

Hitchhiking in the nanoworld

Anjan Kr. Dasgupta adgcal@gmail.com

Sept 2020

Prelude

Hitchhiking in the
nanoworld

Anjan Kr.
Dasgupta
adgcal@gmail.com

Hitchhiking is an unstructured but primitive pivot for human quests. We have hitchhiking traits in our genes. Genetic hitchhiking (or genetic drift) is allele frequency change, caused by neighbouring genes.



Quote

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Anjan Kr.

Dasgupta

adgcal@gmail.com

"Tiny hitchhikers attack cancer cells: Gold nanostars first to deliver drug" - *Is it like requesting a UFO for a ride?*



Failed in Bio - Created nano

Hitchhiking in the
nanoworld

Anjan Kr.

Dasgupta

adgcal@gmail.com

- ▶ Nanotechnology has evolved as a result of some inherent shortcoming of related branches of science e.g., biology.
- ▶ Feynman realized, one needs a science like nanotechnology only after he was frustrated with his biology PostDoc.

Definitions

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Anjan Kr.

Dasgupta

adgcal@gmail.com

- ▶ **Nanoscience** is the study of structures and materials on an ultra-small scale (A nanometre is one billionth of a metre).The physical and chemical properties of matter change at the nano level.
- ▶ **Nanotechnology** has the potential to revolutionise a diverse range of fields, from health care to manufacturing, agriculture to environment, textile to sensing.

Nanomaterials Database

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Anjan Kr.
Dasgupta
adgcal@gmail.com

If 50% or more of the constituent particles of a material in the number size distribution have one or more external dimensions in the size range 1 nm to 100 nm, then the material is a nanomaterial.

- ▶ <http://www.pubvinas.com>
- ▶ <https://cananolab.nci.nih.gov/caNanoLab/#/>

Classification

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Anjan Kr.

Dasgupta

adgcal@gmail.com

The classification of nanomaterials is based on the

- ▶ *number of dimensions of a material, which are outside the nanoscale (<100 nm) range.*

Examples of Dimensionality variations

0D

Accordingly, in zero-dimensional (0D) nanomaterials all the dimensions are measured within the nanoscale (they are essentially tiny 3D materials). **Qdots** are often termed as 0D material.

1D

In one-dimensional nanomaterials (1D), one dimension is outside the nanoscale. **Borophene, Graphene, SAM**

2D

In two-dimensional nanomaterials (2D), two dimensions are outside the nanoscale.

Nanofibres, Nanorod, Nanotube, Nanowire, Quantum wire

3D

Three-dimensional nanomaterials (3D) are materials that are not confined to the nanoscale in any dimension. This class can contain **bulk powders, dispersions of nanoparticles, bundles of nanowires, and nanotubes as well as multi-nanolayers**.

Nano-Trends

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Anjan Kr.

Dasgupta

adgcal@gmail.com

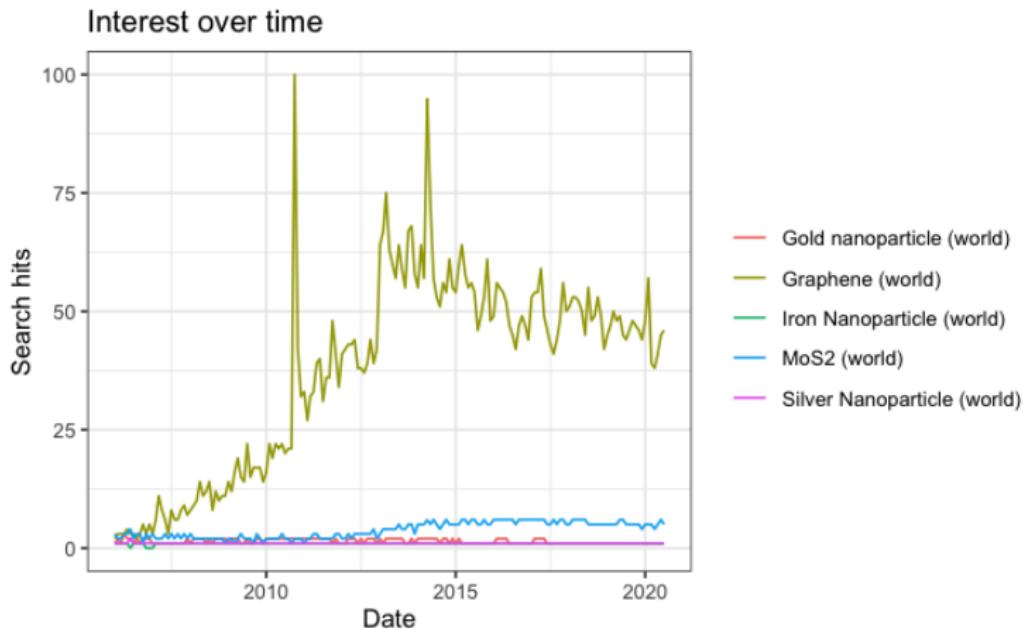


Figure 1: Nanotrend

Our Nanotour began in the year 2006

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Anjan Kr.
Dasgupta
adgcal@gmail.com



ATIP SCOOP™

*Country: India
Technology: Advanced Materials, Biology,
Bio-Nano, Biotechnology, Conferences,
Environmental Remediation,
Government Funding*

Nano-Bio Interface 2006 Kolkata, India, 1–3 March 2006

10 June 2006

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This document is formatted for US letter-size paper

Contents:

1. Overview of Nano-Bio Interface 2006
2. Important Lectures and Presentations
 - A. International Guest Speakers
 - B. Domestic Guest Speakers
 - C. Oral and Poster Presentations
3. ATIP Evaluation
4. References & Contacts

First ever nanobio meet ever held

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Anjan Kr.
Dasgupta
adgcal@gmail.com



The Nanocentre proposal

The proposal for the nanocentre came out in the next year - A significant portion of the proposal contained the small progress that we achieved in our lab at that time.

The image consists of two main parts. On the left is a poster for an "International Conference Nano-Bio Interface 2006" held at Calcutta University. The poster features a blue background with a white rectangular frame containing a hand holding a DNA double helix. Below this is a photograph of laboratory equipment, specifically a freeze-dryer unit. The text on the poster includes "International Conference", "Nano-Bio Interface 2006", "150 years of Calcutta University", "Dr. B.C. Guha Centre for Genetic Engineering & Biotechnology", "Faculty of Science, University of Calcutta", "35, Ballygunge Circular Road, Kolkata - 700 019", and "Venue : SINP Auditorium, Kolkata, Date : 1-3 March 2006". On the right is the logo for the "Centre for Research in Nanoscience and Nanotechnology" (CRNN). The logo features a circular emblem with a stylized atom or molecule model, the letters "CRNN" in a large serif font, and the full name of the center below it.

The proposal for the nanocentre
came out in the next year -
proposal contained the small progress that we achieved in our lab at that time.

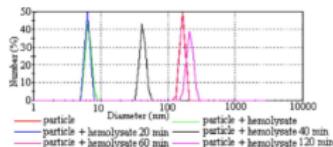
- ▶ We started our almost random nanowalk in the year 2006
- ▶ Jaydeep was working on folding of a protein which most of the protein scientists avoid, but many medical biologists love
- ▶ It was hemoglobin
- ▶ The clinical angle came out from the fact that the hemoglobin structure varies considerably in a disease called thalassemia
- ▶ With the help of Dr. P.Sen who was in possession of copper nanoparticles (using top down ball mill methods) we attempted to study Hb folding using CuNP

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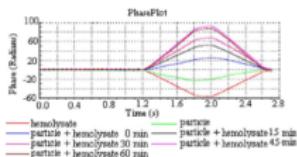
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adgcal@gmail.com

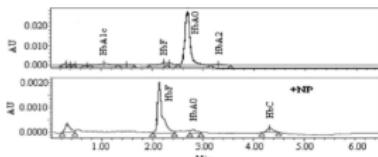
Interaction of hemoglobin and copper nanoparticles: implications in hemoglobinopathy



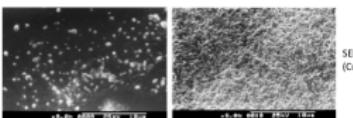
Size distribution of nanoparticles, nanoparticle-hemolysate complex, and their respective size changes with indicative colors.



Zeta potential-dependent phase of copper nanoparticles (CuNPs), CuNPs plus hemoglobin, and their changes with time, represented in different colors.



Comparison of soluble fraction of hemolysate before (upper panel) and after (lower panel) addition of copper nanoparticles (CuNPs). The soluble fraction was prepared after pre-incubation with 1.5 ppm of CuNPs for 1 hour and then centrifuging at 4000g to remove aggregates. High-pressure liquid chromatography was run using the Chromsystems kit under identical flow conditions.



SEM image of copper nanoparticles (CuNPs) and CuNPs + HbA0

Interaction of Hemoglobin and Copper Nanoparticle: Implications in Hemoglobinopathy;
Jaydeep Bhattacharya, Upal Choudhuri, Omprakash Swarach, Prasenjit Sen, Anjan K Dasgupta*;
Nanomedicine:nanotechnology, biology, and medicine 2[3](2006)191-199

Patent: NOBEL METAL NANOPARTICLE SPECIFIC INTERACTIONS IN CLOSELY HOMOLOGOUS HEMOGLOBIN. 39/DEI/2006



Jaydeep Bhattacharya
Assistant Professor
School of Biotechnology, JNU

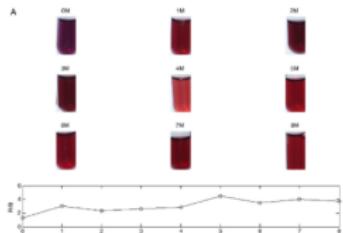
- ▶ In the mean time a new student Tapan (late Tapan Das) synthesized AuNP in our lab.
- ▶ Jaydeep thought it worth trying to probe hemoglobin folding using AuNP
- ▶ Here is what we got

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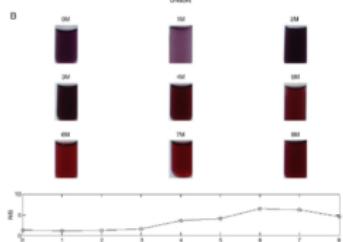
Dasgupta

adgcal@gmail.com

Gold nanoparticle-based tool to study Hemoglobin conformational variants



Unfolding of haemoglobin and BSA were compared in presence of 0-8 M urea by synthesizing the gold nanoparticles from the unfolded template. The different folded states resulted in different size and plasmonics of GNPs and enabled to define the folding states.

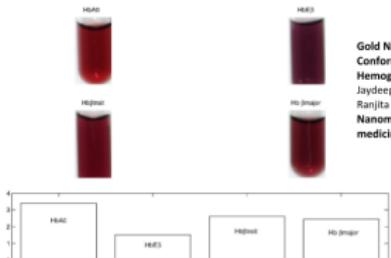


GNPs synthesized from Unfolded (4M urea) haemoglobin variants were compared. The E beta variant was more bluish, as revealed from the diagram, and this was followed by the beta major and beta trait. The normal had the maximal red colour. So the plasmonic based folding sensor can differentiate between protein variants too and can be used as carrier detection

Jaydeep Bhattacharya
Assistant Professor
School of Biotechnology, JNU



Gold Nano Particle Based Tool to Study Protein Conformational Variants: Implications in Hemoglobinopathy;
Jaydeep Bhattacharya, Sinu Jasrapuria, Tapan Sarkar, Ranjita GhoshMoulick, Anjan Kr. Dasgupta*
Nanomedicine: nanotechnology, biology, and medicine 3 (2007) 14-19



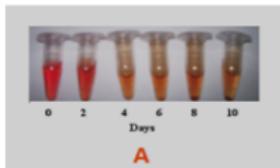
- ▶ Ranjita was contemporary to Jaydeep and was gaining experience in a MD simulation project.
- ▶ She joined in my newly funded DST project on protein Glycation

- ▶ Ranjita came out with an interesting observation that there is a **systematic but compensatory unfolding of protein** it is subjected to synthetic glycation.
- ▶ She published a comprehensive paper on this topic in the BBA.
- ▶ We thought it worth trying to probe the glycation level using Au seeding
- ▶ The result was that different level of glycation led to different sizes of AuNP formation (showing different colors).
- ▶ A primitive glycation sensor was reported

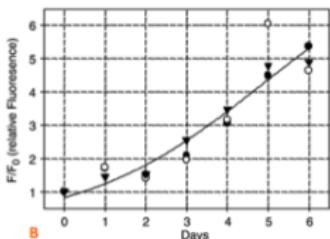
Dr. Ranjita Ghosh Moulick
Assistant Professor

Amity Institute of Integrative Sciences and Health & Amity Institute of Biotechnology

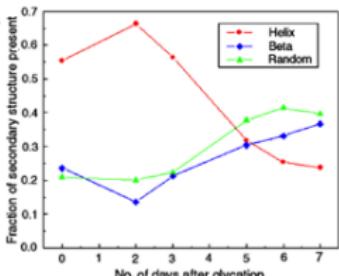
- In Vitro glycation of Hemoglobin and quantification of AGE products-** A. The time dependent changes in physical appearances of hemoglobin B. The increase in characteristic fluorescence emission showing AGE formation. c. Compensatory loss of alpha helix with the corresponding increase in beta and random structure.



A



B



C

- A
- 2. Gold nanoparticles as sensors of AGE products – Using protein templates with different degrees of glycation, an assay technique was designed to determine the propensity of glycation, based on gold nanoparticle formation



- ▶ All of us knew that there is protein aggregation as a result of misfolding.
- ▶ But the direct proof of formation of extended structure was rare.
- ▶ Shibsekhar's entry in my lab was simultaneous with the introduction of a UGC supported instrument zeta size analyzer (Malvern DLS). Most of my colleagues used to look at that instrument with a pinch of suspicion (how it will be useful in a Biochemistry Department).
- ▶ Shibsekhar made a direct measurement of the size of extended structure of Cyt C.
- ▶ Eventually that was also his entrypoint to the nanoworld.
- ▶ I must mention that Shib was the key to the 2006 nano-meet.

Anjan Kr.

Dasgupta

adgcal@gmail.com

FEBS Letters 581 (2007) 5533–5542

Controllable self-assembly from fibrinogen–gold (fibrinogen–Au) and thrombin–silver (thrombin–Ag) nanoparticle interaction



Shibsekhar Roy, Anjan Kumar Dasgupta*

biochemistry, University of Calcutta, 35 Ballygunge Circular Road, Kolkata 700 019, India

Dr. Shibsekhar Roy Received 12 September 2007; revised 20 October 2007; accepted 25 October 2007
 UGC Assistant Prof.
 Osmania Univ.

Available online 5 November 2007

Edited by Veli-Pekka Lehto

Abstract Fibrinogen conjugated gold nanoparticles (fibrinogen–Au) and thrombin conjugated silver nanoparticles (thrombin–Ag) were synthesized by heating (90 °C) the proteins (50 µg protein/ml) with 1 mM AgNO₃ or AuCl₃. The resultant particles were harvested and examined by flow cytometry, scanning electron microscopy (SEM), transmission emission microscopy (TEM), optical microscopy and dynamic light scattering. SEM and TEM images revealed that the fibrinogen–Au and thrombin–Ag particles interacted. The emergent bio-nanoconjugate population could be controlled by addition of thrombin–Ag. The method may be exploited in parametrizing coagulation factors and other clinically important protein–protein interac-

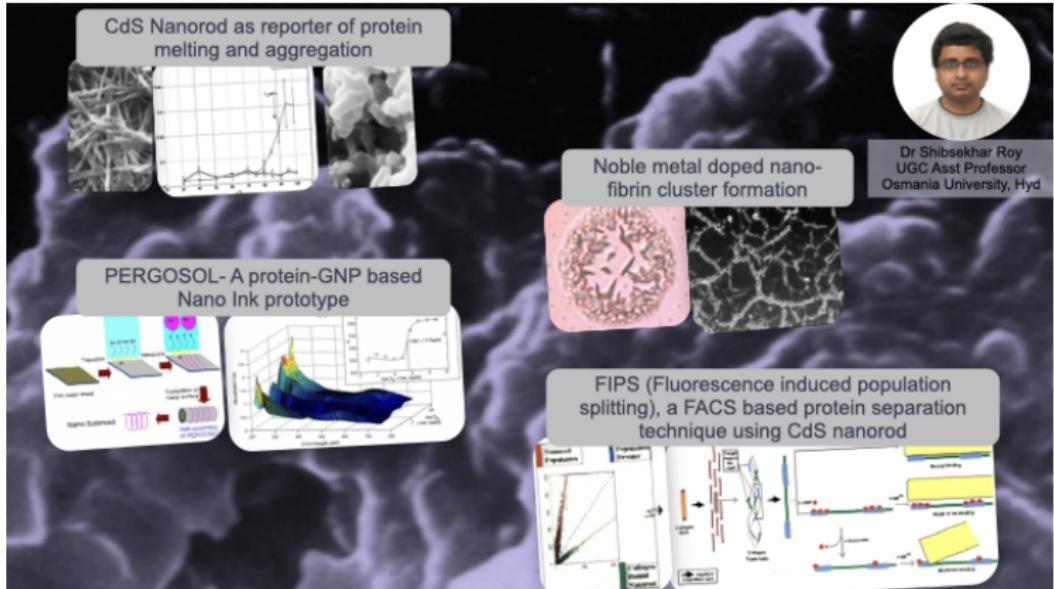
of near micron level structures the population of nanoclusters is conveniently detected by flow cytometry from the scattering behavior of interacting molecules and their proteolysis product.

The fibrinogen–thrombin interaction is a part of the physiological process of blood clotting. The reaction cascade leading to the final step comprises the chemical reaction between the serine protease thrombin and the precursor protein fibrinogen (with subunit Aα2Bβ2γ2) to form fibrin clots. The reaction involves the proteolytic cleavage of fibrinogen by thrombin. The cleavage takes place between Arg16 and Gly17 of subunit Aα and between Arg101 and Glu15 of subunit Bβ to form fibri-

Anjan Kr.

Dasgupta

adgcal@gmail.com



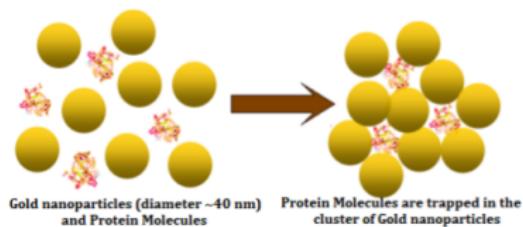
- ▶ Just when Jaydeep Ranjita and Shibsekhar were experimenting on sensing some clinically important protein phenomena, Santi joined.
- ▶ When nothing interesting was happening to him for a year long spell, he thought of exploring the possibility of chaperons properties of AuNP.

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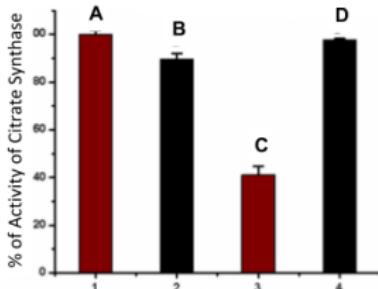
Dasgupta

adgcal@gmail.com

Size dependent chaperone-like activity of gold nanoparticle



- A Citrate Synthase (without heat treatment)
- B Citrate Synthase in presence of gold nanoparticle (without heat treatment)
- C Citrate Synthase (after heat treatment for 1 hr)
- D Citrate Synthase in presence of gold nanoparticle (after heat treatment for 1 hr)



Santiswarup Singha, Ph.D.
Staff Scientist IV
National Institute of Immunology
Aruna Asaf Ali Marg, New Delhi-110067
email: santiswarup@niit.ac.in | santiswaroop@gmail.com

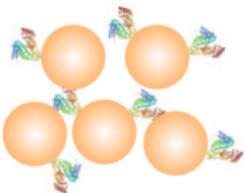
- ▶ But this was not all. He looked into protein glycation from another perspective.
- ▶ Not as glycation sensor
- ▶ But as antiglycating agent

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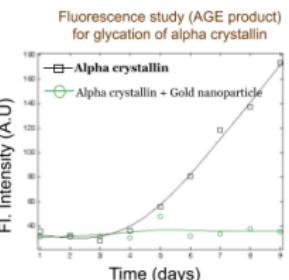
Dasgupta

adgcal@gmail.com

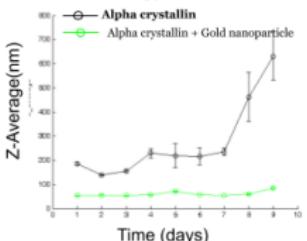
Anti-glycation activity of gold nanoparticle



Gold nanoparticle blocks the primary amine of proteins and prevents the glycosylation



Change of hydrodynamic diameter (Z_{average}) of alpha crystallin during glycation



- ▶ While this lab was comfortable with protein problems a talented biologist,Suryyani Deb joined.
- ▶ As a matter of co-incidence, I just started a Calcutta Medical college collaboration.
- ▶ She joined the newly initiated platelet aggregation project.
- ▶ She did an initial work on agonist thresholding and then switched over to nano-bio.
- ▶ Needless to say she did a pioneering work in the field of nanotoxicology
- ▶ Her investigations proved the type and size of nanoparticles that would be safe for a nano-drug.

Anjan Kr.

Dasgupta

adgcal@gmail.com



Dr. Suryyani Deb
Assistant Professor (UGC)
Department of Biotechnology
Maulana Abul Kalam Azad University of Technology
(Former West Bengal University of Technology)

Major Outcome of her Ph.D Dissertation :

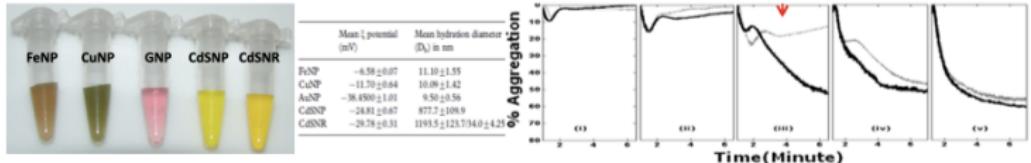
- Her work has been documented as the first ever report on effect of metallic nanoparticles on platelet aggregation
- She reported for the first time the critical dependence on physiological conditions apart from nanoparticle dimension (e.g., lower size can induce more pro-aggregatory effect) on the aggregation phenomenon.
- This in turn open up the possibilities to explore gold nanoparticle as a probe to discriminated anti-platelet drug responder and non responder.
- She has also shown how surface modification of a nanoform can alter its pro-aggregatory effect.

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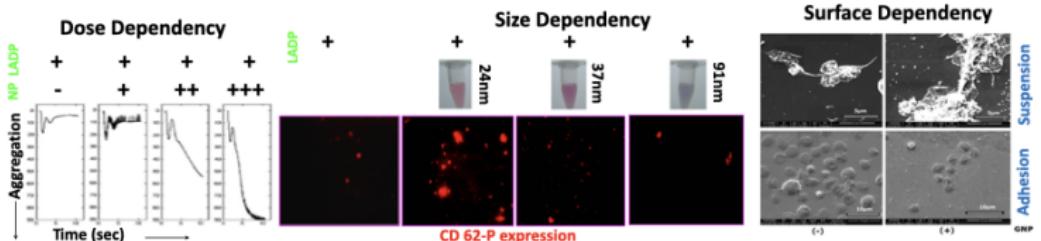
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adgcal@gmail.com

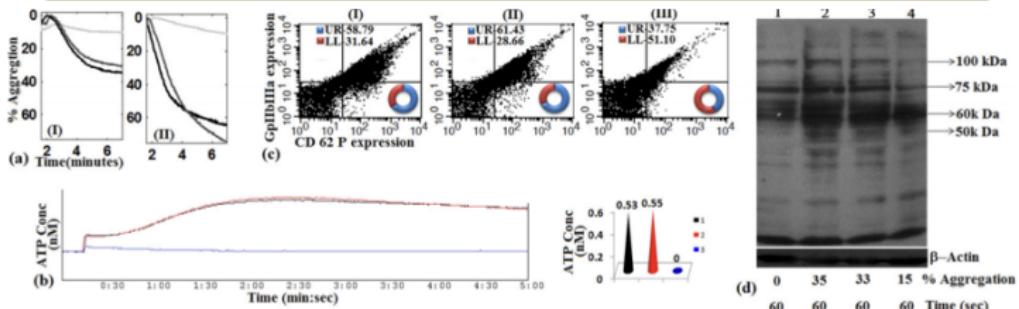
Effect of Metallic Nano-Forms on Platelet Function



Size, Surface and Dose Effect of Gold Nanoparticles on Platelet Function



Size Modification of Iron Oxide Nanoparticles on Platelet Function

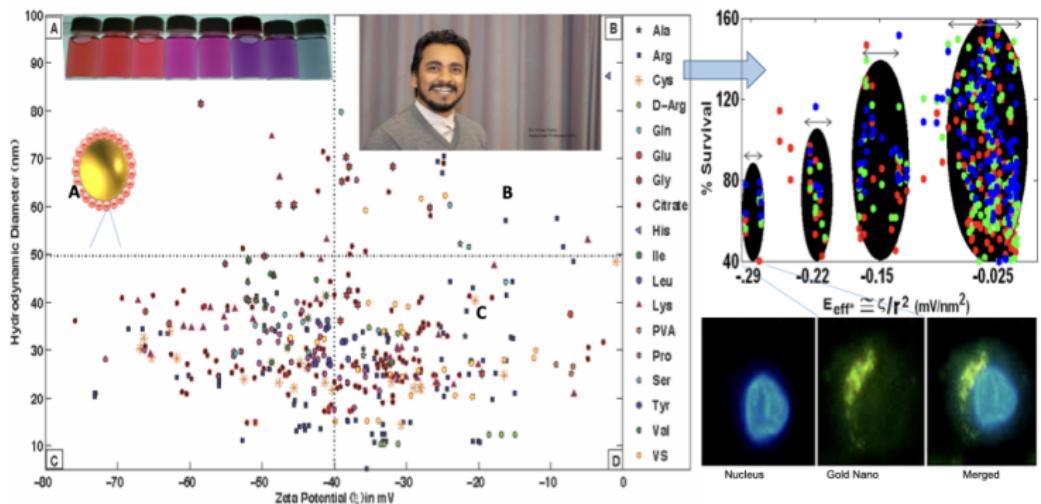


- ▶ Our first tryst with cancer cell nanoparticle interaction started with Hirak.
- ▶ What became a solid new finding by Hirak was the cell specificity of the nanoparticle interaction.
- ▶ The other new finding was selectivity of the size distribution - some nano-sizes were more probable than others.

Anjan Kr.

Dasgupta

adgcal@gmail.com

Patra et al., *Nanomedicine* 2007; Patra et al., *Analytica Chimica Acta* 2009; Patra et al., *Nanomedicine* 2012

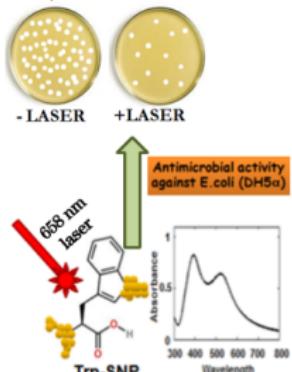
- ▶ Then came Sarita
- ▶ Sarita wanted to try silver nanoparticle
- ▶ The rule of the thumb was that she wanted to do something totally different - Being from chemistry she was fascinated by the chirality concept.
- ▶ She started studying chirality of AgNPs.

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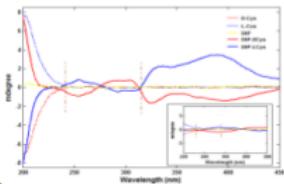
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adgcal@gmail.com

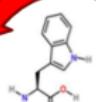
Chemically designed double plasmonic silver nanoparticles as a smart antimicrobial agent



Amplification and emergence of nanoscale chirality upon preadsorption of nanoparticle with biomolecules mainly amino acids

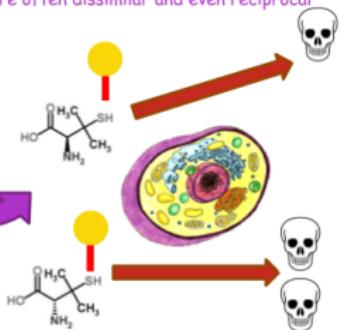
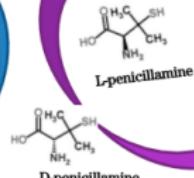
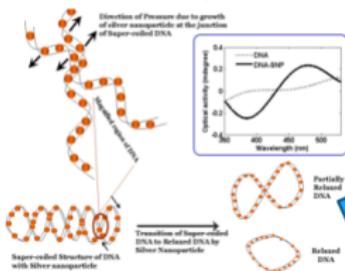


Post-doctorant(e) at Department of Physical Chemistry, University of Geneva



Chirality and the amplified chirality induced reciprocal responses are often dissimilar and even reciprocal

DNA template silver nanocluster and appearance of chirality at nanoscale



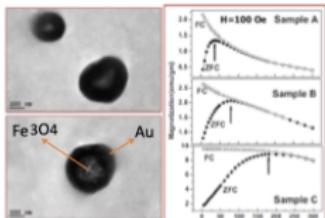
- ▶ It was a memorable moment in the lab when Raja joined
- ▶ like everyone else in the lab he wanted to do something new and totally different.
- ▶ I asked him to probe into a challenging problem in biology
- ▶ Role of static magnetic field.

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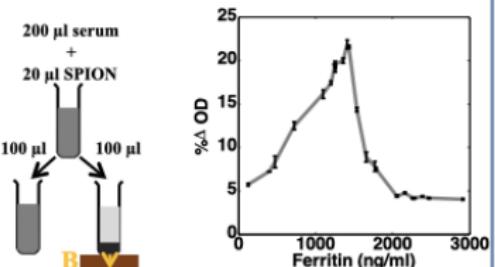
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adgcal@gmail.com

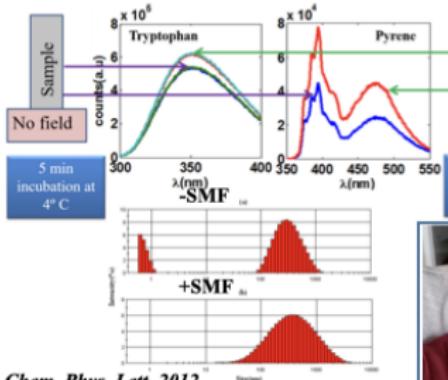
Emergent properties due to interfacial effects-gold coating induced increase in magnetic moment of iron oxide nanoparticle (*J. Appl. Phys. 2011*).



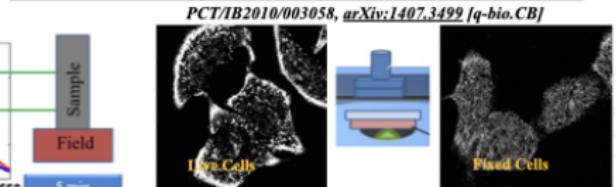
Crosstalk between synthetic and natural iron oxide nanoparticle-an approach towards antibody free serum ferritin detection assay (*WO 2011/141766 A1, bioRxiv 10.1101/211102*)



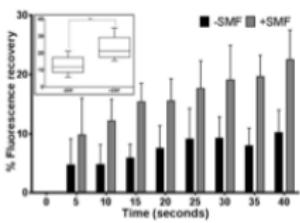
Magnetic memory of biological systems-key to quantum biology



Chem. Phys. Lett. 2012



Dr. Sufi O Raja
Postdoc
Associate
Duke University,
USA

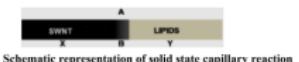


- ▶ Tamoghna was the first person in the lab to try carbon nanomaterial
- ▶ He got himself trained in IIT Kanpur to an expert in carbon nanomaterial
- ▶ After some efforts he came up with the idea of studying interaction of SWNT and lipids.

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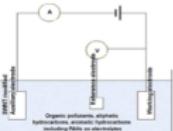
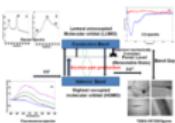
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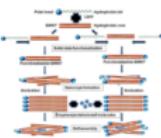
Schematic representation of solid state capillary reaction

- A new insight in characterization of solid state functionalized carbon nanotubes in terms of intrinsic properties of semiconducting singlewall carbon nanotubes and interplay in-between topological and geometrical chirality at nanoscale.
J. of Mater. Chem. A 2 (2014) 3759-3765.

Patent number: 9817093, **Type:** Granted,
Date of Patent: November 14, 2017, **Publication date:** July 2, 2015, **Filed:** August 6, 2012, **Inventors:** Anjan, Kr. Dasgupta, Tamogna Bhattacharyya

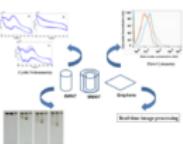


- Carbon nanotube based supercapacitor design for making a hydrocarbon sensor
J. Electroanal. Chem. 706 (2013) 133-139.

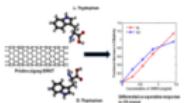


- A novel carbon nanotube self-assembly based supramolecular molecular machine for making versatile molecular trap for making viable bio-sensors (glucose sensor)
Nanoscale 5 (2013) 9231-9237.

Patent number: 9322012, **Type:** Granted,
Date of Patent: April 26, 2016, **Publication date:** March 19, 2015, **Filed:** August 8, 2014, **Inventors:** Anjan Kr. Dasgupta, Tamogna Bhattacharyya, Arka Mukhopadhyay, Nalok Datta, Krishana Chakraborty



- Soft gel based differential electrical diffusion for carbon nanomaterial characterization and purification in large scale
Electrophoresis 36 (2015) 3009-3013



- Chirality Sensitive Binding Property of Pristine Singlewall Carbon Nanotubes: An Approach to Differentiate Geometrical Chiral Molecules
Phys. Chem. Chem. Phys. 16 (2014) 14651-14655.

Patent number: 9726596, **Type:** Granted,
Date of Patent: August 8, 2017, **Publication date:** May 14, 2015, **Filed:** November 12, 2014, **Inventors:** Anjan Kr. Dasgupta, Tamogna Bhattacharyya, Sarita Roy

Tamogna Bhattacharyya
 Carnegie Mellon University
 Research Associate



- ▶ Shounik initially worked in Medical college.
- ▶ At one stage he became interested in nanoparticle effects.
- ▶ His work on platelet cancer cell interaction is getting citations even today.
- ▶ His work on MON (microparticles of nanoparticles) is also an interesting concept.

Anjan Kr.

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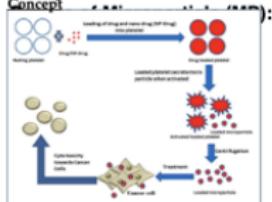
adgcal@gmail.com

MOD/MON: A novel approach towards drug delivery

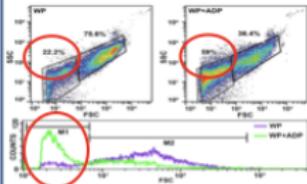


Dr. Sounik Sarkar
Flowcytometry Expert,
BD Bioscience, India

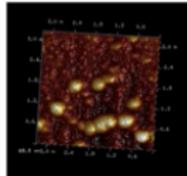
MOD- Microparticle of Drug MON: Microparticle of nanoparticle Concept



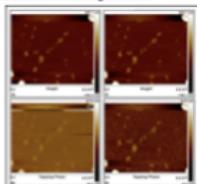
Activated Platelet Releases Microparticles



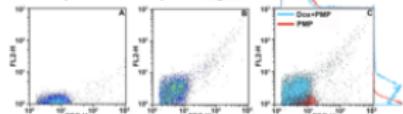
Size of the MP's: AFM Study
300- 500 nm



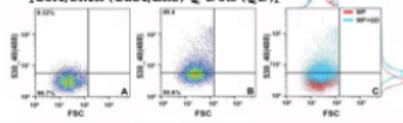
Synthesis of FeMON: MFM study (Iron oxide nanoparticle)



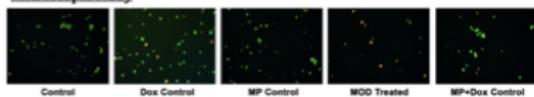
Flow cytometric study of Drug loaded PMPs



Synthesis of QDMON (Core/Shell (CdSe/ZnS) Q-Dots (QD))

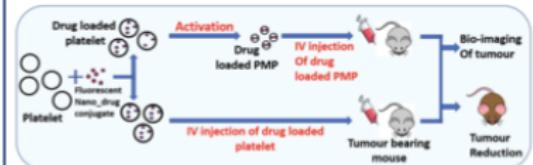


EtBr- Acridine Orange (AO) Staining of Jurkat cells: Fluorescence Microscopic study



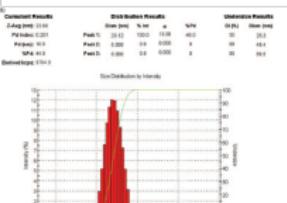
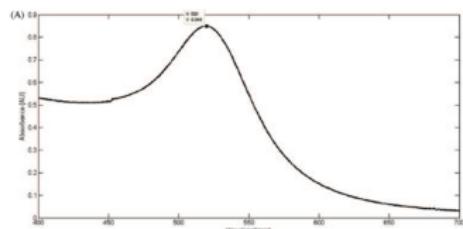
Future Perspective

Establishing platelet/ platelet derived microparticle as the delivery vehicle for **Theranostically** active molecules to treat cancer

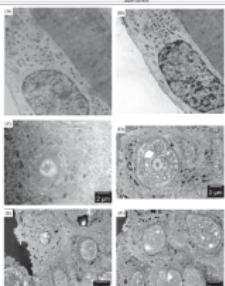
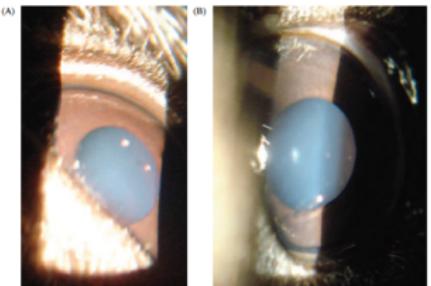


- ▶ Azhar used nanotechnology of eye disease.
- ▶ He is still doing something related to nanotechnology of the cornea.
- ▶ But here is what he did during his PhD

Thesis title: Nanoscale Interactions in Mammalian Eye



Mohammad Azharuddin, PhD
Postdoctoral fellow
Department of Biomedical and Clinical Sciences (BKV)
Linköping University, Sweden



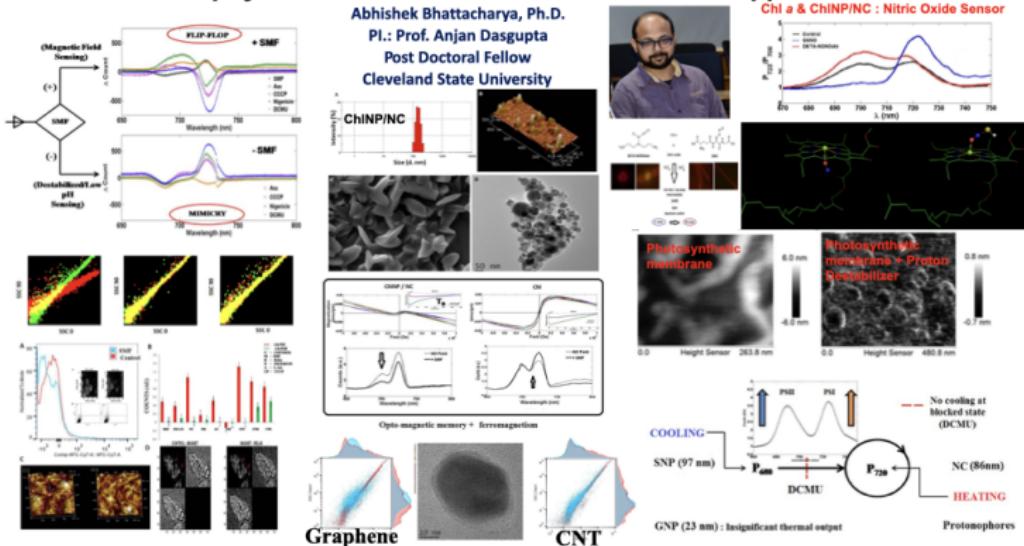
- ▶ Abhishek was one student who made me nervous as he was a plant science student, a background unfamiliar to me.
- ▶ Abhishek started working on the spectroscopic studies on plant photosynthetic system
- ▶ In the process he came up with an interesting sensing behaviour of Chl A Nanoparticle.

Anjan Kr.

Dasgupta

adgcal@gmail.com

Chlorophyll a - Membrane Bound / Nano Scale - Applications



- ▶ I am now describing the concluding part of my nanotour.
- ▶ It was Sanhita who started looking in nanointerface of biofilm
- ▶ She started with conceptualizing a oxygen sensor
- ▶ She then came up with the idea of introducing a nano-inspired synthetic biology. By conjugating the microbial surface with magnetic NP, and then using SMF.
- ▶ She also made some interesting observation on interaction with biofilms with a 2D Dirac material (graphene) .



Microbial community inspired nanotechnology

Sanhita Ray

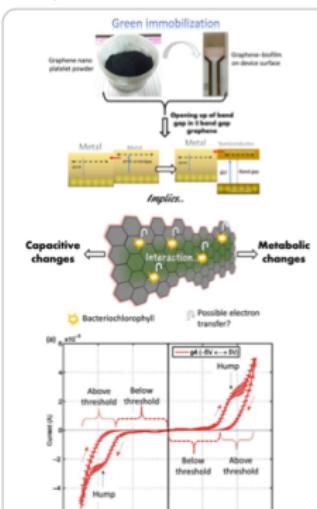
Postdoctoral Scholar

University of California Santa Cruz

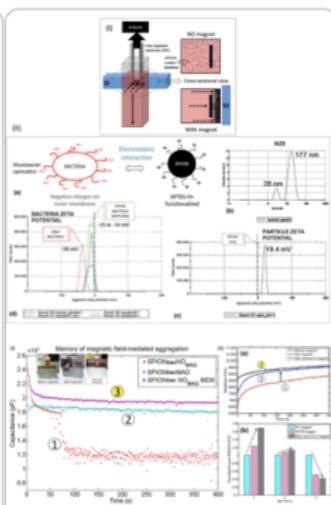
Jack Baskin School of Engineering

Department of Electrical and Computer Engineering

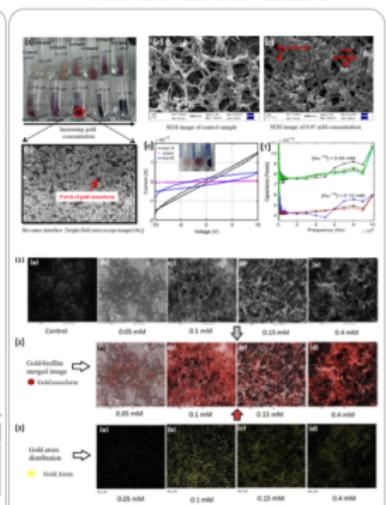
Graphene + bacteria



SPION + bacteria

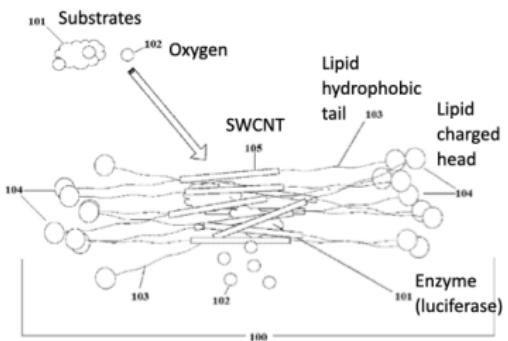


Gold nanonetworks + bacteria



Microbial community inspired nanotechnology

Oxygen sensor



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Back to basics

Hitchhiking in the
nanoworld

Anjan Kr.
Dasgupta
adgcal@gmail.com

The equation expressing the extinction cross section of a spherical nanoparticle within the quasistatic approximation is given by:

$$C_{ext} = 24\pi^2 R^3 \frac{\epsilon_m^{1.5}}{\lambda} \cdot \frac{\epsilon_2}{(\epsilon_1 + 2\epsilon_M)^2 + \epsilon_2^2} \quad (1)$$

Why this simple explanation fails?

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Anjan Kr.

Dasgupta

adgcal@gmail.com

- ▶ The equation predicts that the resonant condition will be independent of the particle size i.e., $\epsilon_1 = -2\epsilon_M$ is independent of R.
- ▶ But we know that the plasmon resonance changes as the particle size becomes smaller
- ▶ Drude equation that overcomes the limitations of the free electron gas approximation.

Modified Drude

If γ is a medium dependent damping factor,

$$\omega_p = \sqrt{\frac{me^2}{m_{eff}\epsilon_0}} \quad (2)$$

$$\epsilon(\omega, k) = 1 - \frac{\omega_p^2}{\omega(\omega + i\gamma) - \beta^2 k^2} + \epsilon_{IB}(\omega) \quad (3)$$

The resonance then becomes size dependent.

A particle in a box approach - The size & shape effect

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Anjan Kr.
Dasgupta
adgcal@gmail.com

Spherical nanoparticle:

$$E_{nl} = \frac{\hbar^2 \chi_{nl}^2}{2m_e R^2} \quad (4)$$

where, χ_{nl} in the n-th root of the i-th order spherical Bessel function.

Cubic nanoparticle:

$$E_{nml} = \frac{\hbar^2 \pi^2}{2m_e a^2} (n^2 + m^2 + l^2) \quad (5)$$

Miepython

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Anjan Kr.

Dasgupta

adgcal@gmail.com

We use a simulation perspective of Mie scattering is a pure Python module to calculate light scattering by non-absorbing, partially-absorbing, or perfectly conducting spheres.

```
import numpy as np
import matplotlib.pyplot as plt
import miepython

# wavelength in microns

radius = 0.1          # in microns
num = len(ref_lam)
m = ref_n-1.0j*ref_k
x = 2*np.pi*radius/ref_lam

qqabs = np.zeros(num)
qqsca = np.zeros(num)

for i in range(num) :
    qext, qsca, qback, g = miepython.mie(m[i],x[i])
    qabs = qext - qsca
    qqabs[i]=qabs*np.pi*radius**2
    qqsca[i]=qsca*np.pi*radius**2

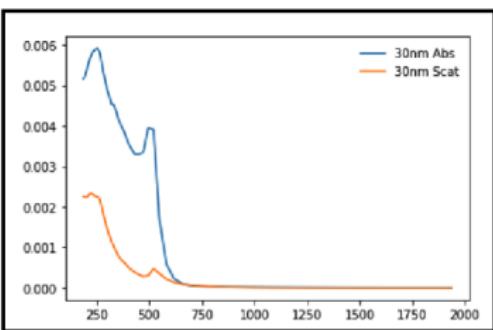
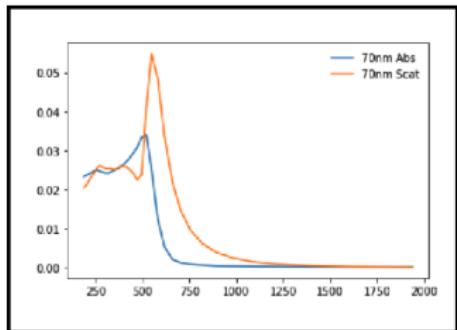
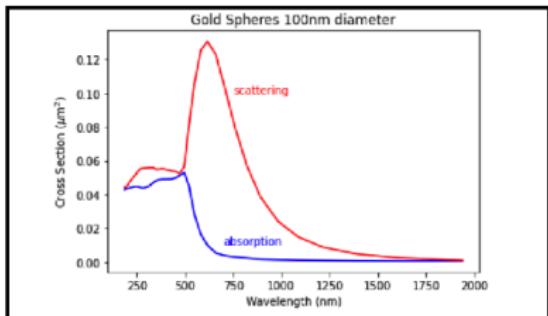
plt.plot(ref_lam*1000, qqabs, color='blue')
plt.plot(ref_lam*1000, qqsca, color='red')

plt.title(r"Gold Spheres 100nm diameter")
plt.xlabel("Wavelength (nm)")
plt.ylabel(r"Cross Section ($\mu m^2$)")
plt.annotate("absorption", xy=(700,0.01), color='blue')
plt.annotate("scattering", xy=(750,0.1), color='red')
plt.show()
```

Plasmon simulation

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Anjan Kr.
Dasgupta
adgcal@gmail.com



A note for the “unsmarts”

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Anjan Kr.

Dasgupta

adgcal@gmail.com

When size of the NP is reduced from 100 nm to 30 nm -
Scattering intensity is lowered relative to the absorbance -
The intensity of both scattering and absorbance lowers - With
higher wavelength scattering is red-shifted to a significant
extent,absorbance slightly blue shifted.

The Sensing lies in the eye of the detector

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Anjan Kr.

Dasgupta

adgcal@gmail.com

- ▶ Why there is Difference of the Absorbance and Fluorescence detections system?
- ▶ Those who have tried to measure plasmon resonance using different detection system will realize that we often get significant variations in the plasmonic frequency when we use spectrophotometer (abs based) as compared a fluorimeter (scattering based).
- ▶ The design of nanosensors may be enriched if these basics of nanoscience are clearer to us.

Future Directions

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Anjan Kr.

Dasgupta

adgcal@gmail.com

- ▶ The main challenges in nanotechnology are the following:
- ▶ Existential; Will the technology will merge with other sister disciplines or it will retain an independent existence
- ▶ How nanotechnology can merge with other trending disciplines like chip development and/or big data
- ▶ How nanoscience can contribute to the emerging disciplines of quantum biology/quantum computation.
- ▶ It is however important for us to realize that we will never have a technology that is sub-nano, but would retain the identity of molecules constituting a given material.
- ▶ Below nanoscale the atoms are no more atoms , and the science therein belongs to a different world of physics (subatomic).

Deep learning the Nanoworld

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Anjan Kr.

Dasgupta

adgcal@gmail.com

- ▶ We are poor in **nano-aerosol** interaction. It will be interesting to probe how nanoforms can be exploited in sanitizing the air quality or removing the undesirable toxicants from air.
- ▶ Nanotechnology may be used in the **pulp and paper** industry
- ▶ **Medical textiles** for Nanofiber-based ‘smart’ dressings.
- ▶ Printed papers using **nanoparticle based electronic component** (inks of graphene, gold and silver being already available)
- ▶ We may use **nanomaterials for developing effective sanitations** (important post-covid step).
- ▶ Deeper understanding of biomaterials nanomaterial interaction would enable us to fabricate smarter sensors.

Gunther Stent's Prediction & a Ray of Hope

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Anjan Kr.
Dasgupta
adgcal@gmail.com

- ▶ By 1969, Dr. Stent “was bored with molecular biology.”.
- ▶ It was just after that, the restriction enzymes were discovered and molecular biology underwent a second revolution.
- ▶ Nanotech is perhaps waiting for such a second generation revolution.

Nanosmart to NanoGate

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Anjan Kr.

Dasgupta

adgcal@gmail.com

<https://phys.org/news/2020-09-nanoparticle-based-architecture-nanoparticle-neural-networks.html>

Their story

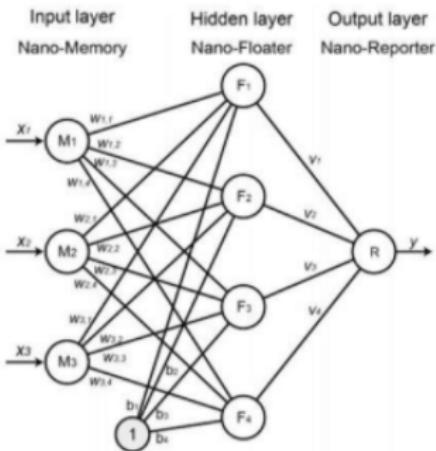
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Anjan Kr.

Dasgupta

adgcal@gmail.com

- ▶ Then they calculated the number of nanoparticle nodes needed to functionally complete Boolean logic operators on the neural network.
- ▶ The hardware relied on covalently modified nanostructures on a lipid chip for multiple executions.
- ▶ They tested the reset function of the system for reusability by dehybridizing all DNA assemblies after exchanging the buffer solution in the setup.
- ▶ The reset allowed thiolated DNAs alone to remain on the nanoparticles, thereby returning to the initial state for the next function.



$$x_i = \{0, 1\} \quad w_{ij} = \{1, 0, -1\}$$

$$b_j = -h \quad (h \text{ is the number of } w_{ij} \text{ equal to 1})$$

$$v_j = \begin{cases} 1 & \sum_{i=1}^n w_{ij} \cdot x_i + b_j \geq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$y = \begin{cases} 1 & \sum_{j=1}^m v_j > 0 \\ 0 & \text{otherwise} \end{cases}$$

Nanoparticle neural network (NNN) for a functionally complete 3-input system. ...

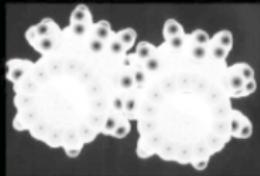
At the END

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Anjan Kr.
Dasgupta
adgcal@gmail.com

THANK YOU — AMITY

FOR GIVING ME A CHANCE TO DESCRIBE THE
NANO-EXPERIENCES



From Nano
Rajesh, to Dhr
Sept 2010