# Changing perspective of physics research


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*Thanks to Alumni Association of IOP*

I am not educated enough to talk about changing perspective of Physics

As a practitioner of the subject and a rather humble worker, I am qualified enough to reflect on Physics Research –

"The practicing of the subject at its highest level"

*I would like to discuss*:

- whether there is indeed a change in perspective?

- and if so what are the changes and what are the challenges ?

- An exciting adaptation of this changing perspective in my own research

*“Perspective”-* there are definitely different angles from which it should be approached.

There is indeed a perspective of :

- A young researcher trying to establish himself.

- An established researcher- who should be trying to maintain his excellence in an ever changing world.

- A Laboratory director who would like to build a team with shared objective to make an impact as an organization.

- A funding agency and fund Managers to show results from their investment,

## Two key factors of physics research:

- The idea around which the research evolves
- A core of individual excellence and commitments

*Collective efforts are very important but there is no substitute for individual excellence*

*However, individual excellence is far from individualistic research*

## *Are great physics ideas "crazy" ?*

Bohr had been in attendance at a lecture in which Wolfgang Pauli proposed a new theory of elementary particles. Pauli came under heavy criticism, which Bohr summed up for him: "We are all agreed that your theory is crazy. The question which divides us is whether it is crazy enough to have a chance of being correct? My own feeling is that is not crazy enough."

"When a great innovation appears, it will almost certainly be in a muddled, incomplete and confusing form. To the discoverer, himself, it will be only half understood; to everyone else, it will be a mystery. For any speculation which does not at first glance look crazy, there is no hope!" ~ Kenneth Brower, 1979, The Starship and the Canoe

*Freeman Dyson ,"Innovation in Physics", Scientific American*

***In 2005 we celebrated the International year of Physics.***

The physics research is standing at crossroads.

How we meet the challenges and use the opportunities will decide the fate of Physics as a subject, the strength of the global physics community and indeed the survival and growth of the Physics community in India.

## *In 2105 will there be a celebration of International Year of Physics?*

- when we talk of changing perspective it is indeed a haunting question.
- Survival of a vibrant community to celebrate this event in 2105 will depend on what we do today and meet the challenges of these changing perspective.
- All changes throw challenges and gives new opportunity.

## *Physics research has co-existing dichotomies*

- It is based on a deep tradition and set of laws yet it is changing and embracing new things.
- It is extremely fundamental and basic but it has generated wealth.
- It is so aesthetic, esoteric and beautiful yet it is so rigorous and quantitative.

*A successful research career depends on how you blend the opposing trends.*

Amidst all changes that would happen, Central role of the idea will remain.

*After all it is idea that moves science continuously but not linearly.*

Physics makes incremental progress enriched by not so big ideas and occasionally great ideas make qualitative changes

- Some times the idea leads to instant success and the growth is spectacular.
- Some times good ideas are much ahead of time and it takes long time after which it gets its due.

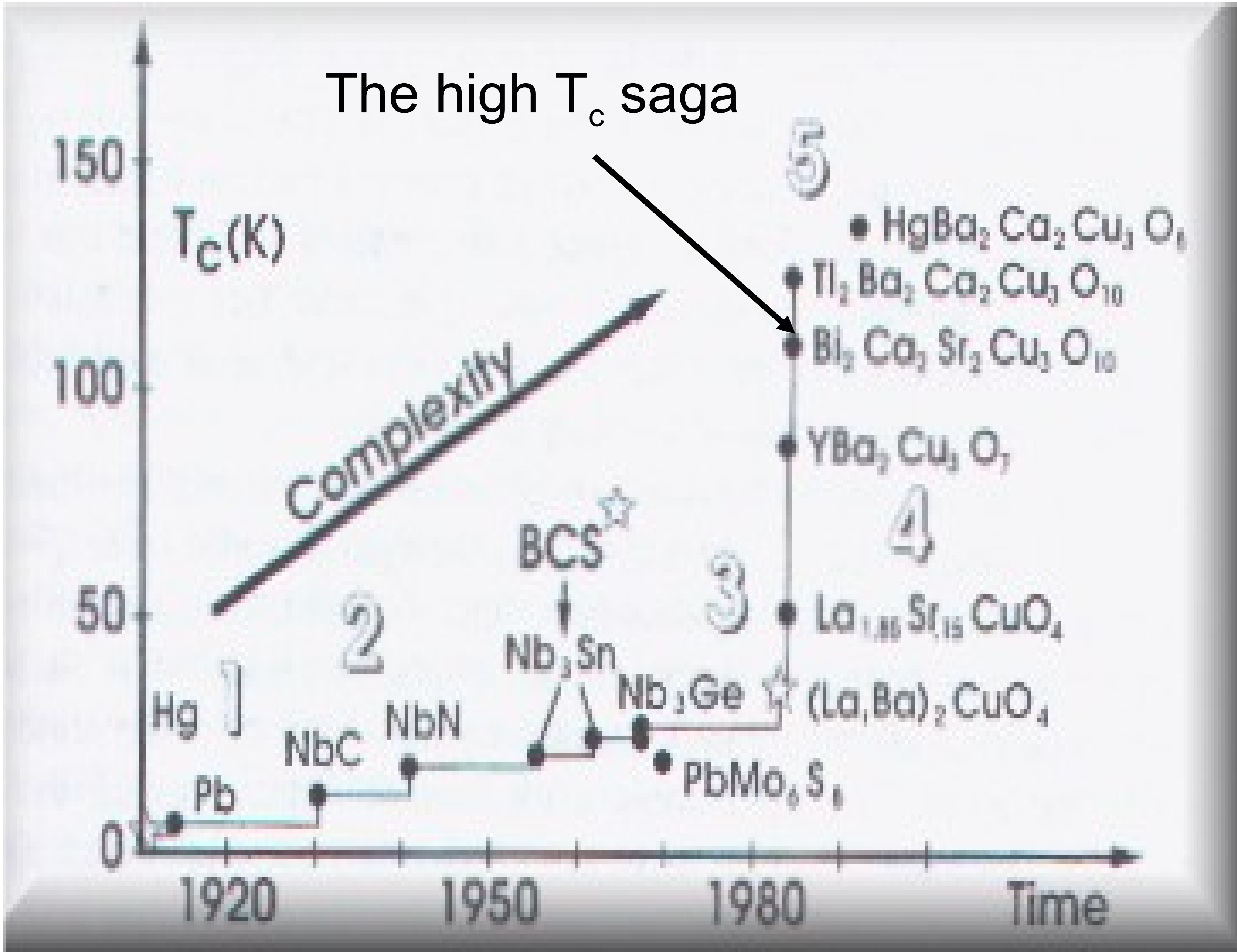
# *History of Optical communications*

| Year | Land mark |
|---|---|
| 1870 | Glass wave guide |
| 1960 | Basic research on optical properties of rare-earth ions in glasses |
| 1964 | Rare-earth ions in optical fibers as amplifiers |
| 1965 | 400 dB/Km fiber |
| 1970 | 20 dB/Km fiber<br>Commercial applications begin |
| 1985 | 0.15 dB/Km fiber- boom in wideband width communication |
| 1987 | Er doped fiber optic amplifier |
| 1995 | Under sea systems with optical Amplifier |

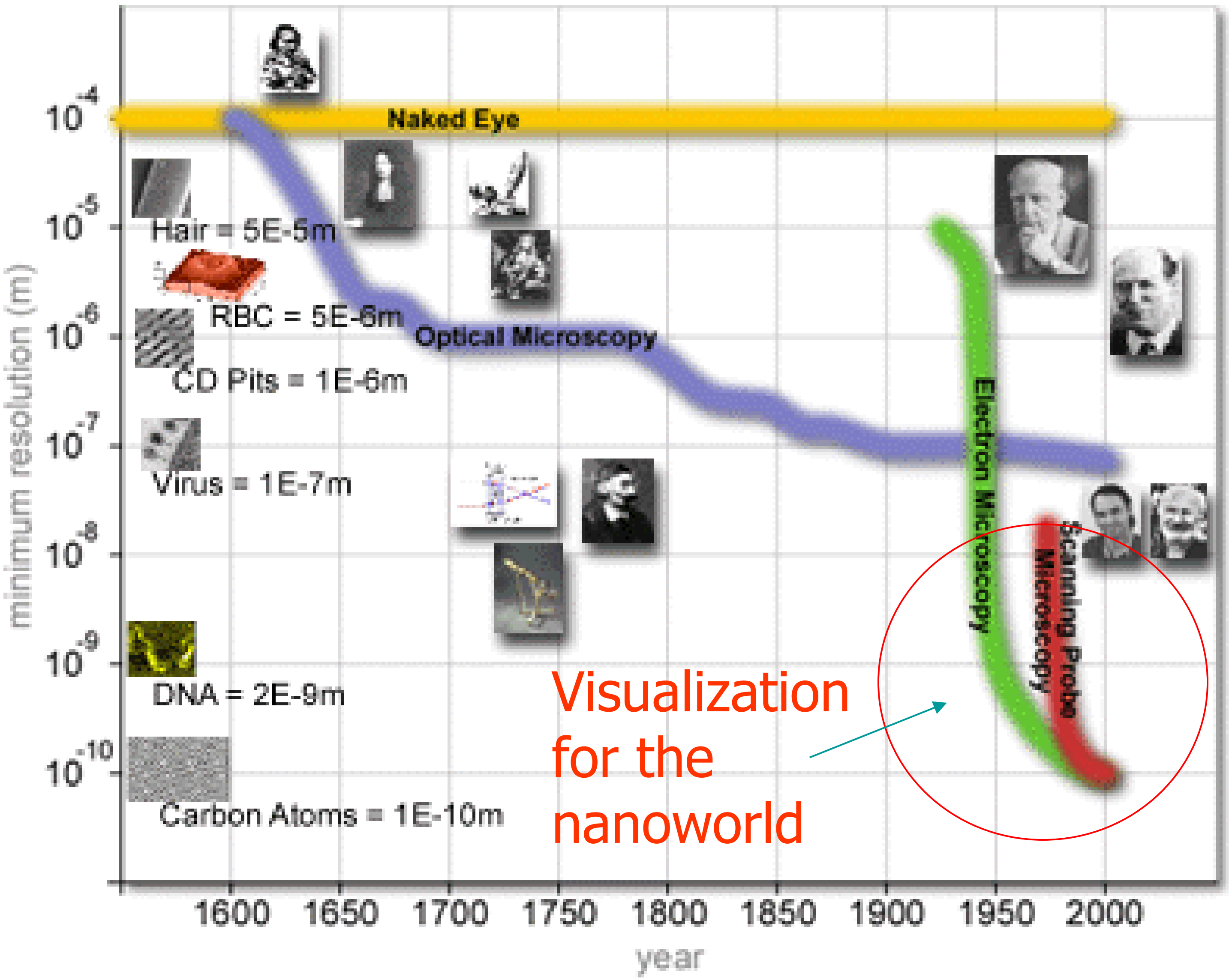
Basic research to understand optical losses in glasses and how to control it.

Development of Semiconductor laser

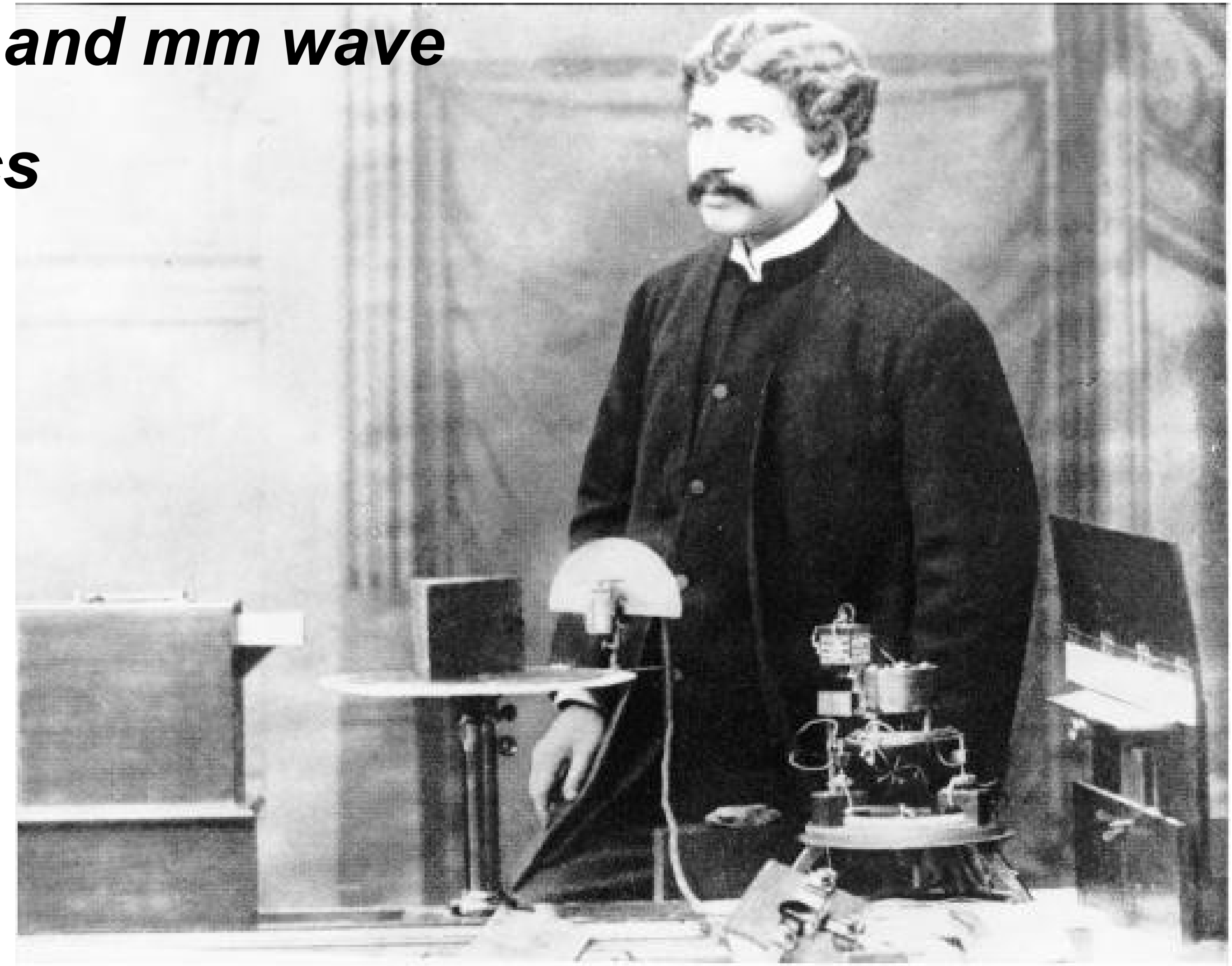
# The high $T_c$ saga



# A brief look at evolution of microscopes



- ***The radio and mm wave***
- ***Biophysics***



*1897 Royal Institutions, 60 GHz*

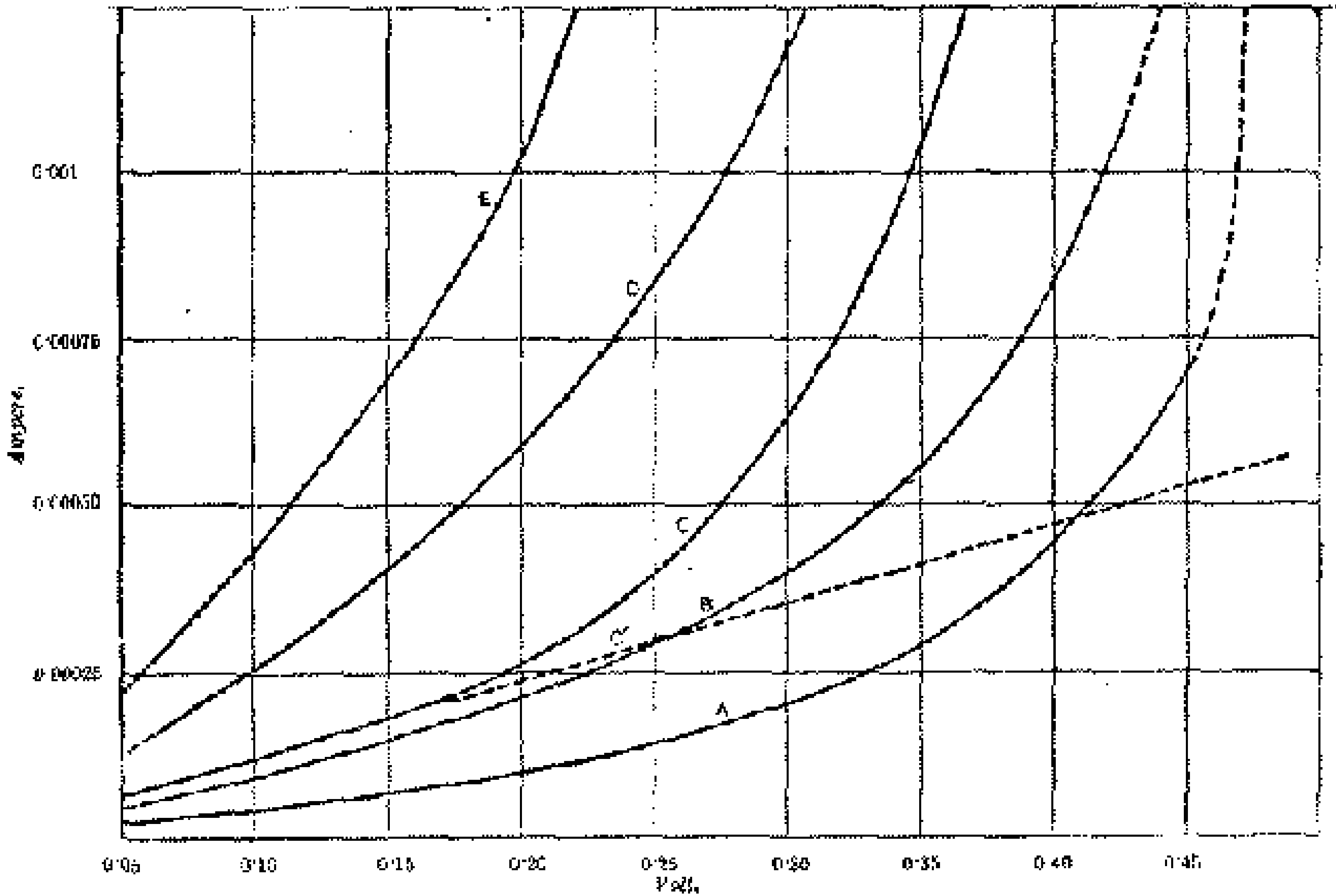



Fig. 52. **Characteristic Curves of a Single Point Iron Receiver.**
A, B, C, D, E are different curves for different initial currents, C′ is the curve for a constant resistance.

I-V curve of point contact detectors,

P and n type semiconductors

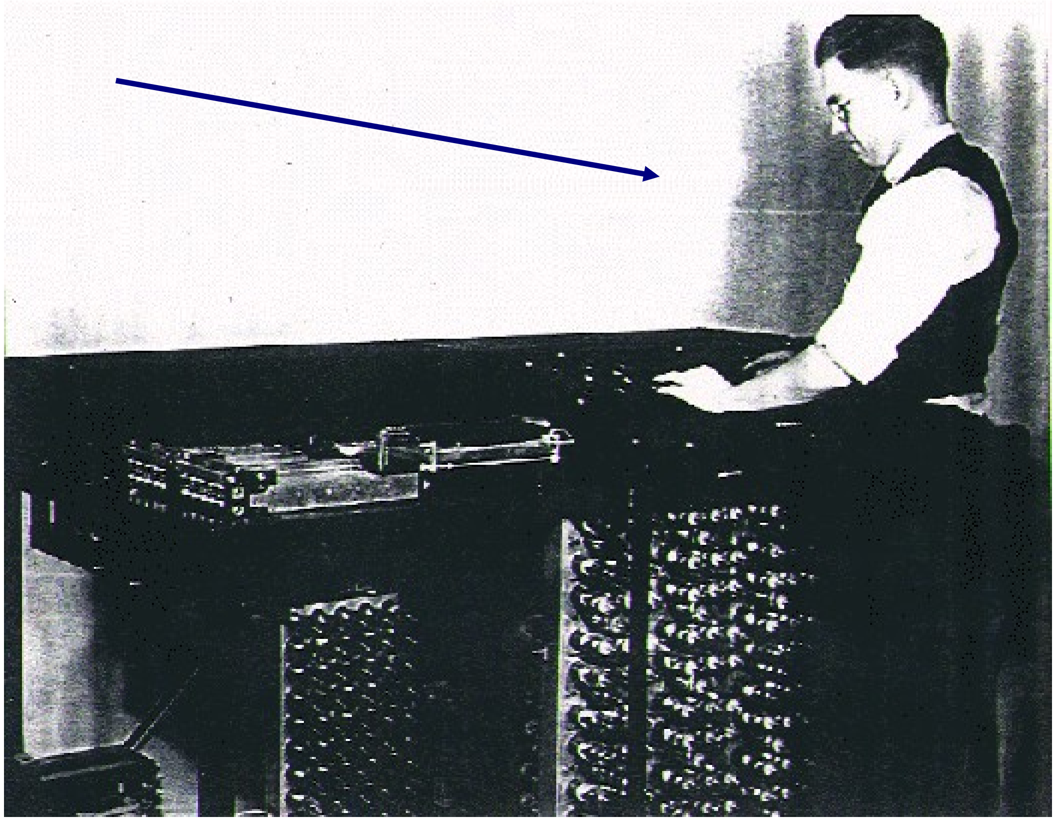
He showed with the help of his newly invented crescograph that plants responded to various stimuli as if they had nervous systems like that of animals. He claimed that plants can "feel pain, understand affection etc," from the analysis of the nature of variation of the cell membrane potential of plants, under different circumstances.

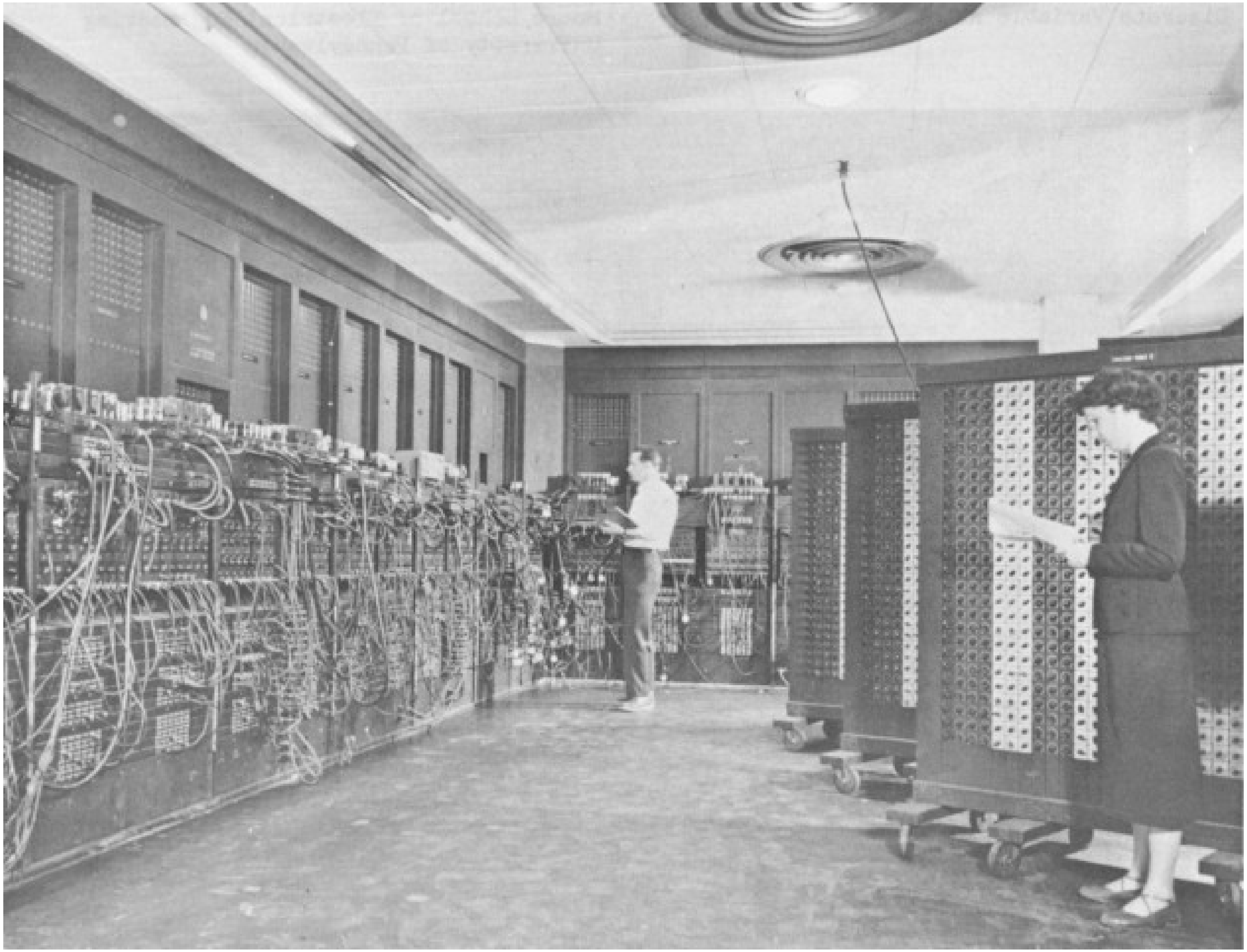
His major contribution in the field of biophysics was the demonstration of the electrical nature of the conduction of various stimuli (wounds, chemical agents) in plants, which were earlier thought to be of chemical in nature.

*These claims were experimentally proved by* ****Wildon et al*** *(Nature, 1992, 360, 62–65).*

This discovery of the electron by physicist J.J. Thompson in 1897 was probably underappreciated when it occurred, just like the development of quantum mechanics. After all, in 1897 it probably sounded like a waste of money to do experiments on a particle that is too tiny to ever see. But of course, now our civilization is dependent on electronics, chemistry, materials science, medicine, etc.--all of which require an understanding of the electron.

The first electronic digital computer was built in the basement of the physics department at Iowa State University in 1939 by Professor John Atanasoff, who had a Ph.D. in theoretical physics from the University of Wisconsin, and his physics graduate student Clifford Berry.





*Another physicist made computer ENIAC, 1945*

It is indeed the case that Atanasoff and Berry did not receive the proper recognition, at least from the general public, who have no idea that an electronic digital computer was created as early as 1939, nor that it was designed and built by physicists *(many think Bill Gates invented the computer?).*

It is amazing to think that the computer industry, now worth in the hundreds of billions of dollars, owes its existence to a brilliant physics professor and his talented graduate student, working away at Iowa State University with a $650 research grant (no that is not a typo), driven by their own curiosity to think, design, and build something truly novel.

*It is certain that they never dreamed their modest machine would have such a profound impact on the world.*

*Atanasoff was given the National Medal of Technology in 1990 by U.S. President George Bush in recognition of his invention.*

*Perhaps the most nonlinear progress is in the field of nanoscience.*

*Nanotechnology came years before nanoscience!*

# The Lycargus Cup

*4th Century AD (now at the British Museum, London).*

*The colors originate from metal nanoparticles embedded in the glass. At places, where light is transmitted through the glass it appears red, at places where light is scattered near the surface, the scattered light appears greenish.*

Surface plasmon resonance

“Labors of the Months” (Norwich, England, ca. 1480). The ruby color is attributed to gold nanoparticles.

***the gold is reduced in exceedingly fine particles which becoming diffused, produce a beautiful fluid Faraday……. (1857)***

Birth of nanoscience-the understanding of color in nanoparticles

b)

# Why are we then talking about nanotechnology today

In last 10-15 years and in last 5 years to be specific there have been tremendous progress in the science and technology of nanomaterials synthesis , characterization , understanding their physico –chemical properties that give rise to distinct application potentials and innovations.

## *Changing perspective-*

Is idea still supreme?

Yes it is
But not alone

An idea becomes acceptable when it has the capacity to change the society and better still the capacity to create wealth.

Or it is economically viable

Dec 17, 1971 maiden flight 2005 , the last flight

## *Changing perspective-*

In the 20th century indeed Physics was the highest mover, it led to discoveries that not only enriched Physics as a subject, physical concepts pervaded through other discipline and it did enrich the Post 2nd World War technological revolutions. Physical Science did rule supreme in the 20th Century at least the better part. And we did do physical research in way that intrinsically assumed the central role of Physics as the prime mover of knowledge.

But is physics the prime-mover of knowledge and contributing to growth of other fields as it did definitely in the most part of the 20th century?

*Answer is definitely not in the affirmative.*

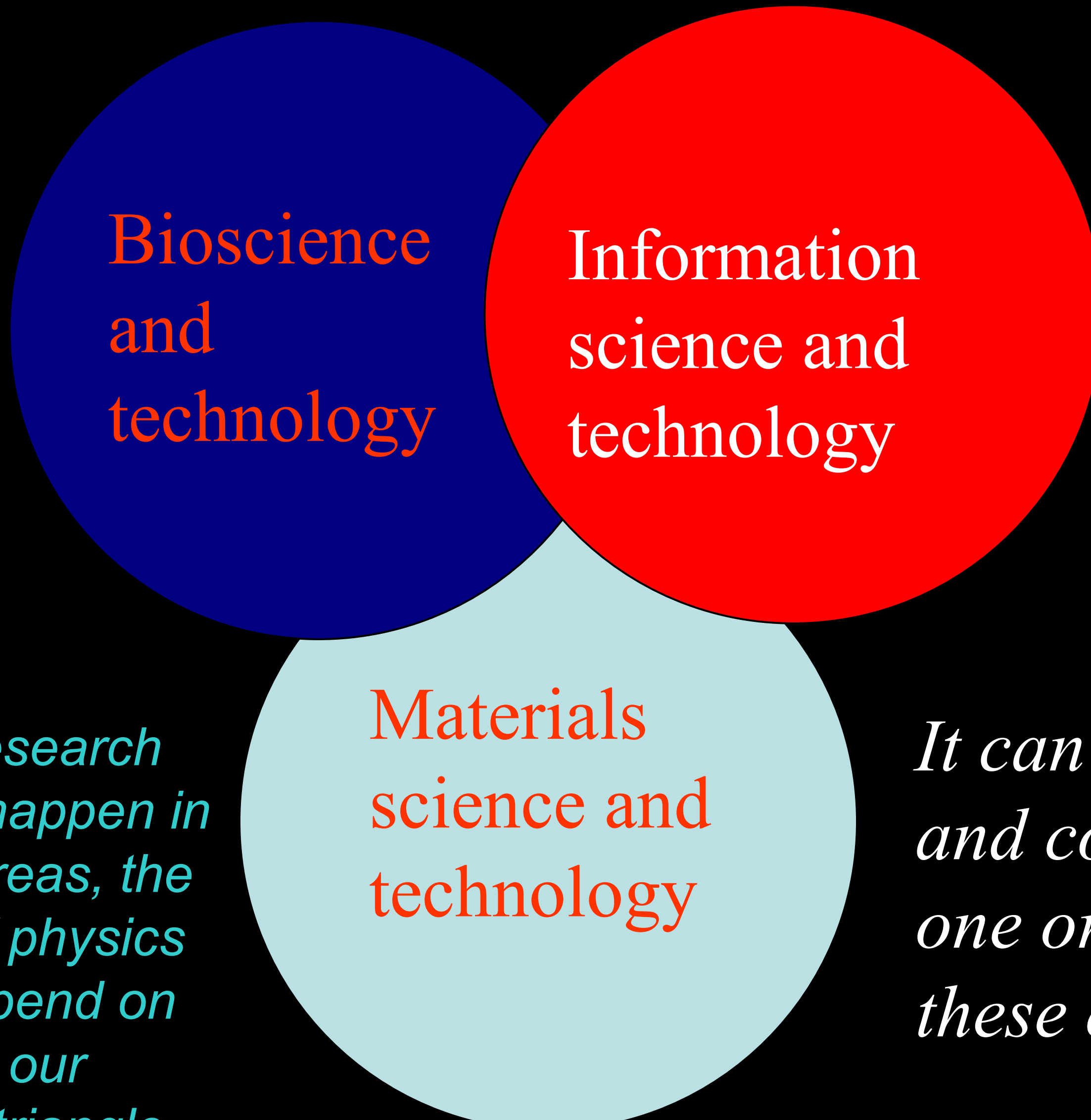
## *Changing perspective-*

Beginning the last quarter of 20th Century and the 21st Century that we can perceive, physics is no longer the prime-mover of knowledge.

The perspective of the physics research has changed and physics today has to learn from other disciplines and need to look for expressing its unlimited strength in problem areas that even few decades back had little to do with physics.

*What are the major areas?.*

# The three core areas of modern science and technology today where physics will have most interaction




*While physics research will continue to happen in other problem areas, the changing role of physics research will depend on how we position our research in this triangle.*

*It can gain from and contribute to one or more of these core areas*

## *Changing perspective–*

## *Innovation, discovery and invention.*

- Discover: Find out. Obtain insight or knowledge for first time.
- Invent : Devise , originate, produce or construct by original thoughts.
- Innovate:  Bring in novelties and make changes.

While the 20th century was mostly discovery and invention driven, there is a perceptible change of physics research as it has added to its strength the ever increasing component of  innovation.

*Definitely physics has components of all. It can discover, it can invent and it can innovate.*

Sir J.C.Bose was an excellent example of a total embodiment of discovery, invention and innovation.

He invented a number of very precise equipments to measure physical properties –some so precise that it can detect changes at single electron level.

He then got the innovative idea to apply these ultra sensitive equipments to measure physiological responses in plants.

This led to outstanding discoveries which I feel was the fore runner of biophysics.

*It teaches us that good innovation can set the stage of good discovery*.

*Changing perspective–*

from Analytical theory to Large scale calculation,
from direct experimentation to large scale simulation.

Often simulation and computation provides a very important route to achieve results that in many cases would have been very difficult and costly to get if not impossible.
In fact, today a good simulation can often tell us whether we should spend time and money to do an experiment. It plays a very important role.
*Simulation often gives rise to new observations that can be tested.*

*Changing perspective-*

From publication or patent to

Publication and patent.

*(This applies even to theory !)*

The idea places the central role in physics research and innovation plays a very important role in physics research. But wealth generation is an integral part of modern physics research at least for some.

The issue comes how do we disseminate our findings to the world at large and thus contribute to the intellectual wealth.

Till very recently the bulk of the physicists in the academics were happy with publishing their results in journal publications.

They left the work of IPR and patenting issues to their colleagues in industrial labs. But not so any more. Now the changing perspective is that the same groups need to do both publishing and patenting.

We need to see this as the two modes as the same activity one complementing the other. After all patents are made on ideas and as ideas take central stage it is important to protect them.

*Those who can afford to do patenting should do so along with journal publications –they are mutually inclusive and complimentary.*

*Brief summary*

*Physics research is changing and the most visible changes are:*

- *Idea to “economically viable” idea.*
- *Physics is no longer the prime-mover of knowledge. It has to learn from other fields as well.*
- *From discovery and invention driven to innovation driven.*
- *From analytical theory to computation and simulation.*
- *From patent or publication to patent and publication.*

*I would like to discuss*:

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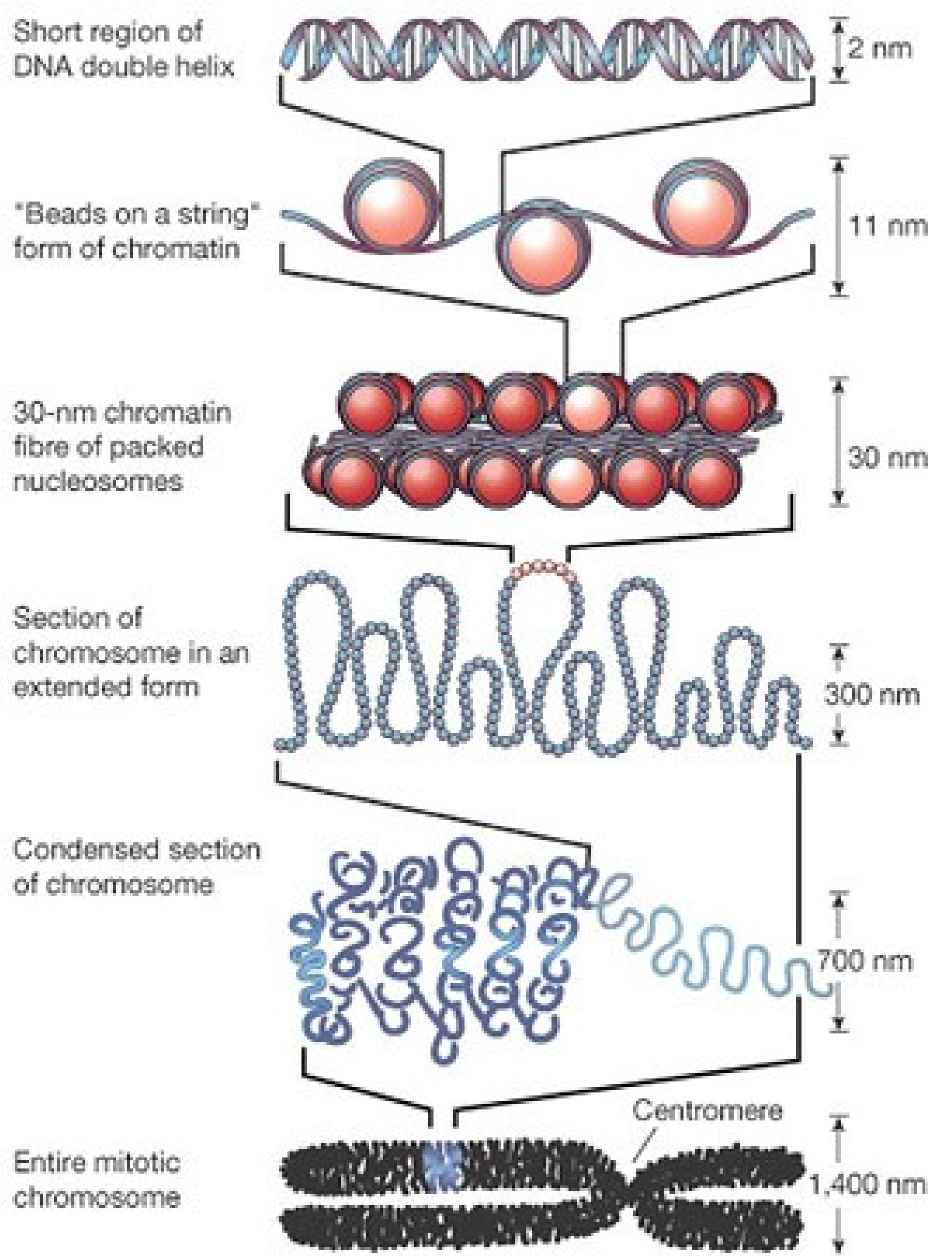
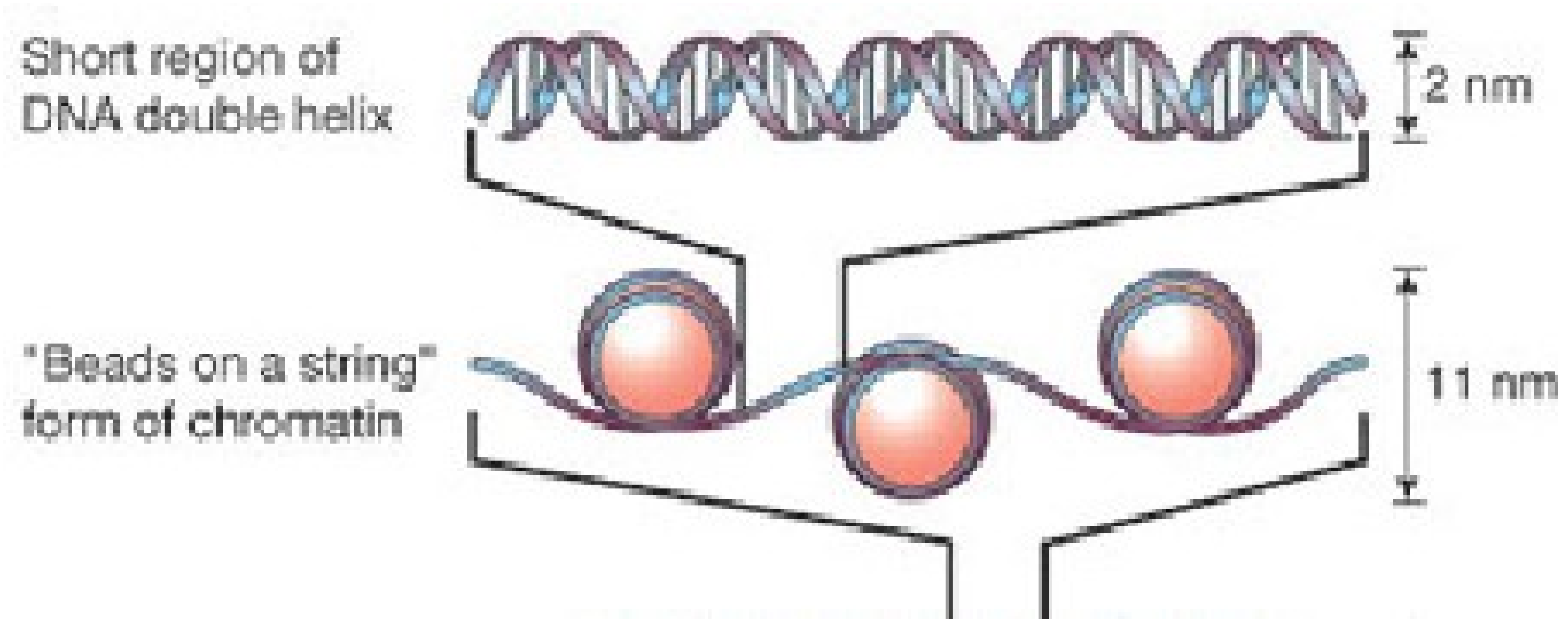
# Chromatin structure : complex




How to pack few meters of DNA in few microns

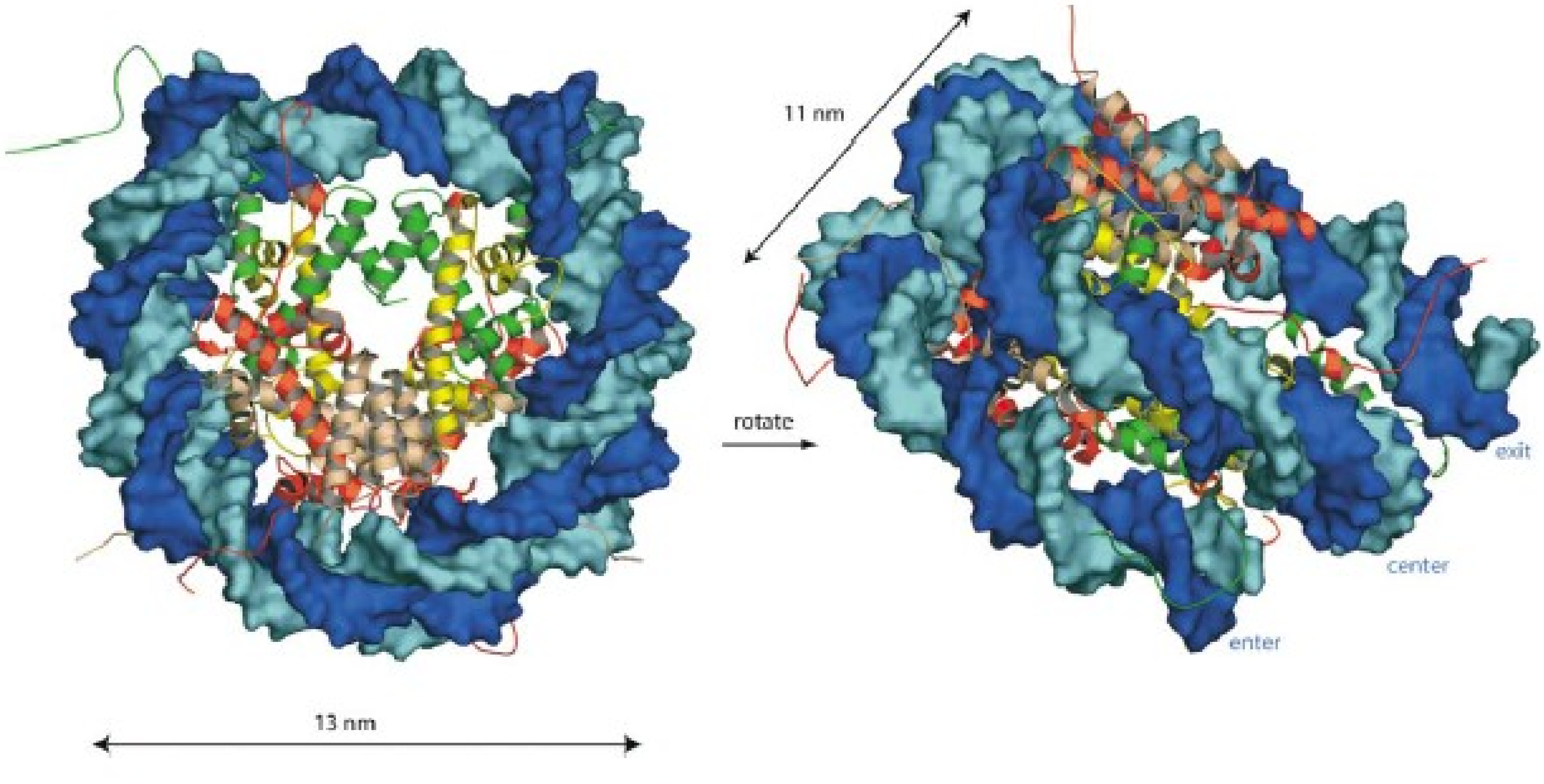
# DNA and Nucleosome



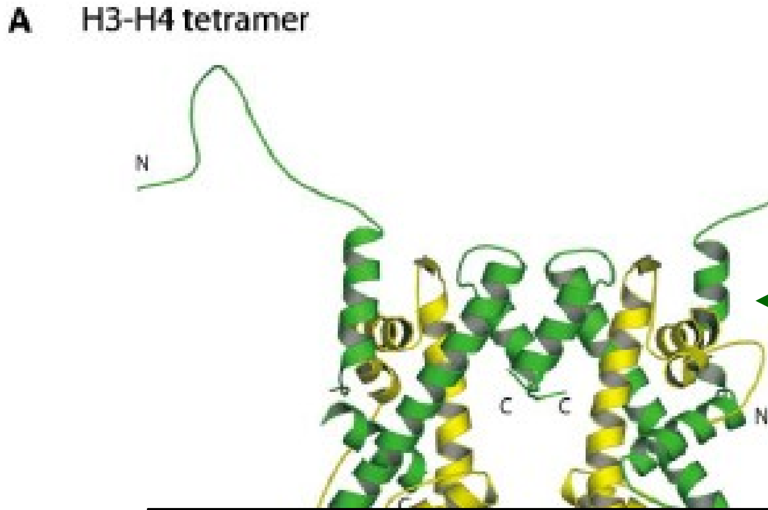

Our experiment deals with DNA, histones (the proteins) and their complex that makes the mononucleosome

# The basic building block at the level of ~10-15nm

Nucleosome- An octomer of histones ( proteins) , 1.7 turns of DNA (140bp) wrapped around it and the linker histone



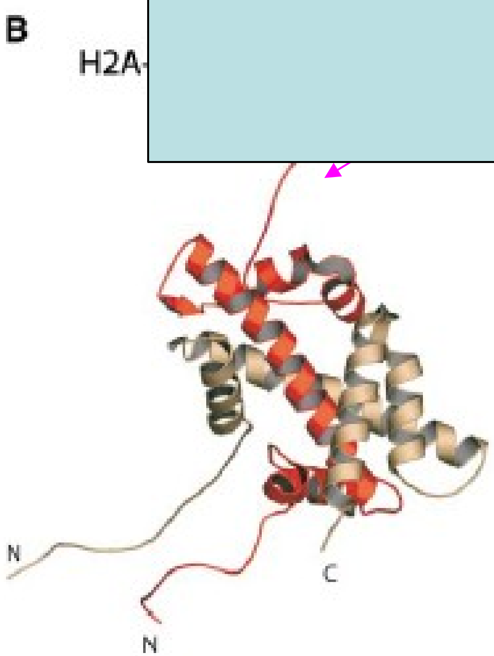
# Histone proteins

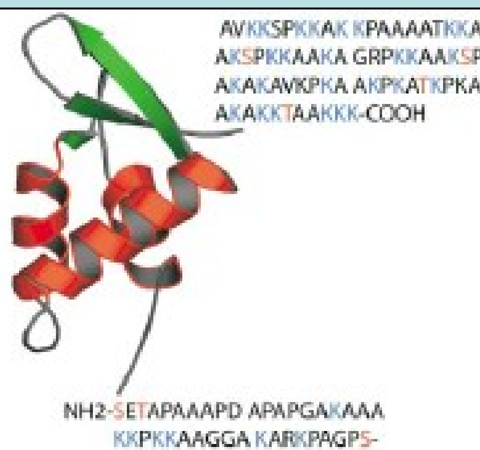


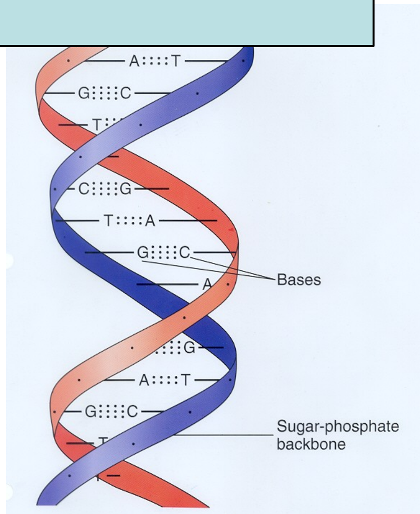

•The octamer made from H3-H4 tetramer and  and the H2A-H2B dimers.

•Linker histone is monomer

DNA is held to the histone octamer by electrostatic interactions



# Some of the open questions:

- The nucleosome is made up of constitutes that have their own structers (DNA, histones) –how does the stability of individual components show up in the over all stability?

- What are factors that makes the nucleosome a stable structural unit

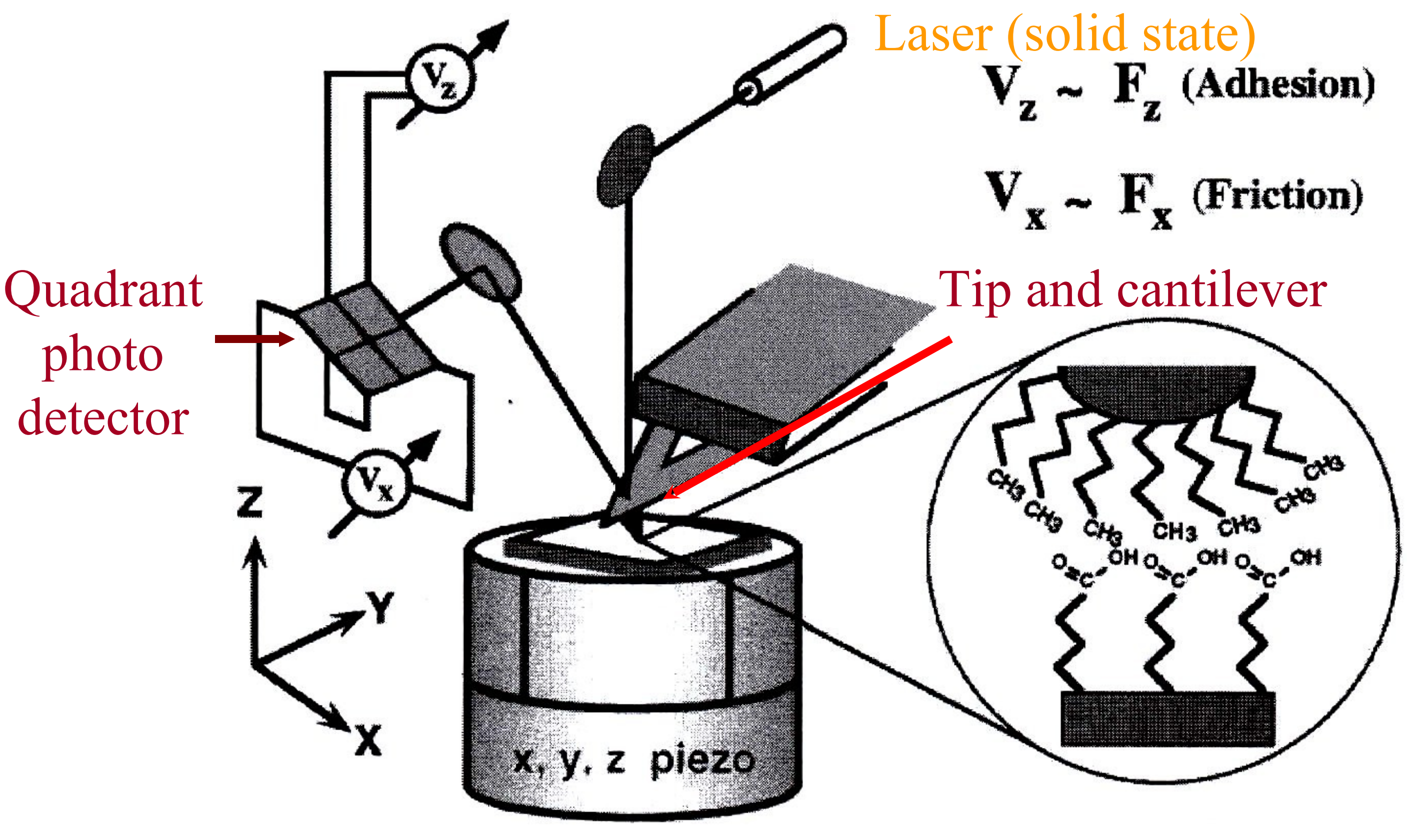
How well-folded are the proteins

The energy landscape for the proteins

Does the DNA denaturate when the nucleosome denaturates?

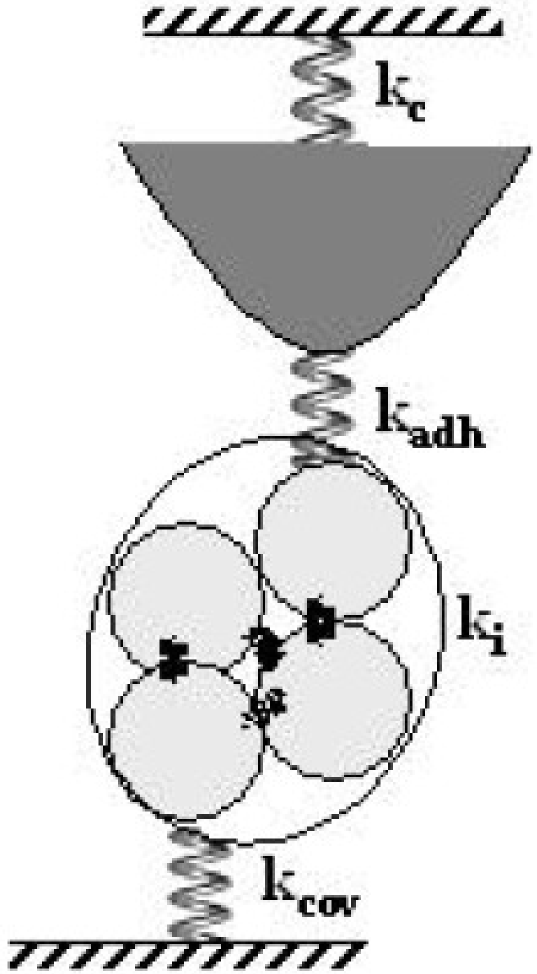
# The tools

## Atomic Force Microscopy

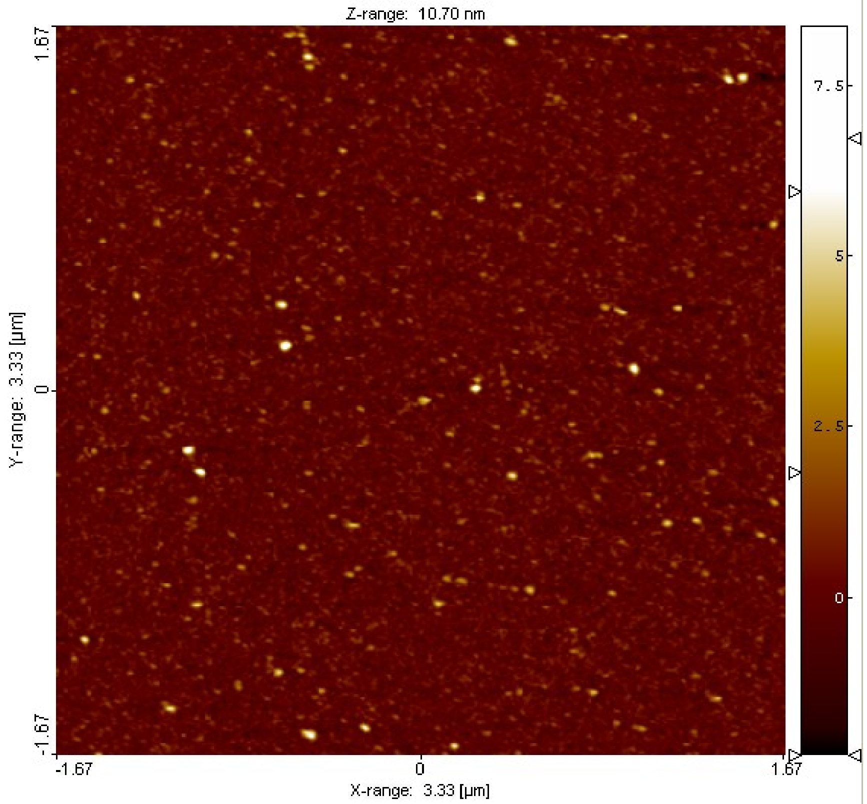



Scanner and positioner

# Nucleosome rupture experiment



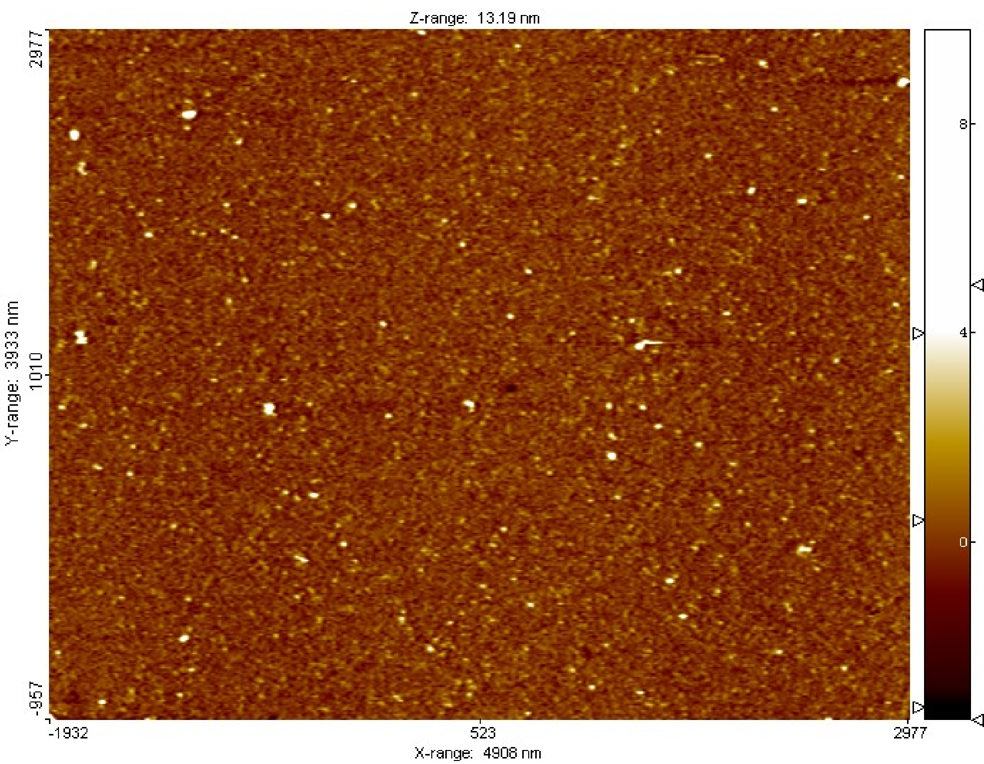
100mm_h2b_002

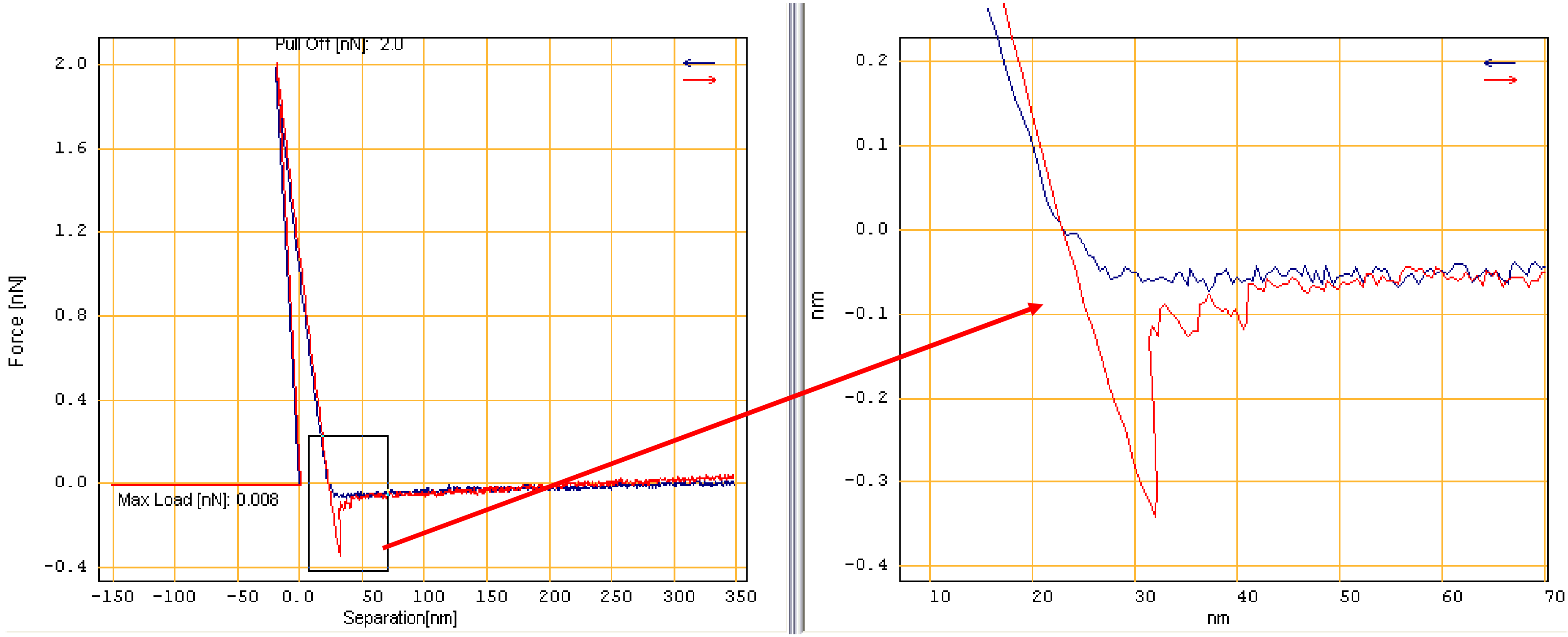


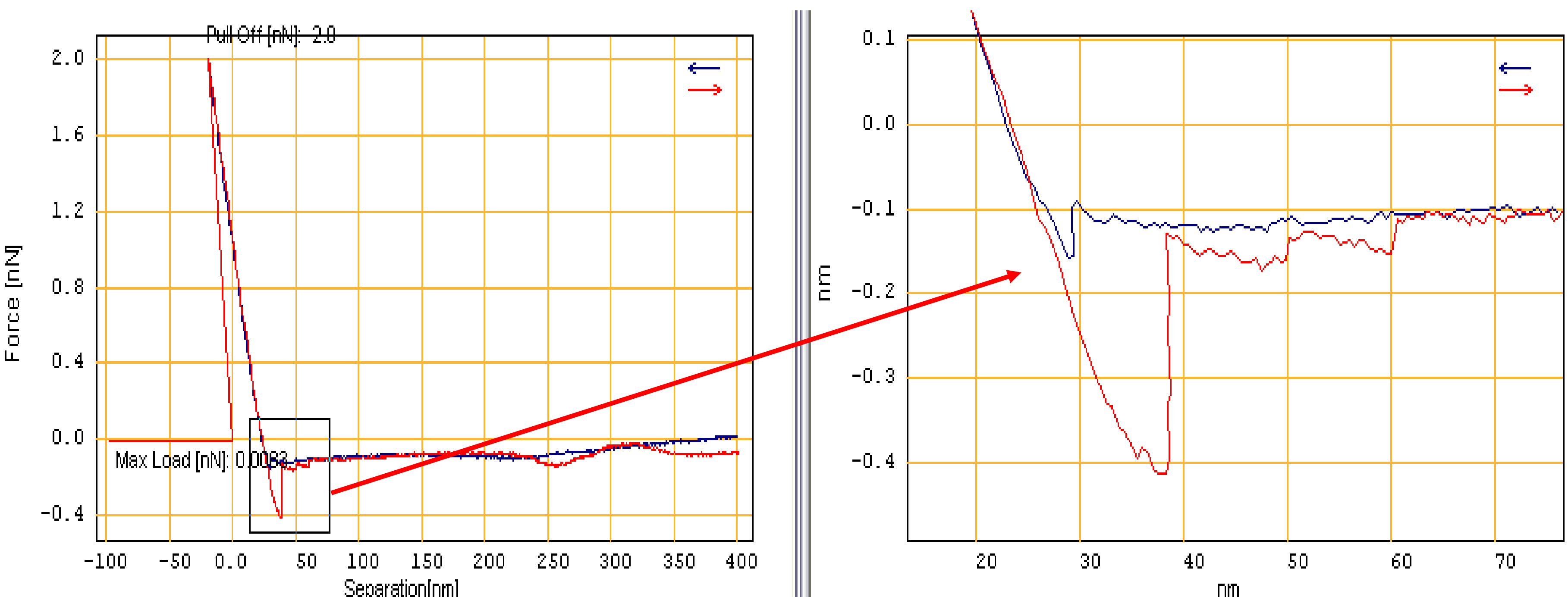

# representative images

The entities of size 8-10nm were used for the rupture experiments

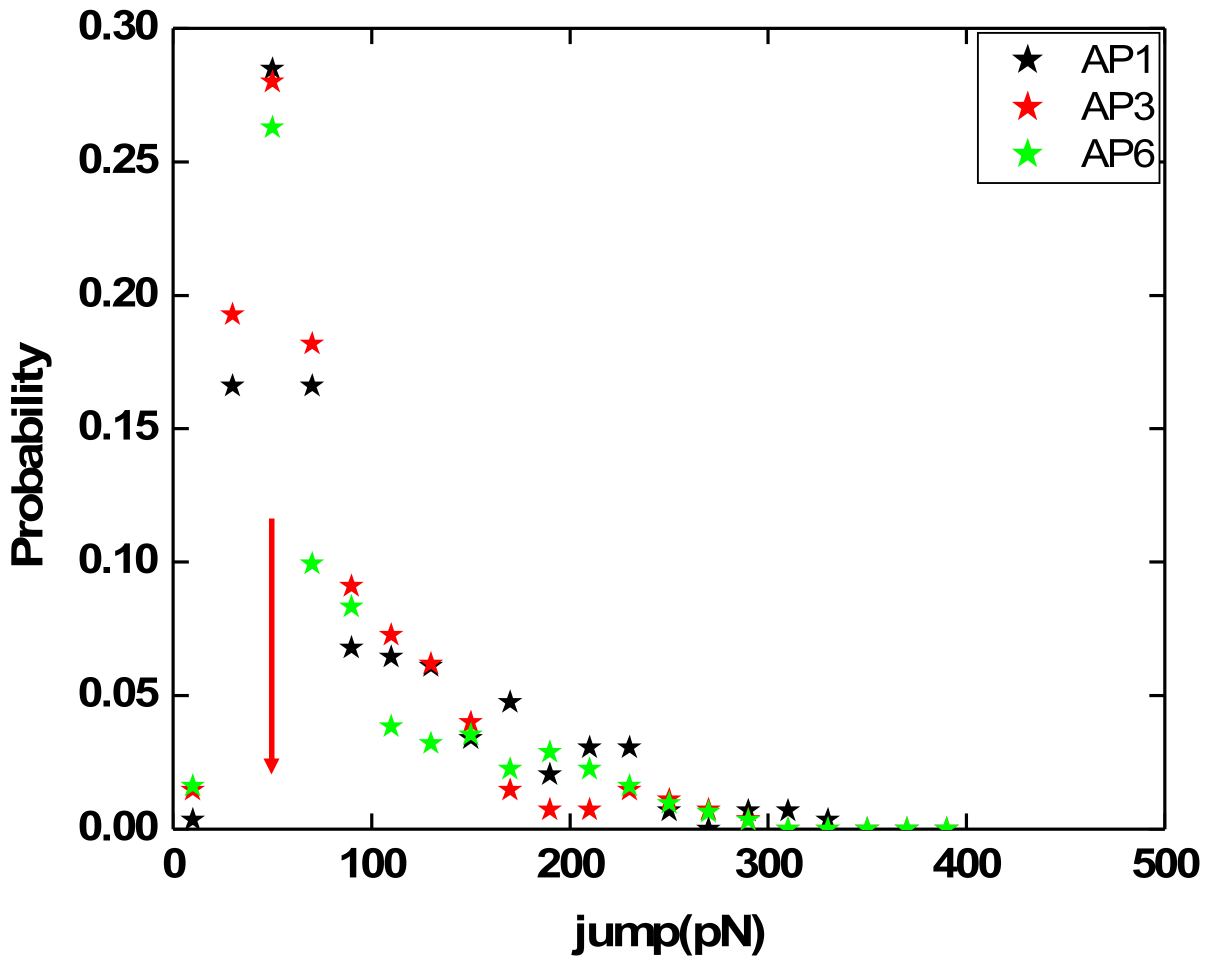
100mm_h2b_004.stp-1.zoom_419x336




Pull Off [nN]: 2.0
Max Load [nN]: 0.008
Force [nN]
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-150
-100
-50
0.0
50
100
150
200
250
300
350
Separation[nm]
nm
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
10
20
30
40
50
60
70
nm


Pull Off [nN]: 2.0
Max Load [nN]: 0.0083
Force [nN]
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-100
-50
0.0
50
100
150
200
250
300
350
400
Separation[nm]
nm
0.1
0.0
-0.1
-0.2
-0.3
-0.4
20
30
40
50
60
70
nm

# A typical rupture force histogram constructed from the force-displacement curves




*Taken at a given rate of approach of the cantilever*

**What is the problem with these experiments - something is missing**

# Thermal Fluctuation Spectroscopy (TFS)*

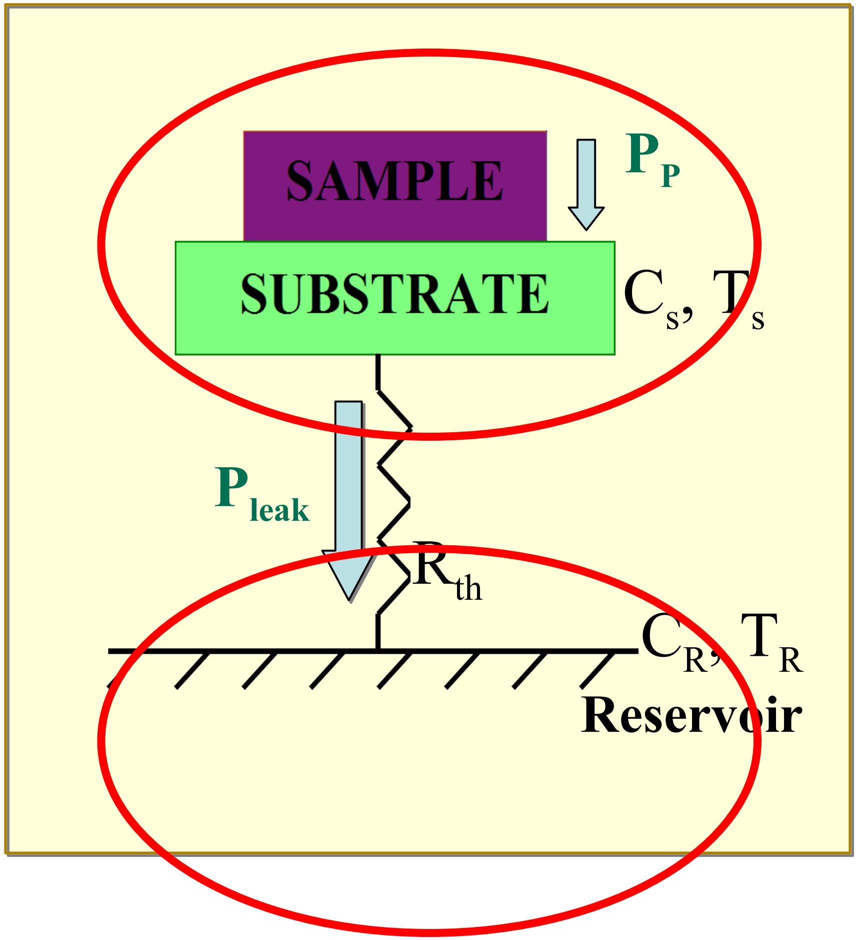
# (Thermal probe)

*K.S.Nagapriya , A.K. Raychaudhuri and D. Chatterjee

*Phys. Rev. Letts* . **96,** 038102 (2006)

# Thermal fluctuation spectroscopy (FTS)

- What is the technique and the underlying physics




- Creating a "micro canonical" ensemble within a time window

- Sample and the thermometer is one sub-system. Internal relaxation time $\tau_S$

- Heat reservoir

$\forall \tau_R$ – Time constant that sub-system comes in equilibrium with reservoir

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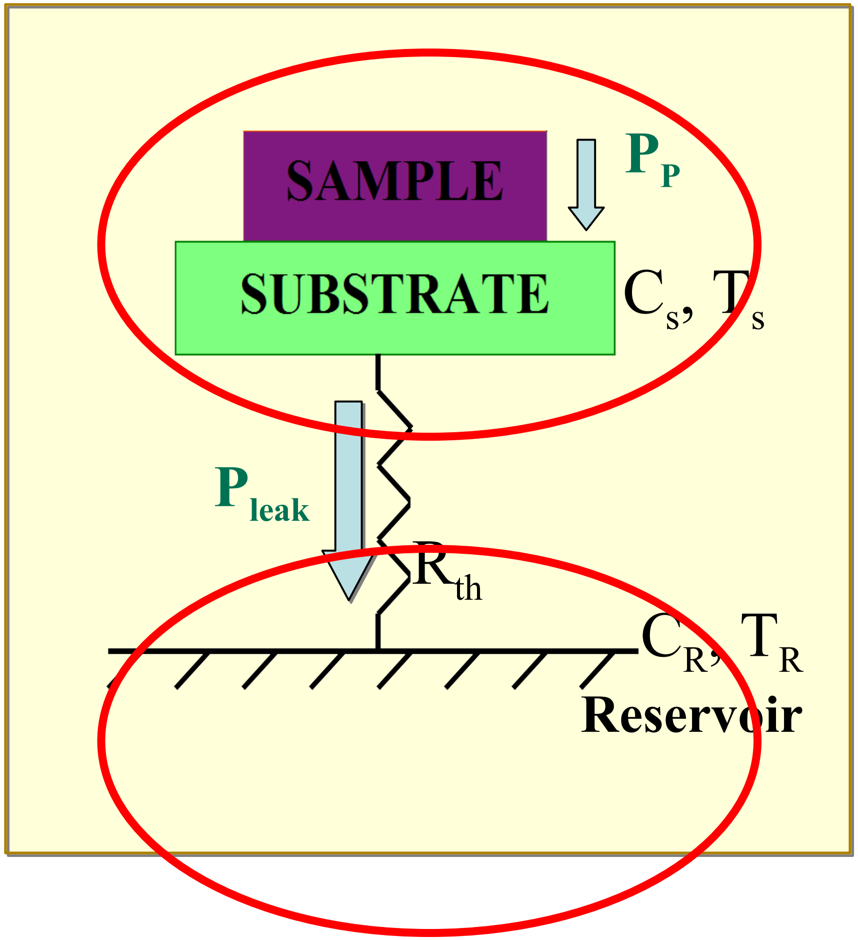


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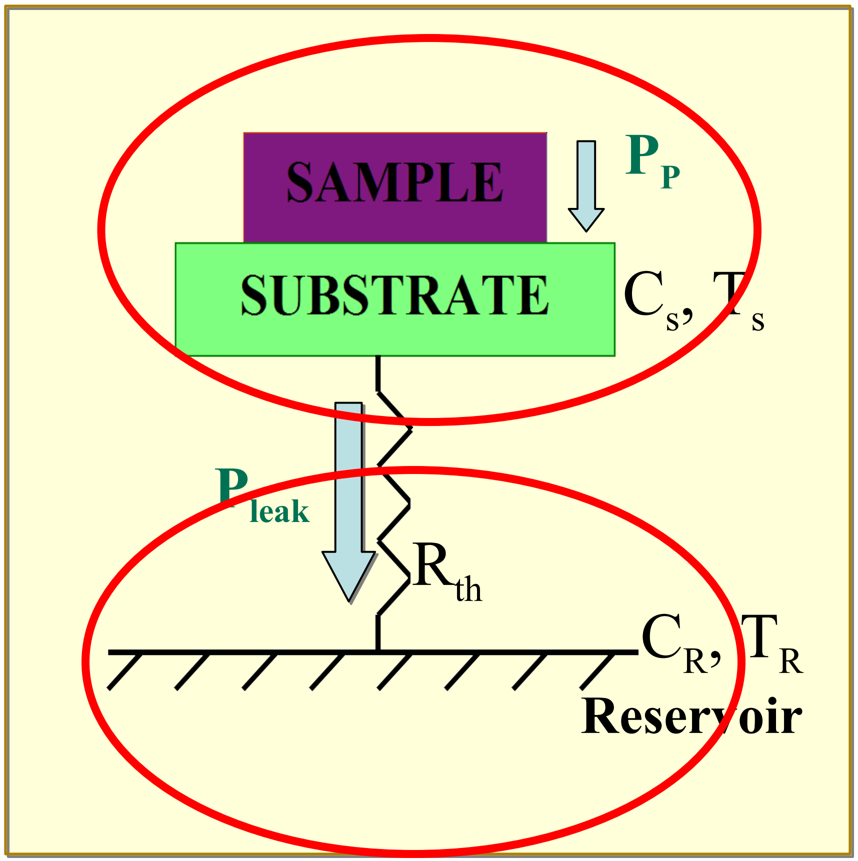
# Thermal fluctuation spectroscopy (FTS)

*What happens in the time scale $\tau_S < \tau_{exp} < \tau_R$?*




The subsystem will be thermally isolated from the reservoir

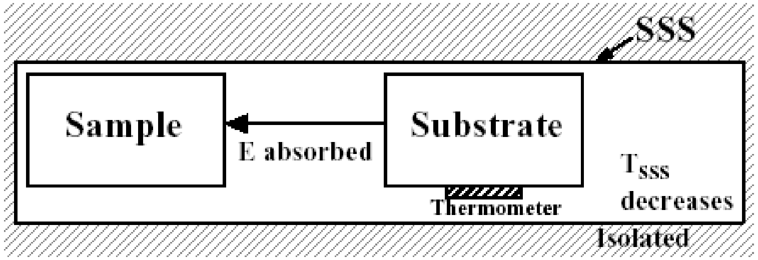
Any energy released by the sample will heat-up the thermometer

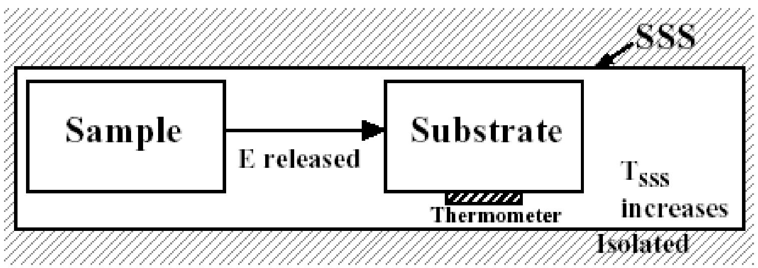
Any energy absorbed by the sample will cool the thermometer

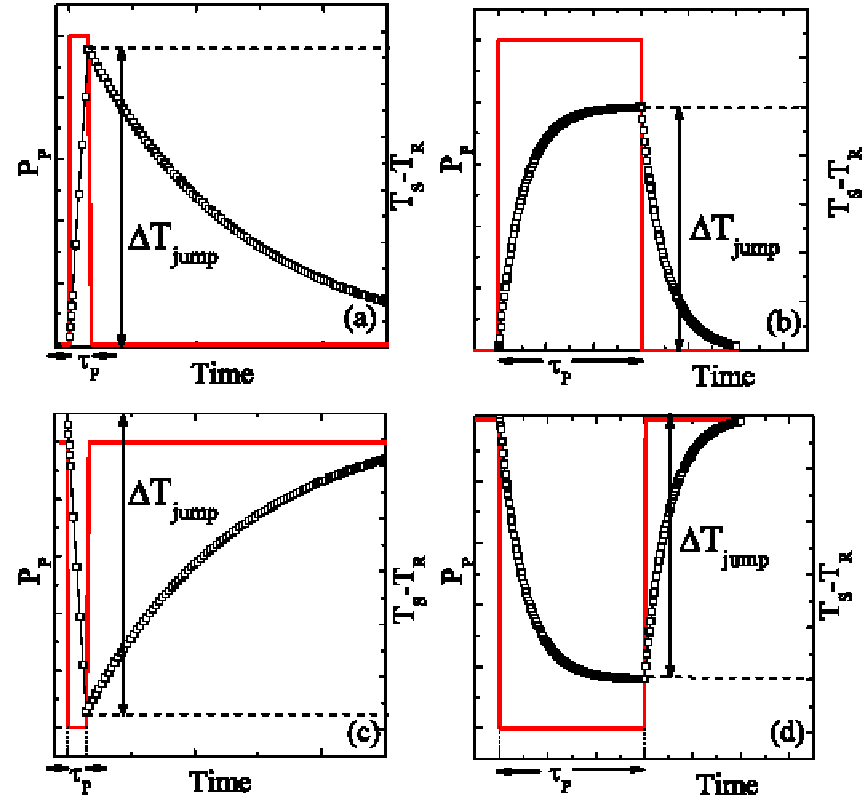
Energy fluctuation will lead to a fluctuation in temperature

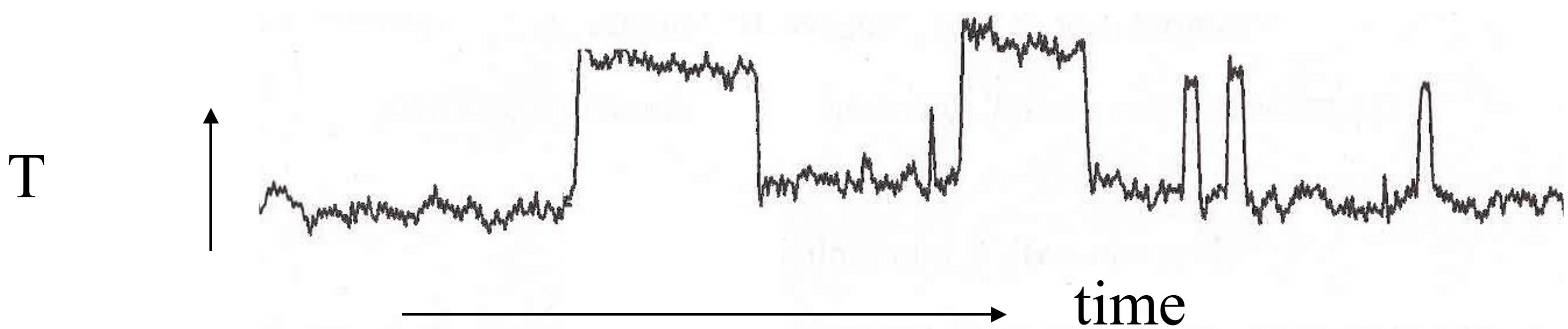
$$\Delta T = \Delta U / C_S$$

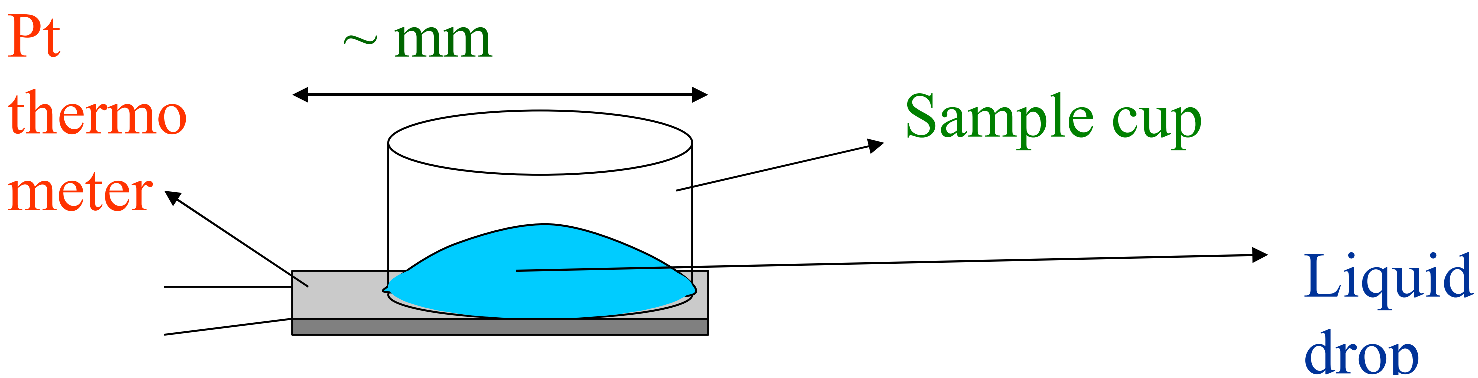
*What makes the fluctuation observable $C_S << C_R$*

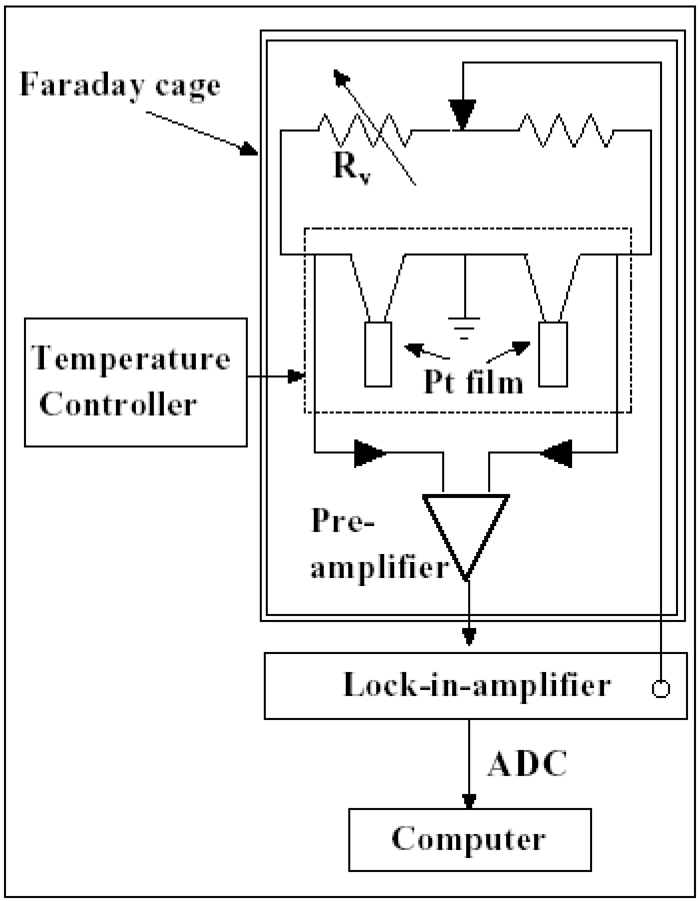

SSS
Sample
E absorbed
Substrate
Thermometer
Tsss
decreases
Isolated

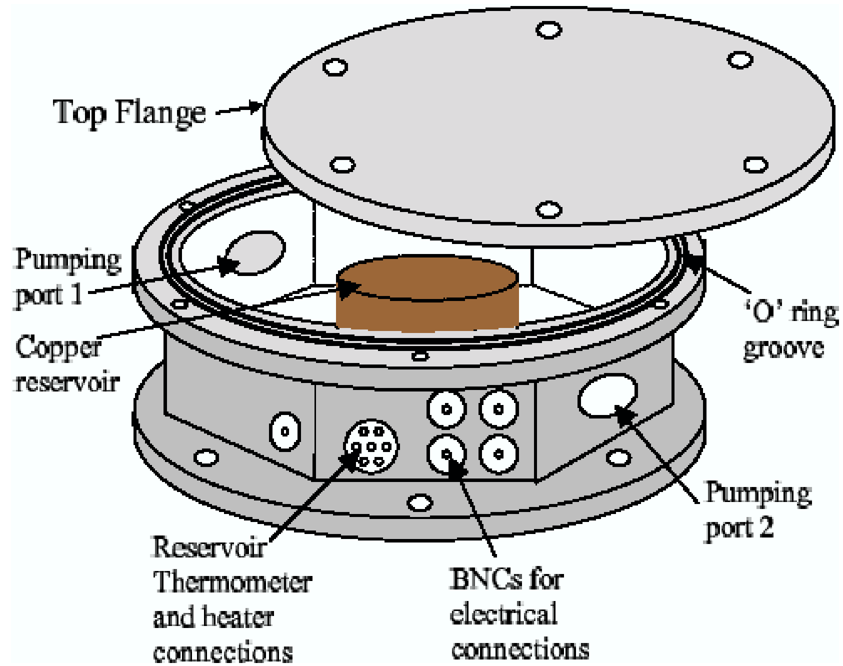

SSS
Sample
E released
Substrate
Thermometer
Tsss
increases
Isolated


P
T-T
ΔT
jump
Time
(a)
(b)
(c)
(d)


T
time


Pt
thermo
meter
~ mm
Sample cup
Liquid
drop


Faraday cage
$R_v$
Temperature
Controller
Pt film
Pre-
amplifier
Lock-in-amplifier
ADC
Computer


Top Flange
Pumping
port 1
Copper
reservoir
'O' ring
groove
Pumping
port 2
Reservoir
Thermometer
and heater
connections
BNCs for
electrical
connections

# Thermal fluctuation spectroscopy (FTS)

Energy fluctuation will lead to a fluctuation in temperature

$\Delta T = \Delta U / C_S$

<u>How large a fluctuation can we detect ?</u>

RMS fluctuation = $(<\Delta T^2>)^{1/2}$

Normalize RMS fluctuation = $(<\Delta T^2>)^{1/2} / T$

We can detect $(<\Delta T^2>)^{1/2} / T \approx$ *3-10 ppb.*

T =300K. Detectable temperature fluctuations ≈ 0.3-1μK

$C_S \sim$ 30 mJ/K. <u>Detectable energy fluctuation</u> ≈ <u>10-30 nJ</u>

<u>A ball park feeling –*can detect melting of 3-10 picogm of water*</u>

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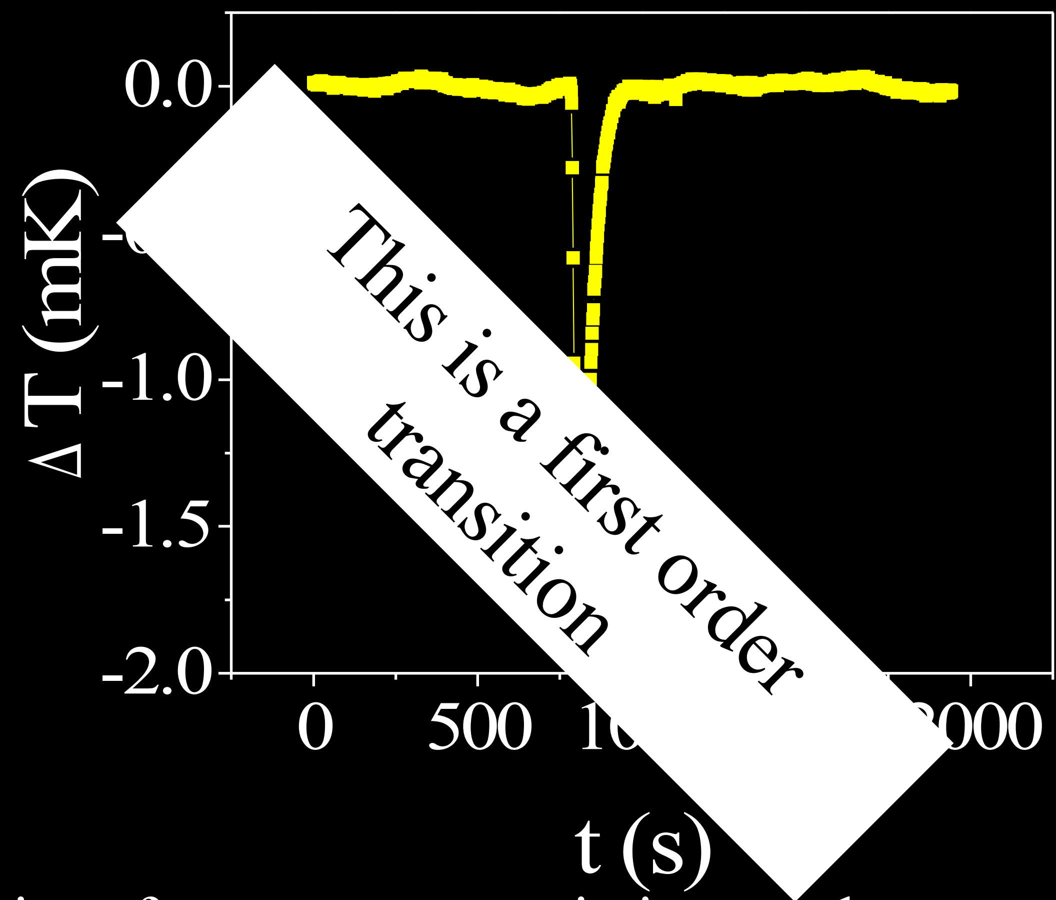
$C_S \sim$ 30 mJ/K. Detectable energy fluctuation ≈ 10-30 nJ

A ball park feeling *–can detect melting of 3-10 picogm of water*




Time series of temperature variations at the *nematic to liquid phase* transition for isotropic liquid crystal 4-pentyl-4'-cyanobiphenyl .

<u>Sample ~ few hundred nanolitre</u>

# Thermal Fluctuation Spectroscopy (TFS)*

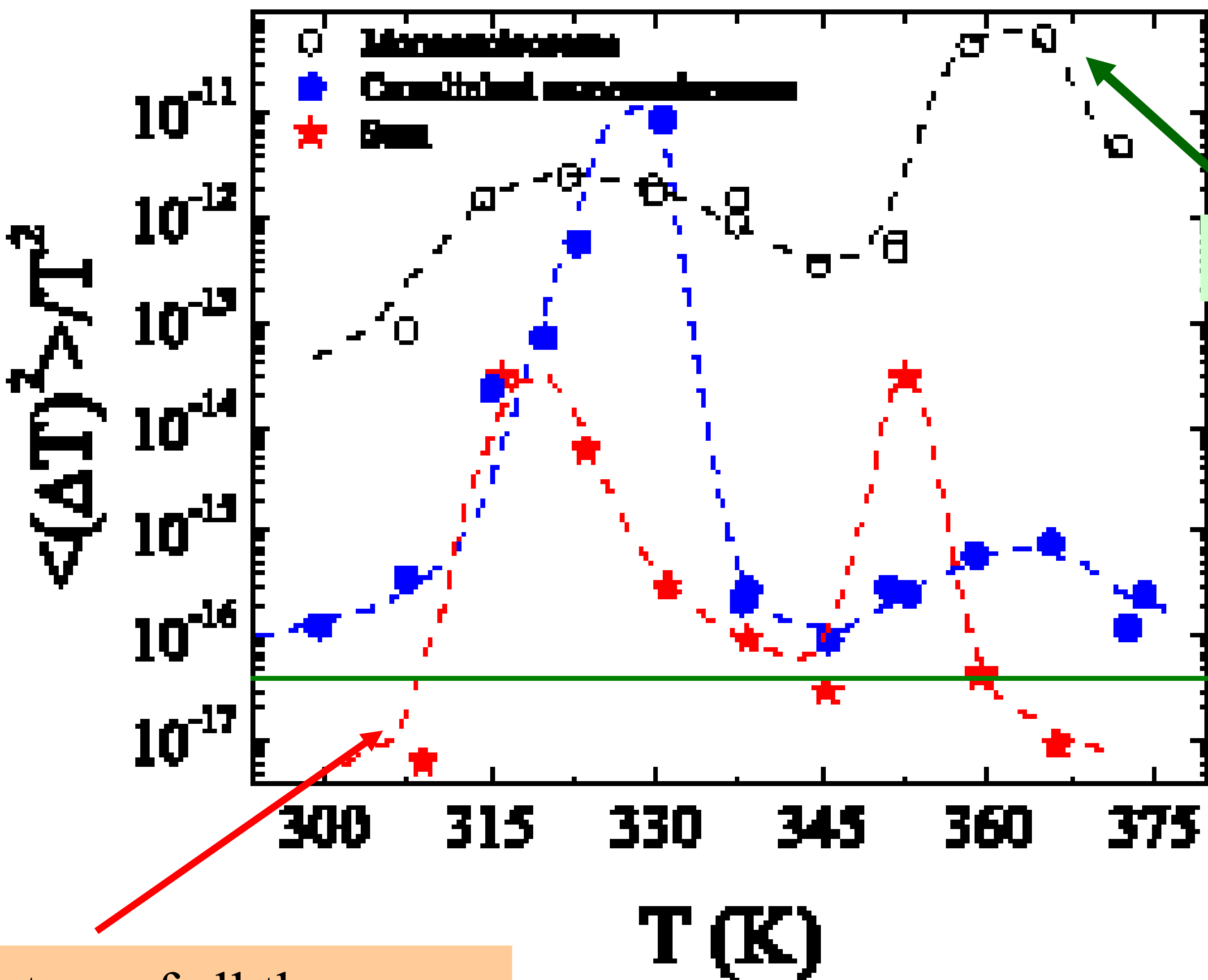
# (Thermal probe)

***Materials studied***

- DNA denaturation *
- Histones, oligomers of histones and monnucleosome

*K.S.Nagapriya , A.K. Raychaudhuri and G.V. Shivashankar

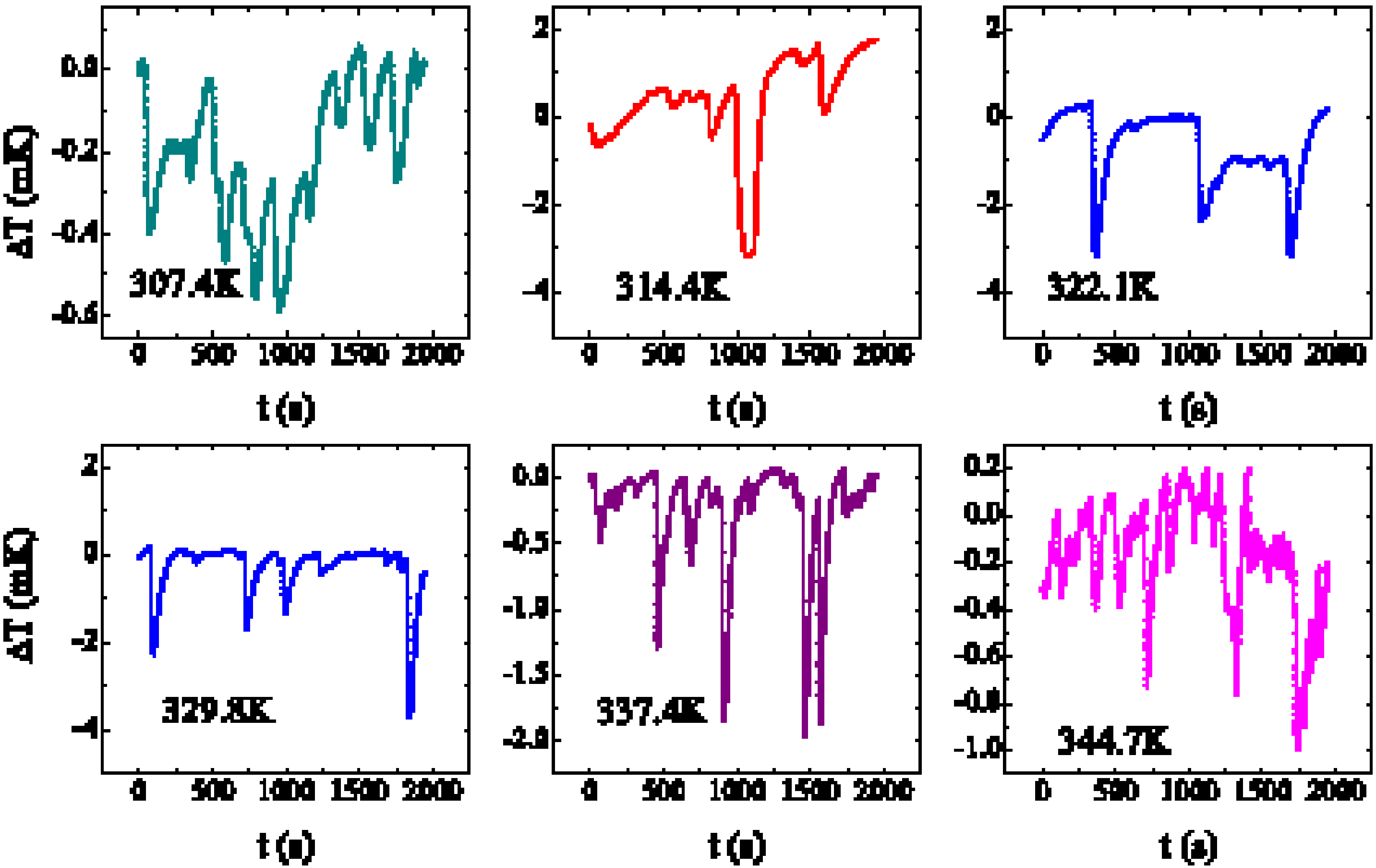
Submitted (2006)

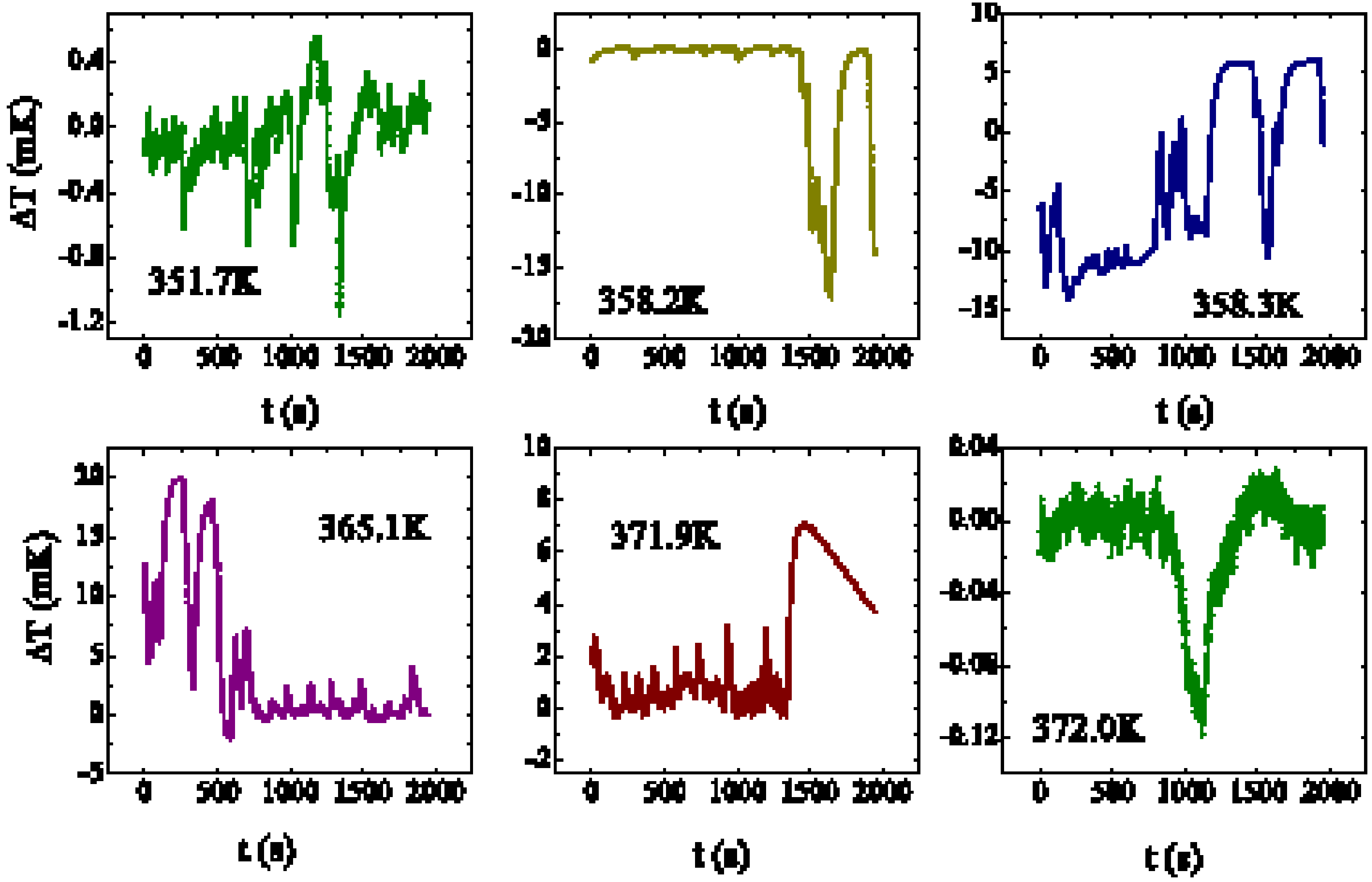



Nuclesome

Mixture of all the constituents in correct proportions

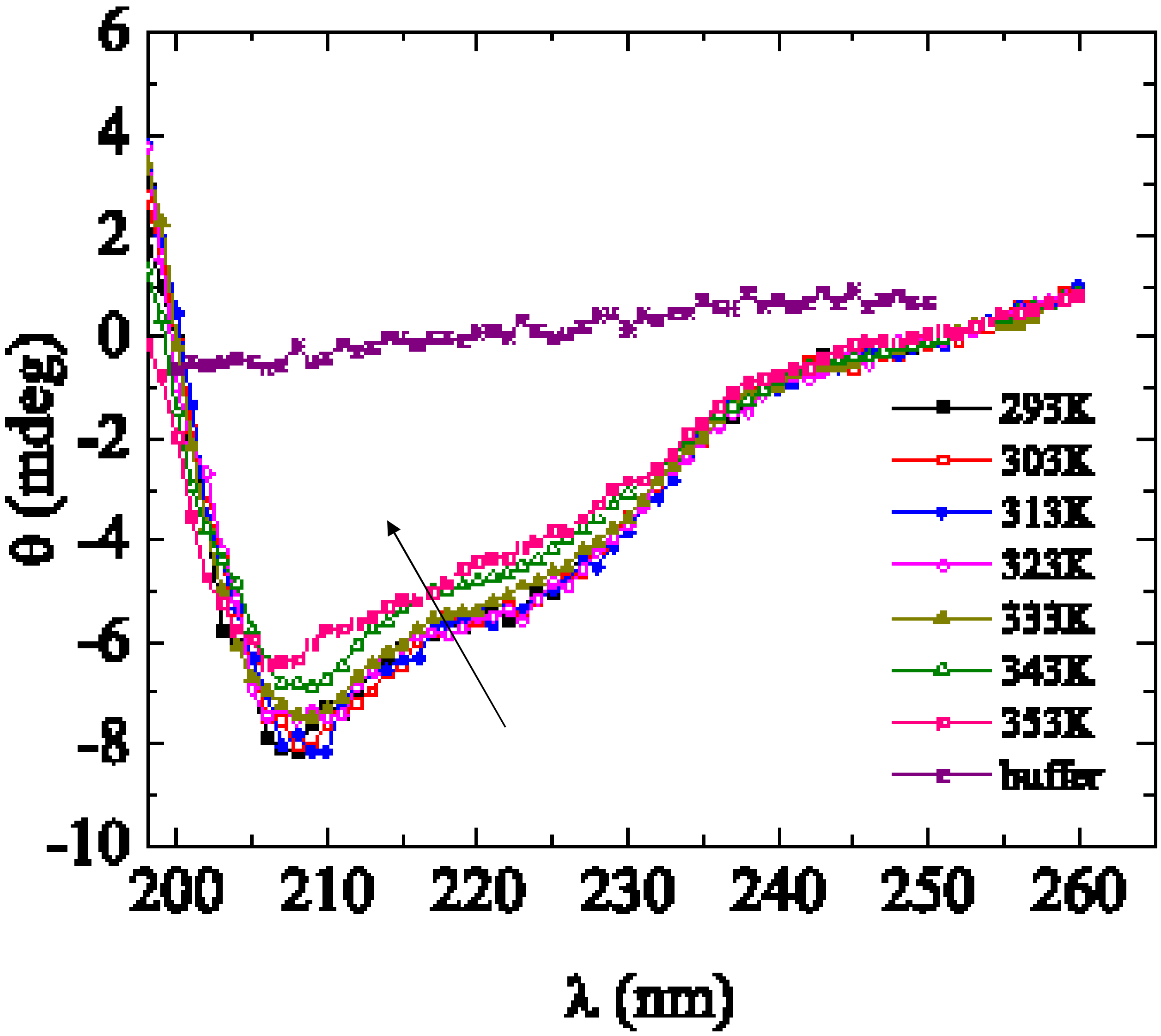
# Time series for nucleosome



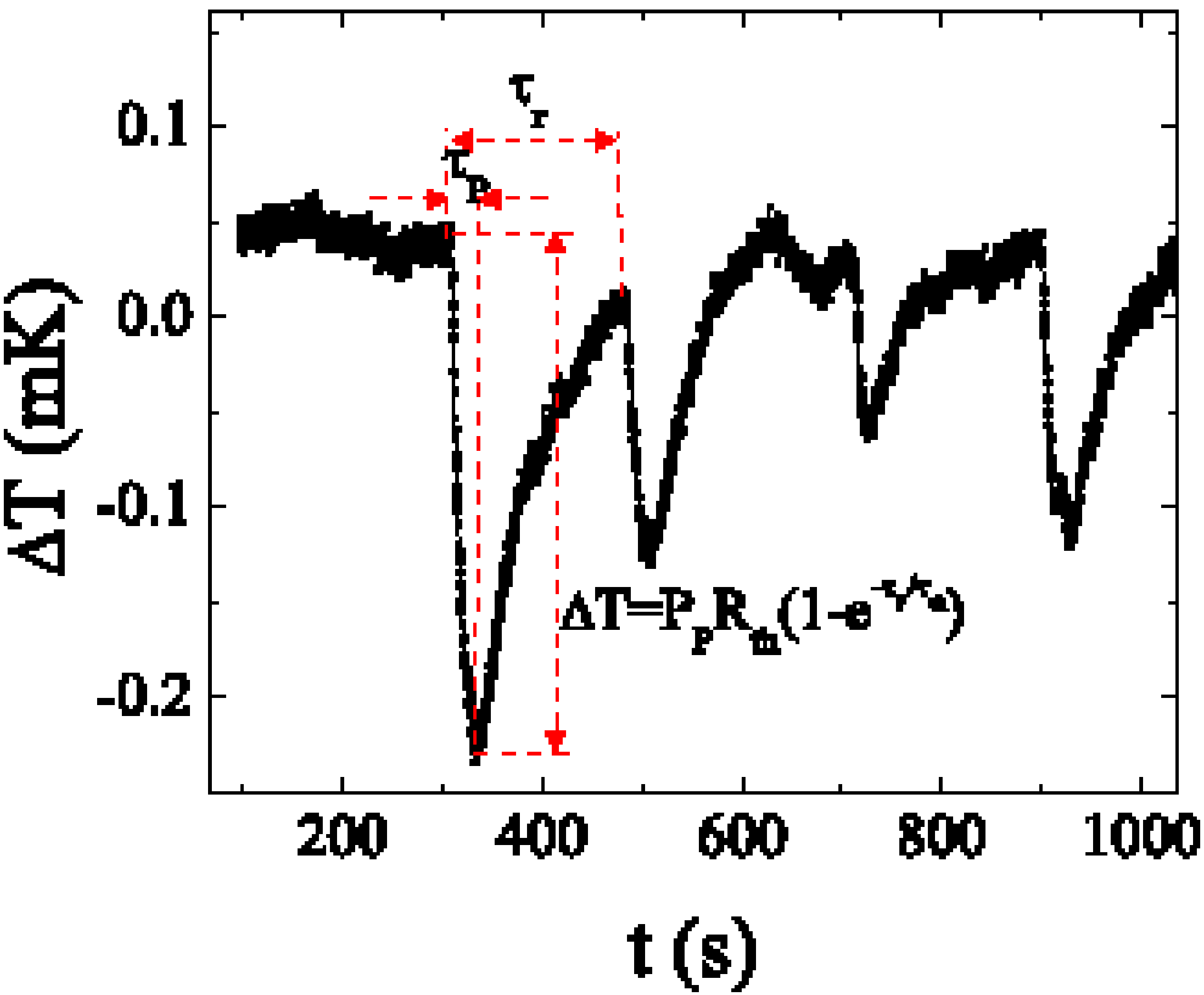


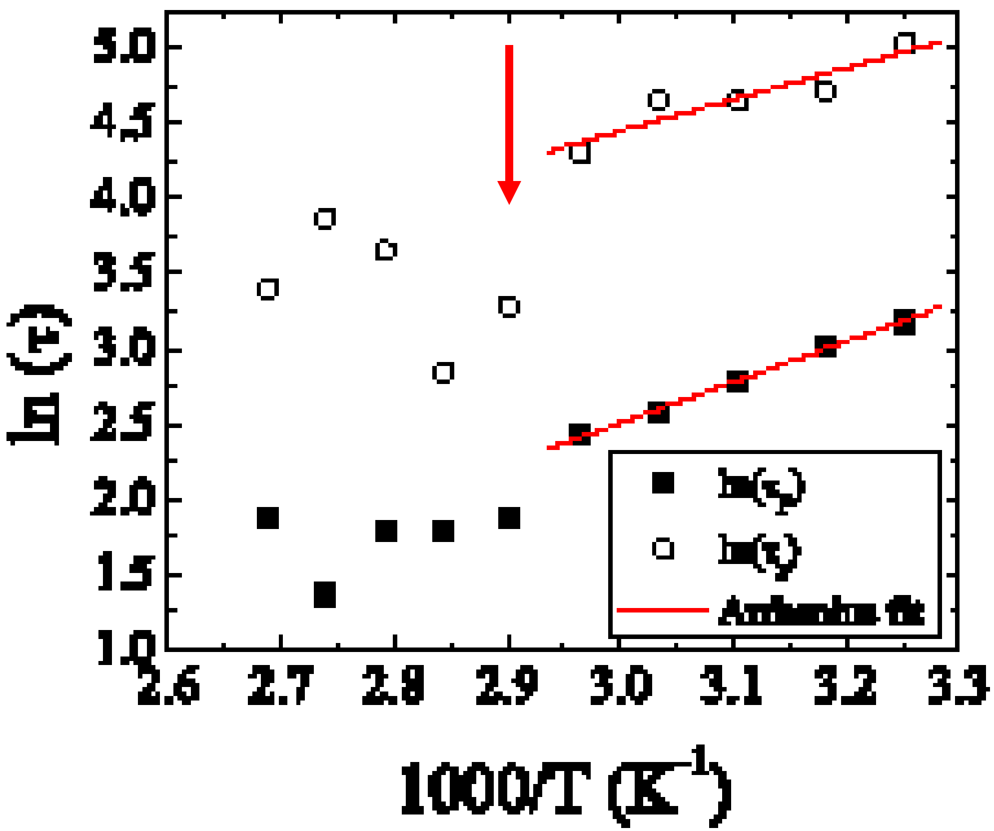
ΔT (mK)
t (s)
351.7K
358.2K
358.3K
365.1K
371.9K
372.0K

# Circular dichroism Spectra



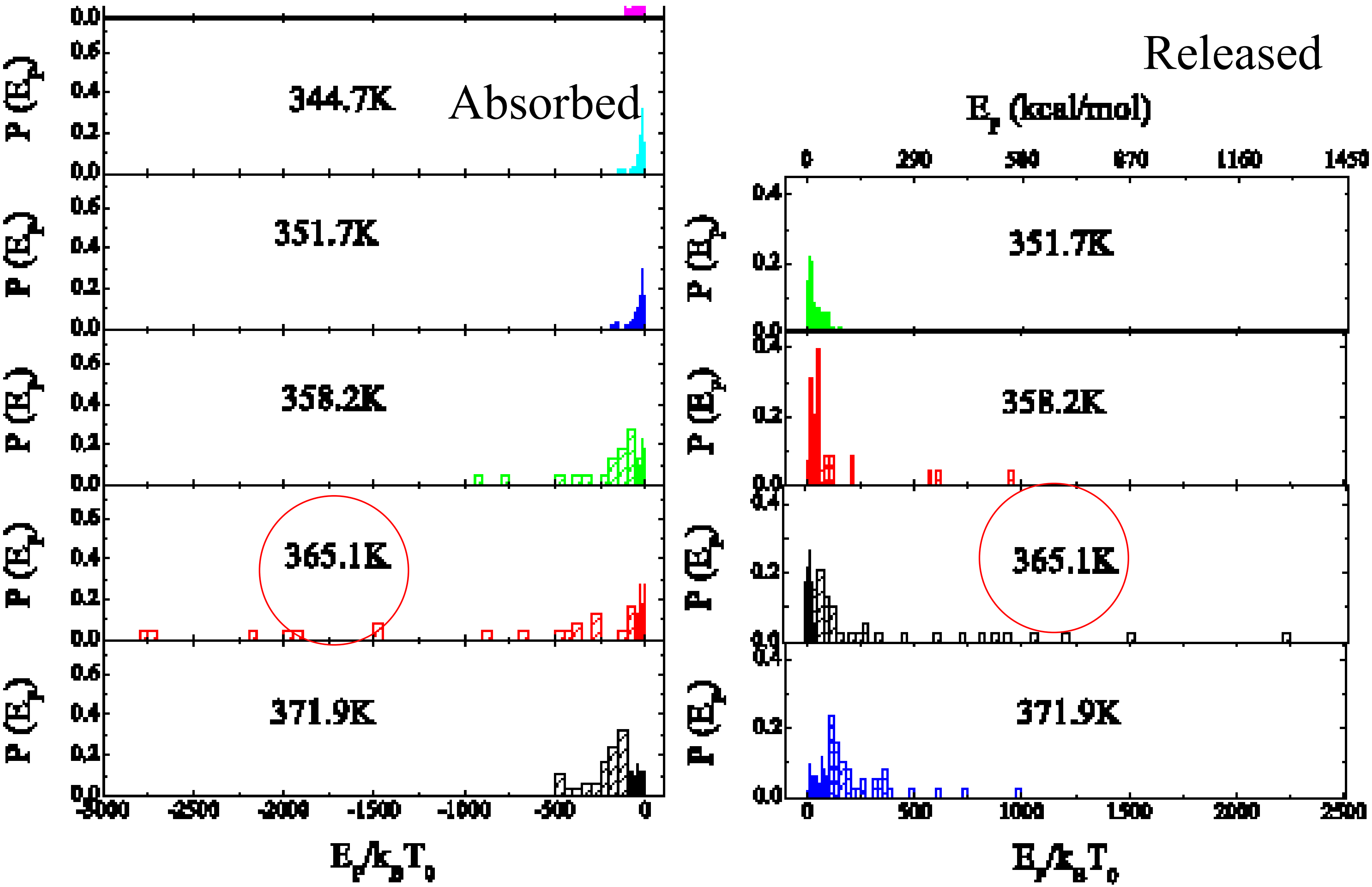
# Analyzing the “jump” data

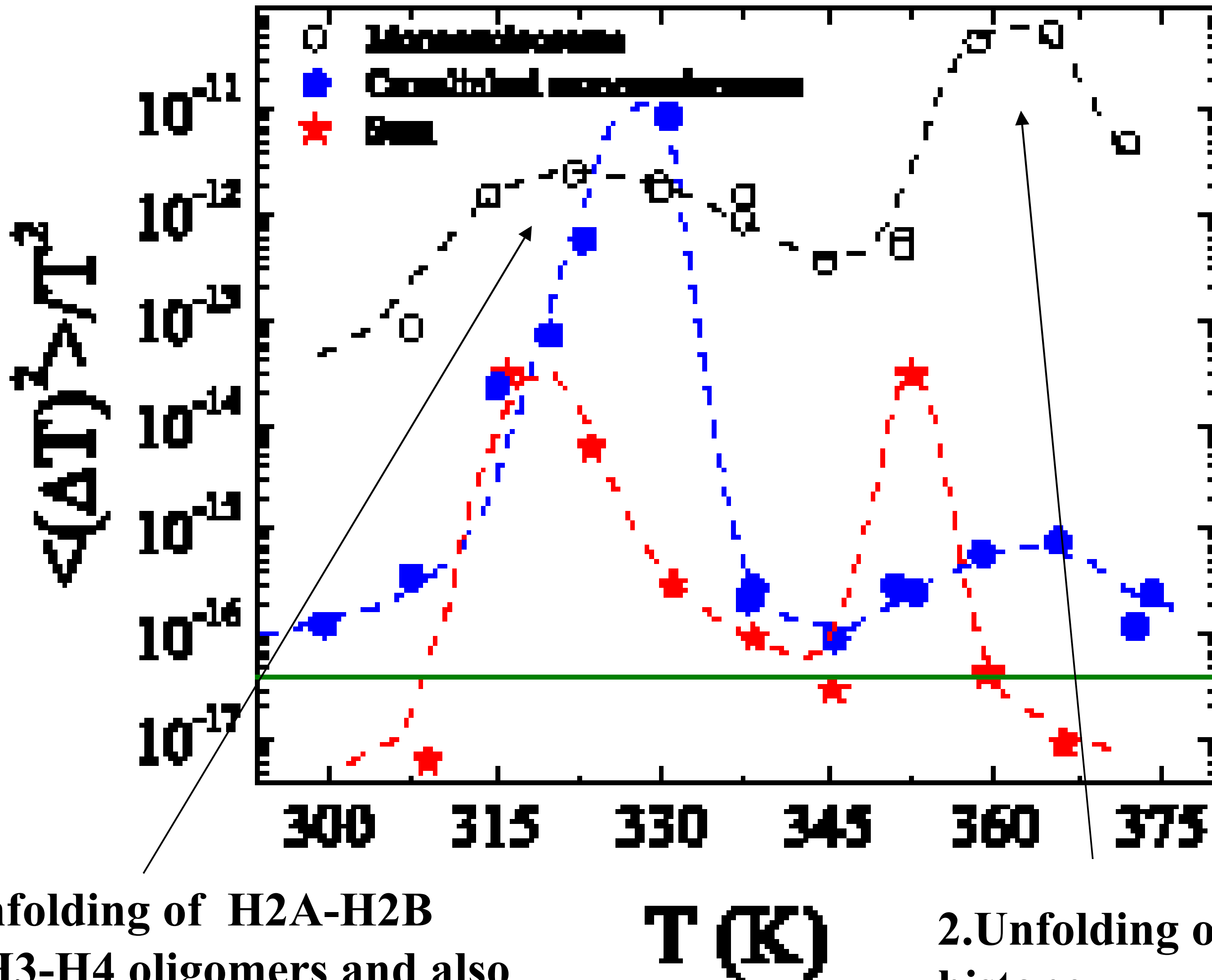





Activation energies ~ 4-5 Kcal/mole

# Distribution of energy in jumps






1. Unfolding of H2A-H2B and H3-H4 oligomers and also likely detachment of DNA

2.Unfolding of H1 linker histone

I tried to share my excitements with you -

The excitements of doing physics

Thank you