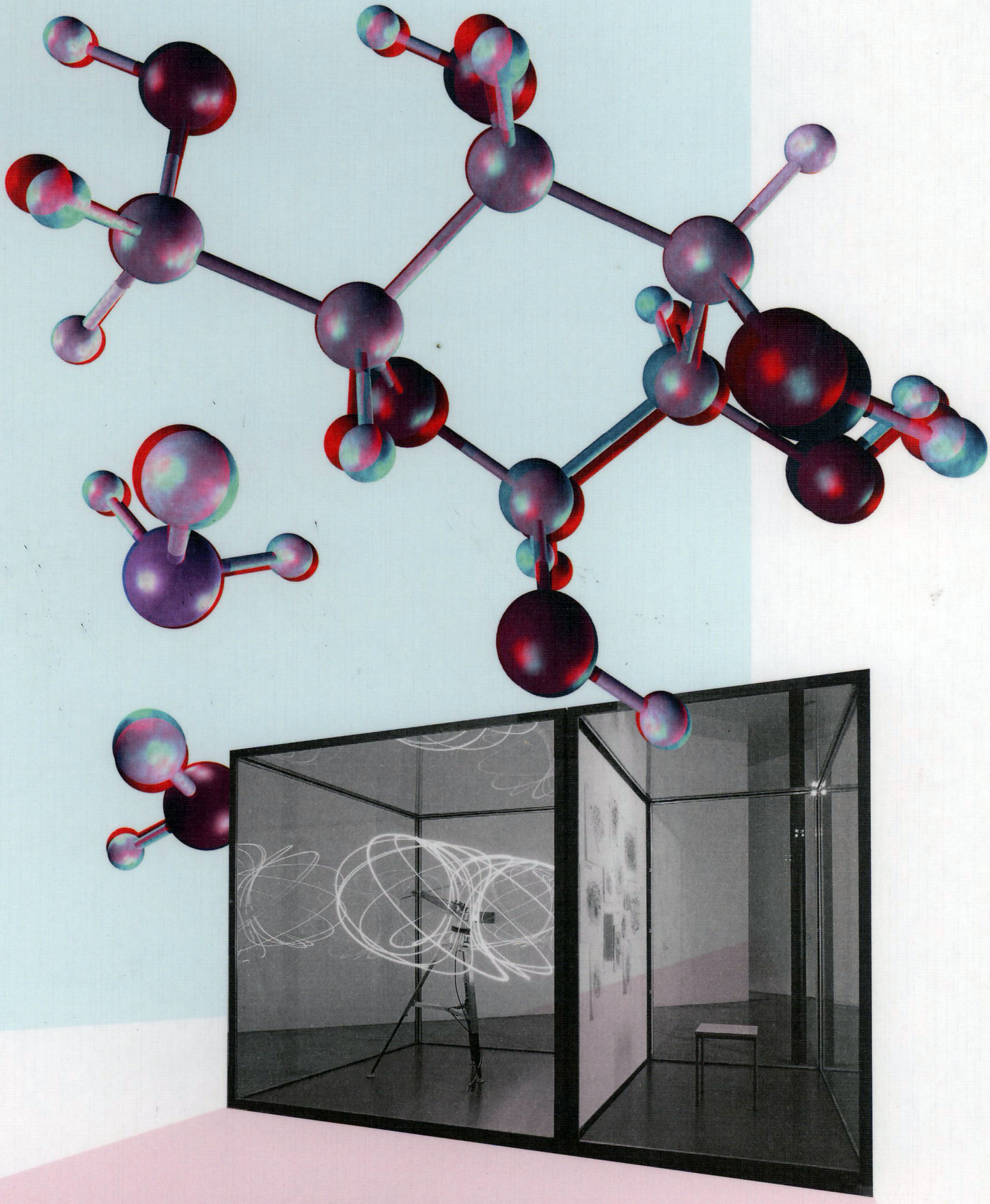

# Molecular Aesthetics

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Wolfgang M. Heckl

# Moleculism

Both the invention of the scanning tunneling microscope – for which Gerd Binnig and Heini Rohrer were awarded the 1986 Nobel Prize for Physics – and soon after that the invention of the scanning force microscope, enabled atoms and molecules to be made directly visible in real space for the first time. Furthermore, the structural principle of a tip that scanned the nanoworld made possible American physicist Richard Feynman's dream of juggling with individual molecules to explore the nanoworld directly. This innovation was the starting point for making use of the findings of quantum mechanics for which Democritus' proposal – that all material can be divided into the smallest of particles – originally provided a physical basis. As such, this was also the birth of nanotechnology, a multidisciplinary technology that not only forms the practical basis for various material sciences from nanoelectronics to nanobiotechnology and nanomedicine. But it has also prompted a new appraisal of the paradigm shift in the culture of the natural sciences and technology, as well as in the fine arts and painting.[1]

The focus here is on supramolecular self-assembly processes, which I call moleculism, because the processes give the molecules that make up a painting their place in three dimensions, and as such, enable a work of art to take on meaning. Spontaneous molecular organizational processes are also the point of departure for our research on molecular evolution, which in the Earth's infant stages some four billion years ago, marked the starting point for the development of orderly living systems made up of organic molecules.[2]

Photographs of atomic surfaces sometimes look like abstract paintings; the mineral molybdenum disulfide for example, is a case in point. In it, one can recognize sulfur atoms as individual, and in some cases (as a result of the electron density clouds being smeared) as light volumes: apparently interlinked spherical bodies in the shape of a hexagon. At the same time, the photograph of the mineral made using the scanning tunneling microscope shows that it is possible to extract a single atom from a crystal structure, thereby creating a gap in the atomic chain. Beforehand, the atomic crystal surface comprising sulfur atoms was a sealed chain. As the atomic distance is 0.16 nanometers, the arbitrary removal of an atom using the atomic tip of the scanning tunneling microscope creates the so-called atomic bit, for which in 1993 John Maddocks and I were honored by the Guinness Book of Records "for the writing of the smallest hole
FIG 1 of the world" (fig. 1).

In the "Nanocene," the evolutionary age of our bottom-up search for knowledge, I have addressed the question of how science and art interrelate from the point of view of a physicist who is attempting to analyze the creative impetus behind his work. The analysis of this process, by which, by means of nanoscopic processes, the transfer of pigments from a brush to canvas creates a macroscopically visible work of art, prompted my coining the term moleculism, – a diminutive form of the term pointillism – to describe the properties that characterize my painting.

## Moleculism

As simple as understanding the process the artist uses might seem, deliberately configuring nanoparticles on a canvas seems to me, on closer inspection, to be somewhat mind-boggling. Particularly the macroscopically visible end result should be cited as that, considering the wide gap between the molecules' dimensions, beginning in single molecules – typically a mole (six times $10^{23}$) of color molecules – and ending in a form one can see with the naked eye.

The following example illustrates the process and as such, the term molecu-
FIG 2 lism: Figure 2 is an early work (1995) depicting a laughing shark.[3] The photograph was taken using a scanning tunneling microscope of some 10,000 in-
FIG 3 dividual adenine molecules (see fig. 3). When transferred from a solution to a surface (the painting process in moleculism), these molecules spontaneously configure in such a way as to create a mono-molecular film consisting of small, individual, tightly packed molecules. However, unique in the work are the (dark) molecular faults that inhibit the emergence of a sealed molecular film. The faults range from spontaneous individual molecule defects (see fig. 2 arrow 1) to an interface that occurs arbitrarily during the molecular painting process in the crystallographic configuration of the local molecular domains (see fig. 2 arrow 2) which served as the starting point for the completion of the picture. The domain boundary became the basis for the contours of a shark's skull, to which two important molecular elements were added. The possibility, using the atomic bit of the scanning tunneling microscope, not only of applying individual molecules to the painting surface – as illustrated in the following example – but also of ablating specific individual molecules, forms the basis of the painting process that will follow: using the atomic brush to electromechanically scratch out specific molecules from the sealed layer. This is clearly visible on the two-molecule wide, and twenty-molecule long ablated line (see

**FIG 1** The world's smallest hole, attributed to Wolfgang M. Heckl and John Maddocks by the *Guinness Book of Records*, 1993.

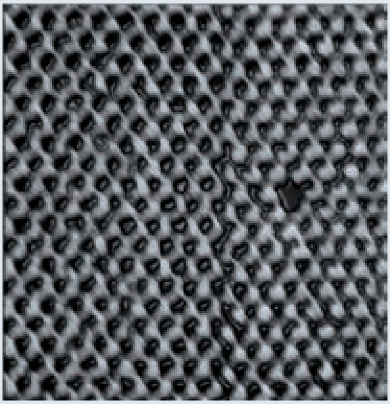


**FIG 2** *HAI 1995 STM*, molecular art made up of adenine molecules

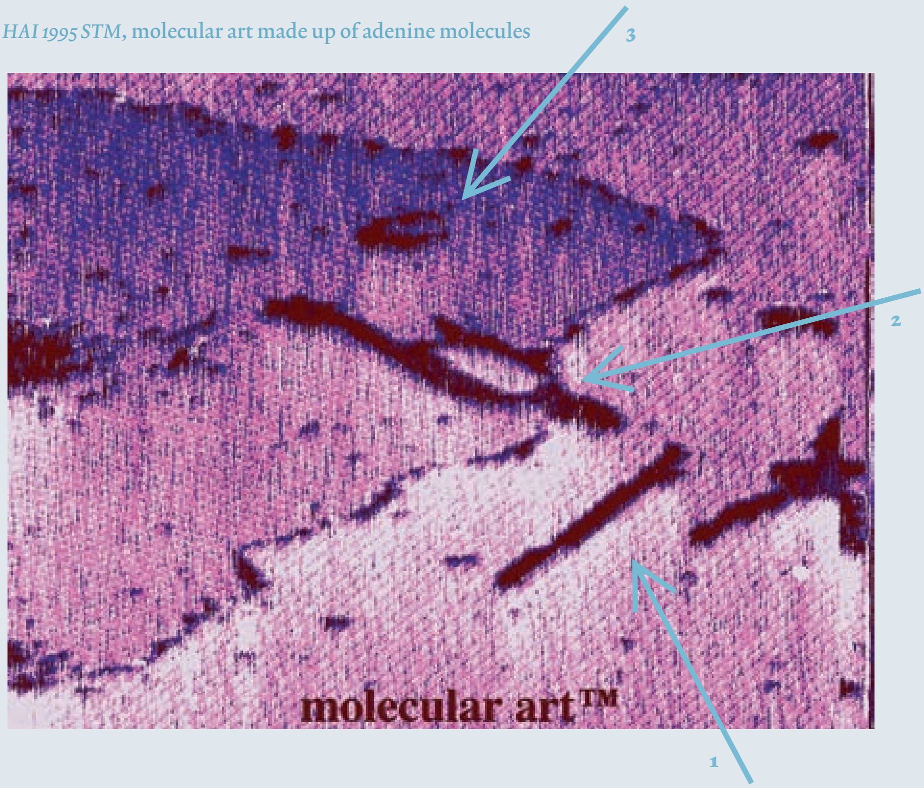



**FIG 3** Chemical CPK model of an adenine molecule

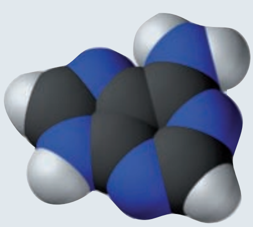


fig. 2 arrow 3), which measures around ten nanometers, and was the technology used to give the shark's head both an eye and a laughing mouth. Thus the first consciously painted molecular picture was created, which, magnified millions of times, can be perceived here.

By using the atomic brush in a reverse process, individual molecules can be applied to a painting base (in this case, the silver surface), as the following illustration of a coronene molecule demonstrates. Magnified some 10 million times in the scanning tunneling microscope, the pigment molecule shows itself as a bit occasionally surrounded by interfering electron-scattering waves in the form of concentric circles (fig. 4, see also fig. 5 for the chemical formula of a coronene molecule).[4]

FIG 4,5

This is the singular elementary process of painting as observed from a "moleculistic" perspective, when colorants are adsorbed on the painting surface. This typically occurs with several moles, rather than individual molecules. Analyzing the process on a nanocale shows that it can be broken down into several individual processes:

**I.** Adsorption by wetting the painting surface with the molecules collected by the brush.

This procedure can be explained in molecular terms by the solid wetting theory,[5] which involves bringing the pigments (usually distributed in a solvent) into contact with the surface of solid matter, the painting surface. For the wetting, or the transfer of the pigments, the fact that these are present in nanoparticular form and are adsorbed on the surface of the solid matter with a binding constant higher than that of the solvent molecules – which can evaporate – is pivotal. This triggers the second process:

**II.** Spontaneous self-organization by the molecules under given conditions – such as adsorption constants, temperature, time, electromagnetic interaction between pigment, and substrate – and lateral interaction among the molecules themselves through chemical bonding. These conditions affect the flow, evaporation, and configuration of the color that emerges, and are visible macroscopically. Molecular chemical bonding here is determined by the energy minimization principle, which leads to the color pigments self-organizing on the painting surface, and whose structures can be foreseen using molecular dynamics cal-

FIG 4 Electron scattering waves surrounding a single coronene molecule, center

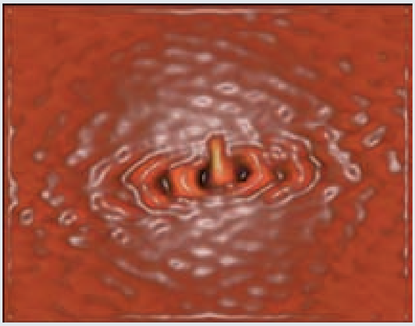
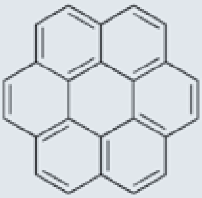


FIG 5 Chemical formula of a coronene molecule's structure



culations and computer modeling. In the self-organizational phenomena, one can distinguish various levels of hierarchy that moleculism brings into play.

**1.** Self-assembly, whereby given units – e.g. atoms, molecules, Lego bricks – interact with one another according to defined regulations for neighbors (in particular stereochemical specific bonds) under external conditions, and they create a topologically concise structure (amorphous, chaotic clusters, expressly disorderly).

**2.** Self-structuring or bundled self-assembly: a process which leads to an orderly system in one, two, or three dimensions and can be defined by suitable lattice parameters (e.g. a crystal).

**3.** Self-organization, or a higher level of self-structuring, in which the desired design of elementary components or the inherent interaction rules lead to emergent structures, but whereby features peculiar to the system emerge that could not be foreseen, e.g. the molecular coding system DNA, molecular machines, schools of fish, or swarms of birds with swarm intelligence.

**4.** Self-construction, or a system built using molecular tools such as molecular motors, ratchets, transport and storage components, functional molecular machines based on a molecular construction plan (ribosome, enzymes, myosin-actin transport system etc.).

With regard to moleculistic painting, the first and second processes are brought to bear in particular. Decisive from here is the intervention of the artist himself, who at a third, macroscopic level, lends expression to his will to create, while the first two processes have occurred involuntarily and been dictated by Nature.

**III.** Through experiments in molecular design at macroscopic level, however, the artist may also exert subsequent influence.

This complex procedure of molecular arrangement, which is neither deterministic in nature, nor able to be precisely analyzed – let alone consciously controlled in nanoscopic detail –plays a role in the final result of a painted work nonetheless.

Representing several other cases, the following example may show the parameters more clearly. It relates to the processes described above when painting with mordant red (Alizarin $C_{14}H_8O_4$) in a solution of eight cyanobiphenyl molecules on graphite (fig. 6, see also fig. 7 for the chemical formula of the molecule) **FIG 6,7**

**FIG 6** Mordant red (Alizarin) as a macroscopic color swab


**FIG 7** The molecular formula of mordant red

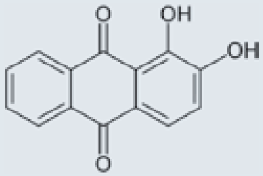


**FIG 8** Polarization microscopic shot of mordant red color particles on the paint surface

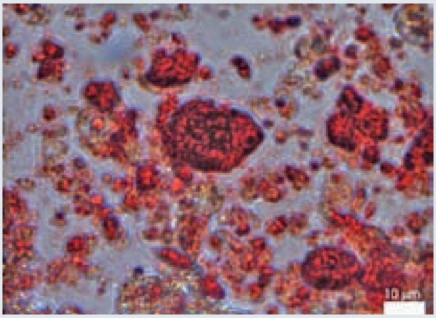


**FIG 9** Molecular self-organizing of the mordant red color pigment molecules

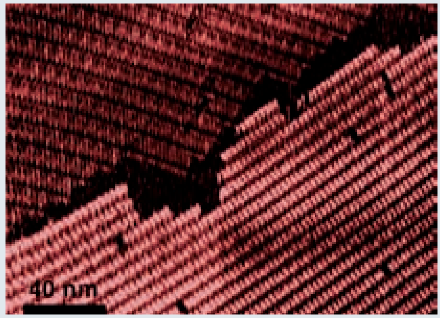



**FIG 10** Chemical structure formula of the trimesic acid molecule

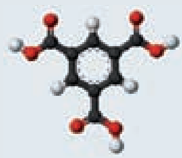


**FIG 11** Self-organizing molecular composition made up of trimesic acid molecules ($C_9O_6H_6$) and co-adsorbed solid (greenish) and rotating (blueish) coronene molecules ($C_{24}H_{12}$) enlarged one million times; captured by the scanning tunneling microscope and artificially colored

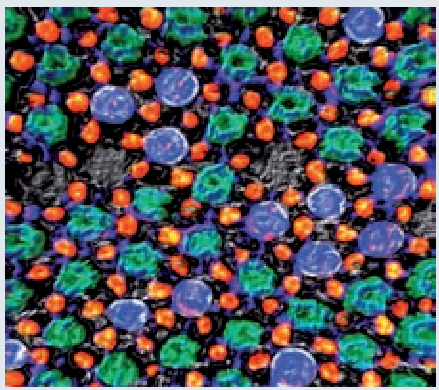


**FIG 12** *DNA*, 1990, acrylic on canvas, 70 x 100 cm

Through a polarization microscope, one can see the lumps of pigment nanoparticles that seem to spread arbitrarily across the surface (fig. 8). The molecular self-structuring in the highly magnified dash of color shows the individual mordant red molecules as a highly ordered, two-dimensional layer, with an interface, as well as individual molecular faults, clearly recognizable (fig. 9). FIG 8 FIG 9

Using mixtures of molecules, this process of molecular construction can be highly aesthetic, in turn, self-structuring in this particular case, its tendency to self-organization being the structuring principle. Individual coronene molecules are deposited in a structure mask comprising trimesic acid molecules arranged in sixes in a plane on the graphite painting surface (in red) (fig. 10). The tightly adsorbed coronene molecules appear greenish, and individual rotating coronene molecules, blue. Unusually, several lattice sites in the middle of six trimesic acid molecules are not occupied, such that the black graphite of the painting surface appears to show through (fig. 11). FIG 10 FIG 11

Under the heading of moleculism, a new approach to observing any form of painting may be taken. Ultimately, the picture stands as a macroscopic expression of moleculism with stylized DNA strands and recognizable contours of its individual DNA basis molecules (fig. 12). The challenge of transferring to sound images any information about the atomic and molecular composition of paintings – information gathered using the scanning tunneling microscope by means of a mathematical transfer algorithm – is described elsewhere, but represents an dimension of making atomic nanoworlds visible and audible. FIG 12

The aim of our project was to develop a new way of portraying atomic and molecular soundscapes, thereby forging a link between science and art in the field of quantum physics. To this end, by setting them to music, the imagery created using the scanning tunneling microscope gave a fascinating insight into the uncharted world of atoms and molecules transported into the world of sound. We investigated a neglected form of access to the world through the most minute material components, namely, the auditory channel. Contrary to the visual channel, the auditory may well allow people to register a different part of reality.[6]

Translated from the German by Jeremy Gaines.

1 See: Wolfgang M. Heckl, "Die Nanoskala – Schlüssel zum Verständnis der Natur," in: Barbara Könches, Peter Weibel (eds.), *unSICHTBARes. Kunst—Wissenschaft*, Benteli, Bern, 2004; Wolfgang M. Heckl, "Das Unsichtbare sichtbar machen – Nanowissenschft als Schlüsseltechnologie des 21. Jahrhunderts," in: Christa Maar, Hubert Burda (eds.), *Iconic Turn. Die neue Macht der Bilder*, DuMont, Cologne, 2004.

2 See: Stephen J. Sowerby, Wolfgang M. Heckl, "The Role of Self-Assembled Monolayers of the Purine and Pyrimidine Bases in the Emergence of Life," in: *Origins of life and evolution of the biospheres*, vol. 28, no. 3, 1998, pp. 283–310, doi: 10.1023/A:1006570726326.

3 See: Wolfgang M. Heckl, *Science &Art*, 2011/2012, published by the author, ISBN: 978-3-940396-36–35.

4 See: M. Lackinger, S. Griessl, W. M. Heckl, and M. Hietschold, "Coronene on Ag(111) Investigated by LEED and STM in UHV," in: *The Journal of Physical Chemistry B*, vol. 106, no.17, 2002, pp. 4482–4485, doi: 10.1021/jp014275s.

5 See: F. Trixler, T. Markert, M. Lackinger, F. Jamitzky, and W. M. Heckl, "Supramolecular Self-Assembly Initiated by Solid–Solid Wetting," in: *Chemistry – A European Journal*, vol. 13, no. 27, 2007, pp. 7785–7790, doi: 10.1002/chem.200700529.

6 See: Wolfgang M. Heckl, "Das Unsichtbare sichtbar machen," in: Maar/Burda 2004; Wolfgang M. Heckl, *Künstlerische Verbindung von Bild- und Tonkanal in der Quantenwelt – Atomare Klangwelten*, Andrea von Braun Stiftung, 2003.