Research in Science impacting on Science Education

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Science is not conducted only based on rational arguments

If all was rational and equations then computers could conduct research.

Scientific research requires innovation.

What does this mean?

- To see things differently;
- To realize that something is not understood;
- To seek a “beautiful” answer - as simple as possible and as general as possible.

It should allow us to predict many new phenomena

What is required for being able to conduct innovative scientific research?

1. **Curiosity.** To ask “How and Why”.

The Question(s)-

Why we are doing this particular research?

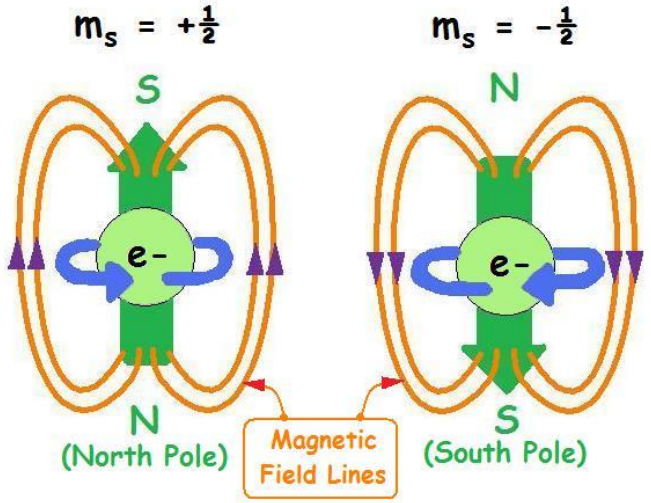
2. **One needs ‘grit’.** To perform the hard work and to be persistent all the way until you find the answer.

3. Finally, it is of course important to have the **knowledge** of the facts and methods to be able to perform the study that leads you to the answer.

The Chiral Induced Spin Selectivity (CISS) Effect

Electron Spin and Chirality
How are they related?

The Spin



The Electron's Spin

- It is the angular momentum of the electron. In a classical way one may think about it as the rotation of a top. It can rotate clockwise or anti-cloclwise and it has two values +1/2 and -1/2.
- Pauli principle (or Hund rule)- Two electrons can occupy one state only if they have the opposite spin.
- The spin is essential for explaining the periodic table.
- Typically one consider the spins in molecules only if they have unpaired electron.
- The electron's spin is not coupled to the molecular frame.

The Electron's Spin

Some History

- Bohr introduced his model without spin (1908);
- Stern Gerlach experiment in 1922 was not meant to measure Spin.
  It aimed at proving that the electron in a S state has angular momentum;
- George Uhlenbeck (December 6, 1900 – October 31, 1988)
  and Samuel Goudsmit (July 11, 1902 – December 4, 1978)
  were students of Paul Ehrenfest. They explained the hydrogen atom
  spectrum obtained by Sommerfeld;
- Dirac Equation formalized the Spin in 1928.

Letters to the Editor

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Spinning Electrons and the Structure

So far as we know, the idea of a quan
of the electron was put forward for the
A. K. Compton (*Journ. Frankl. Inst*
p. 145), who pointed out the possible b
idea on the origin of the natural unit
Without being aware of Compton's s
have directed attention in a recent
wissenschaften, Nov. 20, 1925) to the
applying the spinning electron to interp
of features of the quantum theory of
effect, which were brought to light
especially of van Lohuizen, Sommerfel
Pauli, and also of the analysis of comp
general. In this letter we shall try to s
hypothesis enables us to overcome certain
difficulties which have hitherto hindered
tation of the results arrived at by those

To start with, we shall consider the
spin on the manifold of stationary
corresponds to motion of an electr
nucleus. On account of its magnetic
electron will be acted on by a couple jus
placed at rest in a magnetic field of ma
to the vector product of the nuclear ele
the velocity of the electron relative t
divided by the velocity of light. This co
a slow precession of the spin axis, the
of the angular momentum of the atom
by a compensating precession of the
of the electron. This complexity of
requires that, corresponding to each st
of an imaginary atom, in which the el
spin, there shall in general exist a set of
differ in the orientation of the spin axis
orbital plane, the other characteristics
remaining unchanged. If the spin cor
one-quantum rotation there will be in
such states. Further, the energy differ
states will, as a simple calculation sh
portional to the fourth power of the n
It will also depend on the quantum n
define the state of motion of the non-spin

In conclusion, we wish to acknowledge our indebtedness to Prof. Niels Bohr for an enlightening discussion, and for criticisms which helped us distinguish between the essential points and the more technical details of the new interpretation.

G. E. UHLENBECK.
S. GOUDSMIT.

Institute voor Theoretische Natuurkunde,
Leyden, December 1925.

HAVING had the opportunity of reading this interesting letter by Mr. Goudsmit and Mr. Uhlenbeck, I am glad to add a few words which may be regarded as an addition to my article on atomic theory and mechanics, which was published as a supplement to NATURE of December 5, 1925. As stated there, the attempts which have been made to account for the properties of the elements by applying the quantum theory to the nuclear atom have met with serious difficulties in the finer structure of spectra and the related problems. In my article expression was given to the view that these difficulties were inherently connected with the limited possibility of representing the stationary states of the atom by a mechanical model. The situation seems, however, to be somewhat altered by the introduction of the hypothesis of the spinning electron which, in spite of the incompleteness of the conclusions that can be derived from models, promises to be a very welcome supplement to our ideas of atomic structure. In fact, as Mr. Goudsmit and Mr. Uhlenbeck have described in their letter, this hypothesis throws new light on many of the difficulties which have puzzled the workers in this field during the last few years. Indeed, it opens up a very hopeful prospect of our being able to account more extensively for the properties of elements by means of mechanical models, at least in the qualitative way characteristic of applications of the correspondence principle. This possibility must be the more welcomed at the present time, when the prospect is held out of a quantitative treatment of atomic problems by the new quantum mechanics initiated by the work of Heisenberg, which aims at a precise formulation of the correspondence between classical mechanics and the quantum theory.

N. BOHR.

Copenhagen, January 1926.

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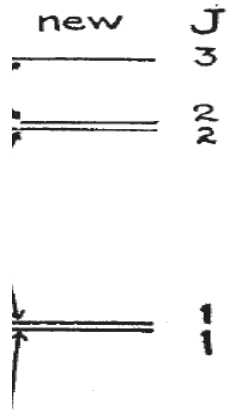
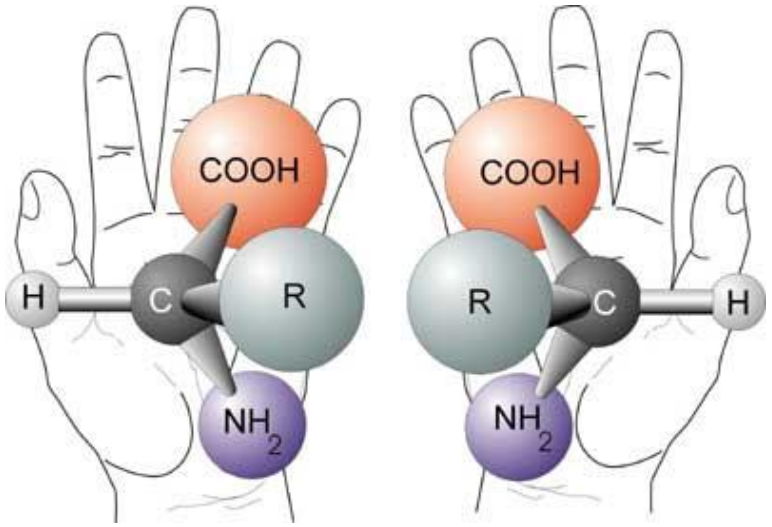
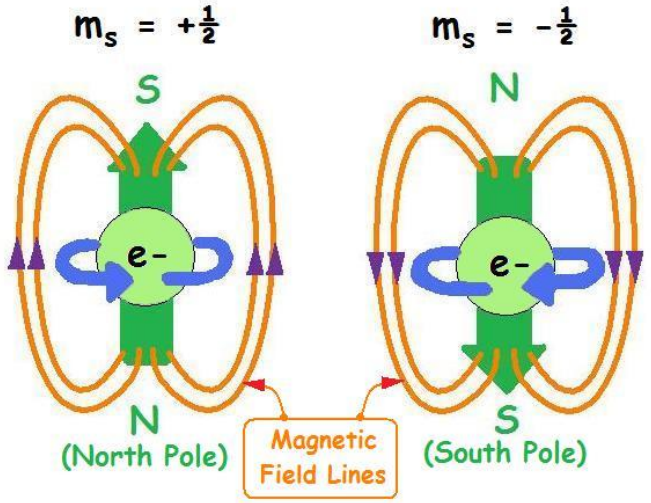


The Chiral Induced Spin Selectivity (CISS) Effect

Chiral Molecules





Chiral Molecules

- Since Pasteur and Lord Kelvin in the late 19th century-
  It was recognized as structural property solely
  (except of the optical activity of chiral molecules).
- Biomolecules appear with mainly one handedness in biological organisms-homochirality. Its origin has been debated for decades.
- The ‘conventional wisdom’ about chirality in biomolecules is that it serves as a structural motif to place chemical functionalities in defined positions and orientations that enable biologically relevant functions.

Despite the fact that homochirality in biological organisms represents an entropy reduction that increases the organisms Gibbs free energy, the question

> “why nature kept chirality so persistently through evolution?”

was rarely asked, and as far as I know was never answered.

Why and How?

- Why are electrons transferred in bio-systems through proteins that are insulators and not through highly conductive molecules?
- Why is chirality conserved so persistently in Biology?
- How can nature be so enantio-selective?

The Chiral Induced Spin Selectivity (CISS) effect

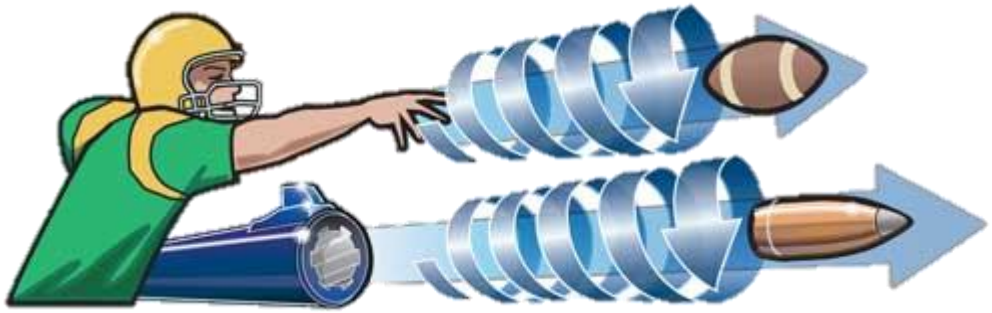
What is the CISS effect ?

The rifle effect- Rifle is a gun with groves

Coupling angular with linear momenta

How can it be transferred to molecular systems ?

The CISS effect



Asymmetric Scattering of Polarized Electrons by Organized Organic Films of Chiral Molecules

K. Ray, S. P. Ananthavel,* D. H. Waldeck,† R. Naaman‡

5 FEBRUARY 1999 VOL 283 SCIENCE

Langmuir Blodget films of L or D stearoyl lysine

Major contributor:
Itai Carmeli

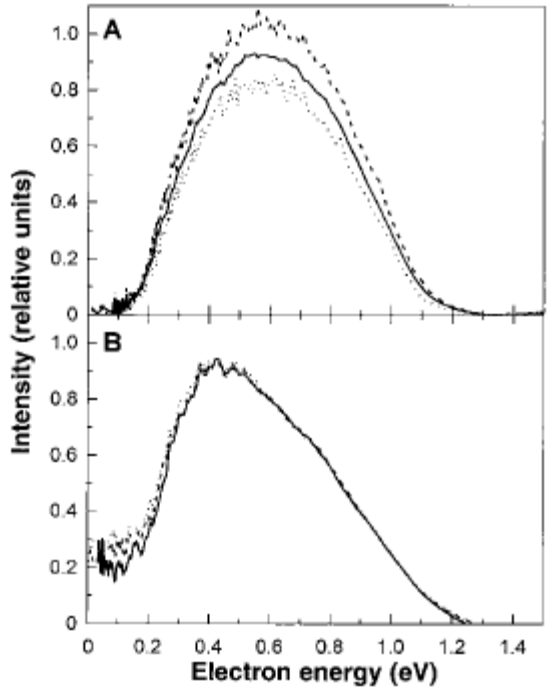
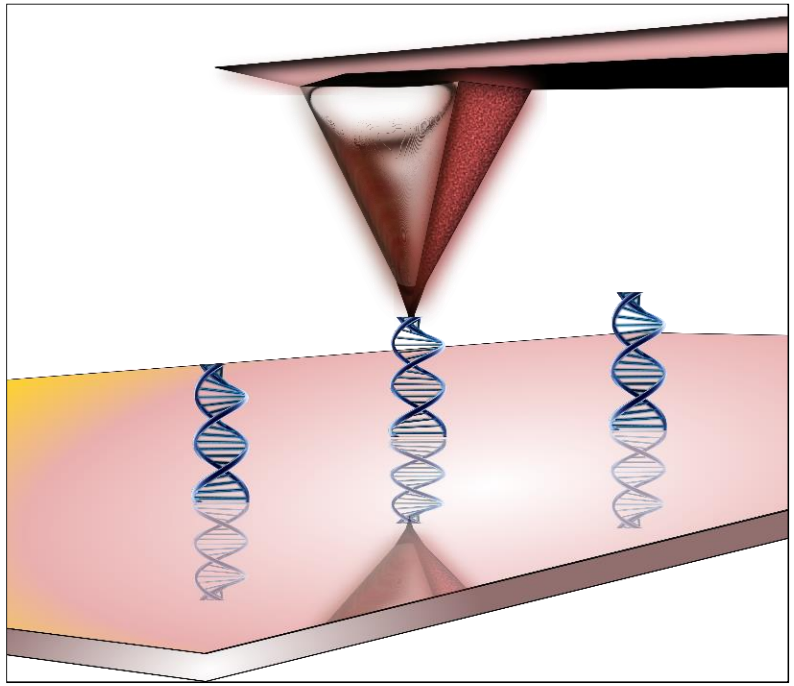


Fig. 2. Electron energy distribution for five layers of L-stearoyl lysine (**A**) and for a five-layer structure in which the monolayers were 99% L-stearoyl lysine and 1% D-stearoyl lysine (**B**). The photoelectrons were ejected with linearly polarized light (solid line), right-handed circularly polarized light (dashed lines), and left-handed circularly polarized light (dotted lines).

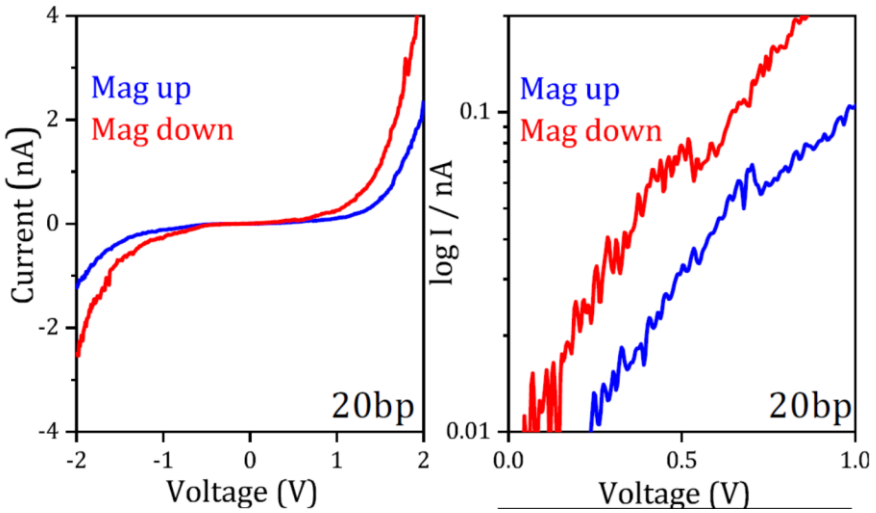
What are the molecular properties that affect the magnitude of the spin polarization?

DNA

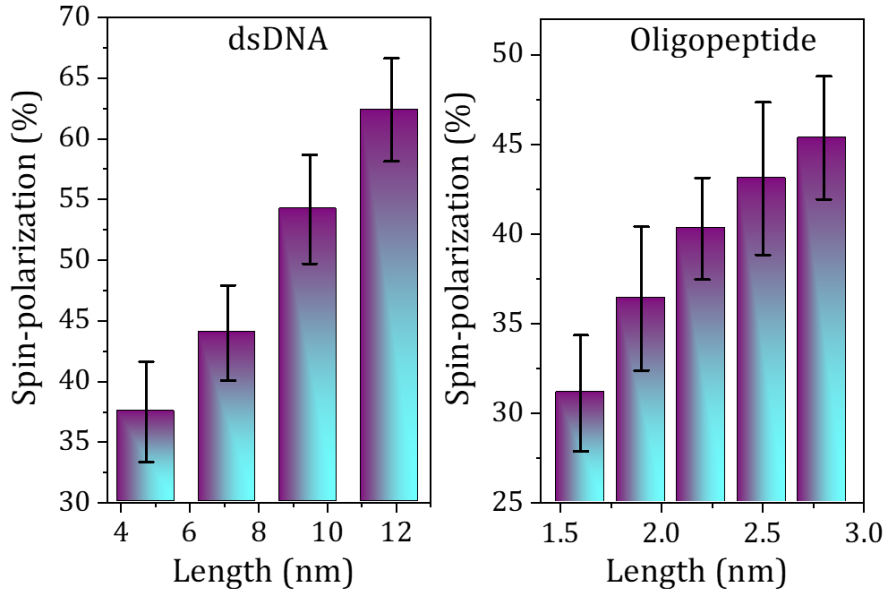
Length dependent of the CISS effect



Typical I *vs* V curves



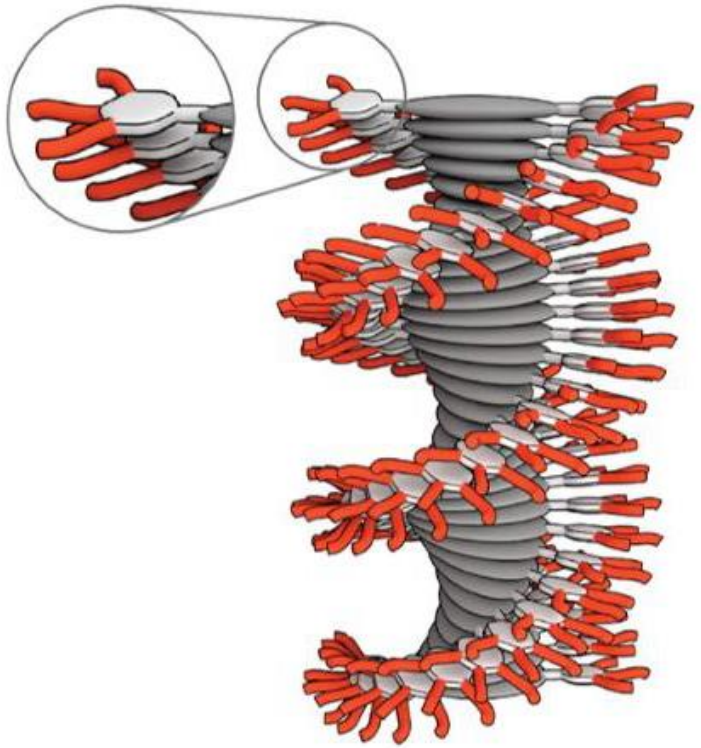
Length Dependent Spin Polarization

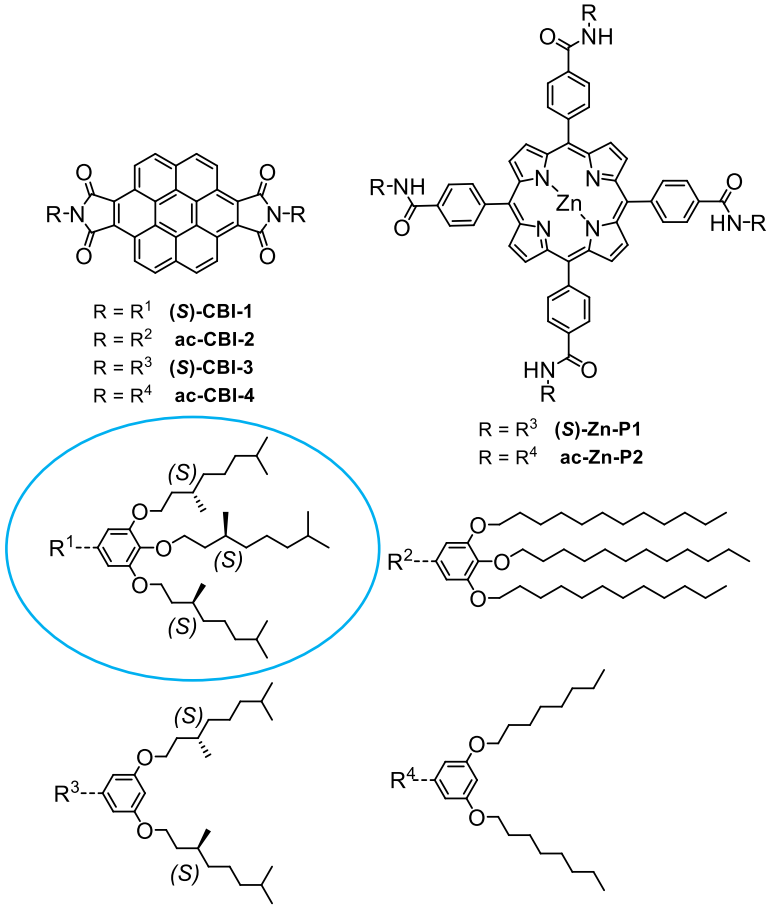


S. Mishra, A. K. Mondal, S. Pal, T. K. Das, E. Z. B. Smolinsky, G. Siligardi, R. Naaman, *JPC C* 124, 10776-10782 (2020).

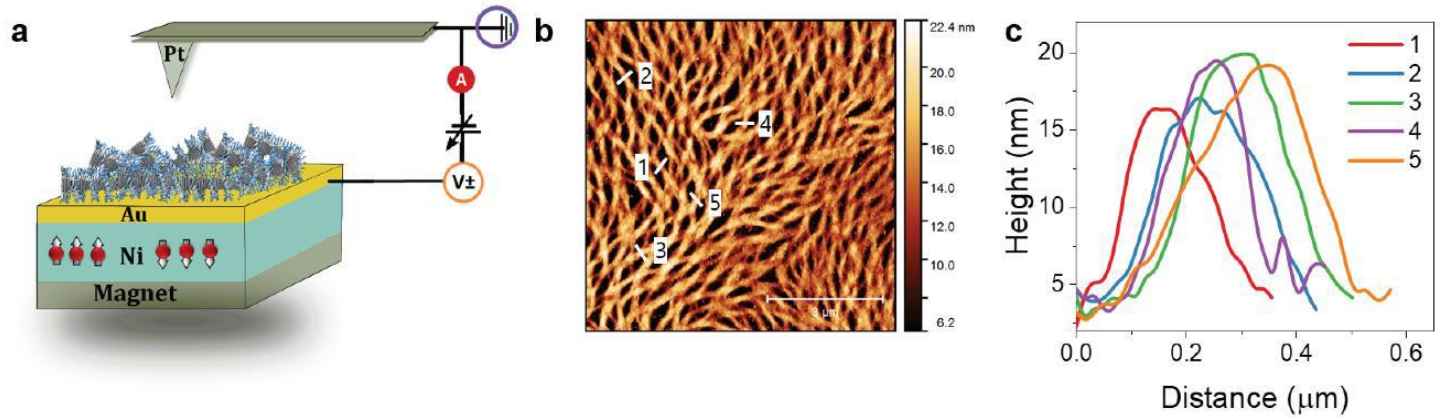
In collaboration with E.B. Meijer- Eindhoven

Chiral and Achiral Fibers





C. Kulkarni, A. K. Mondal, T. K Das, G. Grinbom, F. Tassinari, M. F. J. Mabesoone, E. W. Meijer, R. Naaman, *Adv. Mat.* 1904965 (2020).


a
Pt
A
V±
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Magnet
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18.0
16.0
14.0
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10.0
6.2
1
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Height (nm)
Distance (μm)
0.0
0.2
0.4
0.6
5
10
15
20
1
2
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4
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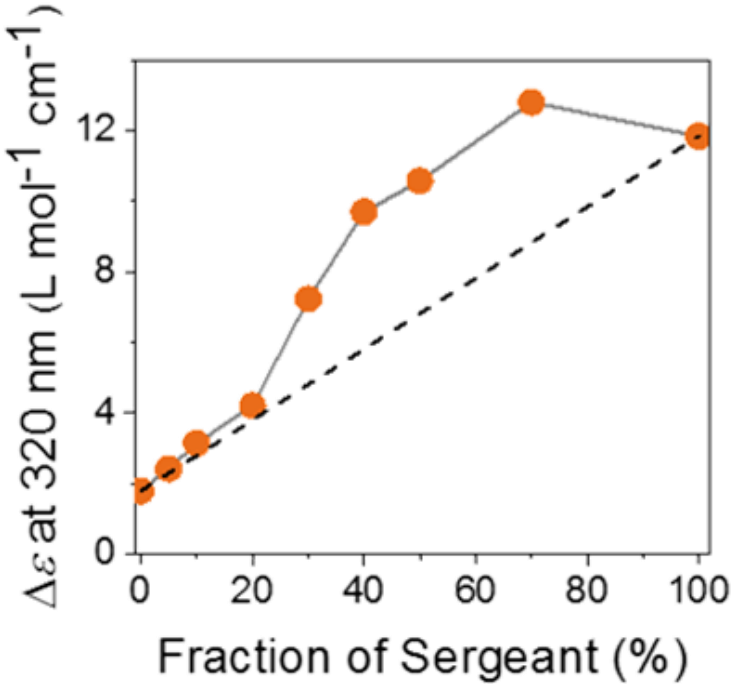
Sergeant and Soldier (S&S) principle for CBI-35 system

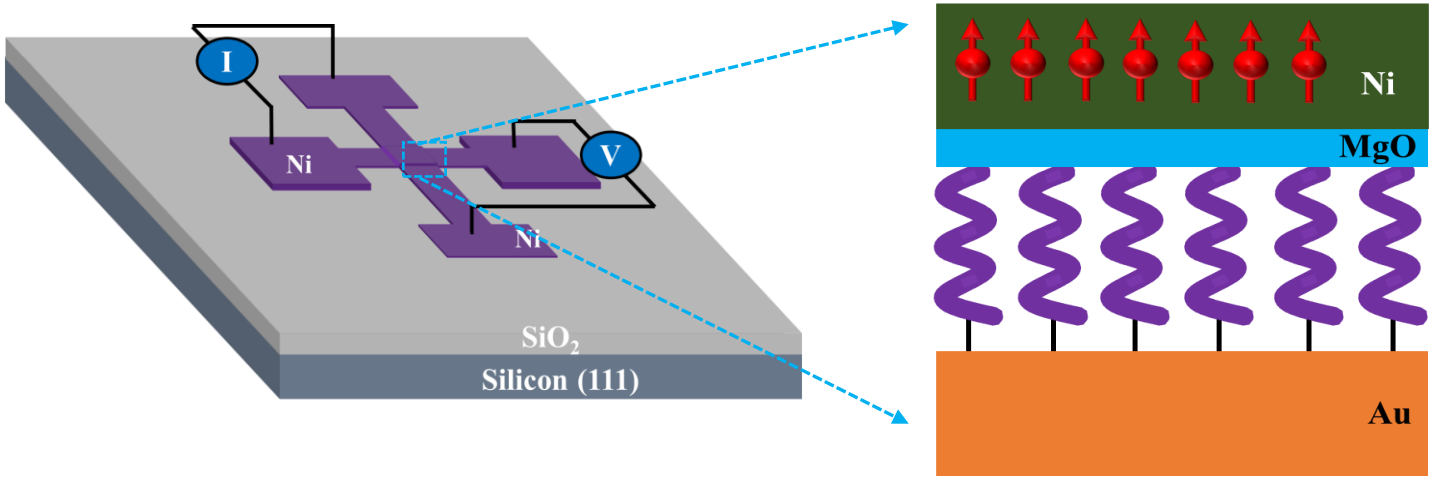
Intensity of the CD peak at 320 nm

a)

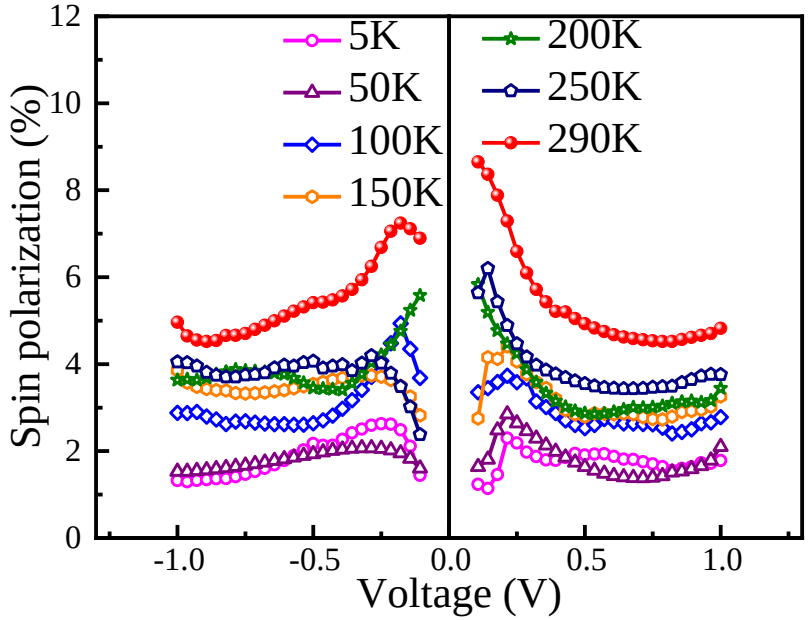


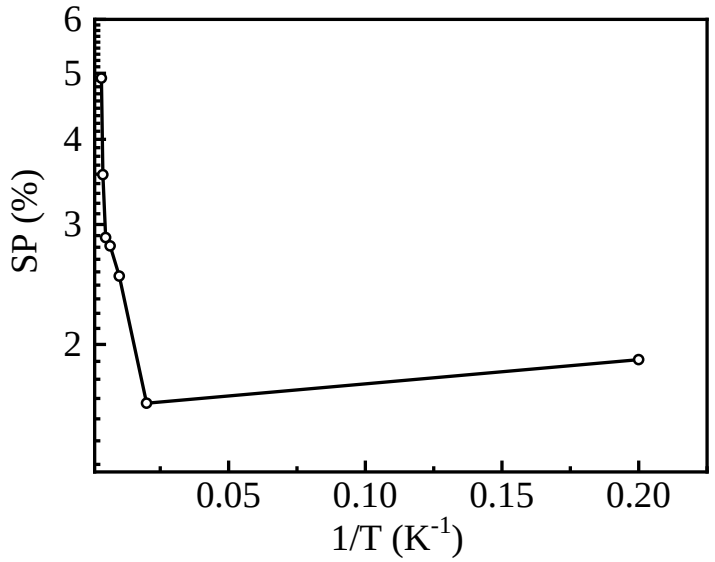
There is correlation between the optical activity and the spin polarization

The role of vibrations

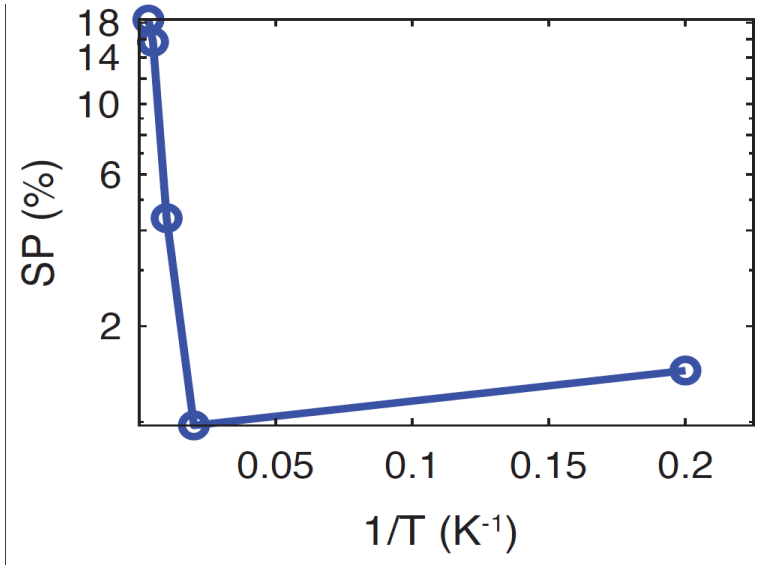


Spin polarization (%)=$(I_{up}-I_{down})/(I_{up}+I_{down})*100$





Theory by:
Jonas Fransson
Uppsala University



The CISS effect is a
"room temperature" effect-
It increases with temperature.

This is opposite to what is known in solid state spintronics devices that work better at low temperatures.

Why and How?

? Why are electrons transferred in bio-systems through proteins that are insulators and not through highly conductive molecules?

! The electron transfer is efficient due to the lack of back scattering. No need for high current

? Why is chirality conserved so persistently in Biology?

! It helps in electron transfer, in bio-recognition, and in controlling redox reactions

? How can Nature be so enantio-selective?

! Beside shape, there is also an electronic term in the interaction that is chiral specific, operating at very short distances

Chiral Molecules and Systems

Pasteur

Chiral molecules-

Pasteur, Lord Kelvin (late 19th century)

Lord Kelvin

Magneto-Chiral
J. A. Rikken

Optical activity

Structural properties

Asymmetric synthesis, enantioseparation

The Chiral Induced Spin Selectivity (CISS) effect (1999)

Electronic and Spintronic properties

Enantiospecific interaction

Enantioseparation

Controlling multiple electrons reactions

Spin selective chemistry

Spintronics applications

Take Home message

- In my opinion the most important part of education in general is to make the students to ask questions;

- In Science Teaching we have to teach three important and sometime conflicting subjects-

i) The process of asking questions and perusing the answers.

ii) The scientific method of searching for answers.

iii) The scientific language: What we **usually** call “learning the facts”.

Thank You

Special thanks to my long time collaborators:
David H. Waldeck, Pittsburgh, **Yossi Paltiel**, Hebrew University

MAX-PLANCK-GESELLSCHAFT
Minerva Foundation

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