Aesthetics of Chemical Products

Materials, Molecules, and Molecular Models

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Abstract: By comparing chemistry to art, chemists have recently made claims to the aesthetic value, even beauty, of some of their products. This paper takes these claims seriously and turns them into a systematic investigation of the aesthetics of chemical products. I distinguish three types of chemical products – materials, molecules, and molecular models – and use a wide variety of aesthetic theories suitable for an investigation of the corresponding sorts of objects. These include aesthetics of materials, idealistic aesthetics from Plato to Kant and Schopenhauer, psychological approaches of Ernst Gombrich and Rudolf Arnheim, and semiotic aesthetics of Nelson Goodman and Umberto Eco. Although the investigation does not support recent claims, I point out where aesthetics does and can play an import role in chemistry. Particularly, Eco's approach helps us understand that and how aesthetic experience can be a driving force in chemical research.

Keywords: *chemistry and art, aesthetic theories, molecules, materials, molecular models*.

1. Introduction: Science and Art[1]

'Science and art', while being an evergreen topic in western cultural history, has attracted growing interest in recent times. Against the continuous process of differentiation and specialization, in society at large as well as in the sciences, reference to aesthetics is expected to provide integrating and reconciling forces. At least it should bridge the gap between 'the two cultures'. Since the 19th century, museums of natural history have presented their exhibits from zoology, botany, and mineralogy in a similar way as museums of fine arts. Nowadays, we can enjoy multi-media spectacles that seek to introduce us both to the beauty and the intellectual background of scientific objects, such as fractal geometry, nuclear spin tomography, or astronomy. Be-

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sides neo-Pythagorean admiration of nature, from Ernst Haeckel to Werner Heisenberg,[2] also scientific-technological products have come into the focus of aesthetic fascination.

In the history of modern philosophy, the relation between science and art has been debated controversially. For instance, Schiller, Schelling, Hölderlin, and even Schopenhauer were inspired by the "aesthetic utopia" of Romanticism (Habermas 1985, p. 44), according to which art is able to reach a higher form of identity, truth, or freedom than science. On the other hand, positivism, materialism, and Kantianism strongly defended the dominance of science in all epistemological matters. It was only Nietzsche who, as part of his voluntaristic destruction of scientific objectivity, tried to found an "artistic metaphysics" (*ibid.*, p. 118) and to "look upon science from the point of view of the artist" (Nietzsche 1972, p. 7). For several contemporary philosophers, like Wolfgang Welsch (1989, p. 136), Nietzsche set up the program of an "aesthetic thinking" that philosophy started to fulfill only recently. Paul Feyerabend (1984) and Nelson Goodman (1973) are the most prominent authors whose work would have performed the 'artistic turn', the dominance of art over science. Yet, such a reading is uncritical, since these authors actually did not take an artistic perspective, nor did they suggest a battle between art and science. To the contrary, both tried to level out the differences between science and art and, rather than taking an 'artistic perspective', they took the perspectives of philosophy of science and semiotics, respectively. In a similar attitude, both Jacques Derrida and Richard Rorty have tried to level out the difference between philosophy and literature or literary criticism.

In this paper, I investigate if certain parts of chemistry are comparable to the fine arts. It should be noted that this is a trivial issue if we take but a sufficiently abstract point of view. For instance, it is trivially true that both are human activities. Also most people would agree that both are creativity-driven, that they continue to produce something novel, and that novelty is an important quality measure in both areas. If van't Hoff's early statistical-biographical analysis is right (van't Hoff 1878), distinguished scientists on average show an extraordinary strong sense for the arts or even practice one or the other fine art in their leisure time. Furthermore, chemistry has in common with the fine arts that both produce novel *material* entities. Yet, all that is true also of many nonscientific activities. On the other hand, if we go further in defining the arts more precisely, we get into the muddle of the variety and arbitrariness of art definitions. If everything could be considered art, as some have suggested, also chemistry is artistic. If art were only what artists do, the answer would be negative, unless chemists begin to call themselves artists. Leaving such useless definitions aside, we may analyze instead if the products of chemistry meet certain aesthetic criteria. Again, the answer depends on what we shall take as aesthetic criteria. It is not so much a problem that aesthetic criteria may be based on subjective taste; the problem is rather to put taste on the formal level of aesthetic criteria. To that end, it is necessary to discuss various aesthetic theories.

It is not before recent times, that chemists began to lay aesthetic claims to their products. Indeed, according to a document analysis of 300 randomly selected chemical papers (Schummer 1997a), at least 2% of the papers nowadays mention the aesthetic value of their molecules as one of the aims of making them. (Note that in absolute terms, 2% of the chemical papers are more than the total of all philosophical papers published per year.) In addition, several papers on 'Molecular Beauty' or 'Beautiful Molecules' have appeared.[3] As Roald Hoffmann, one of the pioneers of molecular aesthetics, said (1993, p. 68), "chemists can either artificially produce molecules occurring in nature or create new structures, the only value of which is their aesthetic attraction." Furthermore, chemistry journals present research results by displaying colorfully designed molecular pictures on their covers, and more recently also in the papers; they celebrate 'molecules of the year or month' just because of their extraordinary symmetries. Particularly molecules in the form of the Platonic solids, on which whole research groups have been working for years, are highly estimated by chemists. Since the soccer ball, buckminster fullerene, was made by chance in 1985, 'molecular beauty' has also come into the focus of the mass media. In addition, supramolecular chemistry is promoted with the flair of producing a miniaturized world, hitherto known only from fairy tales and fantasy stories.

There is no question that chemists increasingly lay aesthetic claims to their products. The question is rather: on what aesthetic ground are these claims laid? Can we find any justification for an aesthetic potential of chemistry, as stated by chemists, in one or the other established aesthetic theory? Or, is praising the beauty of chemical products just another way to call for attention in a public debate that is used to be disinterested in, if not hostile to, chemistry? Taking the claims of chemists seriously, I will discuss the issue in a general and systematic manner. Therefore, it is first necessary to introduce an ontological distinction between different types of chemical products, as there are substances or materials (Sect. 2), molecules (Sect. 3), and molecular representations (Sect. 4). For each of these types, we can then ask whether or not and to which extent certain aesthetic theories apply. Since aesthetics overall is still in a badly developed shape, our answer cannot be definite. Particularly a negative answer would point out the need of further investigations of aesthetic theories. A positive answer, on the other hand, would clarify the role of aesthetics in chemical research and open up a normative discussion about aesthetic values in science.

2. Materials

The products of synthetic chemistry are first of all substances, materials, or, to be more correct, pieces of materials with various sensual properties. Strangely enough, however, none of the chemists who recently pointed out the aesthetic value of their products provides any reference to materials and their sensual qualities. What they have in mind instead are molecules to be praised for their structural features, no matter what the sensual qualities of the corresponding substances are. However faint the piece of material might appear to our senses, say a colorless liquid without smell and taste, it is the molecules that are said to be beautiful. Since the present investigation follows systematical lines, I keep the molecules aside for a moment (see Sect. 3) and start with the aesthetics of materials.

In the western tradition, there is a long lasting domination of aesthetics by very specific issues, such as theories of art and, particularly, of literature. Beyond this narrow focus, the original meaning is much broader and goes back to Greek *aisthesis*, knowledge of our sensations, particularly of how sensations induce emotions, attitudes, and judgments beyond epistemic and moral judgments proper.[4] Paradigm cases of aesthetic phenomena are the sensation of an odor that that makes people feel happy or sick; certain sounds, colors, tastes, or sensual environments that bring people into a certain mood, and so on. Since most of our sensations are based on, or directly referring to, sensual qualities of materials, materials should play a pivotal role in aesthetics. Moreover, if one defines art in the broadest sense as an approach that deliberately provokes aesthetic phenomena, artists should be primarily concerned with the sensual effects of materials. From that it would follow that a science capable of 'composing' new materials with certain sensual qualities meets necessary conditions of art. Before we discuss if chemistry also meets sufficient conditions, let us have a brief look at three examples from chemistry and adjacent fields.

2.1 Aesthetic contributions of chemistry: three examples

2.1.1 Color

Throughout the history and prehistory of chemistry, color played a pivotal role. Archeologists found that colored glass-like stones were made both in Egypt and Mesopotamia before 4000 BC; the earliest synthetic pigment (blue ground frit, $CaO\text{-}CuO\text{-}4SiO_4$) was already produced about 2650 BC,[5] and many should follow in the prehistoric period for uses in painting and cosmetics. Insofar as alchemy has its roots in Hellenistic Alexandria, it refers to the 'coloring of metals', be it by surface treating or by alloying. The alchemical hierarchy of metals – with lead at the bottom, copper somewhere in the middle, and gold at the top – is grounded on an aesthetic hierarchy of colors (black, red, yellow), which is incidentally preserved in the German flag. It might even be said that the whole obsession with gold, before it was established as a currency by convention, was based on nothing else than on the aesthetic preference of its color and shine. It is also well known that the 19th-century success story of the chemical industry had its main source in the mass production of synthetic dyes.[6] Indeed, their cheap and non-fade dyes rapidly spread all over the world and changed the visual environment in such way that it is fair to speak of an aesthetic revolution.

2.1.2 Plastics

A second, more recent example of chemistry's large-scale impact on our sensation of the world started with the mass production of plastics.[7] Used as surrogates for 'natural' materials like wood and metals, they soon became a symbol of modernism, or even futurism, the utopia of an entirely technologically supported form of life that is independent of 'nature' and guided by functional aspects only. There is probably no better example to illustrate the cultural aesthetics of materials, since the mere sensation of a piece of plastic, say polyethylene, may induce strong feelings. Those who subscribe to the futuristic utopia strongly prefer plastics to natural materials beyond functionality, as they relate the material to their own ideas of life. In times and cultures where such ideas are prevailing, a synthetic imitation of a flower may be considered more beautiful than the original. For others, imitations are essentially inferior to their originals, regardless of practical usefulness. If people dislike surrogates simply because of their lack of naturalness and authenticity, their attitude is again based on aesthetic values. Thus, the material is considered either beautiful or ugly.

Whether knowingly or not, chemistry and, particularly, the chemical industry took a prominent position in an aesthetic debate when, for instance, DuPont issued their slogan "better things for better living through chemistry". Based on the opposition of natural versus chemical (=synthetic),[8] they became representatives of a 'synthetic life form', with plastics as its outstanding symbol. The professional aesthetic debate, which goes back to Plato's denunciation of the imitating arts as mere deception,[9] is essentially over the aesthetic priority of nature or art: either nature is the model of beauty such that art can only produce more or less poor imitations of nature, or art is capable of producing genuine beauty from which our sense for natural beauty is only derived.[10] Beyond such ideas about art, the debate reflects different aesthetic attitudes towards the synthetic. It helps us understand that the aesthetic dimension of materials transcends mere sensations and includes knowledge about their (synthetic or natural) origin as well as symbolically mediated values. In that debate, the chemical community has no doubt taken a firm stand.

2.1.3 Taste and smell

A third example relates to the arts that focus on the sensual dimensions of taste and smell. Because the fine arts are concerned with deliberately provoking aesthetic phenomena via our senses, cookery and perfumery would be excellent candidates. There is no doubt that our senses of smell and taste can be developed on a highly subtle level, such as the arts of composing odors and flavors have reached a high level of sophistication. So, what does prevent us from taking cookery and perfumery as fine arts? Since chemistry could considerably assists these arts, both in understanding the olfactory organs and in synthesizing new stimulants: why should we not call chemists working in these fields artists?

The fact that cookery and perfumery are generally not assigned to the fine arts suggests that the issue is somewhat intricate.

2.2 Answers from aesthetics

2.2.1 Idealistic aesthetics

No matter what systematic arguments we apply to decide whether a certain field of activity belongs to the fine arts or not, the final decision is based on societal conventions. There has always been a hierarchy of the arts, at least to separate the 'higher arts' from the 'inferior crafts' as a means to distribute social prestige. Based on models in Greek antiquity and Italian Renaissance, the modern distinctions were tailored by 18th- and 19th-centuries philosophers who should become authorities in aesthetics and among which Kant was most influential.

For Kant (*Critique of Judgment* [*CJ*], § 43), the arts differ from the sciences in that the former are practical and the latter theoretical; and they differ from the crafts which are only useful and purpose-driven whereas the arts develop as a free game. (Note that the experimental sciences had already outdated the first distinction by the time of Kant's writing, while the second distinction led him into many troubles, particularly when defining beauty and aesthetic pleasure as the aim but not the purpose of fine art.) Deliberately avoiding any reference to the senses, Kant derived his scheme of the fine arts on the analogy of three modes of the expression in speech (*CJ*, § 51): (1) words corresponds to rhetoric and poetry; (2) gesture to the 'formative arts', sculpture, architecture, and painting; and (3) tone to music. Needless to say that the analogy favors poetry as the highest art. Arbitrary and eccentric as the linguistic analogy might appear, which Kant himself conceded, his results should become extremely influential, the more as they pretended to comprise the total of the fine arts. By and large, the conventional scheme is still alive and excludes the other traditional arts from the established canon. If new media appear, such as photography and motion pictures, they become only slowly accepted and then as derived forms. Anyway, there is no place for cookery and perfumery.

One might object that 20th-century avant-garde has overcome the old scheme such that, for instance, Eat Art has bridged the gap to cookery. To some extent this was true at least of the founder of Eat Art, Daniel Spoerri, who became famous for opening a restaurant in 1968 and for organizing several Eat Art banquets in the early 1970s. However, Eat Art simply comprises artwork that employs or represents 'edible materials' for different purposes, mostly symbolic and as part of a sculpture. An instructive example is the 2001 'Eat Art' exhibition at the Harvard University Art Museums, presenting works from Joseph Beuys, Dieter Roth, and Sonja Alhäuser "each of whom has used food as a medium to address concerns of social change, satire, or pleasure".[11] As with other materials, Beuys used food in his sculptures as part of his idiosyncratic symbolism. Roth's edible objects display states of decay to the eyes of the visitor and, thus, refer to the vanity still lives of the Renaissance, instead of cookery. Only Alhäuser encourages visitors to consume her work; yet, rather than providing experiences of artful taste, she is "interested in erasing the boundary between the audience and the artwork via the interaction of eating."

The notion of fine arts, as modern aestheticians composed it, did not include the senses of taste and smell. In addition, the sense of touch is, according to Kant, "without regard to beauty" (*CJ*, § 51). Schopenhauer even recommended placing artwork at a distance, so that visitors cannot make a grab at it. Such as music is made only for hearing, such should the enjoyment of the formative arts be exclusively a matter of visuality. Even worse, the visual sense of beauty is confined to the recognition of forms and patterning and, thus, must abstract from colors:[12]

> In painting, sculpture, and in fact in all the formative arts, in architecture and horticulture, so far as they are fine arts, the *patterning* ['Zeichnung'] is what is essential. Here, the fundamental prerequisite for taste is not what gratifies in sensation but merely what pleases by its form. The colors which give brilliancy to the sketch are part of the charm. They may no doubt, in their own way, enliven the object for sensation, but they cannot make it really worth looking at and beautiful. [I. Kant, *The Critique of Judgment*, 1790, § 14]

With surprising rigor, these philosophers completely eliminated the sensation of material qualities from aesthetics. Behind that stood idealistic aesthetics in the Neo-Platonic tradition that should prevail the 19th century.[13] Bound to the duality matter/form, the chorus of modern aestheticians denounced matter as being the antipode of beauty, as Plotinos had already identified matter with the ugly in the third century.[14] Hence, if beauty is to be sought in the form as the medium of ideas, the artist's first rule is to make matter vanish, or, as Schiller wrote in his more poetic style:[15]

> So, that is the master's true secret of art, *destroying matter by the form*.

Idealistic aesthetics is not without puzzles. Once the matter vanishes, the artwork is in danger of getting out of the senses. Here are some famous 19th-century attempts to deal with the puzzle by virtuous wording:[16]

> The spirit [...] wants sensual presence that, while remaining sensual, should be freed from the scaffolding of mere materiality. [G.W.F. Hegel *Introduction to Aesthetics*, 1835]

> The isolation or separation of the form from matter belongs to the nature of an aesthetic artwork, because it is its aim to bring to our knowledge a (Platonic) idea. Hence, it is essential for artwork to present the form without matter and to do this obviously and clearly. [A. Schopenhauer, *Parerga und Paralipomena*, 1851, § 209]

> Matter is compelled to self-denial, so to speak, insofar as it is only utilized for the purpose of expressing such an immaterial object as the visual form of things. [K. Fiedler, *On the Origin of the Artistic Activity*, 1887]

To sum it up, in idealistic aesthetics, the dominating doctrine in the Western tradition since Plato, there is no place for the senses of taste, smell, touch, and color, as there is no place for the sensations of material qualities other than representing the opposite of beauty. The task of the artists is to mediate intellectual, moral, or religious ideas, from which sensations would only divert.

2.2.2 Aesthetics of materials?

As with all radical doctrines, idealistic aesthetics prompted counter-positions. Since the mid-19th century, first in architecture, then in sculpture, and finally in painting, artists began to realize the expressive, symbolic and style-shaping characteristics of materials, calling for 'Truth to Materials' or '*Materialgerechtigkeit*' in aesthetics.[17] Initial movements in architecture criticized the painting of buildings as 'lying', because layers of paint would hide the natural building materials. At the dawn of 'artificial' building materials, like concrete, materials came into the focus of the aesthetic natural-artificial debate in architecture, which was basically a debate between romanticism and futurism. Late 19th-century sculptors started trying out new or rediscovering old materials, beyond the obligatory bronze and marble. Degas' wax statues of young girls were early modest, though scandalous, examples because the flesh-like colored wax provided the statues with a peculiarly sensual flair.[18] Much more radical, regarding both the variety of materials and the dominance of 'matter over form', were the *objets trouvées* or the arbitrarily assembled pieces of garbage of the Dadaists. Since the 1960s, sculptors increasingly employed plastics for specific purposes, like Claes Oldenburg's 'soft sculptures', Christo's wrappings, or César's polyurethane expansions, representing a state of extreme amorphousness.[19] In painting, where colored materials had become means for the purpose of representation by depicting forms or by providing spatial illusions, the recognition of aesthetic values of materials certainly had the most radical impact.[20] If one focuses on the material qualities of paints in a painting, its representational character immediately vanishes, such that the painting turns into a colored piece of material, from an illusionary medium into a real or concrete thing, as new movements of 'realism' or 'concretism' emphasized. This was no doubt the driving force towards abstractionism, as the most fundamental rupture in the history of painting. Whether *abstract expressionism*, the purist *color field paintings*, the spontaneous *action paintings* of Jackson Pollock, the post-war *matter paintings* in Paris (*e.g.* Jean Dubuffet, Antoni Tàpies) or in Italy (*e.g.* Antonio Burri and Lucio Fontana), all pointed out the importance of material qualities of paint (and other materials as used in collages) for their specific ends.[21]

As compared to the revolutions in the arts, professional aestheticians have been rather reluctant regarding the development of aesthetic theories of materials. The main impact was probably a shift from aesthetics as a theory of art perception towards 'aesthetics' as a theory of art production, *i.e.* a (normative) theory about the process of artistic creation with emphasis on the guiding forces of materials. As with idealistic aesthetics, this is full of nebulous metaphors, such as the artist must let speak the materials or help the materials come to their right. Even more, art critics, who by commenting on the revolutions in the arts with homespun ideas of 'modernism' got considerable influence on the art market,[22] have been quick with words but bare of aesthetic theories. In fact, there is no aesthetics of materials worth mentioning. All we have are some exemplary attempts in phenomenology[23] and a growing research in art history, particularly on the iconology and symbolic values of materials.[24] Based on that we may draw only some preliminary conclusion regarding the question if the chemical production of new materials has an artistic potential.

2.3 Preliminary conclusions

(1) There can be no doubt that chemistry can make important contributions to the development of an aesthetic theory in the original sense of a theory of sensation, by improving our biochemical understanding of the sense receptors and by synthesizing appropriate stimulants, particularly for the 'chemi-

cal' senses of taste and smell. Such a chemical understanding is limited, however, to the extent that our sense induced emotions and attitudes are not dependent on subjective or culturally embedded and symbolically mediated values. Recent chemical attempts at producing substances with terrifying odors for everybody, as a way to get round the Chemical Weapons Convention effective since 1997, prove that the scope of 'objective' smells is much smaller than expected.

(2) Chemistry did and can further contribute to the aesthetic shape of our environment, mainly through the development and industrial production of dyes, paints, plastics, and other raw materials used in daily life. This goes far beyond a mere change of 'things', in the naturalistic sense, since the chemical change is part of our cultural history that is symbolically loaded and that prompts symbolically mediated aesthetic attitudes.

(3) Whether all that may be called an artistic activity depends on the definition of art, on which aestheticians pretend to have a monopoly. It is evident that idealistic aesthetics categorically rules out anything related to materials, but that would include also most of the fine arts nowadays. Yet, even in view of a prospective materials based aesthetics, there are at least two general arguments that the mere chemical synthesis of new substances fails to meet general conditions. First, increasing the weight of materials in artwork has always been a matter of degree, and never completely banished the complementary aspect, form, or better, composition or arrangement. To take two famous and extreme examples from the 1960s, even an apparently formless piece of fat or some bottled feces were deliberately arranged in the environment and context of exhibitions. In contrast, the mere chemical synthesis of a piece of material has no compositional element. Second, when chemists produce new materials, it is exactly the novelty that excludes them from any kind of symbolic or cultural context, on which the most elaborated aesthetic concepts of materials depend. An early, tentative list of such aspects by art historian Wolfgang Kemp (1975) includes economical value, dissemination, functional properties and technological use, imitating capacities, magical and fetish meaning in history. New substances are simply too novel to have any bearings in that regard.

Against both objections, the lack of composition and of cultural embedding of new materials, there seems to be only one solution in favor of a 'chemical art', which borrows ideas from alchemy. If materials are too novel, they might be 'composed' out of known, culturally loaded properties, yielding a new, surprising, or interesting 'mixture' of properties. At least, such a 'chemical artwork' would make it extremely difficult for aestheticians to put forward objections on systematical grounds.

3. Molecules

Among the chemists who recently raised their voice in favor of the beauty of chemical products, there is agreement without exception that it is the molecules, and only the molecules, for which claims of beauty and artistic creativity are justified, no matter what sensual qualities the corresponding materials have. The disregard of material qualities and the praise of structural features of the molecules clearly relate these claims to idealistic aesthetics of the 19th century and before, so that we must analyze if molecules may fit in with such theories.

At first glance, there seems to be strong support from idealistic aesthetics. On a closer look, however, we are faced with a puzzle. Molecules do not fit the ontological categories for objects of aesthetic judgments. They are not directly accessible through sensation. Their constitutive structural properties result from the theoretical interpretation of various properties, formerly chemical properties, nowadays mainly spectroscopic properties. Thus, if the molecule shall be an object of aesthetic judgment, it is definitely not an object of direct perception. Apart from objects of perception, idealistic aesthetics offers only ideas or intellectual objects accessible through thinking. Now, if molecules were intellectual objects, chemists would not need to work in their laboratory because creative imagination is sufficient to produce intellectual objects of aesthetic judgments. It would even be a matter of discussion if chemical knowledge is necessary for creating such intellectual objects. That is certainly not what chemists have in mind. Therefore, we are forced to decide between two options: either molecules, because they are neither perceptible nor merely intellectual entities, are no objects of aesthetic judgments, or we need to introduce a new category for objects of aesthetic judgments. In the next section, I will follow the first option and take molecular models instead of molecules as possible objects of aesthetic judgments. In the remainder of this section, I discuss if there is a chance to introduce a new category for molecules.

To that end, we can, strangely enough, directly refer to Plato's 'aesthetics of nature', if his references to beauty in his dialogue *Timaios* may be called so. It even seems as if we could accuse idealistic aesthetics in the Platonic tradition of a grave omission. What Plato explicitly called *the most beautiful bodies in the whole realm of bodies* (*Timaios*, 53e) are not men, animals, plants, landscapes, or whatever kind of natural things the fine arts have tried to imitate. Instead, these are the tiny little bodies, the elemental building blocks of all other bodies in the form of the regular polyhedra. Much too small to be perceived by the senses (*Timaios*, 56 b/c), they make up the four antique elements: fire/tetrahedra, air/octahedra, water/icosahedra, and earth/cubes (*Timaios*, 53c-56c, see Figure 1).

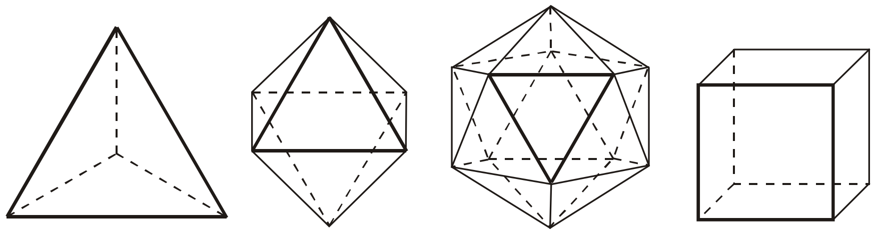

Figure 1. Plato's regular solids corresponding to the four antique elements: tetrahedron (fire), octahedron (air), icosahedron (water), and cube (earth).

The interesting point is that Plato's most beautiful bodies are neither perceptible nor merely intellectual entities. Although they are too small to be perceived, these bodies belong to the material realm of perceptible things. Yet, it is not the senses, but reasoning by necessity and probability (*enagke* and *eikasia*; *Timaios*, 53d) that provides access to these bodies. In modern terms, these bodies are hypothetical or theoretical entities. Thus, we can define a new category of aesthetic objects, which I call '*hypothetical entities*', and to which we can easily assign the chemical molecules.

The fact that theoreticians of art have ignored hypothetical entities was excusable as long as there was no chemical structure theory that unambiguously relates to each pure substance a molecular structure. Since the second half of the 19th century, however, there was such a theory, so that nothing speaks against transferring Plato's aesthetics of nature to a corresponding aesthetic theory of art. As it turns out, modern chemistry is exactly the art (*techne*) that provides creative access to what Plato considered the realm of the most beautiful bodies. Therefore, it is no surprise that chemists put their creative activity also in the service of beauty. The Platonic heritage explains even more why chemists have over decades been engaged in the synthesis of molecules with the shape of the Platonic bodies. As one of them said: "The aesthetic attractiveness of highly symmetrical platonic hydrocarbons can be a reason for planning and performing the synthesis of such unusual compounds."[25]

Drawing on Plato's authority in artistic matters is not as easy as some chemists would probably wish. Indeed, Plato had strong objections against, even hostility to the imitative arts, such as painting and sculpture, and condemned them as cheeky deception. According to Plato, the painting of a natural body is only an imperfect imitation of the natural body that in turn is only an imperfect materialization of an idea, as the true object of beauty. Thus, the Platonic solids are only beautiful because they are related to the original beauty of the mathematical ideas of the polyhedra, *i.e.* intellectual objects recognizable through thinking. If modern chemists, like Plato's *demiurgos*, produce such solids, they do not add anything beautiful but only proliferate the imperfect images, for which Plato saw no need. Not only are the imitating arts the opposite of creativity, they worm themselves into the admiration of spectators by parasitical means and pass their works off as beautiful while actually producing only imperfect imitations. So, it seems that the original Plato would have left nothing good at the chemical efforts to reproduces his solids.

Only the Neo-platonic tradition, first of all Plotinos, turned Plato's aesthetics of nature into a positive theory of the imitative arts for pedagogic reasons. The idea was that, despite of their imperfection, the perception of material imitations might serve to direct the attention of people towards the original beautiful ideas. In this view, *i.e.* in idealistic aesthetics, sense perception of artwork meets pedagogic ends as a step toward the recognition of ideas. As we have seen in the last section, sensations have only instrumental value in idealistic aesthetics. However, sensations are necessarily required as the intermediate steps towards the ideas. That seems to be the reason why theoreticians of art have never considered hypothetical entities, to which our molecules belong, as products of artistic activity. So, we are back to the problem that molecules do not fit in with aesthetic theories of art, because they are neither perceptible nor merely intellectual objects.

Now, chemists could respond that molecules, although not being directly perceptible, can be indirectly recognized by chemical means of structure elucidation, such that an adequate aesthetic theory must be based on indirect access. Yet, such a theory would have to include the sophisticated approach of chemical structure elucidation. It would be an aesthetic theory from chemists for chemists, in other words, an esoteric aesthetics. Chemists who praise the beauty of their products would have to be clear about the point that nonchemists would lack any understanding. In particular, referring to an esoteric aesthetics fails to achieve what some chemists might expect from aesthetics. Rather than bridging the gap between science and nonscience, an esoteric aesthetics would even broaden the gap to the extent that it causes strange feelings among nonchemists.

In sum, molecules fail to fit in with idealistic aesthetics because they are neither perceptible nor merely intellectual objects. Attempts at introducing a new category of aesthetic objects would lead into an esoteric aesthetics. If we wish to retain the perceptible character of chemical products, we must turn from molecules to molecular models. Since chemists frequently do not clearly distinguish between molecules and models of molecules, it may well be that their claims to the beauty of molecules are meant to be claims to the beauty of models.

4. Molecular Models

I will use the term 'molecular models' to denote perceptible objects that are produced to represent or to illustrate molecular structures or ideas, such as drawings, stick-and-ball models, computer graphics, and so on. Being perceptible objects, molecular models belong to the same category of objects as the products of the formative arts. While this allows drawing on aesthetic theories of art, the mere wealth of such theories, and their frequently half-baked state, bears the danger of loosing the systematic character of our investigation. To make a reasonable selection on systematic grounds, I distinguish between three types of aesthetic theories. The aesthetic potential of molecular models might be sought in:

(1) their representational or illustrative functions regarding certain ideas, in the lines of classical idealistic aesthetics;
(2) their symbolic functions as part of a chemical language, for which Goodman's approach is suitable;
(3) their capacities to relate different semantic contexts to each other, for which Eco's semiotic theory of aesthetic messages is a good choice.

All three approaches combine the advantages that we have some more or less well-developed criteria required for the investigation and that chemists have indeed made some direct or indirect references to them.

4.1 Idealistic aesthetics and a closer look at symmetry

Within the framework of classical idealistic aesthetics, a molecular model may be called beautiful insofar as it illustrates a beautiful idea. For the aesthetic judgment, it is irrelevant whether the model also represents an existing molecule or not. Therefore, the specific chemical context of the model does not matter. For instance, a child's drawing of a cube would have equal rights to be called beautiful as the chemist's drawing of cubane. If chemists confine their drawings to those which also represent real molecules, they may have good chemical reasons to do so, but they do not apply aesthetic criteria. In idealistic aesthetics, it is reference to ideas and not reference to material reality that matters. Because the chemical context is contingent, idealistic aesthetics can hardly justify a peculiar chemical art.

Apart form that fatal failure, we may further investigate if or to which extent symmetry may be considered a measure of beauty. Nearly all chemists, when talking about the beauty of certain molecules (molecular models) point out the symmetry and particularly refer to the Platonic solids. Roald Hoffmann, in his "empirical inquiry into what one subculture of scientists, chemists, call beauty" (Hoffmann 1990, p. 191), states that the "Platonic solid of dodecahedrane is simply beautiful and beautifully simple [...] simple, symmetrical, and devilishly hard to make" (p. 192). That is no doubt in accordance with Plato who held symmetry or the simplicity of the mathematical description as the measure of beauty. Yet, as we have seen, Plato is no good source for artistic matters, since his aesthetic ideas in the *Timaios* were only about nature. In addition, following the Pythagorean tradition, he intermingled epistemological with aesthetic aspects of nature, which idealistic aesthetics carefully separated later. Let us regard now if symmetry is a criterion for beauty.

First note that the term 'symmetry' has different meanings. In modern mathematics (group theory), to which chemists refer, the symmetry of a spatial object is defined by the number and kinds of its symmetry elements, *i.e.* formal operations on the object (rotation, reflection, inversion, rotary-reflection) that would leave it unchanged.[26] The higher the symmetry of an object, the more completely can we describe its shape in simple mathematical terms of symmetry elements, such that the shape of the highest symmetrical object, the sphere, is completely determined by its symmetry elements. Thus, mathematical symmetry analysis is also an epistemic approach to grasp the shape of spatial objects. In this system, the Platonic solids actually stand out because of their high degree of symmetry, as they come close after the sphere.

There is a different concept of symmetry, which was in fact the prevailing one in art history, particularly in the ancient aesthetic doctrines of sculpture (Polykleitos) and architecture (Vitruvius), later rediscovered in the Renaissance. It goes back to the original meaning of symmetry (lt. *symmetria*, gr. *syn métron*) and means sharing a common measure for lengths. In this sense, a spatial object is symmetrical if its lengths are in certain proportions. Like the group theoretical concept, it refers to mathematical description but replaces geometrical with arithmetical terms. The important difference is, however, that the proportions characteristic of beautiful forms are still to be determined. Followers of Plato and Pythagoras would measure up the beautiful proportions from geometrical objects. Yet, the dominant approach in sculptural and architectural symmetry took proportions of the human body as the standard of beauty, as did, for instance, Vitruvius, Leonardo da Vinci, and still Le Corbusier (Arnheim 1966). Based on that notion of symmetry, the Platonic solids are not symmetrical, nor are they beautiful.

Ancient aestheticians also raised severe criticism against the idea that symmetry or proportion would be the essence of beauty. If one takes Plotinos as its founder, idealistic aesthetics of art even began with rejecting symmetry (*Enneads* I.6.1). The basic doctrine is a holistic view of beauty, according to which it is impossible to compose a truly beautiful object from unbeautiful parts. If it were only the proportion or symmetry that matters, he argues, one could compose a beautiful object even from the most ugly parts. Emphasizing the unity of a beautiful object, Plotinos introduced a third concept as a measure of beauty, harmony, which is opposed to both mathematical symmetry and proportion.

In the formative arts, mathematical symmetry elements are largely confined to architecture, and mostly appear in ornamentation as translational symmetry, mirror plains, and occasionally rotation axes (Arnheim 1988, p. 8). Whether individually employed or as stylistic features of whole epochs, they express stability, order, and rest, and are frequently placed in contrast to a restless environment. Highly symmetric ornamentations appear to the observer as points of rest or are part of decoration. If a whole building seems to be composed according to strict symmetrical rules, a closer look will reveal well placed breaks of symmetry as a means to attract the observer's attention. The same applies to sculptures of minimal art or other 'purist' styles. In painting, it is even difficult to find examples where mathematical symmetry plays an important role. The famous exception is, of course, M.C. Escher, which made him the mostly quoted artist by chemists engaged in molecular beauty.[27] However, Escher combined mathematical symmetry with iconographical elements, which, incidentally, have many roots in alchemy. The idea that mathematical symmetry would be the essence of beauty to be measured by the number of symmetry elements appears so strange that one wonders how anybody could even think of that. If it were so, all artists reaching out for beauty would do nothing else than producing spheres, or better let the more accurate machines produce them.[28]

The little importance of mathematical symmetry in the arts corresponds to clear statements by modern aestheticians. In his aesthetics, Kant refers to mathematical order and regularities as prominent examples for what is repugnant to taste:[29]

> All stiff regularity (such as borders on mathematical regularity) is inherently repugnant to taste, in that the contemplation of it affords us no lasting entertainment and […] causes boredom.

Ernst Gombrich explains the little attractiveness of symmetrical objects:[30]

> Once we have grasped the principle of order, we are able to learn the thing by heart. […] We have easily seen enough of it because it holds no more surprise.

There is broad agreement among art historians and aestheticians of various schools that mathematical symmetry is by no means an ideal to be approached by artists. That does not mean, however, that symmetry plays no role in the arts. Yet, if theoreticians of art speak of symmetry, their meaning considerably differs from what scientists and mathematicians have in mind. The proceedings of an interdisciplinary symposium on symmetry in the humanities and the natural sciences (Wille 1988) are very instructive in that regard, because it includes discussion notes aiming at mutual clarification of the different meanings. Theoreticians of art mainly use 'symmetry' in the sense of proportion or harmony. Even if they talk of mirror planes, they do not mean exact mathematical reflection symmetry of forms, but rather a balance between two sides in terms of compositional elements, colors, or symbolic content. Taken in this broad sense, symmetry, if deliberately employed in the arts, seems to fulfill two purposes. Either symmetry is one of two opposite compositional elements, the other one being disorder, restlessness, or asymmetry; or symmetry is a conceived or suggested matrix of order from which the peculiarity of an artwork stands out by its specific breaks and elements of disorder. In an early paper on symmetry in the formative arts, art historian D. Frey resumes:[31]

> The decisive agent [of the artistic composition] lies in the tension between symmetry and asymmetry, between rest-on-itself and outwards directedness, between balance and impetus, between rest and movement, between being and becoming.

Psychologist of art Rudolf Arnheim expresses similar ideas:[32]

> Symmetry means rest and tie, asymmetry means movement and detachment. Order and law here, arbitrariness and chance there; stiffness and compulsion here, liveliness, play, and freedom there. […] The difference between symmetry and asymmetry is obviously the mere relation between balance and directed forces. On the one extreme, the relation would turn to the stiffness of complete standstill; on the other, it would turn to the equally terrifying formlessness of chaos. Somewhere at the ladder between the two extremes, every style, every individual, and every artwork finds its own particular place.

Also for Ernst Gombrich, art is engaged in a play of forces between symmetry and asymmetry, "a struggle between two opponents of equal power, the formless chaos, on which we impose our ideas, and the all too formed monotony, which we brighten up by new accents".[33]

The other task of symmetry in the arts is to provide a cognitive matrix of order that allows us to conceive the particularity or novelty of each artwork in terms of its peculiar breaks or asymmetric elements. As Theodor Adorno already stated:[34] "In artistic matters, asymmetry can be grasped only in relation to symmetry." In this sense, symmetry and its correlate asymmetry are an epistemic construct, an aid to understand what tends to evade understanding. Helga de la Motte-Haber stresses the impact of that construct on the history of art:[35]

> The production of art followed a fundamental doctrine that presupposed the explicability of everything and tolerated the unforeseeable and unpredictable only against the background of order as breaks of rules.

To sum it up, apart from early Pythagorean views on beauty in nature, it is difficult to find any source in the whole history of western theory of art that considers mathematical symmetry the essence of beauty. Instead, we have severe criticism of that idea as well as aesthetic theories based either on the alternative concepts of proportion and harmony or on the interplay of symmetry and asymmetry in a broad sense. So, what shall we make of the chemists' praise of the beauty of symmetrical molecules/models? Two explanations come to mind, which I will supplement by a third one in Section 4.3.

According to the quoted analyses of Frey, Arnheim, Gombrich, de la Motte-Haber, and others, we can locate the individual and cultural senses of beauty at a psychological scale of aesthetic preferences, ranging from extreme order to extreme disorder.[36] On this scale, the chemists' enthusiasm for highly symmetric molecules would reveal their extreme preference for order. However, as many studies in experimental psychology have shown, all people have a certain preference for symmetrical forms over asymmetrical ones (Schuster 1990, p. 124). Thus, there seems to be some disagreement between aestheticians and experimental psychologists. A second, much older, explanation may solve the puzzle. Despite of the lack of studies in experimental psychology in the 18th century, Kant was already well aware that the 'common taste' prefers symmetrical shapes. Part of his general critical project, his *Critique of Judgment* aims at delimiting aesthetics from epistemology. If people prefer symmetrical shapes, *i.e.* if the perception of such shapes is accompanied with a sort of pleasure, that pleasure is not of aesthetic but of epistemic nature as it results from grasping the shape by understanding its mathematical regularities. Therefore, praising the aesthetic value of symmetry is based on the confusion of aesthetic and epistemic satisfaction (*CJ*, § 22):

> Now geometrically regular figures, a circle, a square, a cube, and the like, are commonly brought forward by critics of taste as the most simple and unquestionable examples of beauty. […] The regularity that conduces to the concept of an object is, in fact, the indispensable condition (conditio sine qua non) of grasping the object as a single representation and giving to the manifold its determinate form. This determination is an end in respect of knowledge; and in this connection it is invariably coupled with delight.

Kant's analysis of the old Pythagorean mingling of epistemological and aesthetic criteria – beauty guarantees truth such as truth guarantees beauty – explains why scientists are particularly receptive to the appeal of symmetry. Inasmuch as the scientific enterprise aims at finding mathematical descriptions of nature, simple algebraic structures (as with the algebraic symmetries of physical theories, see *e.g.* McMorris 1970 and Zee 1986) and simple geometrical forms (as with the molecules of chemistry) satisfies epistemic needs. Thus, if scientists in these cases talk of beauty, they express epistemic rather than aesthetic delight. Unlike physicists, however, chemists deliberately produce their own objects of delight. It is only in this regard that they resemble the artists.

4.2. Goodman's aesthetics of symbols

With Goodman's symbol approach to aesthetics (Goodman 1968), we leave the classical idea that aesthetics would be a theory of beauty or even of aesthetic judgments. His aesthetics is basically a theory of art and, following the 'linguistic turn' of the 20th century, it is a symbol theory of art that conceives of the artist as a producer of symbols to be interpreted by receptors of art. Since for Goodman the symbol production may create a world of its own, the interpretation of art consists in understanding a world. Against that background, aesthetics, because it analyses the process of interpreting art, is a branch of epistemology. (Note that this is completely different from the Pythagorean mingling of epistemic and aesthetic criteria.)

Several decades before the 'linguistic turn' in aesthetics, there was also a 'linguistic turn' in philosophy of science. Now, if both science and art are seen through the lens of linguistics, common features show up immediately. It was hardly surprising then that Goodman recognized a relationship between science and art, both being engaged in "inventing, applying, reading, transforming and manipulating symbol systems" (p. 265); but he also saw "a difference in domination of certain specific characteristics of symbols" (p. 264).

Regarding our question if the molecular models of chemistry may bear aesthetic characteristics, Goodman's symbol approach is much more promising than idealistic aesthetics. While the latter confines the reference of artworks to ideas, to the effect that our molecular models would loose the chemical context (see above), Goodman took full account of the referring functions of symbols. However, instead of the 'beauty' of an isolated symbol, say a drawing of cubane, the aesthetic characteristics of a whole symbol system are at issue, such as those of the molecular sign language of chemistry. In a remarkable paper on representations in chemistry, Roald Hoffmann and Pierre Laszlo (1991) adopted Goodman's symbol approach to the chemical sign language, in order to show that it bears the same characteristics of what Goodman calls an "aesthetic symbol systems". Yet, their analysis was incomplete, as they pointed to Goodman's comment on the relationship between art and science but neglected what he said about the differences. So in the following, I will analyze if Goodman's difference between the languages of art and science disappears just in case of the chemical sign language.

Unfortunately, Goodman provided neither necessary nor sufficient criteria but only four "symptoms of the aesthetic" that "probably tend to be present rather than absent, and to be prominent in aesthetic experience" (p. 254). Without making definite claims, he said that his four symptoms "may be *conjunctively* sufficient and *disjunctively* necessary; perhaps, that is, an experience is aesthetic if it has all these attributes and only if it has at least one of them" (*ibid.*). Faced with such vagueness, we must confine our investigation to the following. If none of the symptoms apply to the chemical sign language, it can hardly count as aesthetic in Goodman's sense; if at least one applies, there is some likeliness. More precisely, we must investigate if the chemical sign language of structural formulas has at least one of the four attributes: (1) syntactic density, (2) semantic density, (3) relative repleteness, and (4) exemplificational reference.

Before so doing, a brief introduction to Goodman's terminology is required. A *scheme* is a system or a set of connected characters or labels that refers to a certain realm of objects; accordingly a chemical scheme is the system of structural formulas that refers to the realm of possible molecules. A *character* is a set of markers or character realizations that refer to a compliance-class of objects; accordingly, a chemical character, a structural formula, is the set of all drawings or prints of the structural formula that refer to a compliance-class of molecules, *i.e.* all molecules of the same kind. Goodman's *symptoms of the aesthetic* are syntactic and semantic attributes of a scheme, here of the system of structural formulas.

(1) A scheme is 'syntactically dense' "if it provides for infinitely many characters so ordered that between each two there is a third" (p. 136). In other words, syntactical dense systems allow for continuous variation of characters. If the system of structural formulas were syntactically dense, we would miss just its frequently praised unambiguity that every formula exactly refers to one sort of molecules. (Note that syntactical density applies to characters, not to markers; the variation of individual drawings, the markers, of one structural formula does not modify the character, *i.e.* the structural formula.) Because we do not assume a continuum of molecules, but clearly defined molecular entities or states, structural formulas that refer to molecules are by no means syntactically dense.

(2) A scheme is 'semantically dense' if it "provides for an infinite number of characters with compliance-classes so ordered that between each two there is a third" (p. 153). This condition requires that the referred objects, here molecules, show a continuum, which we actually do not assume. (Note that, although bond lengths and angles of molecules vary with temperature and pressure, such variations belong to one compliance-class, *i.e.* one kind of molecule.) The fact that we can reject both syntactic and semantic density on the same ground shows that the system of structural formulas is a notational system with clearly defined rules of denotation, which, for Goodman, is virtually the opposite of an aesthetic scheme.

(3) A scheme is 'relatively replete' if nearly all aspects of the characters are constitutive and nearly no are contingent (pp. 229-30). Goodman explains that by comparing an electrocardiogram with an artistic drawing of Mt. Fujiyama, both showing the same black lines on white backgrounds. For the

drawing, and its corresponding aesthetic scheme of characters, "any thickening or thinning of the line, its color, its contrast with the background, its size, even the quality of the paper" (p. 229) are constitutive. For the diagram, and its corresponding scientific scheme of characters, only the place of each point in the line, relative to the ordinate and abscissa, are important, while everything important for the drawing is contingent here. There can be little doubt that exactly the same holds for structural formulas. They are what Goodman calls 'attenuate' and thus fail to meet his third symptom of the aesthetic.

(4) A character (or its realization) has 'exemplificational reference' if it refers to an object by sharing with the object the same properties. Goodman's main example is a tailor's swatch of cloth, as "a sample of color, weave, texture, and pattern" (p. 53) of the cloth it refers to. Not only is it difficult to find any properties that a drawing of a structural formula and a molecule may have in common (*e.g.*, being at least two-dimensional objects); also such properties do hardly the job of reference. One could perhaps try to make a case for the exemplificational reference of stick-and-ball models, but than we must forget about quantum mechanics. Moreover, such iconic representations or depictions are completely different from what Goodman means by 'exemplification'. "What a symbol exemplifies must apply to it" (p. 55). If the molecular models exemplified molecules, they would have the same chemical properties, which obviously they have not. Hence, we must conclude that structural formulas also fail to meet the forth 'symptom of the aesthetic'.

In conclusion, the chemical scheme of structural formulas shows none of Goodman's 'symptoms of the aesthetic'. It rather seems to be a paradigmatic case of nonaesthetic schemes. Thus, whether or not one agrees to Goodman's approach to aesthetics, it does not support but clearly reject the idea that chemical models bear any aesthetic characteristics.

4.3 Eco's semiotic theory of the aesthetic message

Up to now, our investigation into possibly aesthetic characteristics of molecular models has brought about distinctly negative results. In the framework of idealistic aesthetics, where aesthetic objects refer to transcendent ideas, we loose the chemical reference of the models; what remains, *i.e.* reference to mathematical ideas of symmetry, does not meet standard concepts of the aesthetic but rather epistemic needs. On the other hand, Goodman's symbol aesthetics, with its emphasis on the specific references of symbol systems, rules out molecular models just because of their distinctively chemical reference to molecules. Recalling the order of our investigations, it becomes obvious that there is still one type of aesthetic approaches missing. If both the nonchemical and the chemical references of molecular models each of their own fail to reveal any aesthetic characteristics, what about seeking the aesthetic in the combination of both? Has not art been praised ever since because it combines divergent contexts, brings together what has hitherto been considered disconnected fields, creates novel connections full of tension and surprise?

Before starting an investigation in that direction, I would like to add a preliminary remark. Making connections full of surprise, novelty, and tension could be understood as a formula to describe both scientific and artistic creativity. In this sense, science and art are no doubt similar. However, as has already been mentioned in the introductory section, creativity plays an important role in many other branches of human activity too. Unfortunately, theoreticians of art have failed to develop a specific theory of *artistic* creativity other than the mysterious notion of a genius who is more (Plato) or less (Kant) inspired by divine ideas. Fortunately, however, we have a famous aesthetic theory, though lesser known to theoreticians of art in the English-speaking world,[37] that expands on the notion of tension from an elaborated semiotic point of view. I mean Umberto Eco's theory of aesthetic messages developed in several books since the early 1960s.[38]

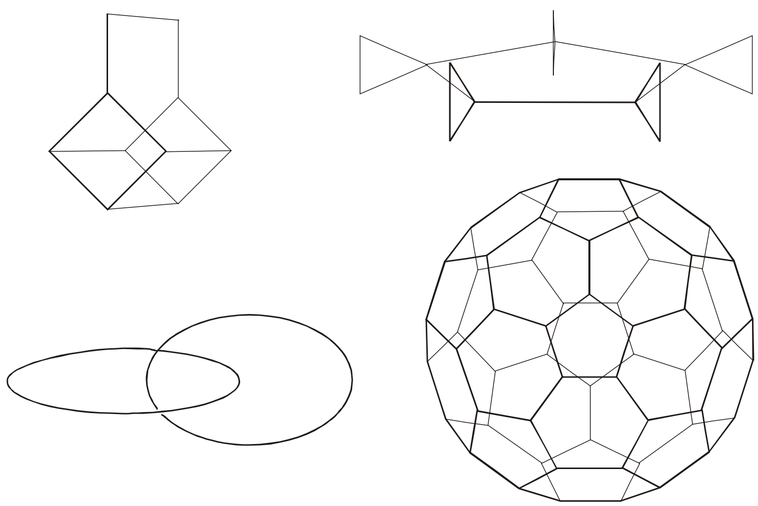

Figure 2: Molecular representations of basketane, rotane, catenane, and buckminster fullerene, also representing a basket, a rotor, two chain-links, and a soccer ball.

The chemists who have recently laid claims to the beauty of certain molecules did not refer to Eco. Their 'beautiful' or 'aesthetically attractive' molecules may be roughly divided up into two classes, the symmetrical ones exemplified by the Platonic solids and those which seem to resemble things of ordinary life. It is the latter class of molecules, or to be more correct, their graphical representations, which meet conditions of Eco's aesthetics. Figure 2 presents a few frequently used[39] examples of molecular representations that also refer to a basket, a rotor, two chain-links, and a soccer ball. I take for granted that the only reason why chemists find these molecules 'aesthetically attractive' is that they resemble things of ordinary life. Yet, it is not the molecules but their graphic representations that bear a certain tension in that they refer to both the chemical world of molecules and the world of ordinary life. (We have already seen that chemists tend to mix up molecules and their representations.) Eco's theory explains such tensions as characteristics of aesthetic messages, so that we may call them aesthetic tensions. What is more, however, is that his theory describes the effect of such tensions, from which we may learn how aesthetics can become a driving force in chemical research.

Eco's theory is an elaborated aesthetics mainly for literature, where he has been active himself as novelist since 1980, but by no means limited to that. Because the chemical graphics need not be great art, we can avoid Eco's sophisticated semiotic apparatus and focus on his general ideas already outlined in his 'pre-semiotic' period. In strict opposition to the formerly prevailing idealistic aesthetics of Benedetto Croce in Italy, Eco conceives of (modern) art as a cultural force that undermines established conventions and induces an open process of reflection and redefinition. To that end, works of art bear a *productive ambiguity*, which Eco considers a necessary condition of the aesthetic/poetic. Evading a simple interpretation, works of art prompt interpreters to recurrent interpretations. This leads to meta-reflections on the interpreter's own interpretative presuppositions (*self-focussing*) which may finally result in changing even the worldview of the interpreter:

> The moment that the game of intertwined interpretations gets underway, the texts compels one to reconsider the usual codes and their possibilities. [...] By increasing one's knowledge of codes, the aesthetic message changes one's view of their history and thereby trains semiosis. While doing this, the aesthetic experience challenges the accepted organization of the content and suggests that the semantic system could be differently ordered [...]. But to change the semantic system means *to change the way in which culture 'sees' the world*. [Eco 1976, p. 274]

Of course, the chemical graphics did not "change the way in which culture 'sees' the world". I suggest, however, that they changed the way in which chemists see their molecular world and that this change, which opened up new research fields, was induced by aesthetic experience.

Let us pause on the little ambiguity of such graphics as presented in Figure 2. Their ambiguity consists in the double-reference to both molecules and things of ordinary life, and that is what chemists actually find aesthetically attractive. Molecules and things of ordinary life are usually two quite disconnected sets of objects. Their only connection is, in view of the chemists, that the former makes up the latter. That notwithstanding, the molecular world is disconnected from the ordinary world of direct experience as it is an intellectual construct based on experimental evidence through reasoning. Now, the double-references of the graphics suggest a link between the two worlds, *as if* molecules and ordinary things would belong to the same world. The tension challenges us to reconsider what Eco's calls the semantic system, *i.e.* the rules of references and meanings for molecular graphics. Such a challenge becomes productive if it prompts a reorganization of the semantic system. How does that go? I suggest that supramolecular chemistry is a direct result of the productive ambiguity of such molecular graphics, as it integrates features of ordinary life into the world of molecules, resulting in an imagined miniature of the ordinary world.

The switch from molecular to supramolecular chemistry, recently subsumed under nanotechnology, is a change of the way chemists 'see' the molecular world. In the classical semantic system of molecular chemistry, each structural formula represents the chemical properties of a single compound, complemented by reaction mechanisms that represent chemical reactions in terms of the stepwise breaking and making of bonds. In the new semantic system of supramolecular chemistry, molecules are endowed with new properties, known only from ordinary life. Beyond the conventional rules of chemical bonds, molecules can now be connected like chain-links; they can receive and transport goods like a basket; they can function as mechanical devices, such as rotors or even parts of 'molecular machines'; they can receive, store, transform, and mediate 'information'; they are even able 'recognize' each other, to 'communicate' with each other, and to perform 'organizational' or 'self-organizational' tasks.[40] What has been criticized as naive anthropomorphism in the new language of chemistry (Janich 1996), of which texts from supramolecular chemistry are particularly rich, is actually a human way to reconcile the molecular and the ordinary world.

Eco's aesthetic theory lays emphasis on the open process of interpretation. In supramolecular chemistry, the interpretative work is performed by chemical means, *i.e.* by inventing and synthesizing new molecular systems. Once the molecular world is 'seen' as the ordinary world in miniature, viewing molecular graphics may inspire the integration of new aspects of the ordinary world into the molecular world, which, in the form of graphical representation, may induce further inspiration, and so on. It is a matter of imagination and personal perspective what aspect of the ordinary world should enter the molecular one by synthetic means. The situation is not so different from a classical artist sitting in front of a blank sheet of paper and contemplating on the question of what aspect of the environment should be depicted. Such as the result of the artist reflects his personal view of the world –

and tells us more about himself than about the world – so do the chemical results reveal specific aspects of the chemists' worldview. By inventing a miniature world, they express their own attitude towards the world, which can be made subject to aesthetic analysis. If we take supramolecular chemistry as the field in which these expressive functions have been most active, the chemists' worldview seems to be a rather technical one, full of mostly mechanical functionalities, devices, and 'machines'. It is the world of *homo faber*, in which also human capacities, like recognition, communication, and organization, are reduced to simple mechanical functions of molecules.

Against that background, the second group of 'aesthetically attractive' molecular graphics, the symmetrical ones, deserve new attention. From a technological perspective on the ordinary world, forms like the platonic solids, stars, prisms, and, of course, the soccer ball seem to evade technical instrumentalization. Whatever the corresponding materials may be good for because of their chemical properties, say as explosives, the graphics of highly symmetrical molecules bear a distinctive nontechnical flair. In paraphrasing Kant, we may say that, while the first group of molecular graphics cause 'interested delight' from a technological perspective, the second group causes 'disinterested delight'. They are subject to disinterested contemplation and play,[41] and thus function as contrast and antithesis to a technological world.[42] The more chemists are bound to the world of *homo faber*, the more do they enjoy periods of rest with such graphics. This, I suggest, is the third explanation of why chemists are particularly receptive to the appeal of symmetry (see Sect. 4.1).

In conclusion, we may say that Eco's approach, if applied to chemistry, provides insights in molecular aesthetics more than any other approach. It does not tell us about the beauty of certain molecules or molecular representation, nor does it allow concluding that chemists are great artists. However, it helps us understand that and how aesthetic experience can be a driving force in chemical research. From the point of view of philosophy of science, where aesthetics is usually considered as worthless, this is more than one could have expected.

5. Conclusion

The relation between science and art, although frequently debated on a general level, has hardly been made subject to systematical investigations. One reason is that theories of art are rather divergent and frequently in too bad a shape for that purpose. Another reason is that science is equally divergent, which theories of science tend to ignore. With our focus on chemistry, we are in a lucky position because chemistry resembles the formative arts just in that regard which theories of science ignore: both produce new material objects. This allows cutting down the overgeneralized issue of the relation between science and art to the concrete question of whether the chemical products bear any aesthetic characteristics comparable to the products of art. Since chemists themselves have increasingly laid aesthetic claims to their products, the issue becomes even more significant because we can examine whether such claims are justified or not.

Because of the poorly developed state of many aesthetic theories, some results of our investigation have only provisional character; *e.g.*, the undeniable aesthetic potential of materials, which was neglected in the whole tradition of western aesthetics until recently and which may be more promising in the future. What we can say with certainty, however, is that the chemists' claim to the beauty of certain molecules cannot be justified, because every attempt at developing an aesthetics of molecules finishes up in a blind alley. Since molecules are neither directly perceptible nor merely intellectual entities, they cannot be made objects of classical aesthetics, whereas any possible aesthetics of molecules would run into the esoteric of chemical structure elucidation. Similarly, certain conclusions can be drawn concerning aesthetic claims to the symmetry of molecules or molecular representations. While mathematical symmetry has of course certain attractiveness, it causes rather epistemic than aesthetic delight and may, for some individuals, function as antithesis to disorder or to the technological realm. Regarding the aesthetic potential of the third kind of chemical products, molecular models, they can of course be equipped with all the splendor of modern design; but products of designers are out of the scope of the present investigation. What makes these models chemical are their specific chemical references, which, at least in Goodman's aesthetics, fail to meet aesthetic criteria. Only if such models combine chemical reference with nonchemical reference, as some models from supramolecular chemistry do, they can bear certain aesthetic characteristics according to Eco's aesthetics.

The results of our investigation may appear disappointing; particularly for the chemists who have expressed aesthetic claims without further substantiation. Yet, there are also promising prospects for both chemists and philosophers. Chemists could take aesthetics more seriously than many theoretician of art do and contribute to aesthetics in the original sense of a theory of sensations, both by working on a better understanding of 'chemical senses' and by producing new materials with interesting sensual properties. Instead of praising the beauty of their products, they could also reflect on the role sensations play in their daily work in the laboratories, lecture rooms, and offices. Beyond its denouncing effect, the phrase 'chemistry stinks' also reveals that laboratory work affects the sense of smell in various directions. While newcomers to chemistry are particularly sensitive to such impressions, chemists tend to deny the effects on their research preferences, which, I am sure, exist.

The most interesting field of aesthetics of science, however, concerns the role aesthetic experience plays in inspiring and guiding innovative ideas. Classical philosophers of science, with their narrow focus on epistemological issues of justification, have left a vacuum regarding scientific innovation. Their theories of science may help understand whether a sentence is justified on certain grounds or not, but they say nothing about how new ideas can originate. Yet, a proper theory of science is expected to provide both, as earlier philosophers like Leibniz still knew. That is where aesthetics could go in, as part of philosophy of science. Although this was not the main topic of the present investigation, with Eco's theory of the aesthetic message and its application to molecular graphics we have come across one example that shows how aesthetics can actually help understand the process of scientific innovation. This requires a shift of the perspective. Rather than the putative beauty of chemical products, further investigations should explore where and how aesthetic experience becomes part or even a driving force of the research process.

Notes

1. This paper is a revised and enlarged version of my former German essay, Schummer 1995.
2. *E.g.*, Haeckel 1899, McMorris 1970, Heisenberg 1977, among an endless list of examples. Neo-Pythagorean statements are particularly wide-spread in popular books about theoretical physics, such as Zee 1986 (pp. 3, 9): "'Let us worry about beauty first, and truth will take care of itself.' Such is the rallying cry of fundamental physicists. […] following the ancient Greeks, […], I will continue to equate symmetry with beauty."
3. *E.g.*, Hoffmann 1988-89, 1990; Vögtle, Rossa & Bunzel 1982; Vögtle 1989a; more references in the following.
4. This roughly corresponds to the notion of Alexander Baumgarten, who first introduced the term 'aesthetics' in his *Aesthetica*, 1750-8. For recent attempts to reestablish aesthetics as a theory of *aisthesis*, see Welsch 1989, Seel 1991, 1996, Böhme 2001.
5. *Cf.* Multhauf 1966, p. 19.
6. Ihde 1964, p. 454 ff.
7. For the early history of plastics, see the anthologies Glenz 1985, and Mossman 1997.
8. See Schummer 2003.
9. *E.g. Sophistes*, 266 c-d and elsewhere.

[10] For an excellent historical survey of the debate, see Seel 1991; for recent approaches to reconcile both positions, see Schummer 1997b.

[11] *Eat Art: Joseph Beuys, Dieter Roth, Sonja Alhaeuser* (Oct 5 through Dec. 15, 2001), Harvard University Art Museums Gallery Series no. 33, Cambridge, Mass., 2001. Quotes from the website http://www.artmuseums.harvard.edu/exhibitions/busch/past/eatart.html

[12] "In der Malerei, Bildhauerkunst, ja in allen bildenden Künsten, in der Baukunst, Gartenkunst, sofern sie schöne Künste sind, ist die *Zeichnung* das Wesentliche, in welcher nicht, was in der Empfindung vergnügt, sondern bloß, was durch seine Form gefällt, den Grund aller Anlage für den Geschmack ausmacht. Die Farben, welche den Abriß illuminieren, gehören zum Reiz; den Gegenstand können sie zwar für die Empfindung belebt, aber nicht anschauungswürdig und schön machen"

[13] *Cf.* Bandmann 1969, p. 83.

[14] Plotinos: *Enneads*, I.6.5.

[15] F. Schiller, *Letters upon the Aesthetic Education of Man*, 1795, 22nd letter: "Darin besteht also das eigentliche Kunstgeheimnis des Meisters, *daß er den Stoff durch die Form vertilgt"*

[16] Hegel: "Denn der Geist […] will sinnliche Gegenwart, die zwar sinnlich bleiben, aber ebensosehr von dem Gerüste seiner bloßen Materialität befreit werden soll." Schopenhauer: "Darum gehört nun diese Absonderung, diese Trennung der Form von der Materie, zum Charakter des ästhetischen Kunstwerks; eben weil dessen Zweck ist, uns zur Erkenntnis einer (Platonischen) Idee zu bringen. Es ist also dem Kunstwerk wesentlich, die Form allein, ohne die Materie zu geben, und zwar dies offenbar und augenfällig zu tun." Fiedler: "Der Stoff wird gleichsam zur Verleugnung seiner selbst gezwungen, insofern er nur dem Zwecke dienstbar gemacht wird, ein so stoffloses Gebilde, wie die dem Gesichtssinn sich darstellende Gestalt der Dinge an sich zum Ausdruck zu bringen."

[17] See Bandmann 1971 and Kemp 1975; for an early criticism of idealistic aesthetics, see also the British philosopher Alexander (1939).

[18] Wax is actually one of the best-investigated materials in art history. An early study is Schlosser 1911; from the time when chemical companies still had an interest in cultural history originates the impressive multi-volume study on everything related to wax Büll 1959-1970.

[19] See Wagner 2001, pp. 187-96.

[20] See particularly Bandmann 1971, and more recently Wagner 2001, chap. 1.

[21] *E.g.* Everitt 1975.

[22] See Schummer 2000 for a critical analysis of this process with focus on Clement Greenberg and color field painting in the USA.

[23] *E.g.*, Soentgen 1997.

[24] Bandmann 1969, Penny 1993, Raff 1994, Bartholomeyczik 1996, Nußbaummüller 2000, Wagner 2001.

[25] Grahn (1981, S. 61): "Schon der ästhetische Reiz der hochsymmetrischen platonischen Kohlenwasserstoffe kann ein Grund sein, Synthesen derart ungewöhnlich gebauter Verbindungen zu planen und auszuführen."

[26] For a comprehensive survey of symmetry in the sciences, see Mainzer 1996, 1997.

27 *E.g.* Vögtle 1989a, pp. 13 ff.; Heilbronner & Dunitz 1993, p. 7; Hargittai & Hargittai 1986, p. 48 et passim; Hargittai 1988, p. 158.

28 In 18th-century architecture, spheres actually became important because of the cosmos symbolism (Vogt 1988); the trend reached its peak in Boulées plans for a spherical Newton memorial.

29 Kant (CJ, § 22): "Alles Steif-Regelmäßige (was der mathematischen Regelmäßigkeit nahe kommt) hat das Geschmackswidrige an sich: daß es keine lange Unterhaltung mit der Betrachtung desselben gewährt, sondern [...] lange Weile macht."

30 Gombrich (1988, p. 104): "sobald das Ordnungsprinzip erfaßt wird, können wir das Gebilde ja auch jederzeit auswendig rekonstruieren. [... Wir sehen] uns leicht daran satt, es bietet uns ja bald keine Überraschungen mehr".

31 Frey (1949, pp. 277-8): "In der Spannung zwischen Symmetrie und Asymmetrie, zwischen In-sich Beruhen und Gerichtet-sein, zwischen Ausgewogenheit und Antrieb, zwischen Beharrung und Bewegung, zwischen Sein und Werden ist das entscheidende Agens [der künstlerischen Gestaltung] gegeben."

32 Arnheim (1988, pp. 8, 15): "daß Symmetrie Ruhe und Bindung bedeutet, Asymmetrie hingegen Bewegung und Lösung. Ordnung und Gesetz in jener, Willkür und Zufall in dieser; Erstarrung und Zwang in jener, Lebendigkeit, Spiel und Freiheit in dieser. [...] Was Symmetrie von Asymmetrie unterscheidet, ist also offenbar das bloße Verhältnis zwischen Gleichgewicht und gerichteten Kräften. Im einen Extremfall würde dies Verhältnis die Starre des gänzlichen Stillstandes mit sich führen, im anderen Extrem die ebenso furchterregende Formlosigkeit des Chaos. Irgendwo aber auf der Stufenleiter zwischen diesem beiden Extremen findet jeder Stil, jeder Einzelne und jedes Werk seinen eigenen, besonderen Platz."

33 Gombrich (1988, pp. 114, 113): "im Kampf gegen zwei gleich mächtige Gegner, das ungeformte Chaos, dem wir Entsprechungen auferlegen, und die allzu geformte Monotonie, die wir durch neue Akzente beleben".

34 Adorno (1970, p. 237): "Asymmetrie ist, ihren kunstsprachlichen Valeurs nach, nur in Relation auf Symmetrie zu begreifen."

35 de la Motte-Haber (1988, p. 29): "Es folgte die Kunstproduktion einer grundsätzlichen geistigen Haltung, die die Erklärbarkeit aller Dinge voraussetzte und das Unvorhergesehene, Nicht-Berechenbare nur auf dem Hintergrund von Ordnungen als Regelverletzungen duldete."

36 de la Motte-Haber (1988, p. 57) even relates such aesthetic preferences to political matters: "Symmetrie gibt Sicherheit und sie nimmt Ihnen das Denken ab. Man kann, was die künstlerische Entwicklung anbelangt, sagen: Je totalitärer ein System, um so symmetrischer die Kunst, weil sie um so faßlicher ist."

37 For instance, both the Blackwell *Companion to Aesthetics* (1992) and the extensive anthology *Art in Theory* (1992) have no mentioning of Umberto Eco.

38 Particularly Eco 1962; 1968, chap. A.3; and 1976, chap. 3.7.

39 For instance, in Vögtle 1989a, Hoffmann 1990.

40 See, for instance, the Nobel lecture of Lehn (1988).

41 For instance, de Meijere (1982, p. 18) refers to the "play with this beautiful, symmetrical molecules". For an analysis of the role of playing in chemistry, see Laszlo 2000.

42 Vögtle (1989a, p. 23-4) considers molecular beauty even as a means overcome the public hostility to technology and science.

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