

Do nanoparticles have a survival instinct?

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An insight into nanosized chemical systems revealed spatial organization of metal nanoparticles that shows similar patterns to those typically observed in human and animal spatial behavior. Based on this fundamental relationship, we can consider the origins of survival instinct as a possible evolutionary development of nanoscale phenomena.

In this article a parallel between the nanoscale chemical process and the spatial behavior within the living world is considered. The discussion starts with a summary of the findings reported for nanosized systems, followed by a comparison with the behavior of animals and humans. A behavioral link between these areas is emphasized for the first time.

Nanoparticles

Nanoparticles are very small microscopic particles with a size smaller than 100 nm (10^{-7} m). Currently, nanoparticle research is an area of outstanding scientific interest due to the wide variety of applications in biomedicine, technology, and electronics. In the area of nanotechnology, nanoparticles can be defined as small objects that behave as individual units with respect to their properties and interactions with their environment.

In spite of its importance, spatial organization at the nanoscale level and the behavior of nanoparticles remain intriguing questions for modern natural science. The research of our group is aimed at understanding the formation and organization of nanoparticles with the help of physical and chemical methods.

Our recent study reported spatial imaging of Pd/C nanosized systems and analyzed non-uniform coverage of a studied surface by metal nanoparticles.¹ In a simplified representation, a nanoscale surface may be divided into regions that contain corners, edges and roughness-free middle areas. Experimental study demonstrated that corners and edges are the preferred locations for attachment of metal nanoparticles (Figure 1). Open middle areas of the carbon surface are occupied only as a last resort, when all the preferred locations are already occupied. Moreover, if a metal particle attaches to a uniform defect-free area of the carbon surface, then the particle rolls-over (re-arranges) until contact with corner or edge (geometry distortions) is made. Binding to corners or edges is much stronger, and such locations will capture the metal nanoparticle.

The process at the nanoscale level was proved by experimental findings and computational modeling, as well as direct observations using microscopy.¹ In particular, if there is a defect site (corner or edge) as well as the uniform defect-free area on a

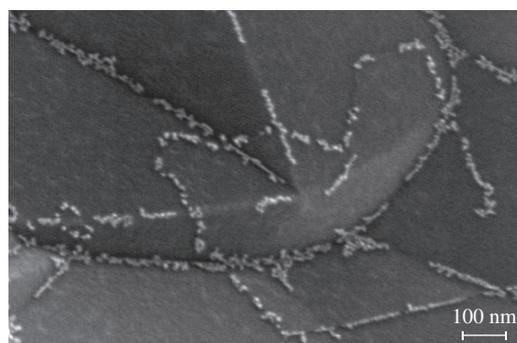


Figure 1 Electron microscopy picture of Pd nanoparticles (bright dots) attached to the carbon surface (grey areas). Preferential attachment to the defect locations over a flat surface is clearly observed. Several types of morphologies – corners, edges and roughness – promote the binding of nanoparticles. Conditions: field-emission scanning electron microscopy (FE-SEM) on Hitachi SU8000 equipment, with the image acquired in secondary electron mode at an accelerating voltage of 30 kV and a working distance of 8 mm.¹

given carbon surface, then the metal particle would first attach to the defect site due to large binding energy. From the point of view of a nanoscale surface, structural defects may form corners and edges, while defect-free areas contain smooth middle space locations. A schematic graphical view of a representative area is provided in Figure 2(A).

Humans and animals

The topic is well addressed in the behavioral and neurobiological studies of animals (see for example, refs. 2–4, among many others). The presence of walls provides safety and reduces the effects of fear and anxiety. Mice typically prefer the walls and avoid open middle space to minimize possible exposure to predators [Figure 2(B)]. Two factors have influenced preferential location near enclosed locations: the absence of danger and the presence of protection from danger. Pavlov's concept on 'behavioral inhibition' as well as a positive modulation of learned safety and security may have an influence.⁴



Valentine Ananikov received his PhD in 1999, Habilitation in 2003, and in 2005 became Professor and Laboratory Head of the N. D. Zelinsky Institute of Organic Chemistry, Russian Academy of Sciences. In 2008, he was elected as a Member of Russian Academy of Sciences. He was a recipient of Russian State Prize for Outstanding Achievements in Science and Technology (2004), an Award of Science Support Foundation (2005), a Medal of Russian Academy of Sciences (2000), Liebig Lecturer by German Chemical Society (2010), and Balandin Prize for Outstanding Achievements in Catalysis (2010). His scientific interests are focused on molecular complexity and transformations.

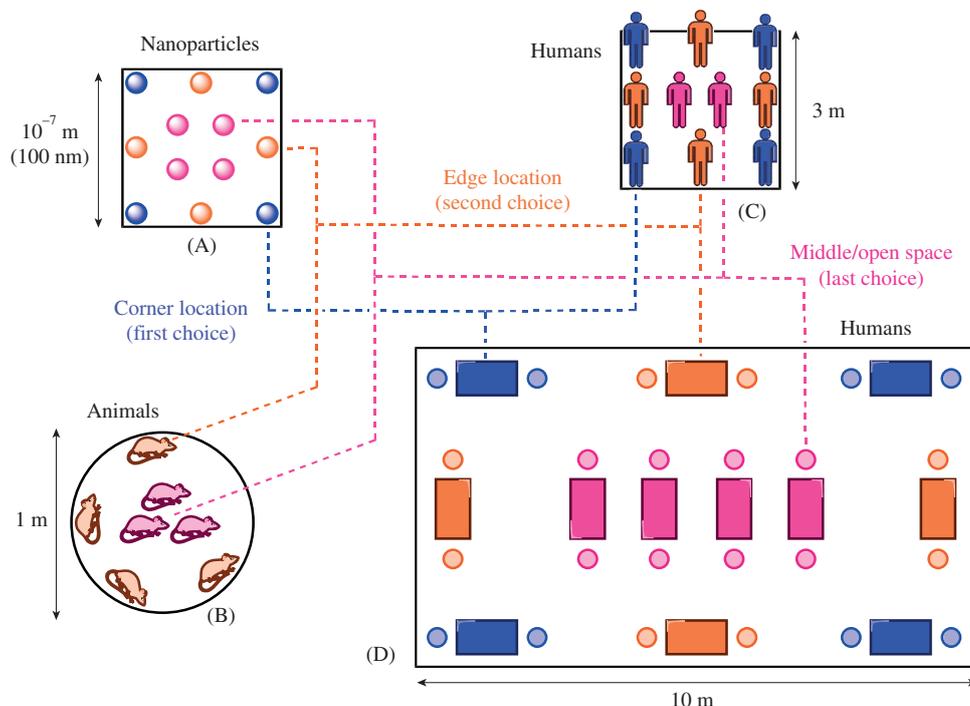


Figure 2 (A) Arrangement of nanoparticles on a surface, (B) arrangement of animals (mice herein) in an enclosed environment, (C) spatial arrangement of humans in an elevator and (D) in a café. Corners (blue color) and edges (orange color) are occupied as preferred locations; free open space (pink color) is occupied as a last option when all corners/edges are already occupied. An approximate scale (in meters and in nanometers) is shown in each case as a rough estimation.

Such behavior of metal nanoparticles shows similar patterns to well-known human spatial behavior (see refs. 5 and 6, for discussion). As two representative examples, we can consider quite typical human arrangement in a café and in an elevator. Spatial human arrangement in an elevator clearly highlights corners and edges as the preferred locations, while open space in the middle is the least preferred [Figure 2(C)]. Moreover, if corner/edge space becomes vacant, then one of those staying in an open area will immediately re-arrange to occupy it. Considering an example of a café as an area of interest: tables in the corners are taken first, followed by those located on the edges [Figure 2(D)]. Tables in the open space in the middle of a room are usually taken only as a last choice. As far as human behavior is concerned, spatial organization originates from a deep survival instinct. Self-preservation instinct, which ensures the survival of an organism, gives a feeling of comfort and safety in a protected place.

A bridge between the living world and nano systems

Self-preservation is an almost universal evolutionary feature among living organisms. For humans and animals, the survival instinct is embedded in the genes and expressed in the form of a neural/behavioral program. Not only is an animal's survival instinct embedded in the genes, but all living things, even simple single-cell organisms, are programmed to survive at all costs. However, this phenomenon has not been observed in inanimate nature.

If we down-scale the phenomenon from biological organisms to the nanosize level, can we project a type of survival instinct for nanoparticles?

Although no proof or direct evidence of the existence of survival instinct for nanoparticles can be judged at the moment, we can draw a clear behavioral parallel (Figure 2). As found in the experiment,¹ the physical nature of the process of nanoparticles' attachment to certain preferred locations originates from a higher interaction energy (greater thermodynamic stability). For humans and animals, the driving force is a feeling of safety and comfort (better psychological stability).

Thus, studying nanoparticle behavior is of great scientific interest, as such studies may provide a bridge between atomic/molecular structures and living organisms. It would also be of particular interest to consider the origins of survival instinct as possible evolutionary development of nanoscale phenomena. One should anticipate more multidisciplinary studies to appear soon in this fascinating field.

To highlight a technological impact of this area, nanoscale catalytic systems play an outstanding role in modern industry and chemical sciences. Various Metal-on-Carbon catalysts are ubiquitously utilized in a range of fields, including the petroleum industry, materials science, and the production of pharmaceuticals. A palladium on carbon catalyst, or simply Pd/C, represents an outstanding discovery of paramount applications in cutting edge research and development. Nanoscale spatial behavior, involving the attachment of metal particles to the areas with a modified structure of carbon surface (*i.e.*, geometry distortions or defect sites), is of primary importance to understand the nature of catalyst formation and operation.

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