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Machines in art and chemistry

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Abstract The present paper is intended to expose an example of similarity between chemistry and art not based on shape or appearance, but rather on the common origins of the concepts involved. Specifically, the subject of this text is about machines and machinery and makes a parallel between the construction of multi-machines in art and chemistry.

Keywords Molecular machines · Metamechanics · Disegno · Technology

> A scientist and an artist confronted the same problem—the nature of time and simultaneity—and resolved it after realizing a new aesthetic. At the nascent moment of creativity boundaries dissolve between disciplines.
>
> Miller A. I.: Einstein, Picasso. Physics Education **39**, 484 (2001)

> Everything moves. Rest does not exist. Don't let yourself be controlled by obsolete notions of time….Resist the anxious impulse to stop what moves, to freeze moments and to kill what lives. Give up constructing «values» that always collapse anyway. Be free, live! Stop «painting» time. Give up building cathedrals and pyramids that fall apart like sugar-candy. Breathe deep, live in the now, live on and in time. For a beautiful and absolute reality!
>
> Tinguely J.: Pamphlet released in 150.000 copies from an airplane above Düsseldorf, March 14, 1959. A more extensive manifesto along the same lines was presented in Tinguely's lecture "Art, Machines and Motion" at the Cyclomatic Evening, ICA, London, November 12, 1959

> Pyramids, cathedrals, and rockets exist not because of geometry, theory of structures, or thermodynamics, but because they were first a picture—literally a vision—in the minds of those who built them.
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> Ferguson, E. S.: The Mind's Eye: Nonverbal Thought in Technology. Science **197**, 827 (1977)

> The creative shaping process of a technologist's mind can be seen in nearly every man-made object that exists.
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> Ferguson, E. S.: The Mind's Eye: Nonverbal Thought in Technology. Science **197**, 827 (1977)

> The designer and the inventor, who brings elements together in new combinations, each are able to assemble and manipulate in their minds devices that has not yet do not exist.
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> Ferguson, E. S.: The Mind's Eye: Nonverbal Thought in Technology. Science **197**, 827 (1977)

Recently, Santiago Alvarez published an opinion-article entitled: '*Music of elements*' in the New Journal of Chemistry **32**, 571 (2008) [1]. Starting from the question: *Is there any relationship between music and chemistry?* he gives numerous examples of parallels that can be found between the Periodic Table of Elements of Mendeleev and the world of music. The conclusion of his article is another question on the possibility of an extrapolation of his findings from music to other areas of art such as painting, movie making or writing: '*From the world of chemistry we can ask ourselves: do we really make efforts to establish connections between our profession and the art forms that*

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bear some relationship to it? Do those of us who teach chemistry in high schools or universities try to stimulate our students to realize that a chemical element, a compound or a reaction can also belong to the world of art? Will a day arrive in which a search for a given compound in chemical databases will provide us with information on paintings, films, and musical or literary works connected in one or another way with that compound?'

Science and art naturally overlap. Both are a means of investigation. Both involve objects, ideas, theories, and assumptions that are tested in places where mind and hand come together—the laboratory or the studio. Like scientists, artists study materials, people, culture, history, religion, mythology, and learn to transform information into something different. In ancient Greece, the word for art was *techne*, from which *technique* and *technology* are derived—terms that are aptly applied to both scientific and artistic practices. Exploring the similarities in their respective early work, Arthur I. Miller published an article [2] entitled : '*Einstein, Picasso*' in which he proposed that the Spanish painter, Pablo Picasso, and, the German physicist, Albert Einstein, were both influenced at the beginning of the 20th Century by the book, *La Science et l'Hypothèse*, published in 1902, by the French mathematician Henri Poincaré. In his book, Poincaré speculated that geometries different from the Euclidian classical geometry could be developed and represented in curved spaces and higher dimensions. Picasso exhibited *Les Demoiselles d'Avignon* in 1907, opening the way to Cubism, while Einstein published his *Theory on Relativity* in 1905. This is a rare example showing the birth of an idea in science and art from the same original problem: the nature of time and simultaneity resolved by realizing a new aesthetic. At the birth of creativity, boundaries dissolve between disciplines. Ideas come from objects and their representation, and one can assume that the same idea may come separately and simultaneously in science and art. This is often found when simply comparing images coming from science and art. For instance, the work of the Deutsch artist Maurits Cornelis Escher has been many times cited by crystallographers and mathematicians because of his ability to use and draw objects with original and uncommon symmetries [3]. The same was done with the geometrical paintings of the Hungarian painter Victor Vasarely. With the development of computers, many scientific images in biology or physics have been compared with artistic digital paintings because they are similar in colour, shape and appearance. Many examples can be found in contemporary popular literature.

The present paper is intended to expose an example of similarity between chemistry and painting not based on shape or appearance, but rather on the common origins of the concepts involved. Specifically, the subject of this paper is about machines and machinery. A few years ago we reported on molecular machines [4, 5]. Although at the time the theme of 'molecular machines' was not exactly our research field, I was impressed by a communication of Kelly et al. [6] reporting in 1994 a reversible *molecular brake*. I was amazed by how simple words in the title were mixing technology and chemistry. I was also excited by the notion of movement taken into consideration: a rotation of a single bond could be chemically stopped. Of interest was also the use of the molecular concept to describe the operation occurring. Since this publication, I became interested in the history and the concepts of molecular machines and the relationship between real-size life objects and molecular objects in chemistry [7, 8]. Following up on a review article entitled '*Molecular Machines*' in which we made a parallel between molecular machines and the drawings and the ideas of Leonardo da Vinci [9], I came to wonder whether similarities could be found between the development of molecular machines and the development of particular concepts in art and more specifically on machines in art. Our review article [9] entitled '*Molecular Machines*' was described molecular-sized systems (either molecular or supramolecular) only exhibiting mechanical properties interpretable in terms of classical mechanics. Such systems are typically formed by the assembly of molecular segments via covalent linkages. They are designed to transmit or modify the application of power forces, eventually inducing motions within the system itself in a predetermined fashion.

In art, when speaking of 'machines with motions', one name quickly comes to mind: Jean Tinguely (1925–1991), a Swiss painter and sculptor. He is best known for his sculptural machines, or kinetic art, in the purest Dada tradition, and officially known as *metamechanics*. Tinguely grew up in Basel and belonged to the Parisian avant-garde in the 1950s and 1960s. He signed the manifest of the New Realism movement (*Nouveau réalisme*) in 1960. Figure 1 shows a representative work of Tinguely. The work is made of steel, wood, painting, a motor, cogs, wheels and diverse materials. Its dimensions are: $280 \times 430 \times 185$ cm.

The works of Tinguely dealing with *metamechanics* stem from ideas proposed by Marcel Duchamp (1887–1968). Duchamp was a French artist (he later became an American citizen) whose work and ideas had considerable influence on the development of post-World War I Western art. Duchamp was the first sculptor to make artwork out of daily life objects. He is often associated with Dada and Surrealism. His participation to Surrealism was largely behind the scenes, and after being involved in New York Dada, he barely participated in Paris Dada. Figure 2 shows an earlier art work of him: 'Bicycle Wheel' (1913) as a model of 'Rotation'.

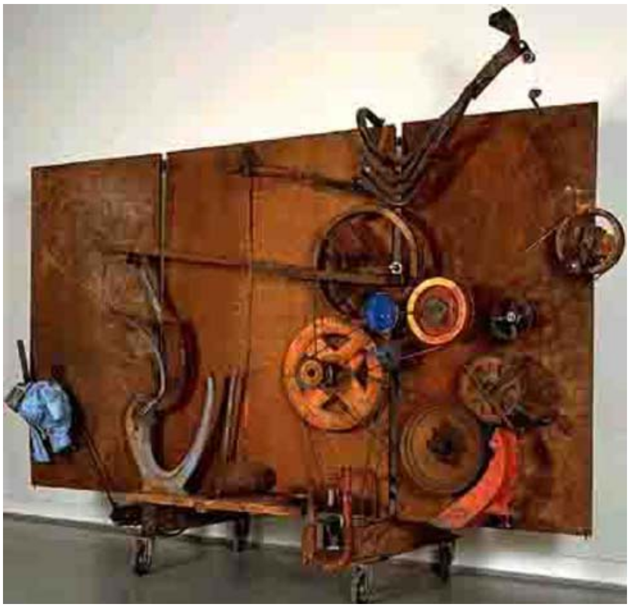

Fig. 1 Jean Tinguely: Reflet bleu: hommage à Schmela, 1978

Fig. 2 Marcel Duchamp: Bicycle wheel. 1913

In this sculpture, a bicycle wheel is mounted onto a stool. In a letter sent to his sister in 1915, he wrote that he particularly appreciated the motion of the wheel because of its hypnotic effect. Following upon his fascination for motion, Marcel Duchamp also made a series of works such as le *Nu descendant l'escalier* in 1912 (Duchamp's first controversial painting, *Nude Descending a Staircase, No. 2* depicts the motion of the mechanistic nude with superimposed facets, similar to motion pictures) or movies such as *Anemic cinema* (1925) or moving objects as *Rotoreliefs* (1935). This artwork is considered the first of a series of object-sculptures named 'Ready-made'. The 'Ready-made' series was in fact an exhibition of individual objects from daily life. In conclusion, when comparing Figs. 1 and 2, it becomes apparent that Tinguely's accumulation of cogs and wheels interconnected by belts and activated by a motor are an extension of the object-sculpture of Duchamp. In this sense, Tinguely has associated different mechanical objects and pieces of engines to give rise to a kinetic machine.

In the field of chemistry, a large number of molecular machines have been created and reported in the literature [10]. Such mechanical devices are identified as brakes, rotors, motors, gears, tweezers, etc. However, these molecular machines are 'single' in the sense that they possess a particular, single function, similarly to that of the 'Bicycle wheel' from Duchamp (the function of which is 'rotation'). To achieve molecular machines with higher working abilities—closer to Tinguely's metamechanics—chemists have more recently designed and synthesised molecular machines made of two single machines. In a precedent publication [8] we highlighted an article by Yamato et al. [11] presenting a 'double' mechanical molecular machine. The system consisted of two calixarenes which assemble and disassemble by H-bonds depending on a cation chelation by one of them. The system was assimilated to two spatial shuttles stowed one to the other until the signal (metal complexation) is given. In this system, one molecule thus acts on another by disruption of molecular interactions in order to release it. A second example was found a posteriori which precedes Yamato's publication by several months. Figure 3 shows the system designed by Muraoka et al. [12]. The larger molecule **1** is constituted of two zinc porphyrins attached to a ferrocene also bearing photosensitive (cis ↔ trans) azobenzene units. The two zinc porphyrins complex one bidentate rotor **2** to give a complex **1** · **2** through the pyridines entities (nitrogen-zinc coordination). Photoisomerization of the azobenzene strap in response to irradiation with ultraviolet (UV) and visible light (Vis) induces a scissors-like conformational changes (left-handed or right-handed) of the zinc porphyrin units. By an allosteric effect via the ferrocene-pivot, a twist of the rotary guest **2** is obtained in either a clockwise or a counterclockwise direction.

Figure 4 shows the mirror images of scissors-complexes **1** · **2**. Using circular dichroism spectroscopy it was shown that the photoinduced conformational changes of **1** are indeed transmitted and induce mechanical twisting of **2**.

In contrast to the single machines, the system reported by Muraoka et al. [12] contains two moving pieces (or single machines) which can work together. Noteworthy, this paper was recently highlighted by Stu Hutson in the NewScientist [13] and other examples of molecular machines incorporating chiral ferrocenes as novel rotary modules have been recently reviewed [14].

Finally, a third example of molecular machine association is offered by the chemistry of nanovehicles developed by Tour et al. [15]. Nanovehicles are a new class of molecular machines which look like cars. In fact, such

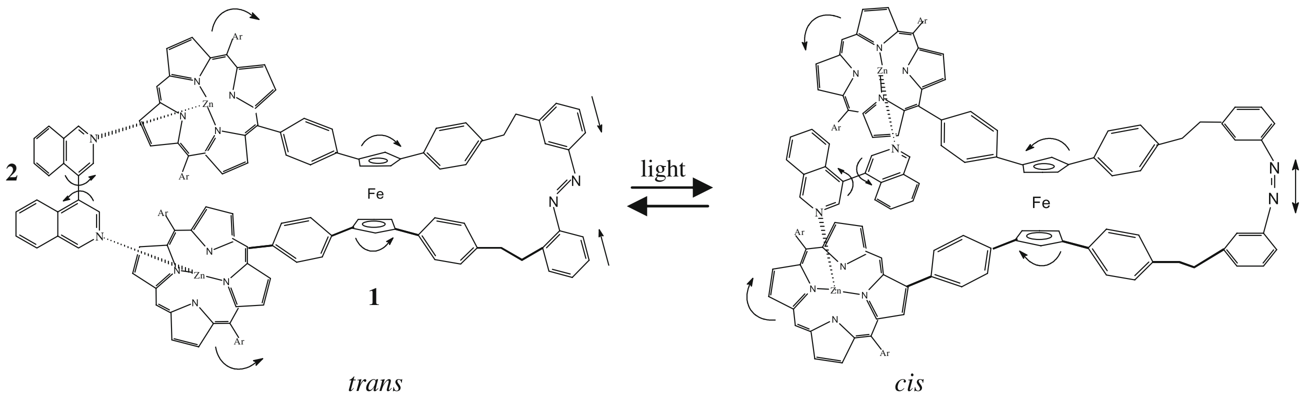

Fig. 3 The system designed by Muraoka et al. [12]

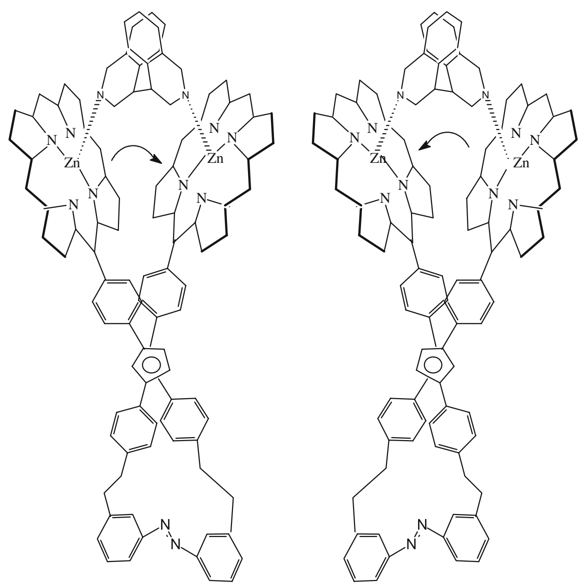

Fig. 4 Mirror images of scissors-complexes **1** · **2** [12]

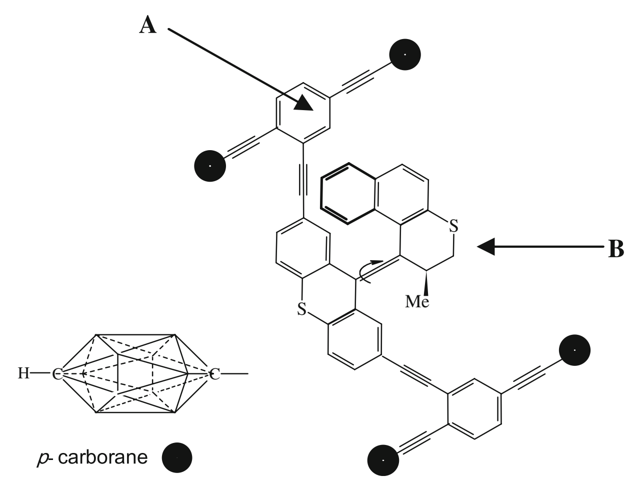

Fig. 5 Nanocar **3** developed by Tour et al. [16]

systems posses a molecular scale chassis, axles, and wheels, and can thus roll across solid surfaces with structurally defined directions. The progress in the design and synthesis of nanocars started from a simple nanotruck to a motorized nanocar [16]. In short, the motorized nanocar is a multi-machine component. Figure 5 shows the motorized nanocar **3**. Nanocar **3** bears a light-activated unidirectional molecular motor **A** acting as a paddle and developed by Feringa et al. [17] as well as an oligo(phenylene ethynylene) chassis and an axle system with four carboranes **B** to serve as the wheels. Kinetics studies in solution show that the motor **A** rotates upon irradiation with 365 nm light, allowing the potential motion of nanocar **3**.

The construction of multi-machine components in art and chemistry, shown herein, bears similarities to the works of Leonardo da Vinci. Leonardo da Vinci is as famous for his paintings as for his scientific works. He is credited to be the inventor of mechanics and machinery. From 1490 to 1495 he developed his habit of recording his studies in illustrated notebooks. In 1493, he sketched a series of plates of weapons, loads, flying machines, geometry, and machinery known as the 'Tratado de Estetica y Mechanica en Italiano' as part of the *Codex of Madrid*. From his mechanical sketches, he drew a multi-machine (in the sense given in this text) made of 13 like cogs in order to maintain a constant ratio of ten to one in each of them, seemingly with no use. In fact, he was designing the precursor of a so-called device for calculation, without knowing it.

The idea of assembling single machines or letters of 'mechanical alphabets of engineers' has been proposed by Ferguson in 1977. In this paper, Ferguson traces the development of nonverbal thought as practiced by technologists back to the Renaissance, and points out the many drawings and pictures that have both recorded and stimulated technological developments. He also reviews the graphic inventions, such as pictorial perspective, which have lent system and clarify to nonverbal thinking. Such nonverbal thoughts are the driving force which permits the creation of machines with higher operations [18], as exemplified by Tinguely's constructions, created from a panel of 'kinematic models' [18].

When looking at molecular structures, organic chemists usually see the functional groups that can be used, recognize to which family the molecules are belonging, anticipate if the molecule will be solid or liquid at room temperature, which color it will have, etc. [19]. With the event of supramolecular chemistry and nanochemistry, as well as the development of the bottom-up approach to molecules, the representation of a molecule received a new identity which can be named *disegno* [20]. This term (very similar to *design*) means "drawing with an intention" or "drawing with a project", and has been used to characterize the drawings of Leonardo da Vinci. In fact, the representation of molecules is with an intention in the field of molecular machines, as it is precisely the representation that invited the chemists to go further with their imagination in the creation of new molecular objects. In comparison to living systems and bio-machinery, Browne and Feringa casted their doubts regarding the imagination of 'nanomotorists' [21]. However, it seems that the main factor against a rapid development of synthetic molecular machinery is not the imagination of chemists but rather the challenges encountered during organic synthesis, assembly of the machine, and characterization of its function.

In summary, machines and machineries have been developed by artists and chemists in the same way that the engineers have developed mechanical machines in technology. Finally, let us reflect upon a sentence from Ferguson [18]: '*Technologists, converting their nonverbal knowledge into objects directly or into drawings that have enabled others to build what was in their minds, have chosen the shape and many of the qualities of our man-made surroundings. This intellectual component of technology, which is non-literary and non-scientific, bas been generally unnoticed because its origins lie in art and not in science.*'

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