Handling Proliferation

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Abstract: The ethics of the chemist identify with those of the citizen, in principle. The observed perversions, such as proliferation of chemicals, stem from the values of a chemical community closed upon itself, and from the attendant identification of a mere know-how with a science. The epistemic degradation produces moral indifference.

Keywords: *ethics, activism, alchemy, discovery, know-how, plagiarism*.

Introduction

The issue of ethics in chemistry is obscured by prejudices. A professional chemist is clearly guilty of criminal behavior whenever s/he perverts her or his expertise to make addictive and illegal drugs for illicit profit. To blame the whole profession for such a lapse is unwarranted. Every profession has its black sheep.

There are also chemists alienating their moral judgment and accepting to do work for the military (chemical weapons), or for a corporation (chemical formulations), with destructive effects on human and on other living beings. Two such examples are napalm and 2,4-T. Again, if there is rot, it affects only a tiny segment of the whole profession.[1] And to view chemists in general as being morally deficient is a biased extrapolation.

Another form of the same obfuscation by too general a blame is chemophobia. Chemists as a whole are viewed as sorcerers' apprentices whose activity (especially if it is of an industrial nature) is pregnant with risks and may have catastrophic outcomes (the names of Basel, Seveso, and Bhopal are quoted), which the collective psyche lumps together with nuclear accidents (Three Mile Island, Chernobyl).

A single example will suffice as an illustration of this particular prejudice. I am quoting it, in my translation, from a recent book:[2]

> One ought to realize that, among the 40,000 chemicals most widespread in the world, 150 only were subjected to a full evaluation. [An OCDE 2000 report is

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> then quoted to that effect.] In other terms, there exist today more than 39,000 chemicals whose medium and long-term effects are totally unknown and which nevertheless are being used all the time.

What these various attitudes have in common, however justified or unjustified, is the direction of the outlook, from the outside of chemistry toward the inside. This is reminiscent of a famous saying by President Lyndon B. Johnson ("I'd rather have him inside of the tent pissing out, than having him stand outside of the tent pissing in.") Hence, I will assume in this article a somewhat different, much needed stand, that from a professional chemist reflecting on the morality, or lack thereof, within our community. This is not to claim that specialized chemical knowledge endows one with authority in moral judgments. However, my view is that human beings individually access universal values about moral principles,[3] that these are gradually built within the self from personal experience and thus ought to be something of a private language (which does not rule out most such private languages overlapping with each other to a considerable extent). I am only reiterating here the classic view that morals as such cannot be taught, can only be learned; and that they are learned from experience.

Lest it be confusing, I now outline the organization of the paper:

(1) the conventional wisdom (that to be found in the media) about the moral shortcomings of chemists is largely irrelevant;
(2) a more interesting issue is that of the moral duty of chemists in their paradigmatic activity, in their routine daily work;
(3) there is a problem, mirroring that of logorrhea in ordinary language, in proliferation of chemicals;
(4) proliferation of chemicals is but a sub-class of chemical plagiarism, which I go on to define;
(5) such chemical plagiarism stems from the value of know-how taking precedence within the chemical community over general scientific values;
(6) and I close with a plea for a return to advancement of scientific knowledge taking priority.

1. Chemistry creates novelty

In this section, I deal first with the issue as seen from inside the chemical community. A strict criterion for editors of journals publishing chemical papers is for the submitted manuscript to contribute something novel. This is understood by many chemists as involving either the isolation of a hitherto unknown molecule or material; or the devising of a new (and presumably improved, more advantageous) route to some molecule or material. Obviously, such a definition of innovation in chemistry is rife with values and thus carries a moral underside to it.

It will be useful at this point to contrast so-called chemical creativity with artistic creativity. In a *Gedankenexperiment*, let us try and imagine Paul Cézanne (say), writing, perhaps in a letter to one of his correspondents: "my goal is to paint a landscape and to improve on what Corot (or Delacroix or Géricault) had achieved." What such an admittedly crude comparison tells us, from the knowledge we have of Cézanne's intent (in particular, he aimed at depicting natural forms as built from elementary shapes as that of the cylinder or the cube; to present a landscape which, instead of being concave from application of linear perspective, would appear as convex, from being self-contained and closed upon its wealth of meaning)[4] is that there is indeed a deep difference.

Artistic creativity seeks to discover a new vision of the world. So-called 'chemical creativity' attempts to complement the sphere of already existing artifacts. If pushed, a chemist may claim that this is the only way in which to achieve a differing worldview for his science.

The two kinds of creativity differ in the degree of insight to be achieved. Cézanne was striving for a new form of insight – which, in the opinion of many, he did succeed in acquiring. The run-of-the-mill chemist identifies the process of extrapolating (or of interpolating) from the known to the unknown with a gain of insight, when it amounts only to an extension of routine abilities.

In this respect, a semantic lexical configuration, prevalent in synthetic organic chemistry, is most revealing, that of the terms 'target molecule', 'selective', and 'specific'. It belongs to the realm, not of the admiring contemplation of the wonders of nature (an acceptable definition of natural history, I believe), but of the action language of the successful completion of a predefined task. It belongs to mission-oriented research and is historically a legacy of World War II and of its aspects as a scientifically-waged war: radar, penicillin, operational research, jet engines, the Manhattan Project, *etc.*

Thus, one witnesses a double transformation of values. In the first such switch, since chemistry as a science of material transformations gives itself an action language, chemical activism arises. And secondly, from chemical activism stems proliferation of chemicals: activism can be defined as action for its own sake; activism translates into a form of acquisitiveness, *i.e.* ever increasing the sphere of chemical knowledge, as defined (lazily) by the numbers of known substances and of known avenues to these.

At this point in the analysis, one may wish to stop and to take stock, perhaps in order to change and to reverse the perspective. The very word 'proliferation' is pejorative. While it is true that the number of chemical species increases exponentially,[5] is it indeed a feature of chemistry alone or is it more general? Is it worrisome, and why?

To raise such questions is to answer them. With respect to the first, we have learned from demographers the exponential increase of almost any quantitative measure of any human activity, from the number of cities having more than one million inhabitants, to the number of aspirin tablets manufactured per year, or to the number of people fed from cultivation of one hectare of land. Thus, proliferation of chemicals is unexceptional and mundane.

Is it at least true that the more chemicals being launched into existence, we know less and less of their possible ill effects on living creatures? Angelism might argue here that, for the last two or three decades, because of Rachel Carson's *Silent Spring*, to the contrary governmental organizations (such at the American Food and Drug Administration; or the European EC) have started impressive efforts at registry of chemicals. Such catalogs are devised so that a lay person can look-up the toxicity of any among thousands of chemicals, either in readily available printed format, or from electronically accessible data banks.

In this context, it is worthwhile to compare and to contrast here, in parallel to my earlier contrasting of the artistic and chemical kinds of creativity, the creativity of the chemist with the creativity of language. In the latter case, a competent speaker of say English has the dual ability of (i) expressing thoughts which are entirely novel, such as a brand-new theorem in mathematics, or a new law in economics, or a piece of poetry, from existing phonemes and words; (ii) coining neologisms and new expressions to enrich the language.

The second point is well documented in history. Witness Shakespeare's contributions to the language: approximately 1,700 new words, such as 'reclusive', 'gloomy', 'barefaced', or 'radiance',[6] and a host of expressions from 'to send someone packing' to 'to be in a pickle'.[7] And the first point is, obviously, empirically true.

I do not find that the creativity of chemistry and of language differ in kind; indeed I have argued elsewhere for the former to derive from the latter.[8] Hence, perversions of the former (such as the unchecked proliferation of chemicals, or the moronic travesty of scientific research known as 'combinatorial chemistry') might usefully be related to perversions of the latter, such as Orwell's Newspeak or the use and abuse of acronyms.

2. Goals

In this section, the viewpoint is, at first, from the inside of the chemical community; and second, it moves to inside of the larger scientific community. Schummer, in an eloquent article in which he analyses statistical evidence from chemical papers, mentions near the end, almost as a summary that "the making of new substances is actually an end in itself in chemistry."[9] Of course, he backs up this statement with ample data, and it has to be taken very seriously.

We ought to ask ourselves in which context this summary is adequate. The converse question, which also has to be answered, is whether there might exist other contexts in which this damning or condemning formula no longer applies.

First then, verification and explanation. Schummer's formula is true, I submit, in the context of a know-how, of chemistry being construed by chemists as nothing else than a technical activity. It is quite easy to define the chemical know-how: it consists of the set of procedures and of the complementary set, of the characterization of new compounds, which are to be found in the experimental parts of the publications. Such know-how thus is collected in data banks. And it is imparted to the budding chemist through teaching laboratories, as a student, and through some form of apprenticeship at the bench, in the laboratory, during preparation of the Ph.D. predominantly. The first systematic organization for transmission of the chemical know-how was arguably Liebig's laboratory in Giessen.

Indeed, the main purpose of the chemistry laboratory, as devised by Liebig and as it has endured, is to train professionals for industry, primarily for the chemical and the pharmaceutical research laboratories. For instance, to consider the present situation, preparation of a Ph.D. in synthetic organic chemistry, during which the graduate student will prepare on the average two or three dozens new organic molecules, is the entrance ticket to an assured and well-paid job in the pharmaceutical industry.

We are thus led to complement Schummer's formula. Rather than 'being an end in itself', the preparation of new substances is a mandatory certification of a young chemist as a professional. It is the means by which the chemical community transmits the necessary technical skills. In other words, in this day and age of the beginning of the 21st century, the making of new chemicals is the equivalent to the masterpiece which artisans in guilds had to perform, in past centuries, to achieve their autonomy.

Now to the converse question of the existence of other contexts, in which Schummer's formula would not apply. What jumps to mind, of course, is that chemistry goes beyond technical know-how, that it has also the dimensions of a full-fledged science. Science differs from a mere know-how: it is taught conceptually in textbooks rather than just manually in laboratories; it has a life of its own, with constantly reorganizing fields of research, with their shifting boundaries; it is a problem-solving activity; and it aims at gaining an understanding of nature in its protean manifestations.[10] In this context of chemistry as a science, Schummer's formula may no longer be pertinent. I shall return to this point in a later section, dealing with the advancement of learning.

I hold science to be an attempt, constantly in need of being restarted and nourished, to provide a truthful narrative about the world. This definition is from the standpoint of a realist, believing the world to exist outside of my representation. Realism is indeed axiomatic, a matter of faith.

As for truthful description or representation, I hold this requirement to provide science with its ethos, with the horizon toward which it strives. For the purpose of this paper, I shall use the easy criterion for truth of 'that which is either impermeable to suspicion, or which successfully resists all attempts at doubting and refuting'.

Hence, I shall take here a naïve view of truth, holding it as a value shared by citizens and by scientists alike. In other words, statements such as 'the sum of the angles in a triangle equals two right angles' or 'citizens give themselves laws and institutions for the common good' are both true as a matter of principle, within their frames of reference (Euclidean geometry and electoral democracy), even if the latter may often be empirically faulty.

Accordingly, I hold as the chief value for a scientist to make a contribution: to propose a new and original view of the world, whether its scope is global or local. The task of the scientist is to advance our understanding. The scientist, just like the artist, has a duty to do original and creative work.

Since I hold it as a defining property, scientific work that does not strive for the truth is a contradiction in terms, an aberration. Unoriginal and uncreative scientific work is morally wrong. These two statements follow, the one from my definition of science, the other from our living in a world of scarcity. When a majority of mankind lives precariously, this last assertion does not need further elaboration.

That brings up a potential immorality, from abusing the trust placed in us, scientists, by our fellow-citizens. They agree to our enjoyment of the huge privilege of a shelter from scarcity, and of the derived privileges of the freedom of investigation, or of choosing only the kind of work bringing us personal satisfaction and enjoyment, in return for our gaining greater public knowledge about the world. Thus, a social contract provides the scientific endeavor with its moral foundation. A breach of this contract, such as performance of a scientific task for one's private and selfish enjoyment, with no return to the public, is in my view morally wrong.

To sum up this statement of principles, a scientist is accountable both to the citizenry at large, s/he has a moral duty to come up with new results and to present them, to communicate and teach; and to the scientific community (peer review), in terms of the truth value of the assertions made about the world, since science moves from private personal representations to shared representations, attempting to be truthful.

3. Chemical plagiarism

Ancient Greek had an adjective, '*plagios*', to denote obliquity, in both a geometric and a figurative sense. '*Plagios*' was also used to denote a person unreliable, lacking sincerity, someone practicing double-talk. Contemporary English usage has a somewhat similar expression, 'a straight arrow', to denote the converse moral qualities. Latin borrowed from '*plagios*' a name, '*plagium*', with the meaning of a con job, of appropriating something that does not belong to you. A derived word, '*plagiarius*', indicted those who would steal property, such as slaves, and make it their own. From that, we have derived the notion of plagiarism, as applied to the theft of intellectual property.

Plagiarism is rampant in chemistry, and this section is devoted to it, as considered from the viewpoint of science as a whole. A first question is: why plagiarism in chemistry? It will be followed by: where is the border between imitative and original work? And the third question is: what are some of the various forms of chemical plagiarism?

Why then would a chemist need or want to plagiarize already existing knowledge, embodied in molecules or in reactions? What makes such imitative work special to chemistry and to chemists? Arguing from imitation through analogy, after all, is not special to chemistry. Other sciences, from mathematics to paleontology, including also astronomy, biology, or atmospheric science also make heavy use of analogy. Metaphor is central to science.[11]

I submit that the Periodic System of the elements is a major and perhaps the main thrust for the imitative behavior of chemists, in their discovery of new elements, new molecules, new materials, and new reactions. Mendeleev's Periodic Table, in pointing to a deep harmony within matter, in setting-up families of elements, in providing chemists with a natural classification, also stands as a permanent invitation to imitative and derivative work. One may supplement this epistemic consideration with a sociological one.

Chemistry is a craft. It has remained so up to this day. In order to become a chemist, one serves one's apprenticeship with a master chemist. The training includes reproduction by the apprentice of established procedures. To take but these two instances, carrying-out a Grignard reaction and monitoring with a polarimeter the acid-catalyzed inversion of sucrose are two such ritualistic transmissions of a know-how, both practical (handiwork) and theoretical (transcribed in the form of chemical equations, also an integral part of the canonical corpus).

Now, to the second question: how to discriminate between routine, unoriginal or secondhand work and genuinely creative work? To be more specific, let us take a concrete example. There is an entire cottage industry of scientists involved in the transposition of well-established results from carbon (organic) chemistry to, for example, the chemistry of silicon, or that of phosphorus. For instance, can one make the silicon analog to polyacetylene? Will it display interesting properties, in its electrical conductivity in particular? While such transfers – arguably the equivalent of translations from one language to another – are totally unimaginative in their conception, they may require extreme technical sophistication to be carried-out successfully. Within the profession, they are sometimes referred to, in rather deprecatory manner, as 'me-too chemistry'. There is also the often-quoted quip, by reference to organic chemists preparing a whole litter of kindred molecules, along the sequence of 'methyl, ethyl, propyl, butyl, …, futile!'

Let me rephrase the question: is it immoral to carry out derivative instead of original research, and where is the demarcation to be found or set? The answer may be constructed from what these chemists would (and do) argue in justification of their approach. They would be likely to invoke the cumulative nature of scientific knowledge, the continuity of chemistry since the Lavoisian Revolution, and the unpredictability of the relationships between future scientific advances and current knowledge. Furthermore, they would stress also accommodation with funding agencies. Basing themselves on peer review, these are much more likely to honor research proposals seeded with promising exploratory results, than leaps into the unknown. Hence, a research idea consisting in the preparation and the study of, say silicon nanotubes, is much more likely to be a winner than would have been, twenty years ago the preparation and study of carbon nanotubes. The latter became part of the field of chemistry and they entered chemical consciousness due to their serendipitous discovery.

My stand here, consistent with what I have already stated elsewhere,[12] is (i) discovery is essential to the spirit of science; (ii) as a rule, discoverers operate from marginal positions relative to the established disciplines and subdisciplines; (iii) *ergo*, it is advantageous to maintain a mainstream within each discipline, despite it being invariably totally sterile (and sterilizing), just so that innovators can become marginalized, or can choose such an uncomfortable position at the boundaries, *i.e.* in the no man's land where discoveries cannot fail to take place. A reviewer has asked, tongue-in-cheek, if one should not then get rid of the mainstream entirely! But one cannot do without, either, both for the training of young scientists and for the value of contrast. Imitation leads to creation.

Hence, the simplest criterion for demarcation between imitative and creative chemical research identifies with the border between mainstream and frontier (or cross-disciplinary) science. Notice the paradox: the research scientist performing standard, paradigmatic work may well turn out to be reprehensible, from an ethical viewpoint (contributing to needless proliferation of chemicals, among other things); whereas the adventuresome research scientist operating in front of the lines, in commando-like action, who opens up a new field of research, may well become exemplary, from the viewpoint of ethics.

There is another consequence, since human beings strive for acceptance within a community. Each of these polar opposites will tend to masquerade as the other type. The 'me-too chemist', the cynical practitioner of a phosphorus chemistry built entirely on borrowings from carbon chemistry, will describe – better yet, he will get someone else to do so, such as academies and prize-awarding committees – his results as 'unusual', 'revolutionary', 'ground-breaking', or yet 'unprecedented', all manifestations of entrepreneurship and of one-upmanship currently endemic in chemistry journals. They are unambiguous signs of conformity and of behavior bordering on plagiarism.

4. Neglect of personal improvement

In this section, I appear to change tack. A major component of the alchemical quest was spiritual improvement. Why would chemistry, which has otherwise inherited so much from alchemy (procedures and apparatus, dualities such as that of analysis and synthesis: *solve et coagula*, symbolic representations, *etc.*) cut out this personal dimension?

The argument which I wish, if not to present in full, at least to summarize here,[13] has for its first tenet that chemical science, whenever it sticks to empirical facts, whenever it goes into theory-denial mode, thus foregoes cognition. Neglect of the advancement of learning – producing new chemical species instead of producing authentic new knowledge, or not being intent upon making the two advances at the same pace – has a price. Chemists lacking in the cognitive fiber, as a consequence become morally deficient. Ultimately thus, a deficit in cognitive values turns into an ethical lapse.

Bypassing and neglecting the advancement of knowledge may result from overvaluing a practical goal, such as synthesis of a target molecule. Indeed, in her/his haste to get from **A** to **B**, *i.e.* to transform a primary material **A** into an intended product **B**, many a chemist won't bother to scrutinize in their precise detail the intervening steps, won't bother to study the mechanism and thus won't even notice the occurrence of a number of intermediates **K**, **L**, **M**, **N**, … along the way. Yet, 'God is in the details'.

Synthesis of **B** from **A** definitely improves the practical know-how. If it is the first time for the **A-B** conversion to have been effected, it adds a new route to those already charted. If this is the very first synthesis of **B**, this also contributes significantly to the know-how. If the **A-B** conversion was known already, this particular occurrence contributes to its public reproducibility. Yet, these all add to a practical know-how rather than they advance learning. They suffer from a lack of generality and from a surfeit of specificity.

Performance of an intended material transformation usually meets with admirable success, and this is one of the triumphs of modern chemistry. But at a rather high cost, when the doing excludes the learning; and when imposition of the chemist's will upon the system prevents listening to the say of things. I cannot help but sense a misunderstanding when fellow-chemists deem it a waste of their time to display idle curiosity. In so doing, they immunize themselves against discovery. I submit that only a misreading of chemical voluntarism would subdue and stifle chemical curiosity.

I submit too that keen observation of a reaction mixture, because it involves cognitive skills, leads to the establishment of values, and thus to defining an ethical code for oneself. And this takes us back to alchemy! To the alchemist, to some alchemists at least, chemical transformations served as metaphors for a spiritual striving, a sublimation, a purifying of the soul, mortification of the old self and a regeneration of the spirit. The chemical transformations taking place in the flask, the athanor, or the crucible, were illustrations; they were outer models for the inner transformations of the adept, by spiritual alchemy.

This brings up the question of a link between cognitive and moral values. The former depend upon one's epistemology. While a physicist may vouch for scientific realism, *i.e.* the truth of a theory will be to him the primary epistemic value, chemists are closer to being either pragmatists (truth is the horizon toward which one strives) or instrumentalists (holding theories to be mere tools, without any truth content). Other chemists are either positivists (seeing is believing) or just want to stick to the empirical facts. My personal position combines that of the instrumentalist and of the pragmatist *à la* Peirce or Putnam.

However, truth retains even more of a transcendent, metaphysical status by being an inaccessible value! As a chemist, I wish my statements to show better than just an empirical fit (predicted, calculated values matching observed values) with the system studied. I want them to carry a deeper understanding. As already stated, to me science is a groping for the truth. By holding on to such a cognitive value, truth being the beacon lighting one's way, less ambitious standards, such as contenting oneself with a goodness of fit, to me smack of immorality.

What I am driving at might be rephrased, in the words of Hilary Putnam, as "some ethical principles at least are likely to have a large measure of objectivity".[14] Or it might also be rephrased, in the context of modern chemistry rather than in that of alchemy, as an inducement to give oneself problem solving skills. These translate into increased self-assurance, better familiarity with one's imagination, the ability to devise experimental tests for ideas, *etc.* These sum up into both an interconnection and interdependence between the material and the conceptual, which is conducive to personal improvement. To the effect of such a necessary link between scientific realism and ethics, I beg to be allowed to quote again Hilary Putnam:[15]

> It is because we are too realistic about physics, because we see physics (or some hypothetical future physics) as the One True Theory, and not simply as a rationally acceptable description suited for certain problems and purposes, that we tend to be subjectivistic about descriptions we cannot 'reduce' to physics. Becoming less realistic about physics and becoming less subjectivistic about ethics are likewise connected.

5. The issue of language

Why such a disinterest in personal improvement? The tribal identity of a chemist is rooted in laboratory training and in a technical language, that of formulas. Both set him apart from non-chemists.

Beyond these platitudes, the chemist inhabits a world of values, that of the chemical community. And most chemists are chemists first. In this respect, of a professional affiliation overruling and pushing into the shadow the other ones, secondary identities – as a scientist, as a citizen – chemists resemble other professionals, such as lawyers or medical doctors.

The values of the group are dominant.[16] Ethics, or the lack thereof, are those of the group. As is well known, such a renouncement to individual judgement and responsibility may have terrifying consequences. Yet, it is not a given:[17]

> […] that the self has to find its moral identity in and through its membership in communities such as those of the family, the neighbourhood, the city and the tribe does not entail that the self has to accept the moral *limitations* of the particularity of those forms of community.

In general, though, belonging to the chemical community is gratifying, and has only mild and inoffensive side-effects.

A comment on one of them is irresistible, though. Sharing one's knowledge with the citizenry is rarely a moral imperative for chemists, as it ought to be. Chemists, taken collectively, could not care less. They pay dearly for their lack of interest in science communication. This is a major cause of chemophobia, on the part of the uninformed or misinformed public.

Disinclination on the part of chemists to popularize their knowledge is one of the causes of chemophobia, from a poorly informed public: this point brings up a more general issue, that of language. Chemists need and enjoy expressing themselves in their technical language, whose lexicon and syntax tend to remain opaque to nonchemists. Thus, chemists wrap themselves in a cocoon of their own making. The public reacts to the *perception* of its exclusion (whether or not such perception is warranted is a moot point) with a counter-rejection; which is to describe once again one of the root causes of chemophobia.

Coming back to the chemical community and its use of an own language, its very activity, that of synthesis in particular, is a combinatorial art very much analogous to that of language itself. Hence, it should come as no surprise if some chemists make new molecules just like advertising agencies try to introduce neologisms into the language. It should be no surprise, either, when a subset of such new molecules is equivalent to unneeded gibberish. Nor is it a surprise when, in like manner to the stereotypes and hackneyed phrases of ordinary language, chemistry has also its worn clichés and its unoriginal productions, out of conformity.

An illustration through analogy will suffice here. Take the word 'beauty'. The English language supplements it with a small number of derived words, such as 'to beautify', 'beautiful', and 'beautiless'. Some other words, also derived from 'beauty' and well-formed according to linguistic rules, are only rarely used, and we do not perceive them as of any great necessity: 'beautydom' and 'beautyship' are two such examples. A third class, that of nonexistent but well-formed words, such as 'beautition', 'beautivity', 'beautisome', 'beautirity', 'beauter' and 'beautor', 'beauture' *etc.* are unnecessary and, for some of them, downright ugly: not all possible words need to be called into existence. An argument by analogy applies to new molecules and against their proliferation.

6. Advancement of chemical knowledge

Above I have made the implicit point that chemical science does not proceed by the mere accumulation of new compounds. If so, what does it consist of?

Concepts. Imaginative concepts. Examples include the chemical bond, selection rules for electrocyclic reactions, the delineation of hypersurfaces for chemical dynamics, and stereochemistry, for instance in organometallic complexes.

Take as an example the chemical bond. It is a fiction; there is no such thing in nature. However, to conceive of atoms in molecules as held in pairs (sometimes in groups of three) by a bond which is furthermore generally to be associated with a pair of electrons according to Lewis and Langmuir, and to the Pauli Principle, is an imaginative leap which has made it possible to rationalize a vast amount of empirical data. The concept of a chemical bond fits nicely within the language of structural formulas as was devised in the 1850s and 1860s. It has led to many of the advances of chemical science during the 20th century. How? By work, individual (Linus Pauling, *primus inter pares*) and collective on this concept.

But what does it mean to work 'on a concept'? I understand this phrase with the full meaning which Georges Canguilhem has endowed it with:[18]

> To work (on) a concept, is to vary its extension and what it comprehends, it is to generalize it through incorporation of exceptional features, it is to export it out of its original field, it is to take it as a model or conversely to seek a model for it, in short it is to give it gradually, though well-ordered transformations, the function of a form.

The corpus of 20th century studies of the chemical bond neatly qualifies, I believe, for the full-fledged work on a concept according to this exacting definition of Canguilhem's. I go further: the task set forth by Canguilhem is equivalent to a set of moral values, too.

So far in this paper, I have suggested that the cognitive aspect in chemical science is flavored with values – I put very high those of originality and of creativity – thus erecting moral principles for the chemist. But what about the converse? Could one not argue the disconnection of the moral from the cognitive dimension?

Indeed, the connection between the two spheres, the epistemological and the ethical, is often quite subtle.[19] Some would argue for its nonexistence. As Ayer did point out,[20] normative ethical judgements are synthetic; they are not reducible to empirical judgements, whereas the only synthetic judgements that can be objects of knowledge are empirical. This radical stand, altogether the opposite of mine, also goes against the whole Kantian tradition of epistemology, since synthetic judgements a priori are held by many as basic to the philosophy of mathematics and of theoretical physics.

My answer here is two-pronged: (i) it is ample time to separate the philosophy of chemistry from that of physics; (ii) it is not because moral truth is not always easy to come by, when the empirical world reveals moral truth, that one should renounce making the effort.[21] Yes, there is a discrepancy between scientific reductionism and philosophical thought, as embodied in ethics.[22] But one should attempt to bridge the gap.

Conclusion

Rather than describing moral lapses as extreme and exceptional behavior, I see them as an integral part of the fabric of chemistry and of the everyday activity of chemists. Are they a consequence of *hubris*, attendant upon the Promethean task of transforming matter? I submit instead that proliferation of chemicals, a direct consequence of the translation of chemical language not into *action* but into *production* – the two notions are not synonymous – belongs in the same region of the moral sphere as pollution. Innocent-seeming individual actions by a citizen (pollution) or by a chemist (proliferation) sum up, overall, as threatening life forms on this planet, because of the sheer numbers of people involved, and behaving irresponsibly.

To give it another description, proliferation of chemicals is a direct consequence of the rat race in academia ('publish or perish') and of patent law in industry. Both the career and the business imperatives encourage surface novelty, at the cost of true originality. We deal here with one of the numerous manifestations of the 'banality of evil', to borrow Hannah Arendt's felicitous oxymoron, by which she characterized Adolf Eichmann's personality.[23]

But this need not be. Chemistry differs altogether from such a living caricature, from the shadow it casts. Chemistry is a science and chemists are indeed natural scientists. Quite a few of us share an attitude of reverence for the wonders we are given to witness in our flasks. Reverence? The word, derived from the Latin '*uereri*', means etymologically something akin to religious respect, awe mixed with fear and forebodings. It is a cognate of the English adjective 'wary'. A good chemist is one who turns admiration for the wonders of nature,[24] into wariness about his/her interference with the real world; since as a rule a chemist goes beyond description, into action, when engaging in the *téchne*, the art of chemistry.

Indeed, the chemist's attitude is not to be construed as one of passive admiration for the intricate beauties of the real world, on a microscopic scale. Often s/he matches the whimsy of the imagination with the exuberant fantasy of the natural forms. It is amazing that the two meet, in discovery. Such a chance encounter thus stems from the playful component. The chemist is at play, with values combining the virtues of the Stoic with the ludic element, akin to and drawn from word games.

But of course, I am only paraphrasing here Kant, when he wrote at the end of his *Critique of Practical Reason*:

> Two things fill the mind with ever new and increasing wonder and awe, the more often and the more seriously reflection concentrates upon them: the starry heaven above me and the moral law within me.

Replace 'starry heaven' with 'molecular playground', and you have it, in a nutshell.

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Notes

1 Even such jobs do not admit of a clear-cut moral judgment and they might receive ample justification from a moral standpoint. See "chemist George's dilemma", as presented by Williams, B.: 'A Critique of Utilitarianism', in: J.J.C. Smart & B. Williams, *Utilitarianism: For and Against*, Cambridge UP, Cambridge, 1973; reprinted in: T. Honderich & M. Burnyeat (eds.), *Philosophy as it is*, Penguin Books, Harmondsworth, Middlesex, 1979, pp. 31-56.

2 Lepage, C. & Guéry, F.: 2001, *La politique de précaution*, PUF, Paris, pp. 61-2.

3 Foot, P.: 1970, 'Morality and Art', *Proceedings of the British Academy*, **LVI**; reprinted in: Honderich & Burnyeat (*op. cit*., note 1), pp. 12-29: "relativism is a true account of some moral judgments […] morality is not compelling."

4 Gilmour, J.C.: 2000, 'Improvisation in Cézanne's Late Landscapes', *The Journal of Aesthetics and Art Criticism*, **58**, 191-204.

5 Schummer, J.: 1997, 'Scientometric Studies on Chemistry I: The Exponential Growth of Chemical Substances, 1800-1995', *Scientometrics*, **39**, 107-123.

6 Bryson, B.: 1990, *Mother Tongue. The English Language.*, Penguin Books, Harmondsworth, Middlesex, p. 70.

7 McCrum, R.; Cran, W. & MacNeil, R.: 1993, *The Story of English*, Penguin Books, Harmondsworth, Middlesex, pp. 81-2.

8 Laszlo, P.: 1993, *La parole des choses. Le langage de la chimie*, Hermann, Paris.

9 Schummer, J.: 1999, 'Coping with the Growth of Chemical Knowledge. Challenges for Chemistry Documentation, Education, and Working Chemists', *Educación Química*, **10**, 92-101.

[10] Hoffmann, R. & Laszlo, P.: 2001, 'Protean', *Angewandte Chemie International Edition English*, **40**, 1033-6.

[11] Turbayne, C.M.: 1971, *The Myth of Metaphor*, 2nd edn., University of South Carolina Press, Columbia, SC.

[12] Laszlo, P.: 1999, *La découverte scientifique*, PUF, Paris.

[13] See also Del Re, G.: 1997, 'Technology and the Spirit of Alchemy', *Hyle*, **3**, 51-63.

[14] Putnam, H.: 1978, *Meaning and the Moral Sciences*, Routledge and Kegan Paul, London, p. 93.

[15] Putnam, H.: 1981, *Reason, Truth and History*, Cambridge UP, Cambridge, p. 143.

[16] "*Qui chante en groupe mettra, quand on le lui demandera, son frère en prison*" (Whoever sings in a group will, if it is asked from him, throw his brother in jail); Michaux, H.: 1950, *Tranches de savoir*, L'Age d'Or, Paris, p. 45.

[17] Macintyre, A.: 1981, *After Virtue. A study in moral theory*, Duckworth, London, p. 205.

[18] "Travailler un concept, c'est en faire varier l'extension et la compréhension, le généraliser par l'incorporation des traits d'exception, l'exporter hors de sa région d'origine, le prendre comme modèle ou inversement lui chercher un modèle, bref lui conférer progressivement, par des transformations réglées, la fonction d'une forme." (Canguilhem, G.: 1963, 'Dialectique et philosophie du non chez Bachelard', *Revue internationale de philosophie*.)

[19] I fully concur here with C.H. Waddington, reminding us that "the most sensible and convincing guides to action do not necessarily possess in their own right the ethical quality" (Waddington, C.H.: 1960, *The Ethical Animal*, George Allen and Unwin, London, p. 21).

[20] Ayer, A.J.: 1946, *Language, Truth and Logic*, 2nd edn., Gollancz, London., chap. 6.

[21] Altham, J.E.J.: 1986, 'The Legacy of Emotivism', in: G. Macdonald & C. Wright (eds.), *Fact, Science & Morality. Essays on A.J. Ayer's Language, Truth & Logic*, Basil Blackwell, Oxford, pp. 275-288.

[22] Recent books have addressed this issue, either by attempting to bring the Two Cultures both under the empire of science or by denouncing once again science as ultimately responsible for the evils of the present society. Two eloquent statements of these two opposed views are Wilson, E.O.: 1998, *Consilience*, Alfred A. Knopf, New York; and Berry, W.: 2000, *Life is a Miracle*, Counterpoint Press, Washington.

[23] Arendt, H.: 1963, *Eichmann in Jerusalem: A Report on the Banality of Evil*, Penguin Books, Harmonsworth, Middlesex.

[24] Daston, L. & Park, K.: 1998, *Wonders and the Order of Nature*, Zone Books, New York.

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