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History and development of nanoparticles and nanostructured materials

Ahmed Barhoum
Vrije Universiteit Brussel, Belgium

Nanoparticles and nanostructured materials are one of the novel classes of materials that have attracted great attention within the scientific community owing to their unique physical and chemical properties. These properties and the potential applications are determined by the composition, size (distribution), and shapes. The ability to change size, shape and composition on the atomic level promises a revolution in many realms of science and technology. Nanoparticles and nanostructured materials have obviously existed in nature for a long time, but also their human use can be traced back to ancient times. Naturally occurring NPs include organic (e.g., proteins, polysaccharides, viruses) as well as inorganic materials (e.g., iron oxyhydroxides, alumino silicates, metals) that are produced by weathering, volcanic eruptions, wildfires and microbial processes. More than 4000 years ago the ancient Egyptians were using NPs based on a man-made chemical process, PbS nanocrystals of ~5 nm to dye their hair. This may be one of the earliest examples of man-made NMs in a practical application. One of the major challenges in nanoscience today is understanding the physical mechanisms by which this level of control is achieved. Indeed, growth control additives are extensively used for effective control in growth and assembly of NPs into in novel nanostructured materials. However, these additives affect their surface properties, processing, and potential applications.

chem_brhom@hotmail.com

Subcellular optogenetics: Optical control of subcellular signaling and cell behavior

Ajith Karunarathne
The University of Toledo, USA

Ability to control cell signaling is a crucial aspect of pharmacology and disease management. Lack of approaches to do so precisely in space and time in single cells to exert control over signaling and cell behavior has been an impediment. We develop and employ optogenetic approaches to control signaling in subcellular regions of single cells, visualize molecular and cellular responses and dissect signal transduction pathways of pathologically important cell behaviors such as cell migration and neuron development. Confined activation of G protein coupled receptors (GPCRs) on the plasma membrane by localized chemical gradients control cell migration. While neurite outgrowth during development is attributed to nerve growth factors (NGF) mediated activation of receptor tyrosine kinases, our findings show that G protein coupled receptors may actively involve in this process. In order to interrogate and map these pathways, we engineer light sensitive organic molecule, opsin, cryptochrome and phototropin based optogenetic-signaling triggers and employ them to optically control (i) GPCR signaling networks, (ii) specific G protein subunits and (iii) selected signaling proteins in these pathways. We employ subcellular optical control to identify signaling activities and cross talk between GPCR active leading edge and inactive trailing edge of migratory cancer cells. Our data shows that neurite outgrowth and cell migration shares Gαi/o pathway to deliver the different responses. Using our optogenetic tools, we examine how immune cells and neurons differently decode the same signal to elicit different cellular outcomes.

ajith.karunarathne@utoledo.edu