Chemethics: Towards an Ethics of Chemical Intervention

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Abstract

The ethics of chemistry occupies an uncomfortable position in the landscape of applied ethics. Even though a significant proportion of the moral challenges generated by contemporary molecular intervention are, at their root, chemical — produced by chemistry's characteristic capacity to decompose, recombine, and produce matter in novel configurations — the living space of ethics of chemistry has been systematically colonised by bioethics, ethics of technology, and public policy discourse. This paper argues that this colonisation reflects a structural misalignment: bioethics is constituted at the level of application rather than at the level of the founding conditions of molecular intervention. To address this gap, the paper proposes the concept of chemethics — an ethics of a type of intervention rather than a disciplinary or professional ethics, applicable wherever chemistry's constitutive agenda operates. Drawing on the genealogy of molecularism, the alchemical dream of total transformation, and the philosophy of chemistry, the paper develops three principles of chemethics — the underdetermination principle, the levels principle, and the limit principle — understood as second-order constraints on any adequate ethics of molecular intervention. The paper concludes that chemethics and bioethics are complementary frameworks: the former addressing the founding conditions of molecular intervention, the latter the application-level questions that arise from them.

Keywords

Chemethics; Ethics of chemistry; Molecularism; Chemical intervention; Bioethics; Phronesis

Introduction

The ethics of chemistry occupies an uncomfortable position in the landscape of applied ethics. Despite the fact that a significant proportion of the moral challenges generated by modern science and technology are, at their root, chemical — produced by the characteristic capacity of chemistry to decompose, recombine, and produce matter in novel configurations — the field of ethics of chemistry often remains chronically underdeveloped, its living space colonised by bioethics, ethics of technology, corporate ethics, and public policy discourse (Gerontas, 2021). When students are presented in the class with the thalidomide case, they reach for clinical trial regulation. When presented with Agent Orange, they reach for corporate responsibility and government accountability. When presented with CRISPR, they reach for bioethics. In each case, the chemical underdetermination at the root of the problem — the fact that a newly synthesised or modified entity's properties cannot be fully specified in advance at the point of synthesis or modification — disappears from view, absorbed into frameworks that were not designed to engage it. This pattern reflects not simply a pedagogical habit, but a structural misalignment between the level at which ethical analysis is conducted and the level at which the intervention operates.

There have been efforts to establish the ethics of chemistry as an autonomous discipline (Schummer & Børsen, 2021), efforts that represent an important step in the right direction. As Joachim Schummer has argued, the ethical specificity of chemistry lies in the fact that its products are not only knowledge but also, and crucially, new material entities that directly transform the world (Schummer, 1997). However, as argued elsewhere, these efforts so far do not yet resolve the foundational problem: they do not demonstrate on conceptual grounds why chemistry, rather than biology or industry or technology, is the primal and decisive protagonist of the moral challenges it addresses — both on the level of the problem and on the level of the remedy (Gerontas, 2021). Without that demonstration, the ethics of chemistry remains a collection of case studies that other ethical frameworks can always claim with equal or greater institutional confidence. The current cultural dominance of molecularism has deepened this problem — the framework, operative simultaneously in scientific self-understanding, popular culture, policy, and commercial practice, in which life is conceived as constituted by manipulable molecular units, and in which knowledge of life is intrinsically linked to the capacity to intervene in and redesign it; a cultural myth, in Mary Midgley's sense, that molecular biology's success made available and that the broader culture proceeded to inhabit (Gerontas, 2026). It is this “cultural” molecularism that has consolidated bioethics as the default primary framework for the moral challenges of molecular intervention on living matter, by making the interventive orientation appear as the natural direction of biological progress rather than a historically contingent development rooted in chemistry's constitutive agenda.

Molecularism, as the term is used here, names an epistemic and cultural framework rather than a scientific theory or a synonym for molecular biology: the orientation in which living

systems become intelligible primarily through their molecular constitution and governable through molecular intervention, so that understanding a system is increasingly identified with the capacity to analyse, manipulate, and redesign it at the molecular level.

This paper proposes a conceptual foundation that complements these existing frameworks by operating at a different level of analysis. The ethics adequate to molecular intervention — to CRISPR, synthetic biology, AI-driven drug design, genomic enhancement, and the full range of practices in which molecularism has become practice — requires a framework constituted not at the level of any particular discipline or profession, but at the level of the act of chemical transformation itself: the manipulation of matter at the level of its constitutive transformability. The social dimensions of technoscientific intervention have been extensively explored in science and technology studies (Jasanoff, 2016; Feenberg, 2002), and the question of values embedded in technological design has been a central concern of the philosophy of technology (Winner, 1980). What has not been proposed is a framework that grounds the ethics of molecular intervention specifically in the constitutive features of chemical transformation as such. This paper proposes the term *chemethics* to name that framework. Chemethics is not the ethics of the chemistry profession, nor the ethics of chemical weapons or industrial pollution — these are disciplinary or application-specific ethics — but an ethics of a type of intervention, applicable wherever the chemical agenda operates: in molecular biology as much as in synthetic chemistry, in pharmaceutical development as much as in materials science, in AI-driven biology as much as in the laboratory.

The argument proceeds in four steps. Section 1 diagnoses the structural limitation of bioethics as currently practiced in the domain of molecular intervention, showing that it operates within the molecularist framework it should be interrogating rather than examining the epistemic and cultural assumptions that make molecular intervention conceivable. The issue is not the absence of reflection within bioethics, but the default framing of problems at the level of application rather than at the level of constitution. Section 2 argues that if biology's interventive orientation is derived from chemistry's constitutive agenda — as established in prior work (Gerontas, 2026) — then the ethics corresponding to this orientation must be grounded there, and develops the concept of chemethics accordingly. Section 3 traces the deeper genealogy of the interventive orientation to the alchemical dream of total transformation, arguing that molecularism's most characteristic ambitions — the perfection of the body, the overcoming of mortality, the redesign of life — can be understood as structural continuities of alchemy rather than novelties of modern science, and that chemethics must engage this genealogy if it is to be adequate to the depth of the orientation it is addressing. Section 4 proposes three principles of chemethics — the underdetermination principle, the levels principle, and the limit principle — understood not as first-order norms but as second-order constraints: conditions of adequacy that any ethics of molecular intervention must satisfy if it is to engage the phenomena at the appropriate level. The paper concludes by arguing that chemethics and bioethics are complementary frameworks operating at different but mutually necessary levels of analysis — the former addressing the founding conditions of molecular intervention, the latter the application-level questions that arise from them.

Because the word *level* will do a great deal of work in what follows, three senses of it should be separated at the outset. There is the *level of intervention* — for the cases at issue, the

molecular level at which matter is manipulated. There are the *levels of biological organisation* — molecule, cell, tissue, organism, population, ecosystem — across which the effects of a molecular intervention propagate. And there is the *level of ethical analysis* — the distinction between an ethics constituted at the level of an intervention's application and one constituted at the level of its founding conditions. When this paper argues that chemethics operates at the level of founding conditions *rather than* applications, it speaks in the third sense; when it proposes a levels principle, it speaks in the second. The apparent tension between the two dissolves once the senses are kept apart: the framework is *situated* by the third sense, and it *directs attention*, through its second principle, to the second.

1. Bioethics and the Founding Conditions of Molecular Intervention

The resources that bioethics brings to the moral challenges of contemporary science and medicine are real and substantial. Over half a century, the field has developed a sophisticated apparatus for ethical reasoning in clinical and research contexts: the four-principles framework of autonomy, beneficence, non-maleficence, and justice that has become the discipline's most influential organising structure (Beauchamp & Childress, 2019); extensive literatures on informed consent, research ethics, organ transplantation, end-of-life care, and reproductive technology; and institutional mechanisms — ethics committees, regulatory frameworks, review boards — that have transformed the conditions under which medical and biological research is conducted (Rothman, 1991). This apparatus has done important work, and nothing in what follows is a rejection of it. The argument here is a bit more specific: that bioethics as currently constituted operates at the level of application rather than constitution, and that this constitutive feature means it is not engaged at the level of analysis that would address the founding conditions of molecular intervention — the conditions that make the applications conceivable in the first place.

The historical roots of this limitation are instructive. Bioethics emerged as a recognisable discipline in the 1960s and 1970s, shaped by a specific set of founding cases: the Tuskegee syphilis study, the development of intensive care medicine and organ transplantation, the thalidomide tragedy, and the first experiments in recombinant DNA technology. What these cases had in common was not that they raised questions about the nature of the interventions involved, but that they raised questions about the governance of interventions whose nature was already understood — or assumed to be understood. The Tuskegee study raised questions about the ethics of withholding treatment and the conditions of informed consent; organ transplantation raised questions about the allocation of scarce medical resources and the definition of death; the thalidomide case raised questions about the regulation of clinical trials and the responsibilities of pharmaceutical companies. In each instance, bioethics was constituted as a discipline for assessing the consequences and governing the practice of interventions that were taken as given. The level of analysis was the application; the intervention itself — what kind of thing was being done, what assumptions it carried, what it presupposed about the nature of the entities it was acting on — was outside the frame.

This constitutive orientation was not a failure of vision but a reflection of the cases that founded the discipline. When molecular biology subsequently generated applications — recombinant DNA technology, gene therapy, genomic sequencing, and eventually the

CRISPR-Cas9 system — bioethics was the available framework, and it applied its characteristic approach: assess the consequences, specify the principles, regulate the practice. The result has been an extensive and valuable literature on the ethics of genetic intervention. Nevertheless, a literature realised, at almost every point, at the level of application rather than constitution. The debate over germline editing — concentrated by the announcement of the first CRISPR-edited human births in 2018 and the international call for a moratorium that followed (Lander et al., 2019) — illustrates the pattern with particular clarity. The debate addresses questions of safety, consent, equity of access, the distinction between therapeutic and enhancement uses, and the governance of heritable modification. All these are genuine and important questions. What the debate does not ask — or asks only at its margins — is whether the molecular level is the appropriate level at which to assess what is being done or not.

The question matters because the relationship between genotype and phenotype is massively underdetermined. The traits most discussed in fashionable enhancement contexts — cognitive capacity, physical performance, disease resistance — are polygenic, developmentally sensitive, and shaped by environmental interactions that current molecular biology cannot fully specify. An intervention that is completely characterised at the molecular level may generate effects at the cellular, developmental, organismal, and population levels that the molecular specification neither predicts nor anticipates. Importantly, this is not a contingent gap in current knowledge that further research will fill; it is a structural feature of the kind of intervention that CRISPR performs — a chemical intervention in a living system organised at multiple levels, each with its own dynamics and regularities that the molecular level does not determine. Bioethics, operating within the molecularist framework that treats the molecular level as the salient level of *organisation*, tends to assess the intervention at the organisational level where it is performed rather than tracking it across the levels where its consequences propagate — even as, in the third sense distinguished above, it remains constituted at the level of *application*. The two are consistent: a framework built to govern given applications inherits from molecularism the assumption that the molecular level is where the relevant description lies.

It should be said plainly, since a reader might reasonably ask, that bioethics does address several of these organisational levels in practice — ecological risk, population effects, and long-term consequences all appear in its literatures. The claim is not that it ignores the higher levels but that it engages them at the level of application: as consequences to be assessed once an intervention is given, rather than as founding conditions bearing on what kind of ethics the intervention requires in the first place. The difference is not the range of levels surveyed but the level at which the framework is constituted.

The thalidomide case makes the structural point in its starkest form — and also illustrates why the point consistently eludes bioethical analysis. Thalidomide was synthesised, its sedative and anti-nausea properties were established, and its catastrophic teratogenic effects were not and could not have been fully anticipated at the point of synthesis: the chemical underdetermination of a novel molecular entity meant that its full range of biological effects was unknowable in advance. The moral problem originated in the act of chemical intervention itself — in the production of an entity whose properties were underdetermined in advance — yet bioethics engaged it only downstream, as a matter of clinical-trial regulation, pharmacovigilance, and the responsibilities of the pharmaceutical

industry (Ruthenberg, 2021). The shift is not from one organisational level to another but from the founding conditions of the intervention to its governance: the underdetermination that generated the tragedy was left unaddressed *as such*, because the framework that took up the case was built to govern applications, not to interrogate the conditions that make them possible. These regulatory responses were necessary and valuable of course. But they addressed the consequences of chemical underdetermination without engaging the underdetermination itself as a structural feature of the type of intervention that produced the problem. The question that bioethics did not ask — because it was not constituted to ask it — was what kind of ethics is adequate to an intervention that characteristically produces entities whose properties cannot be fully specified in advance.

That question is the founding question of the chemethics proposed here. It does not replace the bioethical questions about thalidomide, CRISPR, or synthetic biology. It precedes them — establishing the level at which the ethical analysis must be grounded before the application-level questions can be adequately addressed. Bioethics, for all its sophistication, addresses consequences while leaving their constitutive conditions unexamined. Chemethics proposes to examine them.

2. Chemistry's Constitutive Agenda and the Ethics It Implies

The existing literature on the ethics of chemistry has established two important foundations for the argument developed here. Schummer's 2001 paper in HYLE — a quite systematic analysis of moral issues arising from chemical synthesis — demonstrated that chemical synthesis is not morally neutral: unlike other branches of science, chemistry's products are not only ideas but also new material entities that change the world, and the chemist who produces them incurs ethical responsibilities that cannot be reduced to those of any other scientific practitioner (Schummer, 2001). Mehlich et al. (2017), surveying the ethical and social dimensions of chemistry more broadly, showed that the chemist faces challenges belonging simultaneously to science ethics, research ethics, engineering ethics, and professional ethics — a mapping of ethical territory that confirmed both the genuine distinctiveness of chemistry's ethical situation and the difficulty of housing it within any single existing framework. Neither contribution, however, proposes an ethics constituted at the level of the intervention type rather than at the level of the profession or discipline. Schummer's ethics of chemical synthesis asks what moral obligations the chemist incurs by performing synthesis, stressing that responsibility does not necessarily imply moral judgement; Mehlich et al. ask what ethical challenges the chemistry profession faces; and both remain within the structure of professional or disciplinary ethics. What neither address is the question this paper takes as its starting point: what kind of ethics is adequate to the act of chemical transformation itself, independently of the institutional home in which it is performed and the professional identity performing it?

The difference from Schummer is therefore one of logical order rather than of vocabulary. Schummer specifies first-order moral obligations that the chemist incurs in performing synthesis; chemethics specifies second-order conditions of adequacy that any ethics of molecular intervention must satisfy, whoever performs it and under whatever obligations. The two are not rivals: Schummer's obligations are among the first-order norms that a framework meeting the chemethical conditions would go on to articulate.

The answer proposed here begins with the account of chemistry's constitutive agenda developed in prior work (Gerontas, 2026). Chemistry is not only a science of the molecular constitution of matter; it is, distinctively among the natural sciences, a productive science — one in which understanding a material system is inseparable from the capacity to decompose, recombine, and produce it. Bensaude-Vincent and Simon (2008) identify this productive orientation as chemistry's constitutive agenda: the identification of knowing with transforming, of comprehension with the capacity to synthesise. This agenda is not an accidental feature of chemistry's historical development; it is constitutive of what chemistry is as a form of inquiry. A science that could only describe and explain matter, but not intervene in and produce it, would not be chemistry in any recognisable sense (most probably, it would be a branch of physics).

The ethically significant consequence of this constitutive agenda is Schummer's underdetermination point, now seen in its full structural scope. Because chemistry's primary activity is the production of novel material entities — entities that did not previously exist — the properties of its products cannot be fully specified in advance of their production. This is not a contingent epistemic limitation, but a structural feature of productive knowledge: the entity produced by chemical intervention is genuinely new, and its full range of properties, interactions, and effects in complex systems can only be discovered after it is free to interact with the world. The ethics corresponding to this situation cannot be a simple application of pre-existing norms to known outcomes. It must be an ethics of the encounter with the genuinely new — an ethics of radical novelty as a structural condition rather than an exceptional circumstance.

This structural feature — productive novelty as a constitutive condition rather than an occasional complication — is what bioethics is not constituted to engage, and what an ethics of the intervention type must take as its foundational datum. It is also what makes it necessary to speak of an ethics of chemical intervention rather than an ethics of the chemistry profession. When the productive orientation of chemistry migrates — as this paper's prior work has argued, molecularism has caused it to do so — into molecular biology, synthetic biology, pharmaceutical development, and AI-driven biological research, the ethics corresponding to it migrates too. The chemist performing a synthesis in a laboratory, the molecular biologist editing a genome, the synthetic biologist constructing a novel metabolic pathway, and the AI system proposing novel drug candidates are all performing variations of the same fundamental type of intervention: the manipulation of matter at the level of its constitutive transformability, generating entities whose full properties are underdetermined in advance. An ethics adequate to this situation must be constituted at the level of the intervention type — chemethics — rather than at the level of any of the disciplines or professions in which the intervention is housed.

Chemethics, as here proposed, is therefore defined by three features that distinguish it from the existing frameworks reviewed above. First, it is an ethics of intervention rather than a disciplinary or professional ethics: its scope is determined by what is being done, not by who is doing it or within what institutional framework. Second, its foundational datum is productive novelty — the structural underdetermination of the properties of newly created entities — rather than the application of known procedures to known outcomes. Third, it operates at the level of the founding conditions of molecular intervention rather than its applications: it asks what assumptions about life and matter the intervention carries before

asking what should be done with the results. In this sense, chemethics does not replace the existing ethics of chemistry literature or the bioethical frameworks that address specific applications; it proposes the level of analysis at which both must be situated if they are to fully engage with the phenomena.

3. The Alchemical Dream: Structural Continuity

The argument of this section is genealogical, and the sense of genealogy must be stated precisely, because it is easily mistaken. It is not the claim that modern chemistry inherited the theories, the cosmology, or the mystical apparatus of alchemy; the historiography that has dismantled that picture is by now decisive (Principe, 2013), and nothing here depends on reopening it. Nor is it the claim that a promethean ambition animates molecular intervention *as such*: the overwhelming majority of chemical and molecular work is patient, local, and modest in its aims, and no genealogy is required to understand it. The claim is narrower and structural. What alchemy first made explicit — and what modern chemistry did not so much refute as absorb — is an orientation in which the knowledge of matter is inseparable from its transformation, and in which that transformation is imagined, *at its horizon*, as the overcoming of the given limits of material and bodily existence. It is this orientation — not any doctrine, and not any agent's intention — that constitutes the continuity at issue; and it becomes ethically consequential only where intervention reaches toward that horizon.

That the continuity runs *through* the constitution of modern chemistry rather than around it is not an external imposition on the discipline but something its founders themselves recognised. Reflecting, in the third of his *Chemische Briefe*, on the alchemical search for the philosopher's stone, Justus von Liebig judged the idea to have been indispensable to the science that superseded it: no finer notion, he wrote, could have been conceived to inspire the minds of men, for without it chemistry would not have become what it is, and it was only in the effort to discover that no such thing existed that it became necessary to ransack and analyse every substance known on earth. Liebig's point is not nostalgic. He identifies the philosopher's stone as the organising aim whose pursuit produced the systematic interrogation of matter — the productive orientation itself — even as its literal object proved to be nothing. The dream was constitutive of the method precisely in being unrealisable.

Read through Mary Midgley's conception of myth (Midgley, 2003), this is exactly what a myth in her sense does. A myth is not a false belief held by individuals but an imaginative background — a pattern of pictures and aspirations that organises inquiry and directs practice below the level of explicit doctrine. To identify the philosopher's stone, and its molecular heirs, as a myth in this sense is therefore not to attribute a fantasy to anyone, nor to impute a hidden intention to the molecular biologist or the synthetic chemist. It is to name the imaginative structure within which the interventive orientation acquires its characteristic horizon — the perfection of matter, the perfection of the body, the overcoming of mortality — and against which the question of limits does not spontaneously arise.

Alchemy was organised around an ambition: the transformation of matter to its highest potential. The philosopher's stone, the elixir of life, and the homunculus are not three separate projects but three expressions of a single structural logic — the complete mastery of material transformation, applied to metal, to the body, and to life itself. What is philosophically significant for the present argument is that this logic did not disappear when alchemy's cosmological and mystical apparatus became untenable. It migrated. The Baconian programme — knowledge as power over nature, science as the systematic improvement of the human condition through mastery of material processes — gave the ambition an epistemological and institutional home without its metaphysical scaffolding. What survived was the productive orientation, the identification of knowing with transforming, and the aspiration toward overcoming the given conditions of material existence.

Paracelsus (1493–1541) is the relevant pivot figure here, though not as the last alchemist — alchemical practice remained intellectually active well into the seventeenth century and beyond, as recent scholarship has thoroughly documented (Principe, 2013) — but as the figure who most systematically applied the alchemical logic of perfection-through-transformation to medicine as a programme. In Paracelsus' framework, the physician is not primarily a diagnostician but a chemist: disease is a chemical imbalance, health is the outcome of successful chemical transformation, and the body is an object of productive intervention. This is one of the earliest moments at which the ethics of chemical intervention in living matter becomes a practical rather than merely a theoretical question — one of the first chemethical moments, in the sense this paper has given that term.

The structural continuity with the molecularism of today is precise. The aspiration to edit the genome — to correct inherited imperfections, to enhance desired traits — is the philosopher's stone applied to the biological substrate. The aspiration to overcome aging is the elixir of life in molecular form. The aspiration of synthetic biology to construct living systems from designed components is the homunculus made technically feasible. To call these structural continuities rather than poetic analogies is to claim that the same organising myth — that material transformation, pursued to its limit, can overcome the given conditions of biological existence — is operative in both, regardless of the radical difference in technical means. The claim is not that every genome edit or synthetic construct is driven by such an aspiration, but that where the interventive orientation reaches toward that horizon, it reactivates a pattern that alchemy was the first to make explicit.[1]

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[1] It is worth noting that this structural and imaginative relation has not been lost to the molecular biology community. It is either openly acknowledged, as is most visible in the extreme case of Rifkin's *Algeny* (1983), or reformulated in contemporary vocabulary—as in recent aspirations to "solve disease" in AI-driven biomedical research (Lowe 2025). In the latter case, the potential for conflict becomes apparent: while AI is envisaged as a kind of Philosopher's Stone, a sufficiently capable system may ultimately come to occupy the role of the Alchemist itself.

This genealogy matters for chemethics because it specifies the depth at which the ethics of chemical intervention must operate. The three principles proposed in the following section are not merely technical constraints on molecular research; they answer to an orientation that has long organised the relationship between chemical knowledge and the human body, and, by recent extension, living matter in general. The limit principle in particular responds to a characteristic feature of that orientation: within an imaginative horizon organised around transformation, limits present themselves by default as provisional obstacles rather than as features of the phenomena that might warrant ethical engagement. It is important to be clear about the role the genealogy plays here. It does not *ground* the limit principle — as the next section argues, that principle draws its justification from the structural features of multi-level, underdetermined intervention, not from the genealogy itself. The genealogy's role is diagnostic: it explains why the question of limits is so readily suppressed, and therefore why an ethics of molecular intervention must take deliberate steps to restore it.

4. The Principles of Chemethics

The three principles proposed in this section are not first-order norms—they do not specify what ought to be done in specific cases of molecular intervention. They are second-order constraints: conditions of adequacy that any ethics of molecular intervention must satisfy if it is to engage the phenomena at the appropriate level. This is a meta-ethical move, and it requires brief justification before the principles themselves are stated.

The is/ought problem — the impossibility of deriving normative conclusions from purely descriptive premises — is a genuine constraint on ethical argument. However, the principles of chemethics are not derived from facts about chemical intervention; they are derived from the structural features of productive knowledge that any adequate ethical framework must take into account. The analogy is with the conditions of possibility argument in Kantian ethics: before issuing categorical imperatives, the Critique of Practical Reason establishes what any viable moral framework must presuppose. Chemethics operates analogously at a domain-specific level. The underdetermination of novel entities, the multi-level organisation of living systems, and the alchemical genealogy of the interventive orientation are not facts from which norms follow, but structural features of the phenomena that rule out certain ethical approaches as constitutively inadequate. A framework that ignores them is not engaged with the phenomena it claims to address.

The three principles follow from the three structural features identified in the preceding sections.

The underdetermination principle derives from the constitutive agenda of chemistry as analysed by Schummer (1997, 2001) and Bensaude-Vincent and Simon (2008). Because chemical intervention characteristically produces entities whose properties cannot be fully specified in advance, any ethics of molecular intervention that operates only based on anticipated outcomes is structurally inadequate to the phenomena. This principle does not prohibit intervention with uncertain consequences — it prohibits treating uncertainty as a merely contingent feature of current knowledge rather than a structural feature of productive novelty. Its normative consequence is that any ethics of molecular intervention must build epistemic humility into its foundations, not treat it as a residual caveat. It rules

out consequentialist frameworks that require full specification of outcomes in advance, and it rules out rule-following frameworks that apply pre-existing norms to genuinely novel entities as if novelty were merely a matter of complexity. What it points toward is an ethics of judgment under conditions of irreducible uncertainty — phronesis in the Aristotelian sense, to which we return below. A concrete illustration: the development of CRISPR base editors, initially presented as a more precise alternative to standard CRISPR-Cas9, subsequently revealed unanticipated cytosine deamination at non-target sites and RNA off-target effects that the initial molecular specification did not predict. The underdetermination was not resolved by increased precision — it was reproduced instead at a finer level of molecular resolution.

This underdetermination must be distinguished from two principles that share its name or its vicinity. It is not the Duhem–Quine underdetermination of theory by evidence, which concerns the relation between a body of data and the theories compatible with it — an epistemic relation internal to representation. Nor is it the indeterminacy of quantum mechanics, which concerns the limits of the simultaneous measurement of conjugate variables in a physical system. Chemethical underdetermination is neither representational nor measurement-theoretic but *productive*: the Duhem–Quine thesis says that our theories are underdetermined by what we can observe, whereas the underdetermination principle says that the products of chemical intervention are underdetermined by the specifications under which they are made. The first is a limit on knowing; the second is a feature of making.

The levels principle presupposes, and should be stated as presupposing, an anti-reductionist account of the organisation of matter: the thesis, developed in different idioms by Wimsatt (1994) and Dupré (2012), that the higher levels of biological organisation possess properties and causal capacities not exhausted by, and not derivable from, the molecular description of their constituents. Without this commitment the principle would collapse — if everything true of the organism were in principle readable from its molecules, assessment at the molecular level would suffice. Grounded in this anti-reductionism, the principle draws on the account of biological hierarchy discussed elsewhere (Gerontas, 2026) and on the Dobzhansky argument about the levels of biological organisation. Intervention at the molecular level generates effects at the cellular, developmental, organismal, ecological, and evolutionary levels that cannot be read off from the molecular specification. Any ethics that assesses only at the level of intervention is therefore constitutively blind to a necessary dimension of the phenomena. This is not a call for complete knowledge before action — which would prohibit all intervention — but a structural requirement that ethical assessment operate across levels rather than only at the level where the intervention is performed. It is the structural reason why bioethics operating within the molecularist framework systematically tends to underestimate consequences: it is constituted at the level of application, while the effects propagate across levels that the molecularist framework renders secondary. The introduction of Bt crops — genetically modified to express a bacterial insecticidal protein — illustrates the point. At the molecular level the modification is well characterised; at the ecological level, widespread adoption has generated selection pressure for resistance in target pest populations, altered non-target insect communities, and produced cascading effects on predator-prey relationships that the molecular specification did not (and could not) anticipate.

The limit principle has been the most exposed to misunderstanding, and it is worth reconstructing its derivation so that it rests on the two principles already stated rather than on the genealogy alone. It does not assert that there are fixed ontological boundaries in matter — a sharp line, at the molecular level, between the living and the non-living, or between the natural and the artificial. No such boundary is needed, and the philosophy of chemistry gives little reason to expect one. What the principle asserts is an *asymmetry of justification* that follows directly from the levels and underdetermination principles. If the effects of a molecular intervention propagate across levels that the molecular specification cannot anticipate, and if the properties of the entities it produces are underdetermined in advance, then a given biological limit — the finitude of the lifespan, the boundaries of a species, the stability of a developmental programme — cannot be known to be a merely technical obstacle from the molecular level at which its removal is proposed. Its status as obstacle or as constitutive feature is settled, if at all, only at the higher levels whose functions the molecular framework renders secondary. The burden of justification therefore falls, structurally and not merely as a matter of prudence, on whoever would treat the limit as provisional: the claim that a limit is *merely* an obstacle is a claim about the very levels the intervention cannot see, and it is that claim, not its denial, that requires demonstration.

The alchemical genealogy enters here not as the ground of the principle but as the diagnosis of why the question it raises is so rarely asked: within an imaginative horizon organised around transformation, limits present themselves as obstacles by default. The genealogy explains the blind spot; the levels and underdetermination principles justify its correction. This is why the principle is reflexive rather than conservative. Current research programmes in biological ageing — aimed at extending the human lifespan by intervening in the molecular mechanisms of senescence — illustrate its application. The limit principle does not say such research is wrong, and it takes no position on whether ageing ought to be overcome; it says only that the assumption driving it — that ageing is a pathology to be corrected rather than an evolved feature of organisms organised at multiple levels — must be stated as a claim and defended, not inherited as the natural direction of progress. Ageing is entangled with developmental programmes, ecological roles, and population-level dynamics whose elimination at the molecular level cannot be assessed without engaging the levels at which its functions operate.

Taken together, the three principles identify the natural philosophical home of chemethics as phronesis — Aristotelian practical wisdom. If the properties of novel entities cannot be fully specified in advance (underdetermination), if effects propagate across levels that cannot be fully anticipated (levels), and if the organising fantasy systematically suppresses the question of limits (limit), then the ethics adequate to molecular intervention cannot be a rule-following ethics or a calculation of specified outcomes. It must be an ethics of perception and judgment — the capacity to discern what a genuinely novel situation requires, across multiple dimensions, without the guidance of pre-existing rules that were not designed for it. This is precisely what Aristotle meant by phronesis: not the mechanical application of universal principles to particular cases, but the cultivated capacity to perceive the morally relevant features of a situation and respond to them appropriately (Aristotle, NE VI). Chemethics does not generate a new set of rules for molecular intervention; it specifies the kind of ethical agency — practically wise, attentive to levels,

responsive to novelty, and reflective about its own organising assumptions — that molecular intervention requires.

It may be objected that ethical traditions adequate to deep uncertainty already exist, and this is true. Aristotelian practical wisdom, to which the three principles jointly point, is precisely an ethics of judgement where rules underdetermine action; the precautionary principle, arising in the same technologically advanced societies that produced the interventions at issue, codifies restraint under uncertainty; and several indigenous traditions — the injunction, on Turtle Island, to weigh a decision against its consequences seven generations hence — were framed for exactly the situation in which effects outrun foresight. Chemethics does not compete with these; it draws on the first explicitly and stands in evident kinship with the others. What it adds is not a new attitude toward uncertainty but the identification of a constitutive *object* that these traditions address contingently and chemethics addresses as such — the structural underdetermination, cross-level propagation, and limit-suppression specific to productive intervention in matter. The precautionary principle tells us to be cautious; the underdetermination principle tells us why caution is here a structural requirement and not a policy choice.

Conclusion

The argument of this paper has moved through four steps. It began with a diagnosis: that bioethics as currently constituted is not engaged at the level of analysis that would address the founding conditions of molecular intervention, and that this constitutive limitation is not accidental but structural — the consequence of a discipline formed to govern the applications of interventions whose nature it did not need to interrogate. It then proposed a genealogical grounding: that the ethics adequate to molecular intervention must be constituted at the level of chemistry's constitutive agenda — the productive orientation in which knowing is inseparable from transforming — because it is from that agenda that molecular biology's interventive orientation derives. It traced that agenda further, to the alchemical dream of total transformation that modern chemistry institutionalised rather than dissolved, and whose current form is molecularism. And it proposed three principles — underdetermination, levels, and limit — understood not as first-order norms but as conditions of adequacy for any ethics that takes the structural features of molecular intervention seriously.

The concept that organises these four steps is chemethics: an ethics of the intervention type rather than the discipline, constituted at the level of the act of chemical transformation itself, applicable wherever the chemical agenda operates. The relationship between chemethics and bioethics is one of complementarity rather than competition. Bioethics addresses the application-level questions that arise from molecular intervention — what should be done, by whom, under what conditions of consent and governance — and does so with considerable sophistication. Chemethics addresses a different level: the founding conditions of the intervention itself, the structural features of productive novelty that make the applications conceivable, and the genealogical assumptions that any application-level ethics inherits, whether or not it examines them. Where the two frameworks work in conjunction — chemethics establishing the level of analysis at which the constitutive features of the intervention are visible, bioethics addressing the application-level questions

that arise from them — the combined framework is more adequate to the phenomena than either alone. The ethics of molecular biology, synthetic biology, and AI-driven intervention in living systems is, at its foundations, a chapter in the ethics of chemistry. And the ethics of chemistry is, at its deepest level, an engagement with the alchemical dream of total transformation that five centuries of productive science have elaborated, refined, and made technically feasible without ever subjecting to systematic ethical examination.

The urgency of this examination is not abstract. CRISPR-based interventions are moving from laboratory to clinic. Synthetic biology is beginning to reshape agriculture, materials science, and pharmaceutical production. AI systems trained on molecular data are proposing novel compounds and redesigning biological pathways at a pace that outstrips the capacity of application-level ethics to assess them. In each case, the molecularist framework supplies the operating assumptions and metaphors — life as molecular information, biology as engineering, progress as increasing molecular resolution and control — and the alchemical dream supplies the horizon: the overcoming of given biological limits as the natural direction of the enterprise. Chemethics does not oppose this enterprise. It insists, however, that the framework and the dream be made visible, examined, and justified — that the burden of argument fall where it belongs, on those who treat the given conditions of biological existence as merely provisional obstacles, rather than on those who ask what it means to intervene in living systems whose organisation exceeds the molecular level at which the intervention is performed.

Bioethics will continue to do important work at the level for which it was constituted. The closing formulation is therefore not a dismissal but an invitation to collaboration at a deeper level of analysis: current bioethics is chemethics that has not yet recognised its own genealogy. The recognition, when it comes, will not replace bioethics — it will ground it.

Declarations

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