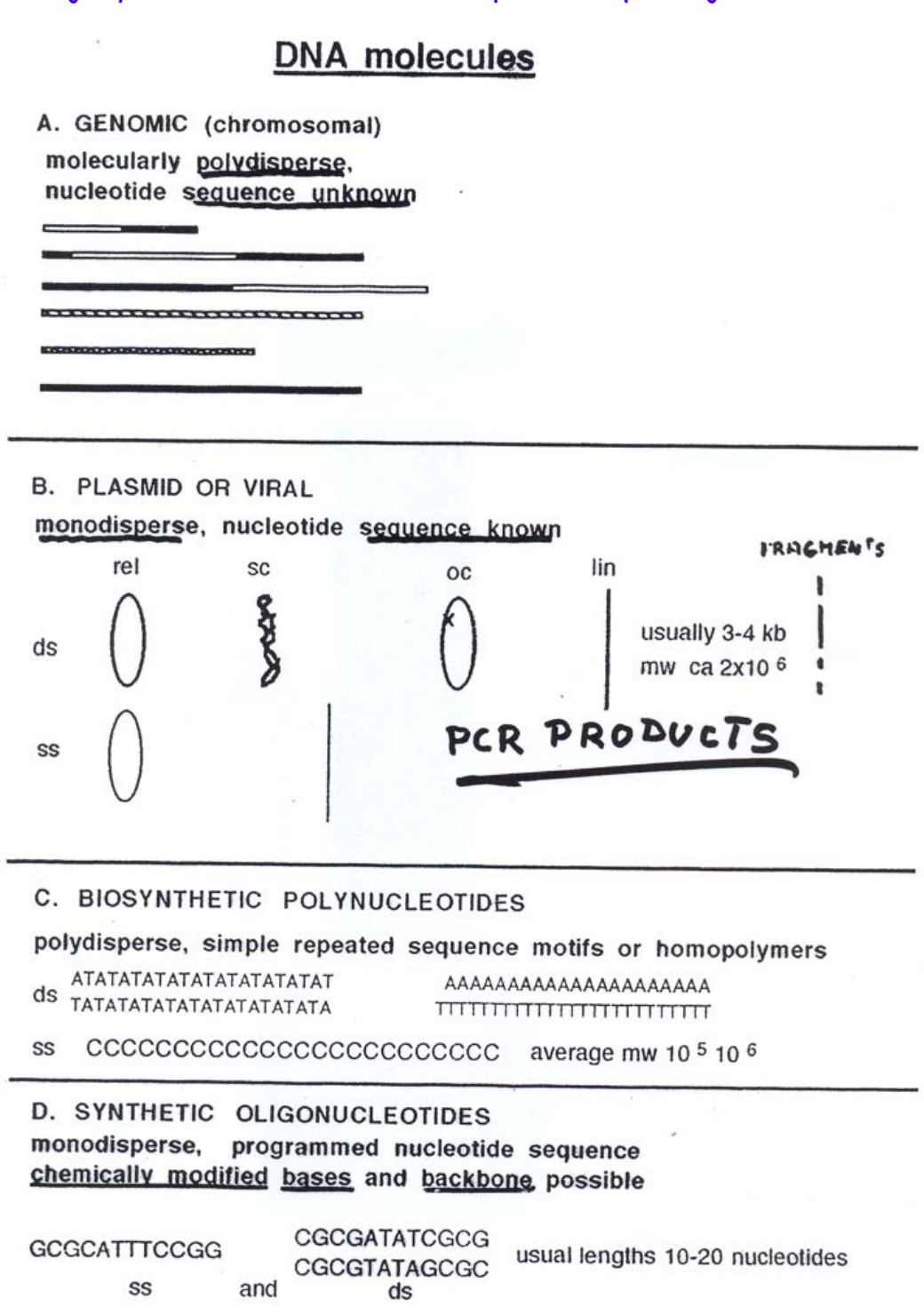
- adsorpcí DNA na elektricky nabitých površích

- interakcemi DNA
(a) s nízkomolekulárními látkami včetně mutagenních látek
(b) s bílkovinami (včetně enzymů
(c) s jinými makromolekulami

- stanovením DNA v roztocích

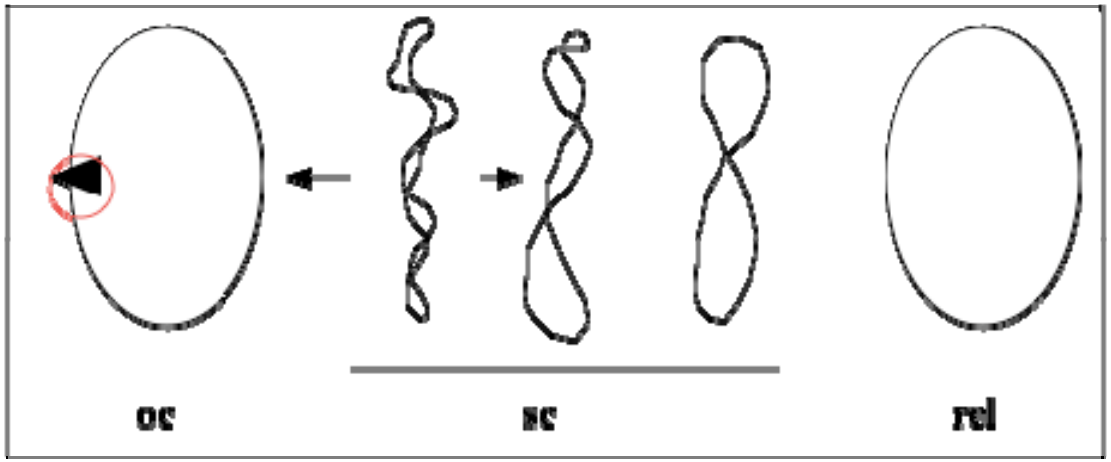
- elektrickými vlastnostmi DNA (např. vodivost) atd.

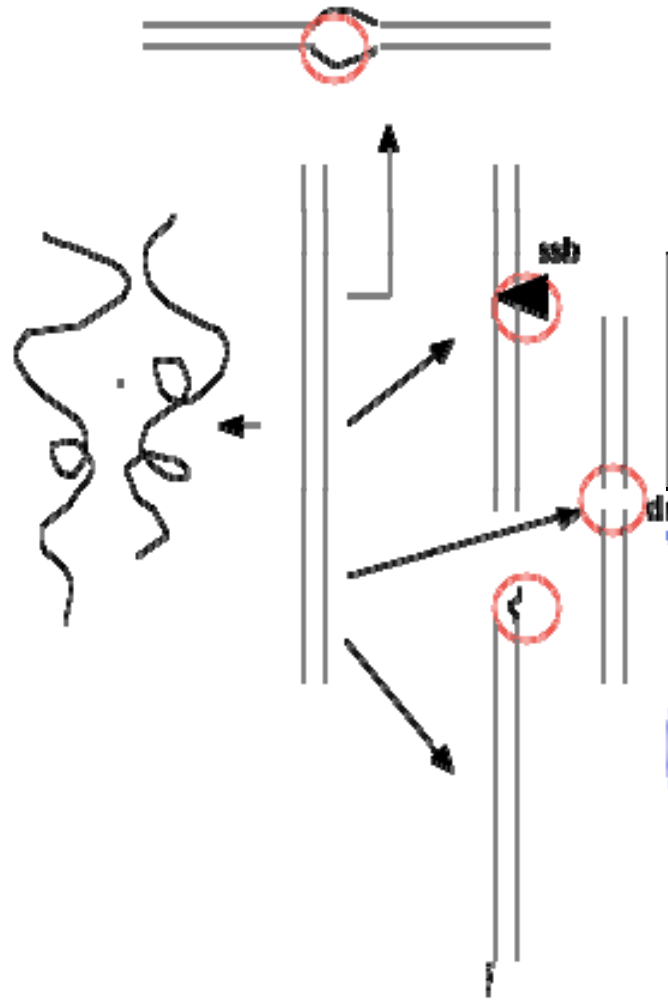
S jakými DNA v současnosti zpravidla pracujeme:



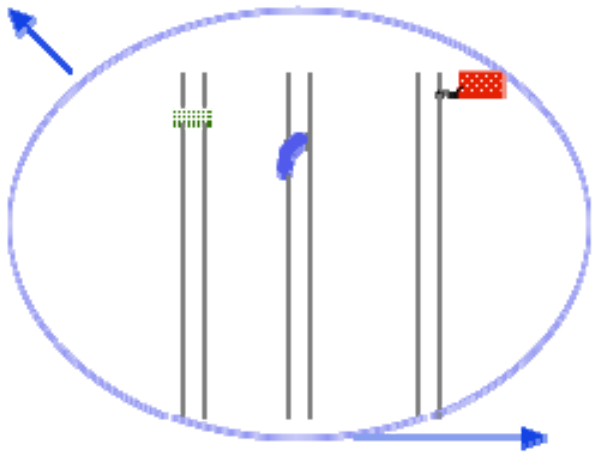
ELECTROCHEMICAL METHODS RECOGNIZE SMALL CHANGES IN DNA STRUCTURE AND DETERMINE TRACES OF IMPURITIES IN DNA SAMPLES

MERCURY ELECTRODES ARE PARTICULARLY SENSITIVE





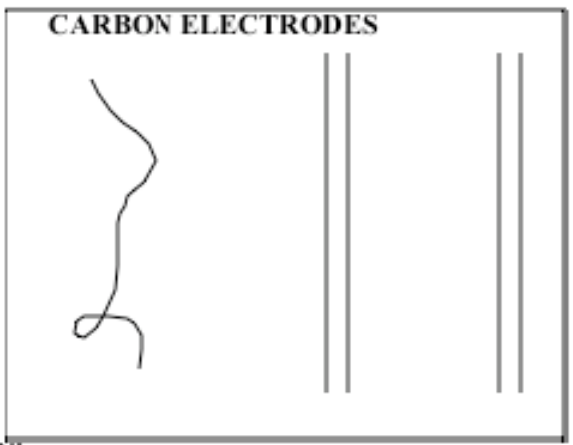
DETERMINATION OF TRACES (< 1%) OF



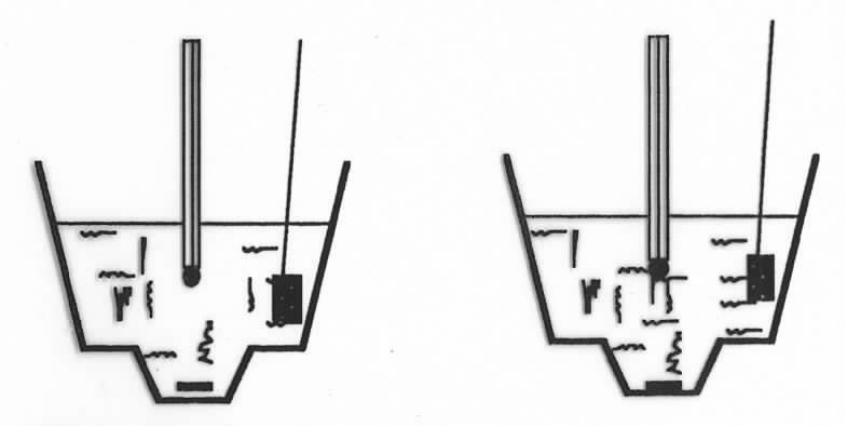
INTERCALATORS COVALENT MODIFIERS

GROOVE BINDERS

CARBON ELECTRODES

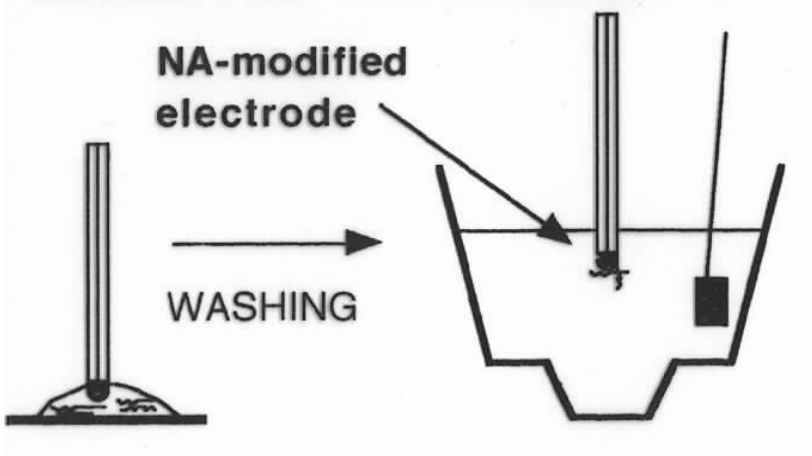


ADSORPTIVE STRIPPING



NA is in the electrolytic cell and accumulates at the electrode surface during waiting

ADSORPTIVE TRANSFER STRIPPING



NA is attached to the electrode from a small drop of solution (3-10 ⌈l)

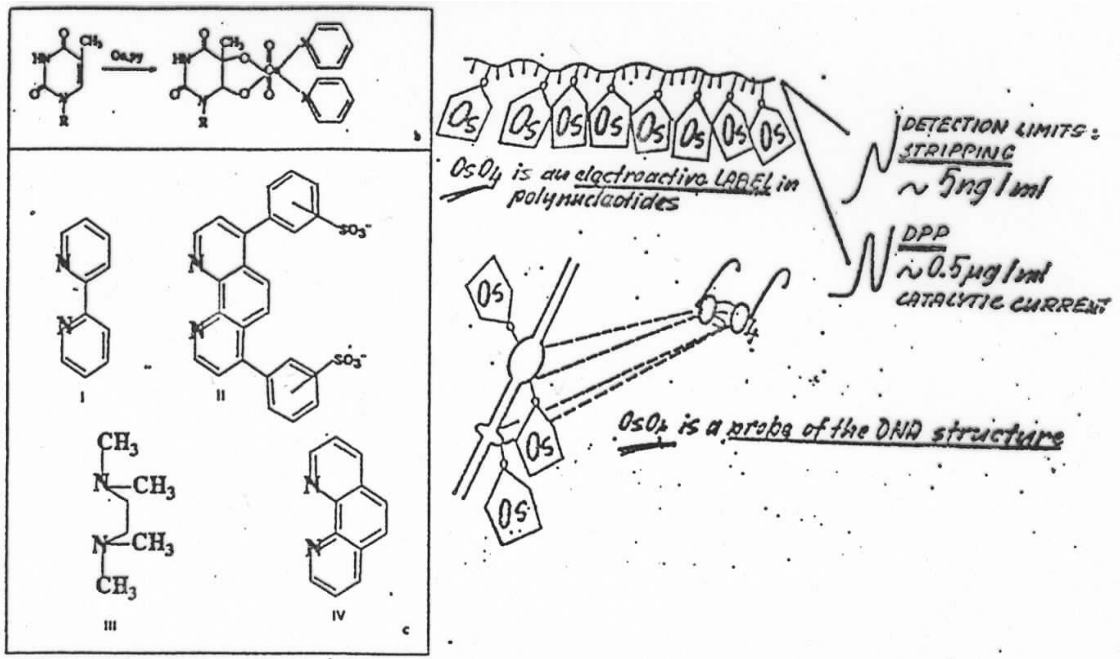
NA is at the electrode but the electrolytic cell contains only blank electrolyte

In 1986 we proposed **Adsorptive Transfer Stripping Voltammetry (AdTSV)** based on easy preparation of DNA-modified electrodes

AdTSV has many advatages over conventional voltammetry of NAs:

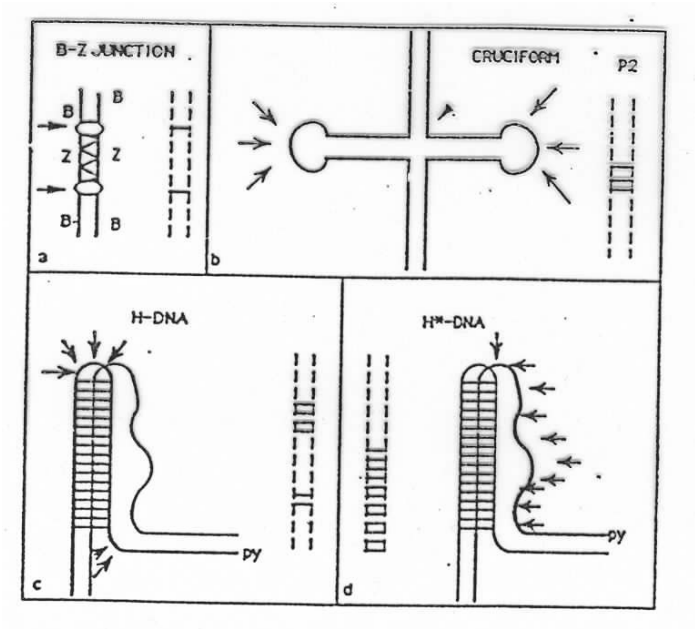
1) Volumes of the analyte can be reduced to few microliters
2) NAs can be immobilized at the electrode surface from media not suitable for the voltammetric analysis
3) Low m.w. compounds (interfering with conventional electrochemical analysis of NAs) can be washed away
4) Interactions of NAs immobilized at the surface with proteins and other substances in solution and influence of the surface charge on NA properties and interactions can be studied, etc.

Probing of DNA structure with osmium tetroxide complexes



We developed methods of chemical probing of the DNA structure based on osmium tetroxide complexes (Os,L). Some of the Os,L complexes react with single-stranded DNA but not with the double-stranded B-DNA.

In the beginning of the 1980‘s Os,L complexes were the first electroactive labels covalently bound to DNA. These complexes produced catalytic signals at Hg electrodes allowing determination of DNA at subnanomolar concentrations



Critical Reviews in Biochemistry and Molecular Biology, 26(2):151–226 (1991)

Local Supercoil-Stabilized DNA Structures

E. Paleček
Max-Planck Institut für Biophysikalische Chemie, Göttingen, BRD and Institute of Biophysics, Czechoslovak Academy of Sciences, 61265 Brno, CSFR

[17] Probing of DNA Structure in Cells with Osmium Tetroxide–2,2′-Bipyridine

By EMIL PALEČEK

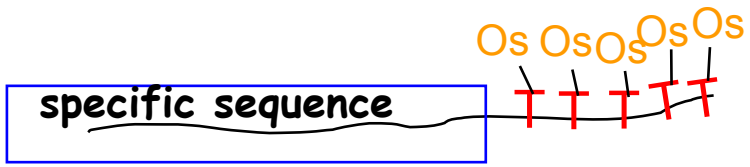
METHODS IN ENZYMOLOGY, VOL. 212

These methods yielded information about the distorted and single-stranded regions in the DNA double helix at single-nucleotide resolution. DNA probed both in vitro and directly in cells.

END-LABELING of DNA and RNA

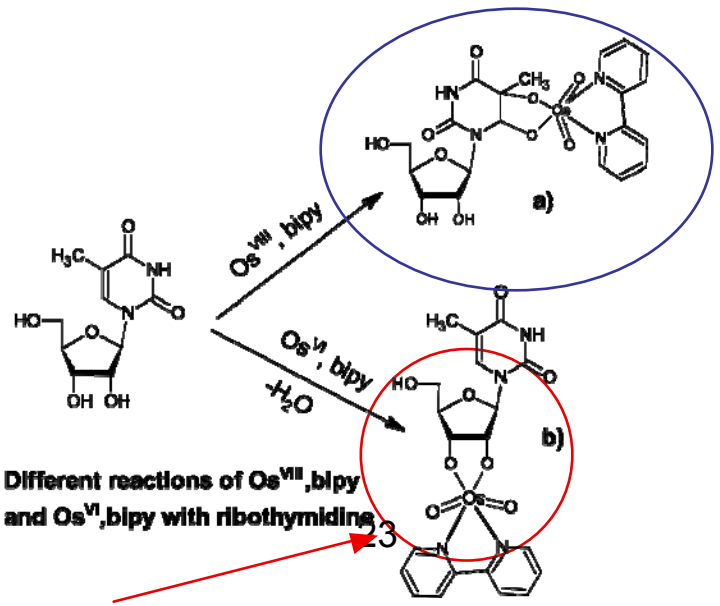
Electroactive labels such as ferrocene, daunomycin, viologen, thionine, etc. were covalently bound to DNA to obtain electrochemical signals closer to zero charge and/or to increase the sensitivity of the analysis. These labels are expensive and can hardly be used for labeling of longer NAs, such as plasmid or chromosomal DNAs.

Already **in 1981** we proposed **osmium tetroxide complexes** with nitrogeneous ligands (Os^{VIII},L) as DNA electroactive labels. They can be introduced in any DNA in an average biochemical or biological laboratory without any special equipment. DNA-Os^{VIII},L adducts produce redox signals at mercury, amalgam, carbon and gold electrodes; in addition, electrocatalytic signals can be obtained at mercury and amalgam electrodes. Multiple labels can be easily introduced.



Trefulka, M., et al. (2007): Covalent labeling of nucleosides, RNA and DNA with VIII- and VI-valent osmium complexes. Electroanalysis 19 (No.12) 1281-1287.

With six-valent Os(VI)L ribose residue can be modified



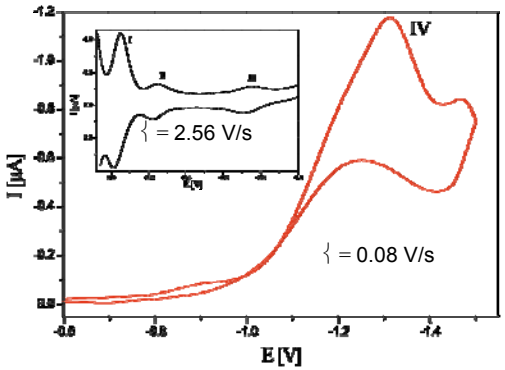
Different reactions of Os^{VIII},bipy and Os^{VI},bipy with ribothymidine

End-labeling of DNA with Os^{VIII},L

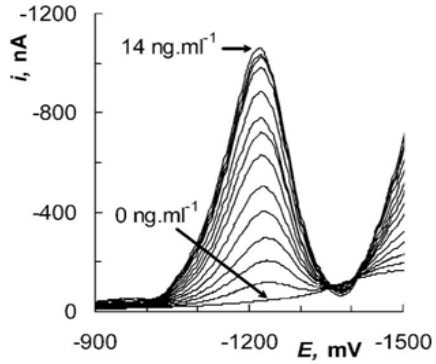
mercury **amalgam**

Catalytic hydrogen evolution

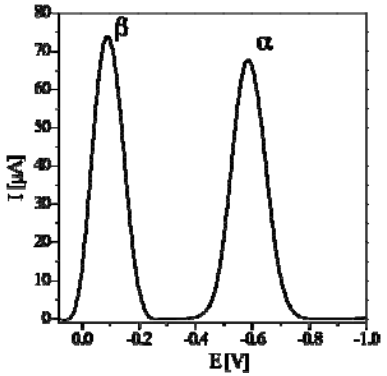
carbon



AdTS CVof CT ss DNA (20 ⌈g/ml) modified by 2 mM OsO4 bipy, electrolyte 0.3 M ammoniumformate and 0.05 M sodium phosphate ,pH 6.90

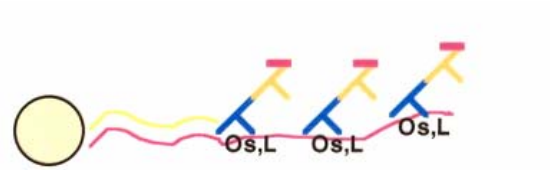


AdTS DPV CT ss DNA modified by 2 mM OsO4 bipy, electrolyte: 0.1M acetate buffer pH 4.8
.



AdTS SWVof $(GAA)_7T_{50}$ (460 nM) modified by 2 mM OsO4 bipy 0.2 M acetate buffer pH 5.0

We generated mononoclonal antibodies against DNA_{base}-Os(VIII)bipy and recently also against RNA_{sugar}-Os(VI)bipy



Large number of papers since 1981 reviewed in E. Palecek, Meth. Enzymol. 212 (1992) 139

Palecek E., Scheller F., Wang J., Eds. *Electrochemistry of nucleic acids and proteins.. Towards electrochemical sensors for genomics and proteomics.*; Elsevier: Amsterdam, 2005

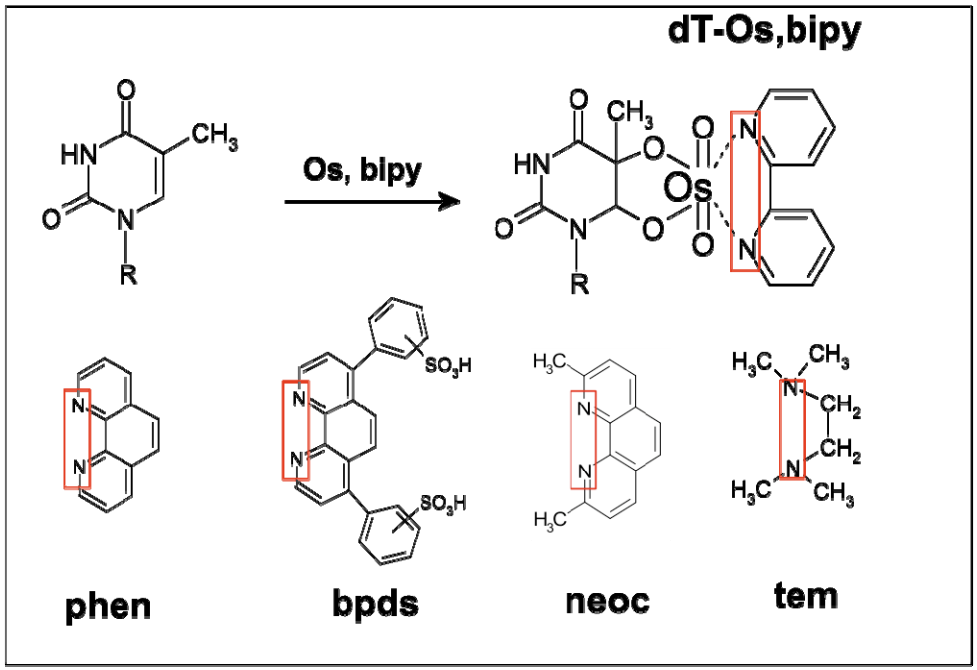
B. Yosypchuk, M. Fojta, L. Havran, M. Heyrovsky, E. Palecek, Electroanalysis 18:186 (2006).

Fojta M., Havran L., Kizek R., Billová S., Paleček E. Biosensors & Bioelectronics 20 (5): 985-994 2004

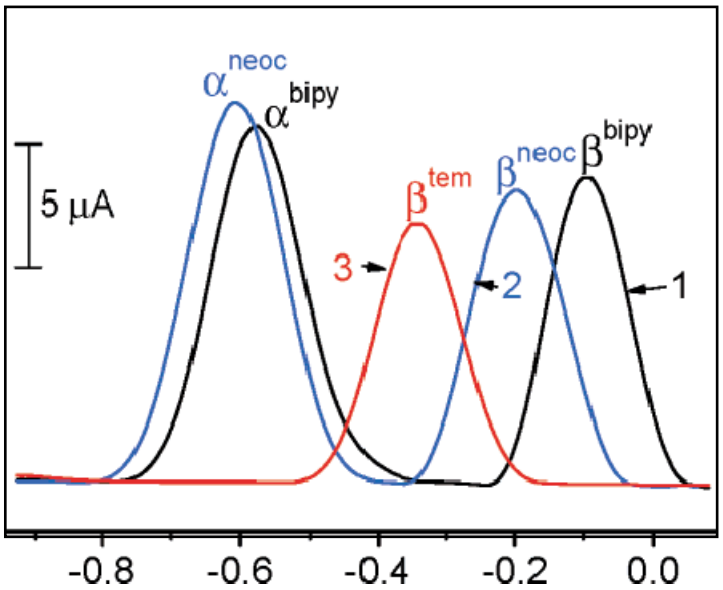
L. Havran, M. Fojta, E. Palecek, Bioelectrochemistry 63:239 (2004).

Palecek, E., et al.. (2002). Electrochemical enzyme-linked immunoassay in a DNA hybridization sensor. *Anal. Chim. Acta* **469,**73-83

Reactions of different Os(VIII)L complexes with DNA yield peaks at different potentials



Carbon electrodes



Fojta, M., et al. (2007): „Multicolor" electrochemical labeling of DNA hybridization probes with osmium tetroxide complexes. Anal. Chem. 79, 1022-1029

IFFY stories

On this day 50 years ago, Watson and Crick published their double-helix theory. But, what if...
By Steve Mirsky (2003)

"I am now astonished that I began work on the triple helix structure, rather than on the double helix," wrote Linus Pauling in the April 26, 1974 issue of Nature.

In February 1953, Pauling proposed a triple helix structure for DNA in the Proceedings of the National Academy of Sciences (PNAS). He had been working with only a few blurry X-ray crystallographic images from the 1930s and one from 1947.

If history´s helix had turned slightly differently, however, perhaps the following timeline might be more than mere musing...

August 15, 1952: Linus Pauling (finally allowed to travel to England by a US State Department that thinks the words "chemist" and "communist" are too close for comfort) visits King´s College London and sees Rosalind Franklin´s X-ray crystallographs. He immediately rules out a triple helical structure for DNA and concentrates on determining the nature of what is undoubtedly a double helix.

February 1953: Pauling and Corey describes the DNA double helix structure in PNAS .....

84 CHEMISTRY: PAULING AND COREY Proc. N. A. S.

A PROPOSED STRUCTURE FOR THE NUCLEIC ACIDS

By Linus Pauling and Robert B. Corey

Gates and Crellin Laboratories of Chemistry,* California Institute of Technology

Communicated December 31, 1952

which are involved in ester linkages. This distortion of the phosphate group from the regular tetrahedral configuration is not supported by direct experimental evidence; unfortunately no precise structure determinations have been made of any phosphate di-esters. The distortion, which corresponds to a larger amount of double bond character for the inner oxygen atoms than for the oxygen atoms involved in the ester linkages, is a reason-

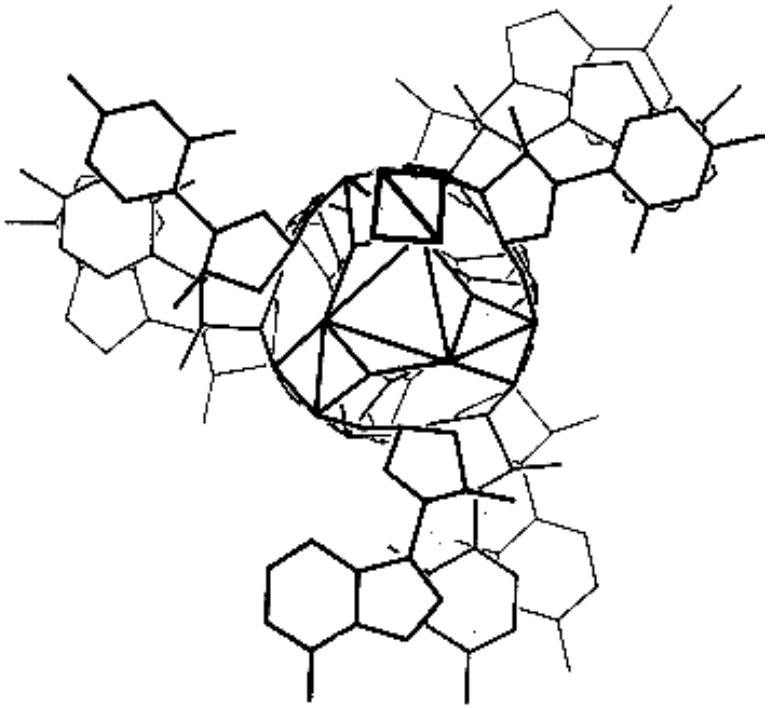


FIGURE 6

Plan of the nucleic acid structure, showing several nucleotide residues.

Triple helix

with bases on the outside and sugar-phosphate backbone in the interior of the molecule

My IFFY story:
If L. PAULING had in his lab an oscillopolarograph in 1952 he would never proposed this structure. Polarography clearly showed that bases must be hidden in the interior of native DNA molecule and become accessible when DNA is denatured

SUMMARY

Electroactivity of nucleic acids was discovered about 50 years ago
Reduction of bases at Hg electrodes is particularly sensitive to changes in DNA structure. The course of DNA and RNA denaturation and renaturation can easily traced by electrochemical methods. Nucleic acids can be labeled; osmium complexes were the first electroactive labels covalently bound to DNA. At present Os labels are perhaps the most sensitive DNA end-labels.

DNA-modified electrodes can be easily prepared;
microL volumes of DNA are sufficient of its analysis but miniaturization of electrodes decreases these volumes to nL. Sensitivity of the analysis has greatly increased in recent years.

At present electrochemistry of nucleic acids is a booming field, particularly because it is expected that **sensors for DNA hybridization** and for **DNA damage** will become important tools in biomedicine and other regions of practical life in the 21st century

Chemie, struktura a interakce nukleových kyselin

2008-09 3.EP/6. PŘEDNÁŠKA 22.10.08

Fyzikální vlastnosti a izolace DNA

Denaturace, renaturace a hybridizace DNA

Biosyntetické polynukleotidy

Fyzikální vlastnosti DNA

Studium fyz. vlastností DNA *in vitro* vyžaduje její izolaci z buněk či virů do zřeď. vodných roztoků, v nichž nejsou přítomny ostatní celulární komponenty. Takto ztrácíme sice informace o jejich uspořádání *in vivo* (interakce s RNA, bílkovinami, atd.) - získáváme však možnost zodpovědět jiné otázky jako m. v., sekundární struktura ap.

Izolace DNA - pokrok v poznání vlastností DNA postupoval souběžně s pokrokem izolačních technik. Např. zjištění lámavosti dlouhých molekul DNA díky působení střižných sil (shear degradation) - čím větší molekula, tím snadnější degradace (vyfouknutí 1 ml roztoku pipetou o průměru 0,25mm za 2 s zlomí DNA T_2 na poloviny. Při vysoké konce. (500 μg/ml) DNA je možnost zlomení menší. Začátkem 60 let byl vypracovány metody umožňující izolaci nedegradované DNA T_2 a T_4 (130.10^6). Tyto DNA se pak staly standardem pro kalibraci metod stanovení mol. hmotnosti DNA.

Důležitým krokem při izolaci DNA je odstranění bílkovin: vysoká konc. solí, detergent, $CHCl_3$- isoamyl, emulsifikace, proteasy a fenolová extrakce. $CHCl_3$-opakované třepání, degradace; lepší je fenol - DNA o m.v. blízké celému chromosomu *E.coli* ($\sim 10^9$) - nebezpečí znečištění fenolu peroxidy (destilace).

Isolace DNA z bakteriofága

a) purifikace fága diferenční centrifugací a/nebo v grad CsCl

b) deproteinace (většinou fenolem)

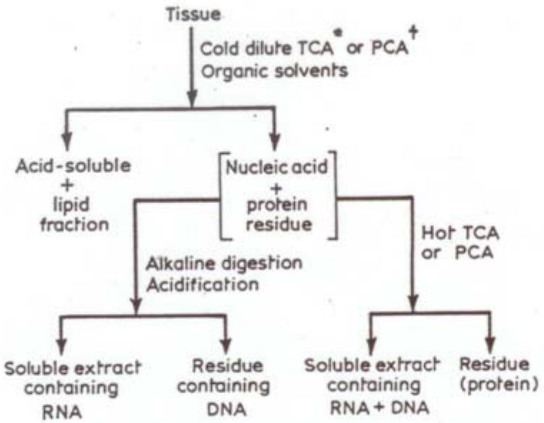
Dnes nejčastěji je používana plasmidová DNA.

Stupeň čistoty a volba metody izolace jsou velmi závislé na účelu, ke kterému má být DNA použita.

V posledních letech jsou k dispozici komerčně dostupné kolonky využívající imobilizaci DNA na pevném podkladu. K separaci DNA jsou rovněž používány magnetické kuličky (magnetic beads)

pokrač. 29.10.08/předn. 4
demo: textbooks+monographic series

IZOLACE DEGRADOVANÝCH NA



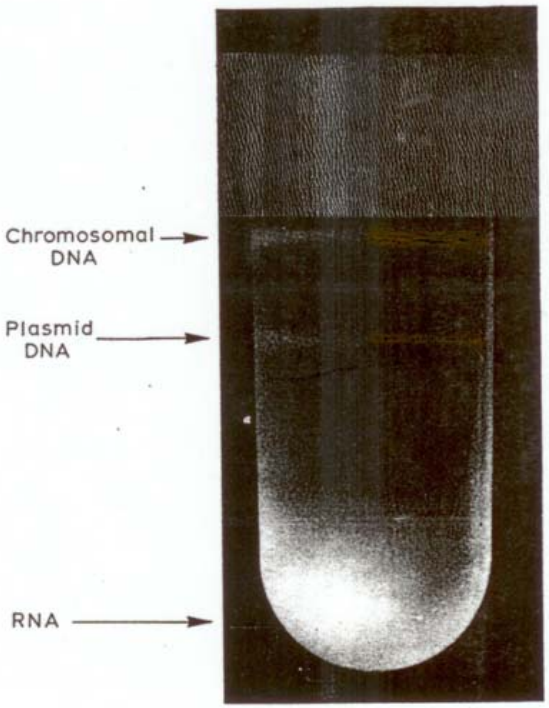
Extraction and fractionation of nucleic acids from tissues. *TCA – trichloroacetic acid, †PCA – perchloric acid.

IZOLACE INTAKTNÍ DNA

J. Marmur

a. z virů a bakteriofágů
b. z bakterií
c. z eukaryotních buněk

Plasmidová DNA



Separation of closed-circular DNA of plasmid pBR322 from *E. coli* chromosomal DNA by isopycnic ultracentrifugation in a CsCl density gradient in the presence of ethidium bromide. The band marked 'chromosomal DNA' may also contain nicked plasmid DNA molecules.

J. MARMUR, Harvard Univ./Brandeis Univ., Boston, Mass.

Izolace DNA z bakterií: 1. lysa buněk

a) mechanicky
b) enzymaticky (lysozym)
c) detergenty (SDS)

2. deproteinace

a) $CHCl_3$
b) fenol
c) enzymaticky
d) ultracentrifugace v grad CsCl

3. odstranění RNA

a) enzymaticky (RNasa)
b) diferenční srážení
c) ulracentrifugace v grad CsCl

Jednotlivé kroky při izolaci DNA jsou často kombinovány se srážením etanolem

4. dialysa

Dnes jsou k dispozici komerčně dostupné přípravky (většinou různé druhy kolonek) pro izolaci DNA z prokaryotních i eukaryotních buněk, které jsou vhodné zejména pro rutinní, seriové izolace DNA

A Procedure for the Isolation of Deoxyribonucleic Acid from Micro-organisms†

J. MARMUR‡

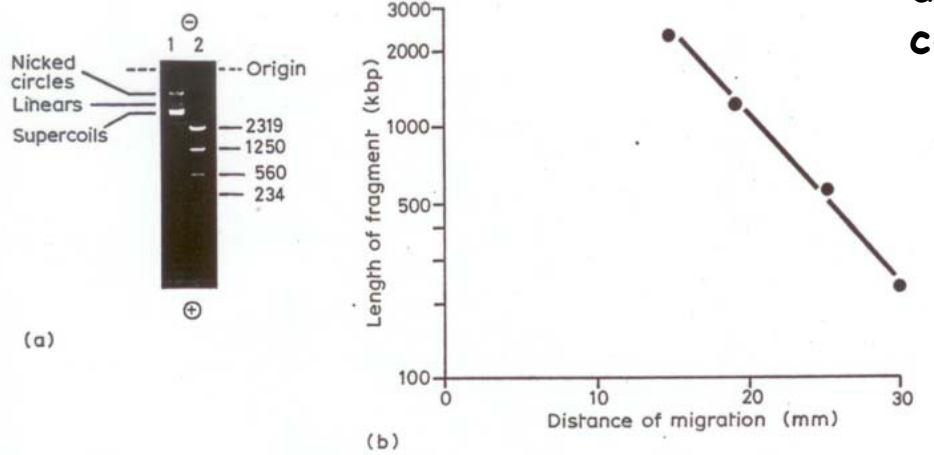
Department of Chemistry, Harvard University, Cambridge, Massachusetts, U.S.A.

(*Received 6 December 1960*)

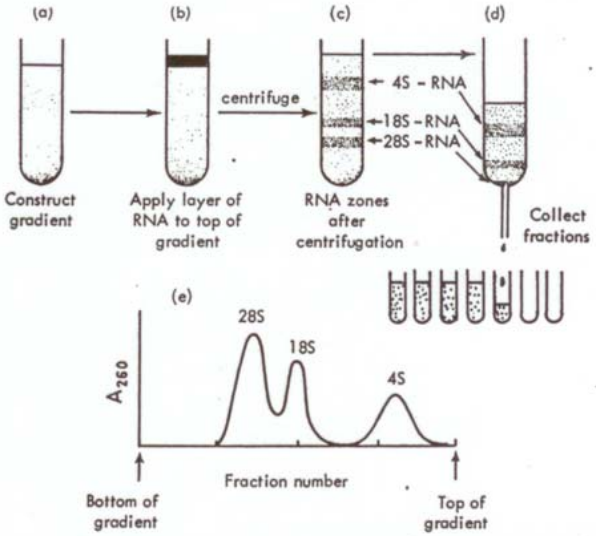
A method has been described for the isolation of DNA from micro-organisms which yields stable, biologically active, highly polymerized preparations relatively free from protein and RNA. Alternative methods of cell disruption and DNA isolation have been described and compared. DNA capable of transforming homologous strains has been used to test various steps in the procedure and preparations have been obtained possessing high specific activities. Representative samples have been characterized for their thermal stability and sedimentation behaviour.

1. Introduction

To facilitate the study of the biological, chemical and physical properties of DNA it is necessary to obtain the material in a native, highly polymerized state. Several procedures have described the isolation of DNA from selected groups of micro-organisms (Hotchkiss, 1957; Zamenhof, Reiner, DeGiovanni & Rich, 1956; Chargaff, 1955). However, no detailed account is available for the isolation of DNA from a diverse group of micro-organisms. The reason for this is that micro-organisms vary greatly



Agarose gel electrophoresis of DNA. (a) Separation of: 1, different forms of DNA of plasmid pBR322; 2, fragments of DNA (lengths indicated in kbp) derived from plasmid pBR322 by double-digestion with restriction endonuclease *Bam* HI and *Bgl* I; (b) Plot of length of DNA fragment (log scale) against distance of migration (linear scale) of data from (a) 2, illustrating linear relationship.



Rate zonal centrifugation of RNA through a sucrose density gradient. A sucrose density gradient is constructed in a centrifuge tube (a) and the RNA solution applied as a layer on top (b). During ultracentrifugation the main components of the RNA separate into zones, primarily on the basis of molecular weight (c). These zones may be recovered by puncturing the bottom of the tube and collecting different fractions in separate tubes (d). The separated RNAs may be visualized and quantitated by measurement of the absorbance at 260 nm (e). Steps (d) and (e) may be conveniently combined by pumping the gradient through the flow-cell of a recording spectrophotometer.

Characterize your DNA sample:
ds x ss, circular x linear
circular: nicked, oc; covalently closed, cc, cd

linear: cohesive or blunt ends
number of base pairs,

purity: protein, RNA .... content
analytical methods

Síly ovlivňující konformaci DNA

a) Elektrostatické síly podmíněné ionizací.

V rozmezí pH 5-9, kdy nedochází ve větším stupni k ionizaci bazí je, DNA **aniontovým polyelektrolytem - polyaniontem**, díky záporným nábojům, které nesou fosfátové skupiny). V roztocích solí jsou záporné náboje vystíněny kladnými náboji kationtů (např. Na^+), které vytvářejí kolem každého záporného náboje iontovou atmosféru. Jestliže je koncentrace kationtů nízká, nabývá na významu odpuzování fosfátových skupin. U **dvoušroubovicové DNA** se toto odpuzování stává faktorem ovlivňujícím významně vlastnosti molekul teprve **při iontových silách nižších než 0,1**. **Při velmi nízkých iontových silách** (kolem 10^{-4} - 10^{-5}) jsou odpudivé síly již tak velké, že mohou zapříčinit **zhroucení dvoušroubovicové struktury** (denaturaci). **Jednořetězcová DNA** (a podobně i RNA) je velmi **citlivá** ke změnám v koncentraci iontů již **při iontových silách nižších jak 1,0**; snižování iontové síly vede ke zvětšování prostoru zaujímaného polynukleotidovým řetězcem.

b) Síly plynoucí z vertikálního uspořádání bazí

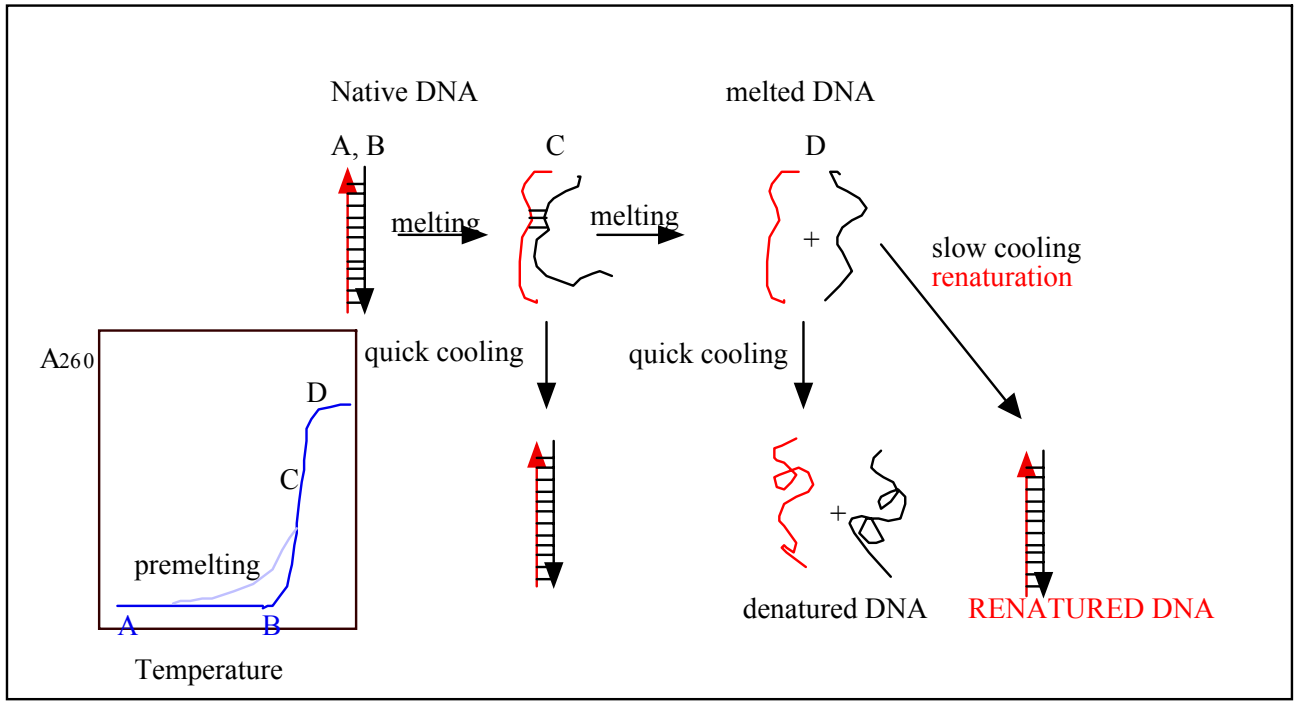
(vrstvení bazí, stacking). Síly působící mezi bazemi pravidelně uspořádanými ve dvojité šroubovici jsou zejména interakce typu dipól - dipól, dipól - indukovaný dipól a Londonovy síly. Existují teoreticky odvozené důkazy, že **tyto síly jsou postačující pro stabilizaci šroubovice**; jejich volná energie odpovídá asi -7 kcal na mól párů bazí. Naproti tomu volná energie vodíkových můstků činí asi -3 kcal pro (G.C) a -2 kcal pro (A.T) pár (na mól párů bazí).

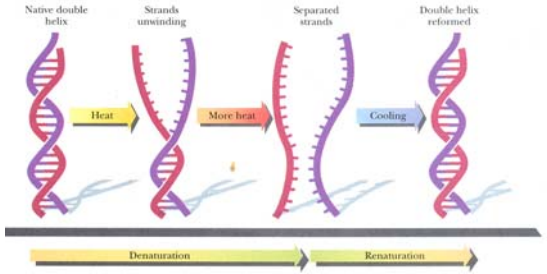
c) Vodíkové vazby (můstky) - představují **jediný známý způsob zajišťující specificitu párování bazí**. Jsou tedy součástí mechanismu jímž DNA realizuje svoji biologickou funkci. Zpočátku se o nich soudilo, že jsou nejdůležitějším činitelem pro stabilitu dvojité šroubovice; experimentálně i teoreticky bylo však dokázáno, že tomu tak není.

d) Hydrofobní síly - tento termín se týká **stability dvoušroubovicové DNA plynoucí z její architekrury**: **polární skupiny** jsou **na povrchu**, zatímco **hydrofobní baze** jsou **uvnitř** molekuly a mají větší tendenci interagovat mezi sebou nežli s molekulami vody. Toto uspořádání **stabilizuje** tedy dvoušroubovicovou molekulu DNA **ve vodném prostředí**. Je známo, že molekula DNA je ve vodném roztoku obklopena **hydratační vrstvou**, která hraje významnou úlohu ve stabilizaci dvojité šroubovice. Podrobné znalosti o této hydratační vrstvě jsou nyní získávány zejmena díky výsledkům rtg. strukturní analýzy krystalů DNA.

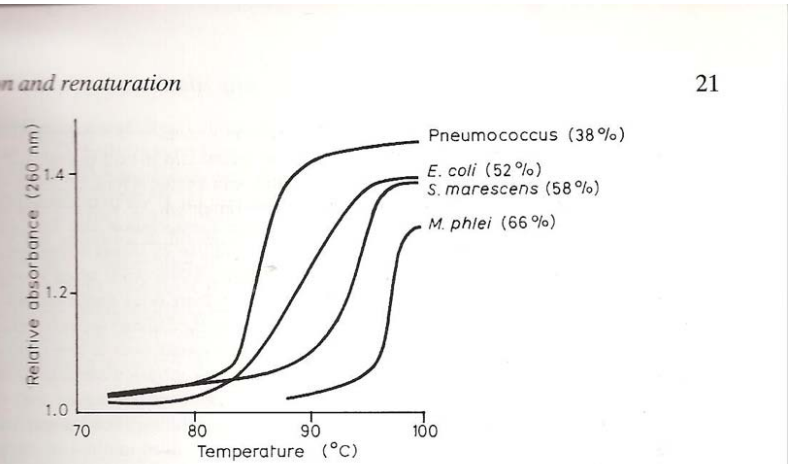
Denaturation x degradation
aggregation
renaturation/hybridization

DNA DENATURATION and RENATURATION/HYBRIDIZATION





J. Marmur and P. Doty



aturation by heat of DNAs isolated from different sources. The figures in brackets indicate the the DNA in G + C (%) (from *Molecular Genetics* by G. S. Stent, W. H. Freeman and Co. – after [116]).

STRAND SEPARATION AND SPECIFIC RECOMBINATION IN DEOXYRIBONUCLEIC ACIDS: BIOLOGICAL STUDIES

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Communicated by Paul Doty, February 25, 1960

It is clear that the correlation between the structure of deoxyribonucleic acid (DNA) and its function as a genetic determinant could be greatly increased if a means could be found of separating and reforming the two complementary strands. In this and the succeeding paper[1] some success along these lines is reported. This paper will deal with the evidence provided by employing the transforming activity of DNA from *Diplococcus pneumoniae* while the succeeding paper[1] will summarize physical chemical evidence for strand separation and reunion.

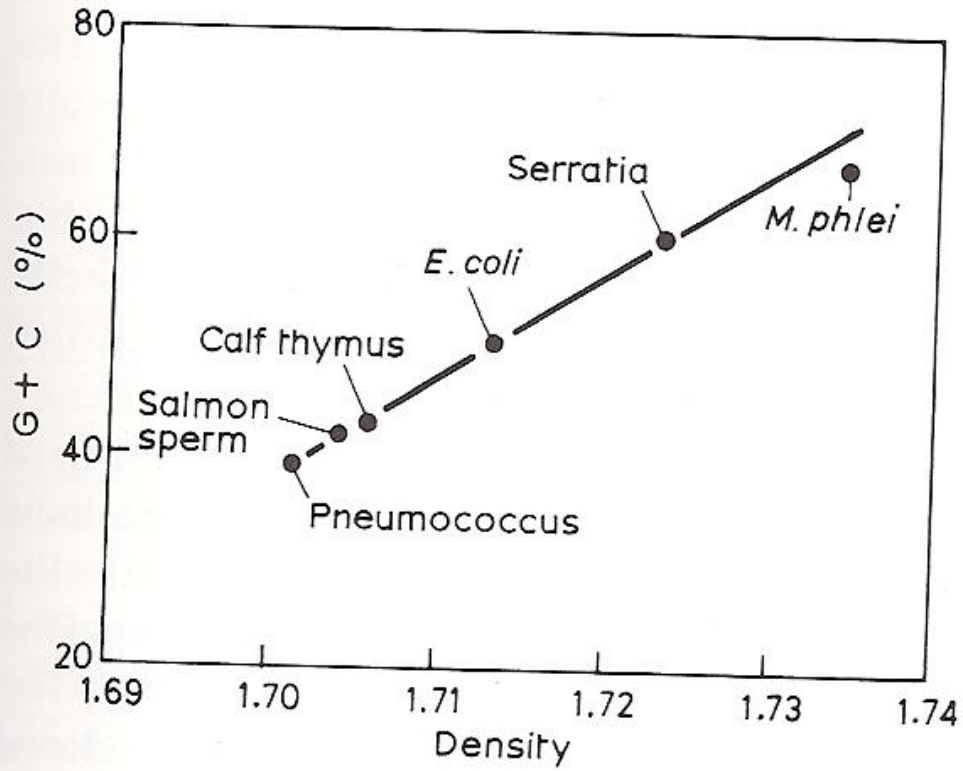


Fig. 2.21 Relationship of density to content of guanine plus cytosine in DNAs from various sources [64].

Source of DNA	Percentage (G + C)
Plasmodium falciparum (malarial parasite)	19
Dictyostelium (slime mould)	22
M. pyogenes	34
Vaccinia virus	36
Bacillus cereus	37
B. megaterium	38
Haemophilus influenzae	39
Saccharomyces cerevisiae	39
Calf thymus	40
Rat liver	40
Bull sperm	41
Diplococcus pneumoniae	42
Wheatgerm	43
Chicken liver	43
Mouse spleen	44
Salmon sperm	44
B. subtilis	44
T1 phage	46
E. coli	51
T7 phage	51
T3 phage	53
Neurospora crassa	54
Pseudomonas aeruginosa	68
Sarcina lutea	72
Micrococcus luteus	72
Herpes simplex virus	72
Mycobacterium phlei	73

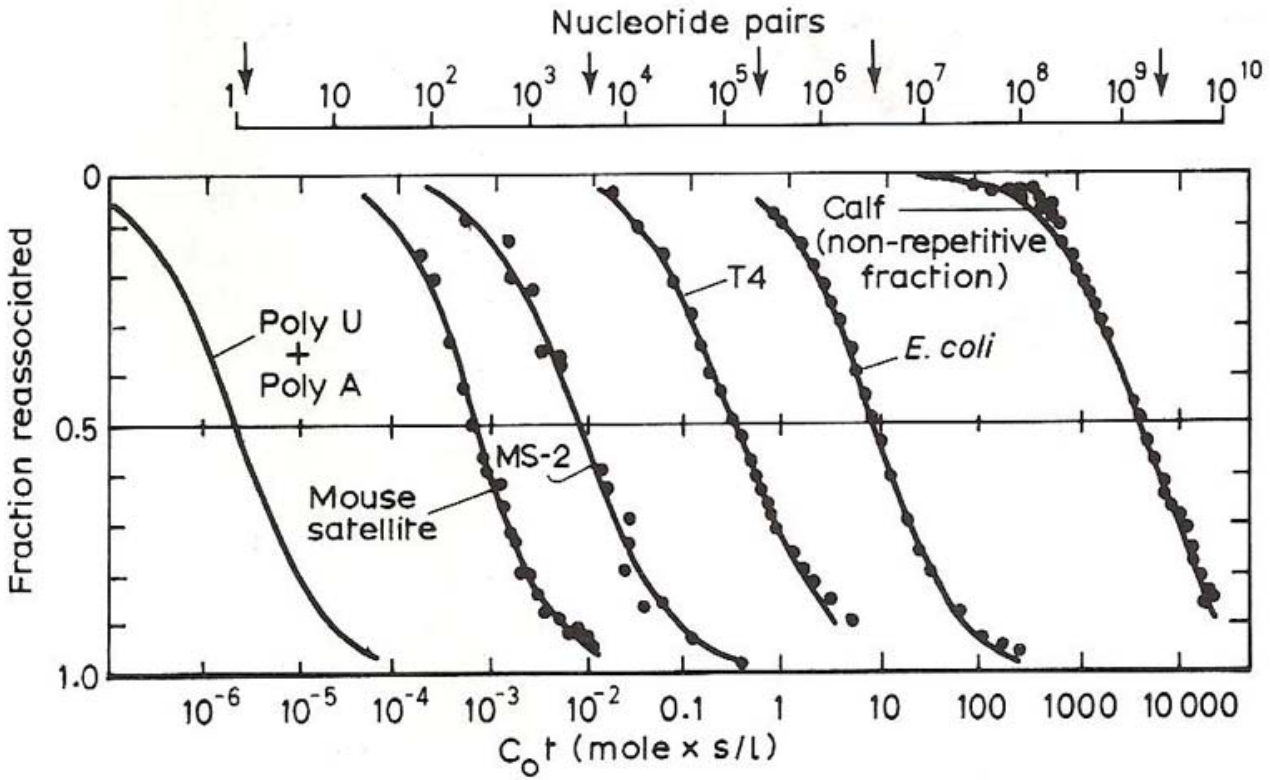


Fig. 2.20 The rate of reassociation of double-stranded polynucleotides from various sources showing how the rate decreases with the complexity of the organism and its genome (from [60]).

DNA renaturation/reassociation depends on the concentration of the DNA molecules and the time allowed for reassociation. Often imperfect matches may be formed which must again dissociate to allow the strands to align correctly. C_0t value of DNA is defined as the **initial concentration C_0 in moles nucleotides per Litre multiplied by time t in seconds**. C_0t reflects complexity of DNA. Methods: S1, hydroxyapatite - dsDNA binds more strongly

Biosyntetické polynukleotidy

Syntetické oligonukleotidy
Dr. L. Havran,

Biosyntetické polynukleotidy -

modely pro výzkum fyzikálních a chemických vlastností a struktury nukleových kyselin

Důležité modely vlivu sekvence nukleotidů na vlastností DNA

POLYRIBONUKLEOTIDY

byly syntetizovány většinou pomocí polynukleotid fosforylázy, která polymerizuje nukleotid-5'-difosfáty (při čemž se uvolňuje anorganický fosfát)

nukleosid-difosfáty
nevyžaduje primer ani matrici

Po počáteční syntetické fázi, dochází k rovnováze mezi syntézou a degradací (fosforolyzou) a vytvářejí se polymery s poměrně malým rozptylem délek

Polynukleotid fosforyláza polymerizuje mnohá analoga nukleosid difosfátů jako 2'-O-metyl, 2'-chloro-, 2'-fluoro- a dokonce i arabinonukleosid-5'-difosfáty a nukleosid difosfáty s různě modifikovanými bazemi.

Nukleozidy mající konformaci syn- (např. 8-bromoguanosin) polymerizovány nejsou. Enzym vyžaduje konformaci cukru 3'-endo.

Tento enzym nevyžaduje pro svoji funkci matrici (někdy očko/primer). Vhodný zejména pro syntézu homopolynukleotidů. Heteropolymery mají náhodnou sekvenci nukleotidů.

nukleosid-trifosfáty

Příprava polynukleotidů s definovanou sekvencí nukleotidů vyžaduje
RNA-polymerázu (závislou na DNA) nebo
DNA-polymerázu (pro syntézu polydeoxyribonukleotidů)

Homopolynukleotidy

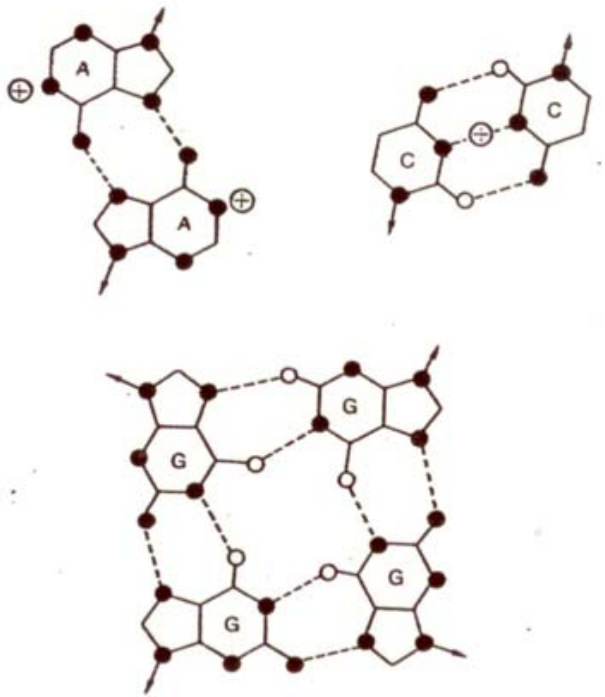
Poly(U) a poly(dT) při pokojové teplotě mají málo výraznou sekundární strukturu, při vyšší teplotě tuto strukturu ztrácejí

Poly(C) v kyselém prostředí tvoří dvojřetězovou protonizovanou strukturu s paralelními řetězci. V neutrálním prostředí tvoří jednořetězovou strukturu stabilizovanou vertikálním vrstvením bazí (stacking)

Poly(A) tvoří v kyselém prostředí dvojřetězovou strukturu s paralelními řetězci (podobně jako poly (C). Párování bazí je ve struktuře poly(A) zajištěno jinak než v poly(C). V neutrálním prostředí má poly(A) strukturu jednořetězovou.

Poly(G) a poly(I) tvoří čtyřvláknové struktury

poly(A)
poly(rC)
poly(dG)
poly(U)
poly(rT)



Polynukleotidové komplexy

Smícháním polynukleotidů (za vhodných iontových podminek) vznikají dvou- a víceřetězové komplexy

Poly(A)·poly(U) tato dvojitá šroubovice vzniká při fyziologické iontové síle za nepřítomnost Me^{2+}. Při vyšších iontových silách může vzniknout trojřetězová struktura poly(A)·poly(U)·poly(U) [poly(A)·2 poly(U)] (Hoogsteen)

Poly(G)·poly(C), poly(I)·poly(C) tyto dvojité šroubovice vznikají při neutrálním pH. V kyselém prostředí se tvoří trojřetězové struktury **poly(G)·poly(C)·poly(C^+)** v nichž je jeden řetězec poly(C) protonizovaný. Podobně interaguje i poly(C) s poly(I)

Tyto interakce jsou silně závislé na iontové síle

Studium vlastností biosyntetických polynukleotidů přineslo v minulosti důležité informace o vztazích mezi sekvencí nukleotidů a strukturou DNA a RNA, např.:

t_m: (rI)·(rC) > (rI)·(dC) > (dI)·(dC) > (dI)·(rC)

poly(dI-dC) a poly (dG-dC) jsou stabilnější nežli odpovídající komplexy homopolynukleotidů

Směsné křivky: