Chapter 2
Dialectics of Technoscience

Genesis of Dialectics

Dialectics is a philosophical method developed by Hegel (1770–1831), but building on an intellectual tradition whose origins can be traced back to ancient Greece. Dialectics was initially practiced as an educational technique for conducting philosophical discussions. For Hegel, however, dialectical processes can be discerned in the dramatic unfolding of nature, history and human thinking as such. The first dialectical thinker, in the genuine sense of the term, according to Hegel (1971), was Heraclitus (535 – c. 475 BC), in whose "obscure" aphorisms Hegel recognises the awareness that dialectics is more than merely a technique to foster critical reflection. Heraclitus already refers to a basic logic guiding the dynamics of nature as such, to a λόγος at work in actual processes of becoming and change, giving rise to contrasting and contradictory developments ("objective dialectics", as Hegel phrases it). For dialectical thinkers, the dialectical method is fundamentally in tune with nature, because nature *as such* is inherently dialectical. Hegel considered Aristotle as ancient philosophy's most thoroughly dialectical thinker, as we have seen, while Hegel himself is regarded as a modern Aristotle (Beiser, 2005, p. 57; Pippin, 2019, p. 301).

Twenty-five centuries ago, in ancient Greece, philosophy teachers taught their students how to think. A philosophy trainer would establish a "think–shop" (φροντιστήριο), as Aristophanes (1962) once phrased it (to contrast it with the menial workshops of artisanal professions). While Heraclitus had been probing the dialectics of nature (his treatise bore the title Περὶ Φύσεως: "On nature"), Socrates and the sophists focussed on the *subject pole* of the knowledge process: on "*subjective* dialectics", as a technique for producing convincing arguments. This is how dialectics is often understood. For Hegel, however, dialectics is not merely a method for the formation of the intellect. Dialectics applies to the *object pole* ("nature") as well. The dialectical method allows us to understand the inherent dynamics of nature as such: *objective* dialectics. For Hegel (1971), Heraclitus was the first to

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realise this, seeing dialectics as a *process*, while seeing Being as being-in-flux. The objective of dialectics is to come to terms with Being as a process of becoming, so that *being* means *being underway* towards realisation. Dialectics is not merely a method for deliberation (*Räsonieren*), but the very principle of Being as such. And Hegel's (unfinished) oeuvre must likewise be seen as "thinking in progress", as a *research program* we are invited to join and develop further.

While ancient Greek philosophy began as the awareness of Being (as the *first moment*), Heraclitus grasped Being and nature as *processes of becoming*, as we have seen, driven by conflict and contradiction. Without this dynamic of conflict, without "negation" as the *second moment*, there can be no dialectics. Heraclitus lived a solitary life, distancing himself from the daily turmoil of urban politics, solely devoted to thinking (Diogenes Laertius, 1925/1972). He taught *and lived* the divergence between thinking and daily existence, as an inevitable moment in the genesis of human consciousness. Eventually, however, this *second moment* of divergence and alienation must be sublated (superseded), and philosophy must again become committed to discerning and strengthening the inherent rationality of the real, – the *third moment*, which includes the inherent rationality of the politics of the polis: as a *concrete* realisation of the idea of a human community, but at the same time as a process of *becoming*, so that the envisioned realisation has *not yet* been completely achieved.

Dialectics conceives becoming as the unity of Being and negativity. Whereas Being is a primary position (the first moment), we experience a deficit and notice absence (the second moment). Being is marked by finitude, deficiency and deprivation. The world is not what it should be, something is missing, a tension is discerned between ideal and real, expectation and existence, ought and is. This negativity can be overcome when we acknowledge that everything is actually involved in a process of becoming, that we are *underway* to the realisation of the idea: to its actual embodiment in the physical-historical world. Realisation and reconciliation are never given, but something to strive for, requiring time and effort. The dialectical method commences with the awareness that we are *not yet* there, that we are struggling to discern a pathway towards insight and truth. Etymologically speaking, "method" (μετ' + ὁδός) literally means considering the path we have to follow, involving multiple intermediary stations and positions. The step from Being to Becoming is important, but in the case of Heraclitus becoming still remains an abstract and one-sided concept, Hegel argues (cf. De Boer, 2010). While Heraclitus persisted in negativity, what was missing was the concrete realisation of the idea, the *third* and final *moment* of concrete positivity (exemplified by the polis as a "concrete universal"). Heraclitus' thinking was not yet focussed on creating positive results (the concrete reconciliation and convergence of the ideal and the real). For Heraclitus, everything was floating and everything was fire (energy), but what was missing at this stage was the return to unity and stability at a higher level of comprehension. Heraclitus did

acknowledge, however, that the process of becoming proceeds in accordance with laws (λόγος) and is intelligible in principle (Hegel, 1971).[1]

The next station on the pathway of thinking (or consciousness) was ancient atomism, represented by Empedokles, Democritus and others. Again, being is not taken for granted as something static and given (the first moment: M_1). Rather, atomism stresses the fluid, changeable and unpredictable aspects of nature (the second moment: M_2). The atomists regard nature and natural beings as composite entities, composed of minute material particles of various shapes, temporarily flocking together and dispersing again.[2] The strength of their vision, dialectically speaking, is that they discern inherent tensions in everything, seeing all entities as the temporary result of juxtaposed forces: attraction and rejection, determinism and deviation. In being in *general* (abstract being), they discern *particular* factors at work. Conflicting tensions and random swerves temporarily give rise to concrete tangible things, but it is difficult to see how high levels of organisation can be attained and maintained, especially in the case of living beings. Their weakness was that they were unable to overcome this emphasis on randomness. The atomists were unable to explain biotic nature: the emergence of *concrete* living organisms. Atomism fails to understand how *concrete* entities such as plants and animals can come into existence and maintain themselves (withstanding entropic pressures from the environment) for extended periods of time and even reproduce themselves (Schrödinger, 1944/1967). In living beings, opposition is overcome and attraction and rejection become reconciled for extended periods of time, so that inorganic chemistry becomes organic metabolism (a cycle of biochemical cycles), until they die and perish into dust (and the process starts anew).

According to Hegel, it was the achievement of Aristotle to really think through the process of Being, thereby realising the third and final moment (M_3). According to Aristotle, living beings are able to maintain themselves because they are the concrete realisation of an idea, a program (in Hegel's vocabulary: a concept, a *Begriff*). Like all dialecticians, Aristotle discerned inherent tensions in everything, especially in living beings, namely between matter and form, concept and realisation, and the living organism precisely *is* this integrated tension, this conjunction of metabolism and organisation, stability and flux, incorporation and excretion. Living beings are inorganic matter shaped by (brought to life by) the "form", the principle of life. According to Aristotle, the soul is the principle of life (Aristotle, 1986, 402a, 415b): it is the *form* or *formula* of living beings. All organisms are composite entities:

[1] This is also the morale of the famous story told by Aristotle and retold by Heidegger. When foreign visitors wanted to see the sage, they saw him warming himself at a stove. Surprised, they stood there in consternation, but he encouraged them to enter, "For here too the gods are present." They had expected something more detached, exceptional and rare: a thinker enwrapped in meditation, but his abode was the real world, the practice of everyday existence (heating rooms, preparing food), exemplified by a thing that brought people together.

[2] In his doctoral thesis, Karl Marx developed a Hegelian reading of Epicurean and Democritean atomism, focussing on the clinamen concept: the declination or swerve of the atom, as an inherent principle of change (Browning, 2000).

fusions of form and matter, resulting in the realisation or actualisation (412a) of a formula or plan (412b, 415b). Dialectically speaking, this formula or plan is the concept or notion (*Begriff*) which realises itself in concrete living entities. In terms of contemporary technoscience, the program or formula of living entities has been identified with DNA (Delbrück, 1971; Zwart, 2018).

A key concept of Aristotle's dialectics is a neologism coined by him: ἐνέργεια. This composite term is based on ἔργον ("work": ἐν–έργεια) and literally means being-at-work, being-active. The term may be translated as "actuality" (or reality) if sufficient emphasis is placed on *activity*: to *act* (on *realisation*). According to Aristotle (1993, 1050a, 21–23), being means being-at-work, a process of self-realisation, underway to stability and fulfilment (the natural end).

Another important station in the development of dialectics was late-medieval scholasticism, notably the work of Thomas Aquinas (1225–1274), where dialectics develops into a series of questions and disputations, which is clearly visible in the composition of his *Summa Theologiae*, the medieval counterpart of Hegel's *Enzyklopädie der philosophischen Wissenschaften* (Aquinas, 1922). The process begins with positing a question (*Questio*). An initial position is taken and a provisional answer is provided (*Videtur:* "It seems to be the case that…"), followed by arguments in favour of this initial position. Subsequently, however, the opposite position is presented and defended as well, giving rise to conflicting arguments (*Sed contra est*: "On the contrary it can be argued that…"). An inherent contestability or tension is discerned, giving rise to experiences of uncertainty and doubt. The original position is negated, and this is an important experience, emphasising the questionability of all provisional positions. As a dialectical thinker, however, Thomas realises that this cannot be the end result, and that the issue has to be worked through. Whereas disputation was usually an assignment for students, the master intervenes to present a third position (*Conclusio*, "I conclude…"), building on the discursive process, but in such a way that both the initial position and the opposite position are duly incorporated and addressed. The question is determined after weighing the evidence, followed by replies to the objections that emerged in the course of the process (Ad primum: "To the first, I answer that…").

This type of dialectics (scholasticism) prepared the ground for experimental thinking (the late medieval *scientia experimentalis*). In an experiment, two conditions are likewise confronted with one another, starting with a hypothesis, the initial view (*Videtur*), but also giving the floor to (and exposing preliminary insights to) rival interpretations and contradictory evidence (*Sed contra est*). The (modern) *idea* of an experiment, as a core component of technoscientific thinking, will be elaborated later, but a crucial difference between technoscientific experimentation and scholastic disputation resides in the role of technology. Experimentation is a technological practice. Both experimentation and disputation rely on standardised vocabularies (technical language), but experimental technoscience involves quantification: i.e. tools for measuring and comparing results (weighing the evidence, but now in a quantitative manner).

Besides using dialectics as a method for organising arguments, however, Thomas Aquinas discerns an inherent dialectics in being as such: a basic concordance

between thinking and being, as reflected in the architecture of his *Summa*, which begins with the existence of God (the first moment), while subsequently human existence is addressed (human virtues and vices, as contrasting tendencies), until (via Christ and the sacraments), the return of Creation towards God is envisioned (the third moment). Human existence equals being underway towards fulfilment and the Christian worldview (from Paradise to Fall towards Redemption) is inherently dialectical.

Dialectics of Technoscience: First Outline

How can Hegelian dialectics allow us to come to terms with contemporary technoscience? Dialectical patterns are discerned at both sides of the knowledge production process: at the subject pole (technoscience) and at the object pole (nature). Technoscientific research practices evolve in a dialectical manner, via contradictions and refutations, allowing researchers to achieve more comprehensive levels of understanding along the way. But contemporary technoscience also reveals how natural processes themselves (from chemical reactions via metabolism and evolution up to climate change) adhere to dialectical patterns, from the organic scale down to the molecular scale and up to systemic levels. Dialectics sees technoscience first and foremost as a *practice*, as ἐνέργεια, as being–at–work. Moreover, dialectics emphasises the *technicity* of technoscience, focussing on the technological means of knowledge production, the technological contrivances through which experimental interactions (experimental dialogues) with nature unfold. Science is *technoscience* because it is an inherently technological endeavour.

This is already apparent in what is perhaps the most famous passage in Hegel's oeuvre: the dialectics of Master and Servant (Hegel, 1807/1986). For whereas the Master *contemplates* nature, the Servant *interacts* with nature in a hands-on, technical and experimental manner, thereby developing a more robust understanding of how nature works. Initially, labour is compulsory labour: a struggle for survival in the face of elimination, in the service of a lord or master, or even of the ultimate Lord and Master: transforming the world *ad majorem gloriam Dei* (Pippin, 1989). The morale of Hegel's "parable" (Pippin, 1989) is that labour requires and produces knowledge (know-how), so that history becomes a process of collective self-edification through the transformation of nature, while Masters become increasingly dependent on the skills and expertise of their Servants. For Hegel, labour is not an "application" of knowledge but an active and productive form of thinking in its own right. Therefore, dialectics not only sees scientific research as technology-driven, but also emphasises how technoscientific revolutions reflect the emancipation of former Servants from the constraints of ideological worldviews.

The three most important dialectical classics written by Hegel are the *Phenomenology of the Spirit* (*Phänomenologie des Geistes*, 1807/1986) published in 1807; the *Science of Logic* (*Wissenschaft der Logik*, 1831/1986) in two volumes, first published in 1812; and the *Encyclopaedia of the Philosophical Sciences*

(*Enzyklopädie der philosophischen Wissenschaften*, 1830/1986a, 1830/1986b, 1830/1986c) in three volumes, first published in 1817, while further elaborated versions were published in 1827 and 1830:

1807 *Phenomenology of the Spirit*
1812 *Science of Logic* ("greater logic")
Part I: Objective Logic I (Doctrine of Being)
Objective Logic II (Doctrine of Essence)
Part II: Subjective Logic
1817 *Encyclopaedia of the philosophical Sciences*
Part I: Science of Logic ("lesser logic")
Being – Essence – Concept
Part II: Philosophy of Nature (*Naturphilosophie*)
Mechanics – Physics – Organics
Part III: Philosophy of Spirit (*Philosophie des Geistes*)
Subjective – Objective – Absolute Spirit

Hegel's conception of dialectics was further expanded by subsequent authors, notably Karl Marx (1818–1883) and Friedrich Engels (1820–1895), but also by twentieth-century scientists such as J.B.S. Haldane (1892–1964), Joseph Needham (1900–1995) and John Desmond Bernal (1901–1971).

Dialectics starts from the conviction that a dynamical λόγος (a logical pattern of development) can be discerned in nature and human history, including the history of human thinking and of technoscientific research. In contrast with historians or sociologists of science, Hegel does not look upon history as an empirical process, but as the progressive self-realisation of a concept. The history of modern chemistry, for instance, is the history of the unfolding of the idea of chemistry as a science, while the history of the university is the history of the unfolding (in various settings and circumstances) of the idea of a university. And the question always is whether a particular chemical practice or a particular academic practice lives up to (is in agreement with) its idea. Everything strives to realise its formative idea, and a university (say, Erasmus University Rotterdam) is an evolving concretisation of this idea, an institutionalised organisation driven by the collective strive for mutual recognition (Pippin, 1989, p. 170), via citations, rankings or otherwise. Historical inquiry into processes of realisation become an integral part of dialectical epistemology (Beiser, 2005, p. 30).

In laboratories around the globe, dialectics is at work both at the subject pole and at the object pole of the knowledge production process. A dialectical dynamic can be discerned, not only in natural processes assessed by technoscience, but also in the ways in which technoscientific concepts and contrivances develop over time and research is institutionalised and organised. Technoscience is itself a dialectical endeavour, studying the dialectics of nature in a dialectical fashion. A technoscientific experiment is a dialectical design, starting with a *general* hypothesis (the first moment) which is exposed to (confronted with) a sample of reality, under *particular* (controlled) conditions, technologically determined. Although first results often

seem disappointing, this actually is an edifying experience, urging the researchers involved to question and overcome their initial biases and misconceptions, resulting in a *concrete* model design (a "paradigm" if you like). In the long run, experimental research aims to confirm that nature is intelligible (that the real is rational) and that experimental designs may be optimised to such an extent that they become replicable by others, even by sceptics and critics, until the next trauma occurs, in the form of a replication crisis, for instance, when empirical data suddenly refuse to live up to (or correspond with) theoretical expectations. But it is only via such laborious processes of working-through that real knowledge can be gained.

Dialectics builds on the conviction that, notwithstanding contradictory experiences, the real is inherently rational, so that our inquiries not only allow us to come to terms with the present, but also to anticipate (and actively contribute to the unfolding of) the emerging future, so that technoscience progresses from analysis and assessment to prediction and pro-activity. Science evolves from *general* conjectures (theory) via *particular* insights (validated by experiments) towards *concrete* outcomes, combining intellectual with practical ambitions: enabling reflection and self-reflection, but also enhancing science as a praxis (by providing informed options for action). Technology facilitates research, while researchers optimise their equipment, so that scientific insight (knowledge) and technological prowess (power) co-evolve.

The Oblique Perspective

An optimal introduction to dialectics of technoscience is provided by Hegel's own introduction (*Einführung*) to his first major work, the *Phenomenology of the Spirit* (1807/1986). Phenomenology, in the Hegelian sense, is the science (*Wissenschaft*) of scientific experience. Whereas natural sciences study natural phenomena, the aim of philosophy is: coming to terms with *scientific knowledge itself* as a phenomenon. Natural sciences are experiential sciences, and the paradigm of technoscientific experience is the experiment. In French, the term *expérience* captures both meanings and may be translated as "experience", but also as "experiment". Science analyses experiences obtained under specific conditions, concerning replicable phenomena. The experimental protocol points out exactly how particular phenomena can be produced; how particular experiences can be obtained. Philosophical phenomenology studies experimental practice as a phenomenon, focussing on the grounding idea that fuels it, such as the grounding conviction that natural phenomena can be grasped through systematic manipulation. If we study experimental science from a phenomenological perspective, we notice that a triadic dialectical pattern is at work here. If the grounding conviction, embodied in a particular experimental design, is considered as the first moment (M_1), this initially gives rise to experiences of frustration, disappointment and doubt: the second moment (M_2), referred to by Hegel as the moment of negation. Preliminary results suggest that the primary conviction is refuted by the refusal of the facts to confirm our expectations.

This experience is inevitable and necessary, however, urging us to improve our design, method and contrivances. Drastic interventions give rise to a higher level of practical performance, where phenomena may confirm our predictions after all (the third moment, the *negation of the negation*: M_3). The grounding conviction that experimental research is a reliable source of evidence is saved, until additional complications and anomalies accumulate again. We have to expose ourselves to this laborious and frustrating experience. Eventually, the experiential route is the only path towards reliable knowledge. And phenomenology follows scientific consciousness on its laborious and winding path in the direction of validated insight. It is only by following this path that scientific consciousness awakes from its slumber and discerns the deficient nature of accepted views. It is only by putting these insights to the test that we become aware of our knowledge deficits. It is only in this manner that we understand that, by relying on accepted and self-serving forms of knowledge, we are neglecting our intellectual vocation.

Technoscience is driven by a *cupido sciendi*, a desire to know (Zwart, 2019a). At a certain point, consciousness begins to question established *ways of knowing*. How reliable is our knowledge? How can we ascertain that our knowledge is adequate? The focus of attention shifts from knowledge as such to the process through which knowledge is produced. Philosophy is precisely the science which represents this shift. While the natural sciences are focussed on knowing the object, philosophy aims to understand *knowing as such*: how are scientific objects known by science? Philosophy is a critical assessment of the ways in which science allows reality to appear, an exposition of scientific research practices as they appear on the scene: the journey of scientific consciousness towards optimised knowledge: passing through various configurations or stations of knowledge towards more comprehensive forms of understanding. For philosophy, science itself is a phenomenon, and philosophy is a dialectical "phenomenology" of scientific experience, discerning the basic logic that guides the development of scientific consciousness.

Initially, this focus on knowledge as such (on the processes of knowledge production) results in discontent, in scepticism and despair. How to prevent knowledge from going astray? How to convince ourselves that our research practices are valid? As Hegel argues, scepticism may end in paralysis, and the fear of erring itself may become an error. Scepticism must be overcome, by incorporating it in our methodologies. Our reliance on existing knowledge practices seems biased and naïve (M_1). The reliability of established practices is questioned, negated (M_2), but, as Hegel phrases it, there is something positive in this moment of negativity. Instead of completely annihilating our results, we rather understand that we are *not yet* there. The knowledge deficit summons us to enhance the knowledge process. Instead of allowing scepticism to become a paralysing trap, it should be "taken up", as an inherent aspect of our methodology: the negation of the negation (M_3), where paralysis gives way to productivity. Dialectics studies this triadic unfolding, from unquestioned conceptions via scepticism and despair up to validated knowledge. Scepticism (negativity) is important, because it reveals the questionability of available conceptions, but it should not become a pretext to keep aloof as a "beautiful soul". We must learn from our experiences.

If we look at scientific research as a phenomenon, what strikes us is the resolve of science not to rely on the authority of others (Hegel, 1807/1986, p. 73): the desire to produce knowledge yourself and to accept only your own products as valid and convincing, even if this initially entails a dramatic *loss* of knowledge (sacrificing and negating accepted conceptions and inherited worldviews). Science is the zealous resolve to follow this process to completion, moreover, notwithstanding multiple experiences of doubt and despair. Science, Hegel argues, is an unhalting process which finds no satisfaction in intermediary stations of knowledge (p. 74) and we should acknowledge this unrest of science which unceasingly disturbs and spoils its own satisfaction: the relentless drive to take the knowledge process further. This is what invokes both fascination and uneasiness (*Besorgnis, Misstrauen*, p. 69): the Faustian dynamic of scientific practice which often eliminates more than it creates.

By analysing the knowledge process rather than the objects (microbes, organisms, galaxies, Majorana fermions, etc.), philosophy opts for a sideways or oblique perspective: a signature feature of dialectics (Zwart, 2017a). Thomas Aquinas (1922) already argued that, whereas human understanding is initially directed towards external reality (the *intentio recta*), critical reflection on human understanding (philosophy) requires a change of perspective (an *intentio obliqua*). A dialectics of contemporary technoscience is a critical but engaged assessment of the way in which technoscience (as a particular instantiation of logos) allows reality to emerge. Adopting an oblique perspective means: raising questions that are usually not raised by practicing scientists themselves, such as: What is nature? What is life? What is truth? What is science? We may use our philosophical hammers and stethoscopes to develop a diagnostic of the technoscientific present, reading technoscientific papers with a philosophical eye and listening to technoscientific deliberations with a philosophical ear. Rather than in viruses, microbes, Higgs bosons or black holes, philosophers will be interested in the ways such entities are envisioned and addressed. Our intentionality is neither focussed exclusively on the object pole (as scientists tend to do), nor exclusively on the subject pole (as sociologists and ethnographers of science tend to do), but rather on the interaction between subject and object, on the mutual interpenetration of both poles, exploring how scientific technicity allows nature to appear in a certain manner and on the inherent ontological convictions that materialise in specific scientific contrivances and the phenomena they disclose, – technoscientific tools as mediators between the subject and the object pole of the knowledge process (Pippin, 1989, p. 245). In dialectics, the axis of attention is tilted, urging us to take a quarter turn, following technoscientific debates with *evenly-posed attention*, until at a certain point in technoscientific discourse something questionable emerges, which triggers our attention and entices us to adopt a more critical, active and questioning stance.

The argument developed so far provides an affirmative response to a question raised by Slavoj Žižek: "Is it still possible to be a Hegelian today?" (Žižek, 2012/2013, p. 193). "Is there a place for modern science in Hegel? Is not the explosive growth of the natural sciences from the eighteenth century onwards simply beyond the scope of Hegel's thought?" (Idem, p. 458). Frederick Beiser (2005) raises a similar question, albeit in slightly different terms: Why read Hegel today?

Although I do not agree with his experience that Hegel's language is so impenetrable and obscure that reading him is "the intellectual equivalent of chewing gravel" (p. 1), – for I have always genuinely enjoyed reading Hegel – the question as such is a valid one. A Hegelian approach to technoscience, I will argue, is not only possible, but more urgent and relevant that ever. Dialectics entices us to study technoscience as an active ("*tätig*"), performative and transformative form of thinking, while Hegel's ideal of restoring the unity of ourselves with nature seems remarkably timely. According to Beiser, we *either* treat Hegel as a contemporary, focussing on what seems relevant to contemporary concerns, *or* we opt for a hermeneutical "author studies" stance, seeing Hegel as a historical figure. Faced with this dilemma, Beiser himself opts for "the older hermeneutical method" (p. 5). My "third" option overcomes both anachronism and antiquarianism, however, focussing on Hegel's dialectical *method*, reading Hegel *from within*, reinvigorating his legacy by incorporating both aspects. For developing a dialectical perspective on technoscience, a careful primary reading is required. The methodological *Geist*, the dialectical ἐνέργεια at work in his writings is what we are after, a way of practicing philosophy that merits to be taken up and developed further. The antagonism "hermeneutics" versus "application" is misleading. Aristotle's concept ἐνέργεια (*act*-ivity, being-at-work) implies we can only understand Hegelian dialectics by actually *practicing* it, combining theory with praxis, reading with actualisation. How to practice dialectics *in* technoscience today, how to enact a dialectical approach to contemporary technoscience? By using our own philosophical experiences (as practicing philosophers) as source material and by participating in technoscientific projects as concrete dialectical "case studies".

The Inherent Negativity of Technoscience

For Hegel, an important dialectical feature of nature is polarity. In order to study something, its opposite must be considered as well. Initially, we know what health is, for instance (M_1): it is the natural way of being-in-the-world, but to really understand health, we need to study disease as well, as the negative of health (M_2). By studying this polarity, health will no longer be taken for granted. Rather, because of this experience of illness, we understand health as a systemic outcome and as a *process* (M_3).

Besides polarity, negativity may take multiple other forms as well. Paradoxically perhaps, research always requires absence. Research begins with elimination, with the creation of a clearing or a void. Take Newton's optical experiments, conducted during the "wonder year" 1666. In order to study light, Newton created its opposite, darkness: a dark room, a *camera obscura*, a darkened room. Here, he made a little hole in the wall, an artificial orifice, a pupil so to speak, to allow a minimum of light (a small beam of sunlight) to enter the darkness, small enough to be manageable and

modifiable with the help of a prism.[3] He thus created an artificial eye, with a pupil (the hole), a lens (the prism) and a retina. The prism diffracted the beam into a spectrum, projected upon a screen. Light requires darkness to illuminate, to become visible and modifiable (with the help of a prism and a screen). You cannot see, let alone manipulate light unless you create darkness first. Optics begins with the *negation* of light, which may seem paradoxical but is quite inevitable, dialectically speaking, because we analyse something by allowed it to stand out against the opposite extreme:

Light as a general and natural phenomenon (M_1) → Otherness (M_2): polarity and diffraction, creating darkness to study diffracting beams of light → (M_3) Understanding white light as a composite unity, a converging spectrum of colours.

Human consciousness itself is this dark ambiance, this night where something flares up and disappear again. We see this night, Hegel argues in his Jena lectures, when we look a human being in the eye, looking into this night, the night of the world. Consciousness is night, the eye is a night, the laboratory is a night (mimicking the eye) and the computer is a night, with a screen on which visible entities suddenly appear. The same contrasting technique is applied by playwrights, where spotlights reveal the actions of the protagonist against a backdrop of darkness: drama as a mis-en-scène, a staged experiment.

Instead of light, we may also use life as an example. Why is life studied *in vitro*, in a test-tube? What *is* a test-tube? At first glance, a test-tube may seem a trivial, quasi-self-evident laboratory item, producible on a massive scale, but on closer inspection, it is actually a rather remarkable thing. It is something completely transparent and empty, a thing which comes close to (which verges on) nothingness: an artificial void, an object without properties, a minimal object, a pure container. All properties have been obliterated and stripped away, until all that remains is a translucent glass membrane. This empty test-tube is waiting for something, standing out towards something, designed to become the recipient of an enigmatic and highly valuable "something" which is not yet there and whose ontological status seems highly uncertain: on the boundary between living and non-living, between natural and artificial. The thing which finally comes to fill the tube is likely to be something contentious, a thing which calls for a deliberation, a critical assessment, a review. Will this thing, this something (this novelty) pass the test? The empty tube inevitably refers to something which one day may come to occupy (and thereby *negate*) its emptiness, as the enigmatic object of technoscientific desire: *the negation of the negation*. In short, the test-tube embodies the three stages of the dialectical unfolding. In order to understand natural life in general as it presents itself to us (the first moment: M_1), technoscience creates a clearing, an empty space, where (almost) everything is negated and eliminated (M_2): a particular ambiance consisting of

[3] Cf. the question raised by the nuns' choir in *The Sound of Music*: "How do you hold a moonbeam in your hand?". Techno-scientifically speaking, Newton had already solved the challenge.

virtually nothing, but therefore (almost) completely under our control. And it is precisely here that something concrete will occur or emerge. Components may be isolated, but a test-tube may also be employed to bring them together again, to reconcile them (Συλλογισμός), thereby concluding a process. If this comes about, the entity *in vitro* will be the concrete culmination and convergence of previous partial insights, acquired through test-tube research, but now reassembled in a concrete singular entity, a concrete universal, containable in a tube (M_3).

The test-tube (as a materialisation of nothingness) exemplifies the dynamics of technoscience as such. To study a living entity (M_1), laboratory research commences with the creation of a clearing, an artificial ambiance (M_2). To study it, life first of all has to be negated and taken apart. Technoscience creates an abiotic, gnotobiotic ("clean") environment where life has been effectively obliterated: the laboratory, the sterilised test-tube, where real (natural) life is kept at bay. Here, isolated instances of life are deliberately introduced, particular (partial) biotic objects, single cell organisms or bacteriophages, for instance.[4] They become fully modifiable in an Umwelt which actually is the negation of a natural Umwelt, so that the object (the entity under study) cannot be contaminated by real life. The trapped entity becomes life in general (*das Allgemeine*: A), life as such. The starting point is a model organism, which serves as a living test-tube, stripped of all particularities, representing life in general. Subsequently, particular factors are isolated and brought to the fore (*das Besondere*: B): environmental factors, or particular genes which are knocked-out or added. And finally, a concrete exemplification or realisation of an idea (a synthetic compound for instance) can be produced (*Einzelheit*: E). A laboratory is a particular kind of clearing where life can be optimally controlled, against an abiotic backdrop of negativity. Where the natural is eliminated, neo-life can emerge.

(M_1) the model organism, representing life in general → (M_2) analysis in vitro, revealing particular genetic or environmental, genotypical or phenotypical factors → (M_3) re-synthesis, neo-life, as the concrete realisation of the laboratory view of life.

Negativity (as a second moment) is an inherent feature of inquiry, pushed to its extreme by contemporary technoscience. Technoscience represents what Karin de Boer refers to as "the tremendous sway of negativity" at work in modern thinking (De Boer, 2010, p. 2). Dialectically speaking, this is quite inevitable.

Suppose that technoscience aims to understand the functioning of a tree for instance. Initially, during the first moment (M_1), we discern the tree as it presents itself to us, as a natural phenomenon: a gestalt in a natural Umwelt, clad in natural daylight. Once this tree enters a laboratory setting, however, negativity sets in. To understand a living being, it has to be taken apart. Technoscience will never be satisfied until this process is pushed to its extreme. During this process (analysis *in vitro*) we discover that the tree as such basically consists of cellulose, a noumenal compound whose chemical composition can be represented symbolically ($C_6H_{10}O_5$).

[4] "[Der Mensch] fixiert Einzelnes, hebt es heraus, nimmt es als ein … Abstraktes und Allgemeines" (Hegel, 1830/1986a, § 24 Z, p. 83).

The living tree is obliterated, replaced by chemical symbols (M_2).[5] The tree as it initially appears to us (the living phenomenon) is reduced to its basic noumenal components, so that we conclude that the tree (essentially) = $C_6H_{10}O_5$.

$$M_1\left(\text{the visible tree as a whole}\right) \rightarrow M_2\ \left(\text{analysis}: \text{a tree} = C_6H_{10}O_5\right)$$

The more technoscience is in control, the more the naturalness of living beings will vanish, so that their richness becomes impoverished (cf. Posch, 2011, p. 189). Dialectically speaking, this is both inevitable and rational, but it is also a disquieting experience. We have evidently lost something underway: the living organism as a whole. How to retrieve this original, organic, organismal unity?

The dialectical process is incomplete and this is where the third moment (M_3) sets in. Somehow, the negativity of technoscience itself has to be *negated* (the negation of the negation) via a concrete countervailing intervention. This return (*Zurückführung*) from splitting (*Entzweiung*) to wholeness (*Einigkeit*) is not a return to the original, purely natural situation, but brought about by a conscious, technoscientific intervention (Hegel, 1830/1986a, § 24 Z 3, p. 88–89). The splitting (*Entzweiung*, *Zerlegung*) of natural entities into their constitutive components is a *result* of human labour, but also *overcome* (sublated) by human labour (p. 89), namely by recombining these components into a synthetic whole (the concrete product).

Technoscientific research fields such as cell biology or biochemistry are about knowing the chemical composition of organisms, and dialectics aims to understand what is gained and lost during this process of knowing, for dialectics (as we have seen) is *knowing about knowing* (understanding understanding). Technoscience gives rise to particular experiences, while laboratories and test-tubes are particular kinds of clearings, allowing life or nature to emerge in a certain manner (stripped of its abundance). The laboratory is a particular ambiance where a particular praxis unfolds and dialectics allows us to discern the basic *experiences* of loss and progress (in the dialectical sense) entailed in biochemistry or molecular biology, as stations on the pathway towards comprehensive knowledge.

Outline of a Methodology

Dialectics entails a triadic pattern of positions or *moments*. An initial situation of relative stability (M_1) is challenged and disrupted by experiences of contradiction, negativity and crisis (M_2), until a new era of stability is regained, but now on a higher level of complexity and comprehension (M_3): $M_1 \rightarrow M_2 \rightarrow M_3$.

[5] "Das Denken übt eine negative Tätigkeit aus; der wahrgenommene Stoff … bleibt nicht in seiner ersten empirischen Gestalt. Es wird der innere Gehalt des Wahrgenommenen mit Entfernung und Negation der Schale herausgehoben (1830/1986a, § 50, p. 132)."

A life form, say: a plant, is contained in its seed as the incapsulated concept or program of the plant to be (M_1). The aim of the seed is not to stay what it is, however, but to come to the fore and expand, even if this entails facing multiple challenges and instances of resistance (i.e. moments of *negativity*: M_2). Plant life *requires* these challenges to thrive, and it is only by overcoming them that the initial seed may develop into a concrete, full-fledged organism, and become what it basically is (M_3). Whereas the environment initially seems hostile to all newcomers (exposing budding life forms to multiple threats), the plant eventually *needs* these triggers from the environment to flourish, needs to find (or create) a viable place in this demanding ambiance (a process known as individuation: $\rightarrow M_3$).

The first moment is never purely empirical, but always already framed by preconceptions. Subsequently, a sense of discontent points to a conceptual deficit. And this provides the impulse to carry the process further. The preconceptions are actively questioned. This second moment (the negation) is a crucial step forward. Besides a negative result (eliminating misconceptions), there is a positive result as well, because it may become the turning point towards genuine understanding: the negative of the negative, and therefore something positive, superseding initial contradictions (Hegel, 1831/1986, p. 563).

Hegel uses the solar system as an example. Initially the sun seems something empirical, something which can be pointed at, but this "pointing at" is always already incorporated in a conceptual context (e.g. the geocentric worldview). Via doubt and scepticism ("doubt that the sun doth move", Hamlet, Act 2, scene 2), we arrive at a more developed form of understanding, i.e. the awareness that the sun can only be fully understood (in its concrete existence, true to its concept) in relationship with other corporeal entities, e.g. planets revolving in elliptic orbits, and distant stars, for the sun is also a star, while stars are suns, consisting of radiating plasma. Something is lost (the geocentric, anthropocentric universe), but a more comprehensive understanding of astronomy is gained. Thus, the sun becomes something systemic, our centre of gravity, keeping planet Earth in its orbit, as well as being our source of energy and light.

A dialectical pattern can be discerned in processes of becoming, not only in nature, also in our scientific efforts to *understand* how nature works. Initially, a natural thing (say, a stone) may strike us as a continuous unity or whole (M_1). Until we realise that discontinuity and punctuality exist in nature as well (Hegel, 1971) and that the stone is actually a porous entity, composed of matter, but also full of emptiness as it were. Continuity and wholeness are "negated" by the insight that all matter consists of molecules distributed through space (M_2). Eventually, however, we will realise that a stone is actually both, a combination of something solid and massive on the macro-level and something porous on the molecular level (M_3).

A similar pattern can be discerned in the way in which we humans relate to nature. Initially, we must have been in awe of nature, and nature must have invoked in us a sense of admiration and respect (M_1). Nature was "observed" by us, in the original sense of the Latin verb *observare*, which means: to *heed*, to *serve* and to *respect* nature. Inspired by this devoted interest in nature, however, human observation became increasingly acute and precise, with the help of precision instruments

to aid our natural sense organs (such as telescopes etc.). And this inevitably resulted in a traumatic experience (M_2), namely that nature is not as perfect as was initially expected. Anomalies and inconsistencies accumulated, and respect for (the perfection of) nature was increasingly challenged and subverted by a growing inability to actually confirm the initial view. This experience (of tension, contradiction or frustration; the second moment: M_2) forced scholars to realise that, apparently, their starting point was one-sided and naïve. The initial position was "negated". In terms of dialectical logic, this moment of contradiction and negation is inevitable and necessary, entailing an important *truth*. Fascination and actual discovery must be reconciled again, but now on a higher level of comprehension, via a more elaborate understanding: a "negation of the negation", a position which *takes up*, but at the same time overcomes the unsettling, disturbing truth of negativity. On this higher level (M_3), we are again humbled and awed by the immensity and complexity of nature, but now informed by a more detailed and sophisticated understanding, engendered by experiences resulting from the use of advanced and sophisticated technologies (as means of knowledge production). Dialectics not only aims to understand, but also to optimise this process of understanding nature, which relies on developing techniques that allow us to systematically assemble and process huge amounts of high precision information.

This triadic pattern can also be captured in slightly different terms. Initially (M_1), being and nature are experienced in a rather *general* and abstract manner. In ancient Greece, for instance, philosophers aspired to come to terms with nature *as such*. They spoke about life, nature and human existence on a general level, they aspired to capture *das Allgemeine* (A) in thoughts. This type of reflection was non-technical: it did not rely on, but rather haughtily looked down upon the practical experiences of artisans and farmers (in interaction with real nature). With regard to living beings, for instance, philosophy tried to develop a general conception of life *as such*. The next step (M_2) is the awareness that *particular* forces or dimensions can be discerned in life and nature, and that these forces or dimensions are often in contradiction or opposition with one another, so that the focus of attention shifts towards these seemingly incompatible components (in Hegelian terms: *das Besondere*, B). Quite often, this means: highlighting one particular dimension at the expense of others. For instance: highlighting "nature" (e.g. heredity) while obfuscating "nurture" (environmental factors). By taking a radical stance, the contradiction is *pushed to its extreme*, moreover. With regard to living beings, this stage typically generates radical claims, such as the claim that living beings *are* (the product of) their inherited *nature* (heredity), or that living beings *are* (the product of) their environment, or (in the case of human beings) that humans basically *are* their brains (that the essence of human nature *is* the human brain), etc. Usually, such claims rely on the employment of *particular techniques*. Eventually, however, this will inevitably result in the more comprehensive awareness that *concrete* living beings are actually the product of the *interaction* between seemingly contradictory forces and components. During the third moment (M_3), the focus of attention shifts towards *concrete* living entities (in Hegel's terminology: *Einzelheit*, E). These are now regarded as products of interaction, between genomes and environments, between heredity and

adaptation, between nature and nurture, etc. Rather than on *one particular* technique, research now employs a broad range of technical contrivances so as to study a particular entity from multiple perspectives. Thus, the logic of dialectics (the basic pattern) can be captured by two formula.

$$M_1 \rightarrow M_2 \rightarrow M_3$$
$$A \rightarrow B \rightarrow E$$

These three moments are often referred to as "thesis", "anti-thesis" and "synthesis", but these are not the terms Hegel himself actually used. Hegel often refers to the first position with the help of terms such as *zunächst* ("initially"), abstract or *Anfang* ("commencement"). The second moment is the moment of negativity, of diremption or *Zerlegung* ("taking apart"), using specific tools to open up the opacity and interiority of natural entities. While thinking (questioning the real) itself already is a negating activity (Pippin, 2019, p. 139), this becomes quite evident in experimental practice. The third moment is the *negation of the negation*: the *Aufhebung* ("sublation", supersession) of the second moment, which is literally "taken up", that is: incorporated and encompassed in a comprehensive view (at a higher level of comprehension), envisioning the concrete whole. For instance, after reducing a living organism (a tree: M_1) to its basic molecular components (cellulose, etc.: M_2), we eventually encounter the cell as a *concrete, integrated whole* (M_3), the *concrete universal* of life. To reach this third position, however, it is inevitable to pass through these moments of negativity. We cannot reach it directly or intuitively. Real insight and knowledge are the products of experience and hard work, with the help of sophisticated, tested, validated and calibrated tools for processing allegedly contradictory forms of information.

This allows us to discern the inherent dynamics at work in nature, technoscience and human existence. Dialectics is not a general (abstract) schema that can simply be "applied". Rather, via exposure to concrete phenomena, to particular (at times unsettling) experiences, we become sufficiently experienced to develop a comprehensive view. Dialectics is a praxis, i.e. a form of philosophy which can only thrive by being put to practice, by being *practiced*. The *general* idea operates in a *particular* context, resulting in a *concrete* outcome, e.g. a case study which allows us to bring together (συλλογίζεσθαι, "take into account") seemingly erratic and dispersed developments into a concrete whole.

The use of dialectics is timely in view of the challenges we are facing. Against the backdrop of a global political and environmental crisis, we witness a conceptual gigantomachia – a tectonic collision concerning our "philosophemes": our answers to questions such as "What is being?", "What is truth?", "What is nature?", "What is life?". It is precisely here that dialectics has a role to play. The basic convictions guiding scientific research are *acted out* in a global scene, and dialectics not only aims to assess the current crisis, but also to contribute to the imminent turn (the effort to supersede the unfolding crisis). Philosophical reflection should not be conducted from an outsider's position, maintaining a distance between philosophy and the other faculties, as Kant (1798/2005) proposed. Philosophy should function as an

inherent component of the technoscientific endeavour as such. Its guiding concepts are active in a performative manner, they are "alive" (Pippin, 2019, p. 255). The question whether we should be guardians of a philosophical past or critics of the technoscientific present is a misleading dichotomy. A philosophical assessment of contemporary technoscience is only possible against the backdrop of an extended temporal horizon and requires a solid embedding in the history of philosophical thinking. Our vocation is to revivify and *rethink* this tradition, exposing it to contemporary developments in global technoscience and their planetary impact.

As indicated, philosophical assessment of contemporary technoscience requires proximity: philosophy practiced as philosophy *in* science. Philosophers should *be there*, should familiarise themselves with emerging contexts of global technoscientific discovery, from an "oblique" dialectical perspective, focussing on the basic philosophemes at work in technoscience. As Hegel argues, phrasings such as "philosophy *and* science" may easily misguide us, as there is more philosophy at work *in* contemporary technoscience than we tend to be aware of, and the vocation of dialectics is to bring this inherent philosophy (these latent philosophemes) to the fore, so as to become conscious of them and question them, from a position of close proximity, in dialogue with the practicing scientists involved. Scientists and philosophers will both benefit from this mutual exposure, this dialectical interpenetration of praxis and reflection.[6]

Another misguiding dichotomy suggested by the word "and" is the phrase "science and society". Here again, we are actually facing mutual interpenetration (Levins & Lewontin, 1985, p. 5). Science and society mutually pervade one another. In contemporary social environments, technoscience is omnipresent and pervasive, while socio-economic and socio-cultural realities are emphatically present in technoscience as well. The Anthropocene concept reflects this mutual interpenetration of contemporary technoscience and the global lifeworld (Lemmens & Hui, 2017). Let this suffice as a first introduction, based predominantly on Hegel's *Phenomenology*. In the next sections, this view on dialectics will be further elaborated, using the first two volumes of Hegel's *Encyclopaedia* (his shorter *Logic* and his *Philosophy of nature*) as our guide.

Hegel's *Logic*: The Interaction Between Philosophy (as a Science) and Science

A comprehensive introduction into the logic of dialectics is provided by Hegel's so-called "shorter logic" or "encyclopaedia logic", i.e. the first part of the *Encyclopaedia of the Philosophical Sciences*. Here, Hegel argues that philosophy is

[6] The design of this chapter reflects this: moving from rereading Hegel as our primary source, via particular confrontations (with chemistry, genomics, synthetic biology, etc. as "other"), resulting in a concrete methodology as product.

science, i.e. laborious, methodological work, conducted in close collaboration with the natural sciences ("Hand in Hand mit den Wissenschaften"; *Vorrede*, 1830/1986a, p. 15). Until the eighteenth century, Hegel points out, the science–philosophy divide as we know it today was inexistent. Philosophy entailed an oblique, reflective perspective, albeit on the basis of active involvement. Philosophers (from Cusanus up to Leibniz) made decisive scientific contributions. If we consider this as the starting point (the first moment: M_1), then the current situation of separation, segregation, alienation and opposition ("*Entzweiung*") between philosophy and the natural sciences is the "negation" (the second moment: M_2): something that must be overcome, by systematically incorporating the experiences of scientific research into philosophy, while making philosophical questioning an inherent part of science. Philosophy of nature and natural science must reunite (although they will remain recognisable as *moments* within a comprehensive approach). Thus, a higher level of comprehension ("sophistication") may be reached (the third moment, the "negation the negation": M_3).

Philosophy is an active endeavour: being-at-work, a praxis of working through ("durcharbeiten"), processing and questioning the results of the natural sciences, while discerning and assessing the basic convictions (the "philosophemes") at work in them. Thus, philosophy profits from, but also critically reflects on the results of centuries of hard scientific work (p. 28). Philosophy is a dialectical endeavour, starting from abstract concepts and convictions (M_1) which are challenged and questioned by empirical findings (M_2). This dialectical process enables philosophy to understand that the real (nature) is intelligible (rational), that logos is at work in nature, so that, ultimately, genuine (comprehensive) understanding is possible (M_3).

In order to understand empirical science, philosophers should closely study it, not from a purely theoretical perspective, but as a praxis, so as to recognise how experimentation (under the sway of negativity) destroys to phenomenal object (the empirical shell, § 50, p. 132) in order to reveal the noumenal essence of nature as such. Contemplation (e.g. Eleatic thinking about being as such) gives way to experience, to active thinking (*Tätigkeit*) as a practical endeavour, exposing and assessing preliminary convictions with the help of precision instruments (thermometer, barometers, etc.), which were initially known as "philosophical instruments" (§ 7). Philosophy acknowledges and employs the validity of empirical scientific work ("*Arbeit*") and its results (§ 9, p. 52). Thinking is inherently dialectical, and this also applies to the empirical sciences (§ 11, p. 55). They offer the stimulus ("Reiz") to overcome the self-satisfying position of abstract thinking and to incorporate the conceptual results of technoscientific experience.

The term "experience" is ambiguous (§ 66). On the one hand, it refers to our experience of specific phenomena, here and now. Ultimately, however, such experiences give rise to experience in a cumulative sense (tested and validated insights). It is only because our initial a priori convictions are challenged that genuine progress can be made, while the empirical sciences are working their way towards philosophy ("entgegenarbeiten", § 12, p. 57). Indeed, philosophy owes its development to the hard work of the empirical sciences, whose results are incorporated and processed (p. 58), for logos is at work there as well. The objective of philosophy is to

incorporate these partial knowledge components into a dynamically evolving encyclopaedic system, – again the result of hard work. Thus, philosophy considers the actions and products of science. While being–in–the–world (§ 19, p. 70) is a precondition for thinking, the world is affected and compromised in many ways by the activity of thinking as well, so that there is a continuous interpenetration between thinking and reality, science and environment, subjective and objective rationality, subject pole and object pole (p. 71).

In modern society, thinking itself became a real power, exercising enormous influence. So far, however, critical thinking has failed to realise its ambitions: it has been criticising, disrupting and overthrowing existing reality in many ways, but without sufficiently contributing to affirmative reconstruction and transformation. Also in the case of dialectics the emphasis has too often been on the moment of negation. Time has come to contribute more actively to the rationalisation of the real, building on and affirming its inherent rationality. Overcoming the initial position of abstract metaphysical thinking (M_1) is like a fall from grace, and intellectual labour is an "effect" of this disruption, but it is also the only way to overcome the apparent gap between the rational and the real, both in a practical sense (politics, etc.) and in an academic sense: cognitive labour as a decisive factor on the path towards reconciliation (§ 24, Z3). Technoscience can only become a vehicle for governing and transforming our world as part of a comprehensive approach.

While philosophy uses the results and experiences of science to criticise abstract metaphysics, it also assumes a critical stance towards the natural sciences themselves. Conducting empirical research means practicing metaphysics, unconsciously as it were: employing metaphysical categories, but often in a thoughtless and uncritical manner (§ 38). The empirical sciences summon us to stop roaming in empty abstraction: use your hands! (§ 38Z, p. 109), and this obviously is a valid point. Moreover, in order to acquire genuine experience, empirical science must proceed from mere observation to analysis ("Zerlegung"), must progress from object to concept. Especially in chemistry, but also in biology, analysis is vital. But analysis inevitably destroys the phenomena it studies, exerting a negative effect (§ 50, p. 132). This is most evident in research with animals and Hegel sees trials involving the decapitation of rabbits and frogs by researchers such as Treviranus, Von Haller and Legallois as "torturing" animals (§ 356Z, p. 461; cf. Rand, 2010). Negativity is a necessary evil, because the function of organs can only be studied by surgically removing them in living organisms.[7]

Technoscience is under the sway of negativity, so that a gap emerges between living phenomena on the one hand and our scientific conceptual understanding of them: a disunion ("*Entzweiung*"), which must be overcome by sublating mere observation into experience and insight. Rather than claiming that nature in itself (the thing in itself) is inaccessible to us, philosophy and technoscience (conceptual work and empirical research) join forces to disclose and come to terms with the

[7] The reverse process, organ donation, could perhaps be considered as a final anthropocentric result of destructive physiological inquiry (vivisection), and therefore as the negation of the negation.

noumenal realm, conjoining phenomenal observations with conceptual thoughts, because the noumenal real is rational. Hegel wholeheartedly rejects Kant's restriction of the scope of human knowledge to phenomena (Pippin, 2019, p. 10), positing the noumenal things-in-themselves as inaccessible. A core dialectical insight is that the noumenal realm is effectively disclosed by technoscience, via a dialectical interaction between advanced technology and advanced mathematics. Whereas premodern philosophy believed in the correspondence between thinking and things (Hegel, 1830/1986a, p. 79: M_1), modern thinking *negated* this initial position by emphasizing the gap (*Gegensatz*, *das Getrenntsein*) between human cognition and the things in themselves (M_2). Contemporary technoscience, however, has dramatically expanded not only our range of perception (via precision instruments) but also our thinking capacity (via artificial intelligence, the distributed intelligence of global research networks), giving rise to qualitative leaps in research capacity, increasingly independent of the limitations of human cognition and sensitivity, so that new research fields (e.g. quantum physics, molecular life sciences, etc.) are now able to disclose the noumenal dimension of natural objects, processes and entities (M_3). Technoscience reveals, moreover, that the noumenal entails polarity: a conjuncture of positive and negative components. On a more profound level of insight, instances of polarity prove reconcilable. Although Hegel himself, writing in the early nineteenth century, does not mention this of course, one is tempted here to think of technoscientific entities such as atoms and molecules as conjunctions of positive and negative elements (protons and electrons, matter and anti-matter, conservation and entropy, etc.), products of knowledge in which a plethora of technoscientific experiences accumulate. Although the initial results of dialectical experiments tend to be disruptive, there is an affirmative final result, as technoscientific experience is processed and sublated into genuine knowledge which, ideally, can be employed to rationalise the real, e.g. by making human practices biocompatible and less disruptive.

Dialectics and the Real

Dialectics is not a mere art or technique (§ 81), as we have seen, but the progressive self-actualisation of thinking. Abstract convictions are exposed to real-life circumstances, in order to be superseded, as we become aware of their limited validity and one-sidedness. It is by the conscious employment of dialectical principles that thinking becomes science. The basic structure of human experience is dialectical.

The same dialectic is at work in nature and reality as well however (§ 81 Z1). In nature, everything finite has the inherent tendency to move towards its opposite. Everything may be viewed as an instance of dialectics ("Alles, was uns umgibt,

kann als ein Beispiel des Dialektischen betrachtet werden", § 81 Z1, p. 174).[8] Dialectics is an irresistible dynamic affecting everything. We see dialectics at work in all natural and historical phenomena, from the movement of the planets (determined by the interaction between velocity and gravity) down to complex meteorological processes (where various factors continuously interact to produce relentless change). In history, we notice how particular movements, through radicalisation (i.e. the inherent tendency of a movement to push itself towards its extreme), unwittingly strengthen or even turn over into the opposite position, so that anarchy gives rise to despotism, but this also applies to the history of science, where an overestimation of the importance of "nature" for instance, inevitably gives rise to a pendulum swing towards the opposite emphasis on "nurture" and back (Nelkin & Lindee, 1995/2004; Zwart, 2014). Rather than getting stuck in an interminable alteration of incompatible views, however, dialectics spirals towards a positive result, so that genuine progress is actually made, while that which is overcome is not completely annihilated or repressed, but rather incorporated as a constitutive moment (a guiding experience) of the subsequent position (§ 81 Z2).

Thus, the primordial Eleatic idea of being (nature, Earth) as a perfect *sphere* (M_1) was challenged by negating conceptions of infinite emptiness and erratic chance events (M_2). Eventually, however, both moments were retained in a dynamical, meteorological understanding of the earthly *atmosphere* as a relentless cyclical process of becoming and overcoming (M_3). Quality (warm versus cold, health versus disease, etc., M_1) gave way to quantity (physical measurements with the help of instruments, i.e. modern science: M_2) and, eventually, to the systemic idea of a dynamic equilibrium (M_3). The concept of the sphere is regained on a higher level of complexity, as a cyclical, meteorological process (§ 94). Likewise, the abstract concept of infinite being was negated by the recognition that all beings are finite, until both opposites were acknowledged as moments of the early modern concept of infinite space (as the negation of the negation), not as a relapse into abstract metaphysics, but as a positive result. And likewise, the combination of alkali and acid does not result in mere neutrality, but gives rise to an interactive chemical process which can be conceptually grasped, so that the conceptual (e.g. the chemical equation) is the truth of the material (e.g. of alkali and acid as material substances). Thus, mere observation evolves (via *Zerlegung*) into synthetic science and practices of recombination; so that the term "*aufheben*" means to negate and eliminate, but also to preserve ("*aufbewahren*", §96).

Another example mentioned by Hegel is the shift from Eleatic abstract being (as the first idea of Western metaphysics) to atomism (the second stage in the historical development of understanding matter). Modern scientific chemistry is only possible, however, if we realise that atoms (as material minima, as elementary particles)

[8] In her examination of Hegel's impact on French philosophy, Judith Butler emphasises how Alexandre Kojève rejected Hegel's "panlogistic" view of nature, seeing Hegel's doctrine of a dialectic of nature as mistaken, and subjectivity and desire as distinctive attributes of humans (Butler, 1987, p. 65). Human desire transcends biology (p. 67). Kojève's reading prefigures Sartre's view of human consciousness as that which transcends rather than unites with nature (p. 71).

should not be considered real entities, for they actually represent a metaphysical idea. Indeed, according to Hegel, atomists are metaphysicians (§98, §103).[9] What is still missing is a rational understanding of molecular entities as compositions of positive and negative components (in technoscientific terms: of protons and electrons, etc.). As Slavoj Žižek (2016/2019) convincingly argued, Hegel's criticism of Greek and modern atomism was vindicated by quantum physics, precisely because quantum physics eliminated to intuitive idea of atoms as indivisible, material particles floating in a vacuum. For quantum physics, the void is not the empty space *around* the atom (p. 39). Atoms *themselves* are weird, kenotic, empty spectres, composed of subatomic particles which result from quantum waves. Positing atoms as material particles entailed a metaphysical position. Reason commences with wholes, never with atoms, and the concept of an elementary atomic particle only works if it enables us to understand connectedness and interaction, for instance in the context of a chemical process, resulting in the synthetic construction of chemical products (as a movement from primary substance via analysis to synthesis). Hegel emphasises, moreover, that analysis and synthesis are processes which mutually refer to and depend upon one another (no synthesis without analysis; while the former is the ultimate aim of the latter).

In mathematics, we notice a similar tendency to determine a particular *quality* through *quantification* (= analysis), with the help of instruments, while both aspects are eventually incorporated in the idea of proportion ("*Maß*", §106): the unity of both (e.g. in music, architecture, chemistry, ethics, etc.). We find the same dialectics in the solar system (proportionality between velocities and orbits of planets), in the chemical composition of rocks (quantitative ratios determining qualitative characteristics) and in the shape of fossils (where we encounter similar proportional shapes both in miniature specimen and in giant ammonites). Inchoate neutrality and stability (the first moment) may temporarily give rise to disproportionality (e.g. excessive growth, the second moment) until equilibrium is restored (the third moment, §109).

An obvious example of the dialectical principle, mentioned by Hegel, is the increase or decrease of the temperature of water. Initially, such quantitative changes are captured in qualitative terms (warm, cold, lukewarm, etc.). Subsequently, these changes are quantified (with the help of a thermometer). As soon as a certain extreme is reached, however, water suddenly suffers a *qualitative* change and is converted into steam or ice (§108). A similar dialectics is at work in ethics, which is about finding the right measure (proportionality = justice; virtue = the proportionate middle between rashness and cowardice, wastefulness and thrift, etc.). Virtue is not the starting point (not a given), but a *result*. The capacity to determine the right measure is based on experience and therefore informed by instances where the limits are passed and extremities are reached. Again, the right measure is not the

[9] It is not the concept of the atom itself that Hegel considered problematic, but how it was conceived as primal and self-subsistent (Posch, 2011). Sub-atomic particles such as quarks do *not occur as self-subsistent natural unities*, but in combinations, in various modes of relatedness, as moments in nuclear processes. Therefore, while contemporary quantum physics concurs with Hegel's logic, nineteenth century "metaphysical" atomism did not.

starting-point, but a dialectical outcome (taking multiple, seemingly contradictory experiences into account). Initially, we experience matter in the primary sense, as that which is tangibly there, but in a diffuse and inchoate manner (M_1). Gradually, differences are discerned, distinctions are made and categorisations are implemented (M_2). This is basically the work of chemistry: to determine particular substances, similar to how linguistics distinguishes particular families of languages, on the basis of specific linguistic characteristics, e.g. the absence or presence of certain features (§117; §118). Eventually, this gives rise to a comprehensive, well-organised system of similarities and variations (M_3). In chemistry, the Periodic Table may count as such a result, albeit a result which, in Hegel's lifetime, was still work in progress.

Hegel also mentions the discovery of the circulation of blood, where modern anatomy initially succeeded in eliminating self-contradicting views (blood as a kind of bodily juice) by developing a purely mechanistic (machine-like) understanding, with the heart acting as a kind of pump, a view that was already questioned by Leibniz. Eventually, this mechanistic view was superseded by a more mature, organic understanding of processes occurring in living bodies (§121). The germ (in contemporary language: the genome) is the plant-in-itself ("*die Pflanze-an-sich*"), stimulated by external circumstances into a process of becoming, via interaction with exteriority and otherness: an example which already shows how mistaken the idea is that things-in-themselves are allegedly inaccessible to human cognition (§ 124Z). Likewise, we should refrain from opposing the noumenal *core* from the phenomenal *shell*, for living entities are both at the same time, Hegel argues, quoting Goethe ("*Natur ist weder Kern noch Schale/Alles ist sie mit einemmale*", §140Z, p. 275). In biological terms: living entities are both genotype and phenotype, and result from the productive tensions between the two.

All concretely existing things are a temporarily result of dialectical processes, so that chemical analysis not only means taking things apart, it also means taking a step backwards in time: from the current composite whole to the previous parts (i.e. regression), although these parts do not exist independently, but as integrated components of geologic or organic existence (§126). The limbs and organs of a body are not mere parts, because it is only in their unity that they are what they are, affected by and affecting this unity (§135n, p. 136). Limbs and organs become parts only when they fall in the hands of anatomists, who work with corpses rather than living bodies. Dissection ("*Zerlegung*") is an inevitable moment, but does not allow us to genuinely understand a living, functioning organism. Anatomical results must be incorporated in a more comprehensive, holistic view. The same applies to psychology, where specific psychic faculties should not be compartmentalised. We are what we do on the basis of our *descursus vitae*, and this notably applies to performances in art and science (§140Z, p. 277). Reality is ἐνέργεια: the realisation of an idea, which is actively at work ("*das wirkende Wirkliche*"). The abstract concept must come into existence. The ideal and the real are not in opposition to one another, they interact. The ideal has an impact on the real, while the real is not completely passive, but driven by an urge. The real is not what is empirically and accidentally given, but a process of realisation (ἐνέργεια). Technoscience uncovers the

inevitable in what apparently seems contingent. The contingent will be consumed by a new reality already emerging. The immediate and accidental will be negated and consumed by self-realisation.

Hegel distinguishes three dialectical stages in modern metaphysics (§153 – §157). The first stage focussed on substance: that which necessarily exists, the given, not requiring something else, e.g. Spinoza's concept of infinite substance as God or Nature (M_1). The differentiation between cause and effect, however, gives rise to the concept of causality, as exemplified by the epistemologies of Kant and Hume, where reality is comprehended as an extended series of causal relationships between external objects, where causes give rise to effects, which become causes in their own right, giving rise to particular effects as well, and so on, ad infinitum (M_2). Eventually, however, causality gives way to the systemic idea of interaction ("*Wechselwirkung*"), where reality emerges as a process, involving multiple factors mutually affecting each other (M_3). While substance remains an abstract concept, causality is a partial process considered in isolation (in the context of a technoscientific experiment, for instance). Such artificially insulated causal relationships must become incorporated (sublated; brought to full development) in the context of a system or process: that which is real, an interactive realisation, a living substance, in which also the experimenting subjects themselves are embedded as well. Systemic interaction is the *truth* of cause and effect, which (in retrospect, from a more holistic or systemic perspective) are now mere moments.

The idea of a dialectical process also applies the "subject pole" of knowledge, to the way in which research is organised. Research requires the renunciation of our immediate (subjective, capricious) interests, biases and aims, but there is something in return, a compensation ("*Ersatz*", § 147), namely: becoming involved in a collective and evolving process of knowledge production. Thus, negative or abstract freedom gives way to concrete, positive, affirmative freedom, allowing us to endorse a collective objective, in which our talents and "energy" (in the dialectical, Aristotelian sense) can be meaningfully invested and sublated until we reach a higher plateau of understanding. Hegel emphasises the institutional embedding and embodiment of human subjectivity in general and of scientific thinking in particular (Ferrini, 2014). For Hegel, in contrast to thinkers such as Descartes, Kant, Fichte, neo-Kantians and others, the "I", the ego of science ("*Ich*", "*Ich denke*", cogito) is not a starting point, but a dialectical result of what Gaston Bachelard (1938/1970) referred to as the "formation" of the scientific spirit. A diffuse, inchoate, polymorphous individual (M_1) is exposed to the technical and practical challenges of laboratory life, is immersed in the ascetic spiritual exercises of logical and mathematical thinking, is emptied as it were (M_2), transformed into a "kenotic" subject,[10] and finally converted, reformed and edified by the logic and practice of scientific thinking, adopting the position of an accurate, self-critical and reliable producer of knowledge (M_3). Unhappy consciousness (undirected, alienated) evolves into a scientific ego,

[10] "κένωσις" refers to a process of catharsis, a cleansing of preconceptions, to become optimally receptive to the logic of science. Cf. Catharine Malabou's views on kenosis and the Pauline/Lutheran concept of "Entäußerung" (alienation; Malabou, 1996/2005, p. 82, p. 91).

as the concrete exemplification of a rational mind, for whom science is a vocation. The scientific ego is itself a concept which comes into existence via a dialectical process of self-realisation (Pippin, 1989).

From a dialectical perspective, reality is a process (ἐνέργεια), continuously in transition, an ongoing work-in-progress of becoming (§161). A plant develops out of a germ (M_1), which already contains the plant, but in an abstract manner: as a program or idea. Not in the sense that the germ is a kind of box which already contains the various components in miniature. Rather, it is a process of transition, for which the dialectical moment, the exposure to otherness (M_2) is essential. In the course of the process, the outward material form will change (in terms of quantitative expansion or metamorphosis or both), until the idea is fully and objectively realised (M_3). Whereas the germ contains the *generic* concept or idea ("das Allgemeine", A), the developmental transition takes place under *particular* circumstances and conditions ("das Besondere", B), until the plants realises and materialises itself as a concrete exemplification of the idea: as something real and *concrete* ("*Einzelheit*", E; §163). The initial idea nonetheless continues to be at work as a formative force. In other words, as soon as the germ (A, M_1) commences its process of development, a separation takes place between inside and outside, program and environment, essence and appearance (genotype and phenotype if you will): as *particular* dimensions (B, M_2). This process of differentiation continues to unfold (so that a plant will develop specific parts, e.g. roots, leaves, flowers, etc.), until the organism realises itself as a concrete mature living being, an organic whole (E, M_3). Again, the concept is not only present at the start of the process, but remains active ("*tätig*") throughout the whole trajectory of transition and realisation (§166).

The Chemical Process as a Syllogism

Rationality not only pertains to thinking, but to reality as well: rationality *realises* itself. A syllogism is not only a logical technique. For Hegel, a syllogism is something real. Dialectically speaking, everything is a syllogism. A plant, for instance, is a syllogism. Starting from a general concept (the germ), a primal process of division and differentiation is initiated, which explains why, in German, "*Urteil*" not only functions as a logical term, but also (literally) points to the process of division and differentiation ("*Teilung*") until this process is brought to its *conclusion* in the maturing plant, where the process is literally *concluded*, brought to a closure (cf. the German verb "*schließen*"). Thus, dialectically speaking, a natural process *really is* a syllogism. A similar logical structure can be discerned in inorganic chemical processes, where we start with a (neutral, general) substance (M_1), which is subsequently exposed to and brought into interaction with a *particular* environment (in the context of a chemical experiment for instance, M_2), until this process of interaction is brought to its conclusion through the formation of a stable product, as the outcome ("*Abschluss*") of the process (M_3). Allow me to zoom in on this, elucidating Hegel's understanding of the chemical process in more detail.

The chemical process is a syllogism. From source material (the general: M_1), particular substances or components are derived (via analysis, diremption or differentiation: M_2), which are then recombined, resulting in a chemical compound as product (M_3). Thus, the chemical process consists of three moments, moving from the *general* (the source material, A) which is exposed to *particular* circumstances and analysed into *particular* components (B), and finally recombined into a *concrete product*: A (M_1) → B (M_2) → E (M_3). Dialectically speaking, this is the logical structure of a chemical process. During the second moment, the components, although separated from each other, are still logically related to each other. They may even be yearning for each other: lying in wait to be reunited as it were. Even when they exist side by side, they form a whole, although this whole has to be re-established in the conclusion of the process. During the second moment of separation, they still constitute a totality (mutually referring to each other), even though they exist separately. Their one-sided existence (as opposites) is a contradiction which has to be sublated, conjoining them into the real whole (the product), thereby realising something which they, in principle, already are. This joining together (synthesis) has the structure of a syllogism, where two opposites are brought together via a third, a mediating entity: a medium, a link. As soon as this intermediary is available, the reunification may take place. The term syllogism literally (i.e. etymologically) means that two components are *thought together* (in the case of a *logical* syllogism) or, in the case of a chemical process, are *brought together* (Συλλογισμός = συν + λογίζεσθαι).

Etymology is an important source of insight for dialectics. From a dialectical perspective, etymology itself is a dialectical process, a syllogism, a dialectical movement of signifiers. A primal word (a *general* term, with a relatively broad range of applications) is exposed to *particular* circumstances and may respond to this exposure, for instance by evolving into a different term, by incorporating particular syllables or letters, or by combining with another term, so that a new (stable) signifier results from this, a product, whose origin or genesis may no longer be obvious. In the case of a neologism, we are faced with a conscious procedure (in chemistry, for instance, neologisms are consciously produced, in accordance with a validated method). A neologism may be regarded as a linguistic polymer, i.e. a combination of multiple units, forged together. In other words, the logic of chemistry (the chemical syllogism) has external validity and may also apply to language (to linguistic processes, so that etymology is in accordance with the logic of chemism), but also to music or to the psychology of human interaction.

The logic of chemism entails that something which is general or neutral (an earthy substance, A) is dirempted and separated into two (or more) contrasting (particular) entities (B). These substances clearly differ from one another, but their externality is not self-sufficient, so that we notice a deficit (instability), until these separate substances are conjoined together to form a concrete, stable, chemical compound (the *concrete* product, E). The components involved are not indifferent to one another. In acid-base chemistry, a base and an acid may coalesce to produce a salt (salts result from a stabilising reaction of an acid and a base). Hegel also refers to electrochemistry, notably the research conducted by Luigi Galvani concerning

"animal electricity". Via metallurgy (the moment of diremption) two different metals are produced, for instance copper and zinc. As a third (intermediary) component, Galvani used a leg or a decapitated body of a frog, connecting a metal wire with the frog's spine for instance. Together, these three components (copper + zinc + decapitated body) formed a circuit, – which was demonstrated by the fact that the frog's leg or body would start to move and contract in response, indicating that, in animal bodies, electrochemistry generates contraction. When two pieces of metal are joined together (via a third, organic, intermediary component), electricity (energy) results as product.

Thus, the chemical process commences with *general* earthy substances (matter, ore). The practice of metallurgy extracts *particular* metals with the help of a furnace, resulting in, say, pieces of copper, tin or zinc, which are separated from their source materials. The Greek term μεταλλεύω means searching for or digging for metal (μεταλλεύς is a miner), so that metallurgy is a "polymer", a combination of μέταλλον and ἔργον (= work). This not only emphasises that chemistry is a hands-on practice (manual work), but also that it is inherently logical, albeit not in a bookish sense. What Hegel's logic aims to achieve is to provide a logical structure for real-life *practical* endeavours, including chemistry and metallurgy. The initial result of metallurgy is separation (diremption) of earthy matter into particular metals, which are then consciously recombined together (in the right measure and under the right circumstances) into a metal product, combining copper with zinc and tin to produce bronze for instance: a bronze spade or statue. Again, etymology (the dialectics of terms) is important here, because "metal" literally means something which is combined "with something else" (μὲτ' ἄλλο; § 332Z). The word "metallurgy" is a polymer consisting of three components (μὲτ' + ἄλλο + ἔργον), indicating how a metal worker (μεταλλουργός) *works* to combine a particular metal with *other metals*. The term "metallurgy" is itself the result of a process, forged to capture a syllogistic practice.

In the case of bronze, the result is a (relatively stable) alloy (a "concrete universal", as Hegel phrases it, representing a historical epoch, the Bronze Age). In the case of electrochemistry, the product is a set-up where the separation between the metals (say copper and zinc) is maintained, but in such a manner that the two pieces of metal nonetheless continue to interact with one another via a third component, a medium (e.g. water, or a decapitated frog, as in Galvani's trials). This set-up is a product (produced by and used by researchers-at-work). Through the subsequent work of Allesandro Volta (1745–1827), Galvani's set-up evolved into a battery, as a concrete universal, representing modern industrial society (where batteries are employed on a massive scale to create electric circuits, thereby enabling a broad spectrum of practices). This already indicates that, although Hegel did not, strictly speaking, develop a philosophy of technoscience, his logic nonetheless provides a *logical scaffold* to support technological practices, so that the elaboration of Hegel's logic into a full-fledged philosophy of technoscience is indeed an inevitable next step (Juchniewicz 2018).

It is only in laboratories that such a syllogism – from general earthy substance (A), via metallurgy (diremption, B) down to a concrete electrochemical installation

(e.g. Galvani's set-up to study "animal electricity") – can be carefully studied in isolation. Real (outdoors) nature is a grandiose interplay of interlocking syllogisms ("*Wechselwirkung*"). And it is only in a living cell (as a natural laboratory) that chemical processes can be orchestrated into a self-sustaining whole. Chemically speaking, inorganic nature consists of a series of unfinished, disrupted chemical processes. As indicated, the logical structure of chemism (the chemical process as a syllogism from source material to end product) has a much broader validity and is applicable to other domains as well (Burbidge, 1996). Goethe thematised human relationships in terms of attraction, repulsion and elective affinities ("*Wahlverwandtschaften*"), whereby the latter results in a relatively stable outcome (Bates, 2014). Hegel's philosophy of chemistry is work in progress. Lavoisier's discovery of Oxygen (in 1778) heralded a scientific revolution in chemistry, turning chemistry into a rigorous science. Together with colleagues, he proceeded to publish a scientific nomenclature for chemistry, a systematic method for producing chemical neologisms and for labelling chemical compounds. This revolution generated a plethora of chemical experiments. Hegel was dissatisfied because of the conceptual (logical) deficits of this evolving research practice, this "work in progress", and his philosophy of chemistry was intended as a contribution to a more systemic and rigorous approach. Yet, his intervention remained work in progress, and a consistent chemical system was still decades away. Mendelejew introduced his periodic system in 1869. This historical process can again be framed as a syllogism in its own right. Lavoisier's initiatives represent the first moment, preparing the ground for modern chemistry by putting chemical research practices on a scientific footing, enabling a research practice resulting in baffling discoveries (Ruschig, 2001). Hegel (in his critical reflections) pointed to numerous inconsistencies and disparities between concept and reality, while at the same time aiming to contribute to the development of constructive solutions. In other words, Hegel's own work entails negativity (criticising deficits) but also points to the need for a systematic approach. Mendelejew's periodic system represents the "end" of the chemical revolution inaugurated by Lavoisier and assessed (mid-term) by Hegel. Dialectically speaking, the periodic system is the concrete realisation of the idea of nineteenth century chemistry as a systematic science.

From Syllogism to System

All natural processes are syllogisms. Chemical, biochemical or biological experiments are syllogisms studied in isolation. In a laboratory, we may study the development of a germ into a plant, exposed to a particular environment, or we may study the chemical transition of substances (exposed to a particular environment) into concrete novel compounds. Real nature is not a mere aggregate of isolated syllogisms, however, but a *cycle of syllogisms* ("*Kreislauf*", 1830/1986a, §181, p. 332), a cyclical system of interactive syllogisms. The standard format of a syllogism reflecting a natural process is: A → B → E, where a generic substance (A) realises

itself into a concrete entity (E) via the exposure to particular circumstances (B). This syllogism ("*Schluss*") can be discerned in an experimental design. Other syllogisms apply as well, however, for instance when we conclude ("*schließen*") that a *concrete* cranial aquatic organism which we encounter in nature, seeing that it is lacking limbs but is equipped with *particular* organs (e.g. gills), can be considered a fish (E → B → A). In such a syllogism, a particular property (presence or absence of gills) is emphasised to subsume the living being under a general heading. It is a logical *operation* which we conduct on a daily basis, but which may also become part of a validated scientific methodology. Another example of a syllogism is: all metals (as a particular group of substances) conduct electricity; gold is a metal; ergo gold is a conductor (B → E → A). Or: Earth is a celestial body; Earth is inhabited by living organisms; ergo, other planets may be inhabited as well (the grounding hypothesis of astrobiology, the technoscience of extra-terrestrial life). Although extra-terrestrial life is a logical possibility, its realisation depends on particular circumstances (e.g. the presence of an atmosphere, of water, etc.).

A syllogism is a basic component of the logic of a discipline, but also occurs in nature. Dialectics overcomes the subject-object divide and aims to *objectify* and *realise* itself (§192). Rather than seeing nature as mere contingency, dialectics sees natural entities as the realisation of an inherent idea. Being is underway towards realisation. This is the dialectical process which evolves from general *concept* into concrete *object* (objectification): something really existing, as part of a real and interactive ambiance. An object is the transitory outcome or *product* of a dialectical process (§193). The abstract concept as such (M_1) aims to realise itself by overcoming resistance (negation, M_2), objectifying itself as something which *must* exist (M_3), albeit as something singular, and therefore transitory, bound to be consumed sooner or later. Coming into existence entails a form of indebtedness (as living beings are indebted to parents, germs, circumstances, care-givers, etc.) and they can only repay their dept by being annihilated sooner or later. The emergence of a new generation of living beings constitutes the negation of their negation.

An object is an ambiguous entity. It has independent standing, but at the same time remains dependent on its context. Moreover, an object may initially strike us as "other", but the goal of scientific research is to diminish the object's alterity by discerning the concept which reveals itself in the emerging object. The relation between subject and object, between science and reality is of a "dialectical" nature (§194 Z1, p. 351). As objectivity is a realisation of the concept, the rational is at work in the real. In other words, the object is not something inflexible, it is a *process*.

Three forms of objectivity can be distinguished (§194): a mechanism (composed of various components without any intrinsic connection); a chemical process (where components are defined by their relationships to one another) and a living being (as embodiment of an inherent telos, the realisation of an idea, in which mechanisms and chemical processes are incorporated as moments). A mechanism is an aggregate consisting of partial objects which can in principle be replaced (§195). To some extent, the body of an organism can be conceived in such terms: with limbs and organs functioning as partial objects. Yet, eventually, this conception becomes an obstacle, obstructing a more adequate understanding of living organisms. Life

cannot be adequately conceived within the conceptual constraints of a mechanism (Kisner, 2008). In living entities, the mechanism is far from absent, but it is no longer the decisive principle (although it becomes more dominant in cases of dysfunction). We may also notice mechanical behavioural repertoires, also in humans, e.g. in routine behaviour.

The object's objective is to strengthen its independence by affecting its environment, overcoming dependence as a contradiction. Even a stone makes the ground on which it lies more solid by its weight, so that the boulder regains its stability. We see this in the chemical process, with its tendency to move towards situations of increased stability, but also the solar system can be mentioned here as an example of an interactive process aimed at stability. Although a planet may seem a massively self-sufficiency entity (M_1), its place and position is actually determined by and dependent on gravitational relationships (M_2): a mutual struggle, resulting in systemic stability (M_3). The identity of chemical substances (M_1) is determined by their interactive differences (M_2), resulting in processes of integration (M_3). The chemical process entails a return to neutrality, but passing through turbulence and differentiation, until a more comprehensive situation of neutrality is reached: the concrete chemical product. The initial neutral substance (M_1) can be segregated into extremes (via analysis or diremption), until tension expires in regained neutrality (M_3). Thus, a chemical process consists of two steps: a diremption of what is initially indifferent ($M_1 \rightarrow M_2$) and a sublation of difference into a more integrated form of neutrality ($M_2 \rightarrow M_3$): the *product* or *conclusion* of the process.

Living beings are subjects with ends they aim to achieve. Initially, there is a negative relationship or contradiction between the objective environment as immediately given and the aims that living beings aspire to achieve. The environment is an obstacle, something to be overcome. The activities of the living being are directed towards superseding negativity and conflict, by realising a negation of the negation, which amounts to self-realisation (§204). By satisfying its needs, the living being overcomes the tension between subject and object. One-sidedness and conflict give way to embeddedness. The living organism now feels at home in its world, becomes one with its environment. The latter contains particular entities (e.g. food) which may serve as means to realise this end (§205). Accomplishing this aim is a *conclusion* in which subjectivity and objectivity, aim and object are joined together ("*zusammenschließen*"). Even survival is a syllogism. Humans are not only forced to subjugate and appropriate external objects to realise their aims, they first and foremost have to take their own body into possession, overcome its resistance, domesticate it as it were, in order to realise their (physical and spiritual) ends. Again, this self-domestication involves a transition from the body as an inchoate given (M_1) via conflict and tension (M_2) towards unification and individuation (M_3). Dialectics is not only at work at the individual level, moreover. Even if individual actors are focussed on their personal interests (opting for competition rather than for collaboration), the cunning of reason ensures that convergence prevails over disruption. Initially, for instance, the idea of a university is merely a concept (M_1), in need of students and scholars to turn it into a thriving academic community. And although tension, conflict and competition will inevitably arise (M_2), the result of the process

is a concrete realisation of the idea under particular circumstances: the university as a concrete universal ("*das konkrete Allgemeine*", M_3, §210), the actualisation of the concept. A "true" university is true to its concept (§213) when instances of partiality and conflict are incorporated as inevitable moments in a process of unfolding, conjoining the ideal and the real.

Life is a concept which realises itself. In terms of contemporary science: a genome realises itself in a phenotype. The living cell is a cycle of syllogisms, of metabolic processes, such as the citric acid cycle. From the point of view of molecular biology, Hegel's conception of life as a hypercycle (a cycle of cycles) seems astonishingly adequate (Hösle, 1987, p. 314). Hegel's philosophy is *not* an a priori enterprise of pure thinking (Pippin, 2019), but an exposition of concrete scientific *experience* (§246; cf. Westphal, 2003), organising and systematising technoscientific results (Beiser, 2005, p. 108), resulting in a system, a "diamond net" of concepts, in which the formative concepts, the philosophemes at work in the natural sciences, are explicitly considered in terms of their dialectical interconnections (§246 Z, p. 20). This diamond net of concepts articulates the logos at work in technoscientific practice. Yes, all that which in nature is noisy with life, falls silent in the quietude of though (§246 Z); but this does not mean that there is a divide between a priori thinking and empirical research. Scientific experiences provide a stimulus for developing a *Logic*, while the *Logic* offers a syllogistic scaffold for natural science. In philosophy (as a rational consideration of a real process) logical thought and empirical research are brought together (Engelhardt, 1976). For Hegel, scientific experiences are realisations of a working concept. That is why chemistry and biochemistry build on triadic syllogisms and why philosophy and the natural sciences co-evolve through interaction.

Initially, the living entity (as agency) is confronted with an external reality (as otherness) which seems foreign and hostile, but eventually the living organism manages to assimilate external reality in a process of productive self-realisation. The result of living activity is not a neutral product, but individuation and self-enhancement, until, after the death of the organism, chemical processes recommence their destructive activities. In technoscientific terms: life is the relentless struggle against entropy although on the individual level, the triumph of the organic over the inorganic is a transitory situation, made perennial through reproduction. The living process is enhanced by consciousness and knowledge. And this requires an active stance (§226), as knowledge and experience result from interaction, until genuine insight is gained in a systematic fashion.

Insight requires conscious activity: analysis and diremption, reducing a concrete substance into something general (in chemistry, into elements: nitrogen, oxygen, hydrogen, etc.). This process of "*Zerlegung*" results in a contradiction, however. For instead of acquiring real knowledge about the object, the latter is actually annihilated (§227). Therefore, we need the reverse approach as well: synthesis, resulting in a concrete product. Metallurgy is the conscious recasting of basic components into something tangible and concrete (e.g. a plough, something which enhances our capacity to domesticate the environment), while plant breeding allows particular traits to become recombined, resulting in new variants as concrete agricultural

products. Thus, from a dialectical perspective, scientific knowledge builds on actual human praxis and results in systematisation. The discordance between the concept and the real is overcome in the course of the process (§234), while self-contemplative thinking is the final *result* of collective processes of working-through (§236).

Extrapolations

We may further elucidate Hegel's logic with the help of some examples from contemporary technoscience. A global, transdisciplinary research area known as genomics starts from the conviction that human beings are basically determined by their genomes (their DNA), so that human beings basically *are* their genomes (a position known as genetic determinism). In a similar manner, brain researchers may claim that human beings basically *are* (determined by) their brains: the neuro-centric view. Obviously, such claims are closely connected with particular technologies such as genome sequencing machines or magnetic resonance imaging (MRI) machines. Claims such as "we are our genome" or "we are our brain" articulate the metaphysical convictions materialised in such machines. On the other hand, scientists may claim (or even demonstrate in their research) that human beings are the product of their (social, cultural and physical) environments, now using different sets of tools. This collision of scientific positions (and the technologies on which they rely) results in the nature–nurture debate. Whereas life scientists or neuroscientists are more likely to opt for neuro-centrism or genetic determinism, sociologists or cultural anthropologists are more likely to adopt the "nurture"– view. We notice a pendulum swing, moreover, in the sense that during the nineteen-seventies, the nurture-paradigm was more dominant (resulting in the idea that human beings can be altered by changing their environments), while genetic determinism resurged during the nineteen-nineties, when automated genome sequencing machines were develop and the Human Genome Project was unleashed (Nelkin & Lindee, 1995/2004; Zwart, 2009, 2014).

Dialectically speaking, although genetic determinism is "negated" by research which demonstrates the importance of the environment, both research strands are logically connected. The one is the logical reverse (the "truth") of the other. They represent two stages through which our efforts to deepen human self-understanding must necessarily pass. While initially the idea that human existence is determined by our genomes seems very enlightening and productive, researchers gradually realise that this "philosopheme" is too restricted and one-sided to be convincing. A different (apparently contradictory) approach inevitably presents itself. The validity of both positions is limited, but their results allow us to understand how we may attain a more comprehensive approach in with both "moments" are acknowledged and combined as complementary views. Human existence results from the continuous interaction between both dimensions, mutually challenging each other, as interpenetrating opposites. Both moments must be recognised as partially valid. Every radical effort to understand human existence solely in terms of "nature" will

strengthen the other side of the spectrum and fuel the endorsement of the contrasting view. In dialectical terms, this is known as the negation of the negation: whereas genetic determinism is *negated* by environmentalism (and vice versa), the moment of negativity and contradiction must itself be sublated (superseded, overcome), namely by developing a more comprehensive view which encompasses ("lifts up") both conflicting aspects.

Dialectics strives to capture the present in thoughts, to conceptualise the basic *truth* of a particular era, its conceptual core. The spirit (zeitgeist) of an epoch, Hegel argues, is a *general* principle which expresses itself in all *particular* domains of socio-cultural existence, including scientific research (Zwart, 2020c). Whereas the focus on nurture expressed the (more or less leftist) zeitgeist of the 1970s, the resurgence of genetic determinisms reflected the (neo-liberal) zeitgeist of the 1990s. As to our own era, globalisation could be considered our "principle": the dominant tendency towards increase of scale and planetary connectivity, but also the various forms of recoil and resistance it engenders ("fundamentalism", "populism", viral pandemics, etc.). Both contrasting tendencies are part of the same dialectical constellation, as action and reaction (Zwart, 2020a, b). Globalisation is also an important factor in contemporary technoscience, moreover, as technoscientific research is evolving into a global web of interconnected laboratories, electronic journals, research consortia and research sites. At the same time, competition between scientific superpowers (China versus the U.S., Asia versus the West, etc.) is an important trend. Dialectically speaking, this conflation of apparently contradictory tendencies (globalisation versus competition) is inevitable.

Another important principle ("philosopheme") of technoscience is the current conviction that life is becoming technologically reproducible, so that the divide between biosphere and techno-sphere, between living and non-living, natural and artificial ("synthetic"), is inevitably evaporating. This idea, that life has finally come under the sway of technoscience, is a guiding conviction for contemporary technoscientific research practices, both on the molecular micro-level (e.g. synthetic cell research) and on the meteorological macro-level (e.g. geo-engineering).

Dialectics allows us to discern the inherent logic at work in this. It entails a dynamical research program, inviting scholars to join the effort. Contrary to the position of "beautiful souls", who bemoan the current crisis while overlooking how they themselves are deeply *involved* in what they deplore (Hegel, 1807/1986; cf. Žižek, 2010, p. 399), Hegelian dialectics fosters self-reflection, making us aware of how we ourselves are always already entangled in the very processes we criticise, while also outlining emerging options to actively contribute to and become part of the imminent transition, thus pointing beyond the current crisis. Dialectics is neither a mere exegesis of oeuvres (although a careful reading of the dialectical canon is required), nor a secondary polemics. Rather, the focus is on further developing the dialectical method as a research program, emphasising its potential for addressing intellectual challenges emerging in contemporary technoscience, from synthetic biology up to climate research.

Philosophy of Nature

Hegel's *Philosophy of Nature*, the second volume of *The Encyclopaedia of the Philosophical Sciences*, is perhaps the most neglected part of his oeuvre (Engelhardt, 1976; Petry, 1987; Horstmann & Petry, 1986). Critics discarded it as insufficiently modern. Hegel seems to deny, for instance, the concept of evolution (1830/1986b, § 249), and even philosophy of nature *as such* seems to have gone out of fashion. Dieter Wandschneider (1987) already emphasised that, while in contemporary discourse epistemology and philosophy of science are flourishing, philosophy of nature is virtually non-existent. A philosophical assessment of technoscientific practice therefore requires an exercise in retrieval. Building on Aristotle, Hegel sees living beings as the realisation of the idea of life, as *logos* becoming flesh, and in the era of genomics and genetic biology, this idea seems more relevant than ever, now that this logos has assumed the concrete form of molecular letters: DNA as the program of life.

Although in the nineteenth century philosophy seemed eclipsed by remarkable breakthroughs in scientific research, Hegel argued that philosophy had a role to play precisely in such a setting (1830/1986b). There is more philosophy at work in technoscience than scientists tend to be aware of or willing to acknowledge (1830/1986b, p. 11), not only in the sense that traditional metaphysical convictions are challenged by insights produced by technoscience in a rather profound way, but also in the sense that philosophy, as the "torch-bearer" of self-consciousness (Hegel, 1818/1986, p. 402) should bring this hidden metaphysics to the fore for critical conceptual assessment. By taking up this challenge, a new dawn ("*Morgenröte*") seemed imminent for a field that had fallen silent (p. 403). The era of philosophy did not end with the rise of technoscience.

The question "What is nature?", for instance, is as daunting as it is inevitable. We may try to evade it by focussing on facts and findings of empirical research, but sooner or later the forbidding question will resurge (1830/1986b, *Einleitung*, p. 12). It is a philosophical question, but in order to address it, the natural sciences must be consulted, for it is here that the beginnings of contemporary metaphysical reflection can be discerned. There is a hidden metaphysics at work in science and the assignment of philosophy is to bring this philosophical dimension to the fore, so that we may explicitly address it (1830/1986b, § 246 Z, p. 20). To do this, we must read science from an oblique perspective, focussing on the basic, conceptual content. Thus, the sciences provide philosophy with indispensable conceptual input.

Technoscience does not approach natural entities as they immediately present themselves to us. Rather, technoscience aims to look *through* them as it were, so that questions of nature can be addressed on a noumenal level (addressing "das Innere des Innern" 1830/1986b, § 246 Z, p. 22). Rather than seeing living organisms as a unity (a Gestalt), technoscience tears its objects apart. Research entails dissection (*Zerlegung*), a destruction which reveals their inner tension (technoscience "zersplittert, zerstückelt, vereinzelt, zerreißt…" 1830/1986b, § 246 Z, p. 21). Thus, unity (oneness) gives way to polarity (twoness), although the syllogism of

technoscience eventually requires a negation of the negation, i.e. a holistic turn, towards a concrete whole (e.g. the living cell), where polarity becomes complementarity and systemic interaction.

Polarity

One of the key discoveries of modern physics, according to Hegel, is the discovery of *polarity* in nature (1830/1986b, § 248, p. 30). An object (say, a piece of glass) which seems apparently neutral (M_1) may conceal an inherent tension between two opposite dimensions: positivity and negativity (M_2). This is not a purely empirical observation, but the result of active interaction with the phenomena at hand. In the case of glass, this inherent polarity can be revealed through friction, in the context of an experiment for instance. What such an experiment reveals, is polarity as an inevitable dimension of reality, as a necessary relationship between two opposites, in the sense that the positing of the one (say: positivity) inevitably entails the positing of the other (negativity), so that they together constitute unity. In other words, polarity not only involves opposition, but also the desire to overcome this opposition and to return to unity, albeit on a higher level of comprehension (M_3).

This shift from (contingent) observation to genuine understanding can also be discerned in the history of this type of research. Initially, polarity was captured in empirical (descriptive) terms, namely as "glass" ("vitreous") electricity versus "amber" ("resinous") electricity, but in the course of the eighteenth century, this distinction was reframed in more abstract symbolic terms, namely in terms of a positive (+) or negative (−) charge. This substitution of an empirical entity (glass, amber) by an abstract concept, a symbol (+ or −, positive or negative) exemplifies a shift (inevitably at work in technoscience) from the empirical (the real) to the conceptual. Technoscience basically entails a conceptualisation or symbolisation of the real (+, −), a crucial step towards genuine understanding.

Dialectically speaking, polarity (the second moment: the moment of divergence) can never be a final state, for the positive (+) necessarily refers to (or even yearns for) the negative (−). In other words, polarity strives towards its own abolishment: its sublation into regained neutrality. Thus, a third term (regained neutrality, M_3) inevitably comes into view. Polarity initially presents itself as a duality (+/−) but actually implies this third term from the very outset, so that the dual relationship is inevitably turned into a triadic one. In short: unity (M_1) gives way to duality (M_2) which in turn gives way to an abolished duality, sublated into regained neutrality (M_3).

This same dynamic can be discerned in other research areas as well. In modern chemistry, the ancient elements (earth, water, air, fire) are broken down into more elementary components: chemical elements. As Hegel explains (1830/1986b, § 328), chemistry entails analysis (*Zerlegung*) of the ancient *physical* elements (immediately visible for us, as natural phenomena) into more abstract *chemical* ones (C, O, N, H, Au, etc.). Most entities encountered in nature are mixtures or

compounds, and it is only in laboratories that their purified forms can be isolated and brought to the fore: a result of negativity, dialectically speaking, because natural matter is actively taken apart (*Zerlegung*). Chemistry entails a conceptualisation of the real, systematically replacing recognisable physical elements with chemical symbols (H_2, O_2, H_2O, etc.). Water as a natural phenomenon is reduced to hydrogen and oxygen, while air is reduced to nitrogen, carbon dioxide, oxygen, etc.: the process of analysis (*Zerlegung*: $M_1 \rightarrow M_2$). Water is not only the primary substance (M_1), however, but also the product (the third term) of a chemical process ($H_2 + O_2 = 2H_2O$), the result of a synthesis ($M_2 \rightarrow M_3$). This process can be captured with the help of a dialectical formula:

M_1 (water as a physical element) → M_2 (analysis: $2H_2O \rightarrow 2H_2 + O_2$,) → M_3 (synthesis: $2H_2 + O_2 = 2H_2O$, water as a chemical compound).

In chemistry, Hegel explains, the primary substance is often referred to as the *Agent* (M_1) and the antithetical substance (drawing the Agent into a relationship of polarity or duality) as the *Other* (M_2), while the third term is the *Product* (M_3).[11] Thus, the dialectics of chemistry can be captured by the following equation:

Agent (M_1) + *Other* (M_2; revealing an antagonism: + versus –) = *Product* (M_3: the interpenetration of these two opposites, striving towards regained neutrality).

In a primal unity (M_1), an inherent contradiction is discerned (M_2), but this duality is overcome in the form of a concrete product (M_3), on a higher level of stability. In our example, the result (product) of this process is water again, but precisely *because* of this process (this experience) we now know what water (chemically speaking) *is* (on the noumenal level). From now on, we know that water is not only a physical element, but first and foremost a chemical composite.

Polarity (M_2): Agent (+) versus Other (–)
Trinity (M_3): Agent (+) + Other (–) = Product (+/–)

This same dialectical logic can be discerned in (extrapolated to) other areas of research. How to dialectically grasp, for instance, the work of Gregor Mendel? Mendel began his research with a "unity" (M_1), namely the pea plant (*pisum sativum*) as a model organism, a visible gestalt, representing life *in general* (for Mendel was not particularly interested in peas, he could have chosen a different model: he was interested in life *as such*). The sway of negativity was at work in Mendel's research practice, notwithstanding its apparent quietism. Rather than questioning nature in an aggressive manner, Mendel applied softer skills, such as painstaking brushwork. His work implied caressing rather than torturing nature, carefully moving his paintbrush among the delicate petals in order to fertilize his plants. Indeed, Mendel proved that nature reveals her secrets when she is *stroked* (Mawer, 1998, p. 61). Nonetheless, his method came down to "castrating", "de-sexing" and

[11] This syllogism from *agent* via *other* to *product* will later be taken up by Jacques Lacan, notably in his theorem of the four discourses (Chap. 4).

"emasculating" his plants. Even in Mendel's experiments there was the element of negativity or violence (Zwart, 2008, p. 204). It may require a *theory* (e.g. Hegelian dialectics) to actually *see* this (θεωρέω means "to see").[12]

In the course of his (allegedly peaceful, yet violating) pea trials, an inherent genotypic polarity was revealed (M_2), a tension between two antithetical components (the moment of *Zerlegung*, dialectically speaking), namely between *A* (the dominant factor) and *a* (the recessive factor). Mendel discovered that a recessive (hidden) element of greenness (*a*) could be present in a yellow pea plant (whose yellow alleles are dominant over the recessive green alleles). By consciously dissociating, isolating and recombining these elements or factors in various combinations, the hidden polarity was brought to the fore (M_2). This opposition (this negativity, this polarity) was sublated, however, and the antagonistic components were brought together (*aufgehoben*) into a third term: the hybrid plant (Aa) with yellow peas. This process can again be captured in the dialectical formula already employed above:

M_1 (the standard pea plant, with yellow peas) → M_2 (analysis: *A* versus *a*, dominant *yellowness* versus recessive *greenness*) → M_3 (synthesis: *Aa*, the hybrid plant form as concrete product).

A hidden duality (a *coniunctio oppositorum*) is brought to the fore, is set free, only to be abolished again by the product: the hybrid, where apparently incompatible opposites are brought together once again. In the next generation, four concrete outcomes result from this experiment (AA, Aa, aA, aa), involving pea plants whose peas can be either yellow (75%) or green (25%). In the latter case, latent otherness manifests itself. In follow-up experiments, similar polarities (Bb, Cc) were brought to the fore, so that the experiment became a full-fledged research program. Whereas yellow and green indicate phenomenal qualities (naturally visible as phenotype), Mendel's experiments revealed the noumenal "factors" at work (the genotypes), which are not immediately visible, but are represented symbolically (A, a). Therefore, the same logical structure which determines the chemical process can also be discerned in living organisms.

Agent (the unity: apparently uniform) → *Otherness* (negation, polarisation, bringing hidden otherness to the fore) → *Product* (the return to neutral unity, but on a higher level of comprehension).

Particularity (yellowness versus greenness: B) is revealed in a general, apparently homogeneous form (the initial common pea plant: A) and brought together again in the *concrete* product of hybridisation (E).

[12] A similar ambiguity can be pointed out in the case of Nobel Prize laureate and cytogenetics pioneer Barbara McClintock (1902–1992), who worked mostly with maize. Whereas Evelyn Fox Keller (1983) in her biography foregrounds the affective and sensitive aspects of McClintock's research practice, Nathaniel Comfort (2001) emphasises rationality, systematicity and the strive for control.

Domestication Domesticated

Aristotle (1980) experienced nature as φύσις, i.e.: that which emerges, comes forward on its own accord, that which has its own inherent principles of movement and change, that which is there without our doing: the first "moment" (dialectically speaking) of the human-nature relationship (M_1). Already in ancient Greece, however, this was a detached perspective: the perspective of the Master, rather than the Servant. Since the Neolithic era, the cunning of reason developed a plethora of tools and methods bent on mastering nature (Hegel, 1830/1986b, § 245), as was lucidly articulated in Sophocles' famous chorus in *Antigone* (1830/1986b, p. 13), enabling humans to use nature's particular forces *against herself*, so that technology basically represents "negativity" against nature: the second moment (M_2). Under the sway of negativity, nature became a resource for human domination and self-preservation. As natural beings, humans are exposed to instances of lack, e.g. hunger or thirst, Hegel argues: a threat to our self-preservation: a potential "negation" of ourselves by the continuous loss of energy and bio-matter (nature threatening to consume us). This negation can only be abolished by sacrificing and consuming ("negating") other natural entities, which allows us to temporarily restore our wholeness. Thus, humans as "agents" are increasingly able to effectively safeguard their own well-being, at the expense of nature as "other". Yet, as Hegel argues, this negative view entails a shallow, utilitarian understanding of our relatedness to nature, which fails to capture nature *as such*, nature on a grander scale: nature as a self-sustaining, goal-directed system or process, as something which works *through* us, and in which we remain firmly embedded. This recognition (of acting both against *and* in accordance with nature) requires a "sublation" of the (negative) utilitarian understanding into a more comprehensive view, which enables us to comprehend nature as a *process*: the self-sustaining ground and soil of our existence. Eventually, the spirit (*Geist*, i.e. the intellectual dynamical force driving human practice and human thinking) discerns and recognises itself in the dialectical dynamics at work in nature (the third moment: M_3), so that technoscience and nature can become reconciled again.

But precisely here, at this third moment, one could argue, a radical shift has taken place since Hegel developed his dialectics (Zwart, 2009). In agricultural societies, before the onset of the Anthropocene, nature and technology could perhaps still be reconciled, so that, although particular natural *entities* become damaged, disrupted and consumed by human activity, nature *as such* remains more or less intact. In the present situation, however, planetary nature *as such* (life on earth *as such*) became affected (Zwart, 2017b). Nature *as a whole* is being consumed by human consumption; nature *as such* is facing "negation" (a dynamic which eventually results in human self-negation). In other words, the third moment (M_3, the "negation of the negation") seems unattainable, as the second moment (negation: persistence in negativity) becomes rampant and runs adrift ($S_2 \rightarrow | S_3$). The challenge of the Anthropocene (dialectically speaking) is to once again accomplish the envisioned "negation of the negation" (M_3), but now under drastically altered conditions. Somehow, the negative sway of technoscience over nature must be "sublated", so

that nature and technology can become reconciled again. This requires a critical intervention, taking us to a higher level of integration of technoscience and philosophical reflection, guiding us towards a new plateau as it were.

In other words, whereas the second moment (from the Neolithic revolution onwards) focussed on the *domestication* of nature, the anthropocenic present must domesticate technology itself, must domesticate domestication, as a particular instance of the negation of the negation. Rather than nature, technoscience itself must now somehow be "tamed", so that nature and technoscience can become "reconnected" (Blok, 2014). This will require advanced forms of practical cunning, bent on using the forces, dynamics and creativity of *technoscience itself* in order to effectively *subdue* its negativity: the basic ambition of a particular strand of technoscientific research known as biomimicry (Benyus, 1997; Plumwood, 1993; Van Hout, 2014; Blok & Gremmen, 2016; Zwart et al., 2015; Zwart, 2019b). In a similar vein, Yuk Hui (2016, 2019) refers to the unification of nature and technology, cosmos and culture through technical activities as "cosmotechnics". Dialectics allows us to envision both technoscience and nature as interactive, dynamical systems.

Nature is no longer invulnerable (beyond our grasp). Nature and technoscience are currently seen as being in contradiction with one another, and this is not only a logical, but also a practical contradiction, so that technoscience becomes a *disruptive* factor. The negation of the negation requires as *sublation* of technoscience into a bio-compatible (sustainable) endeavour. As Hegel himself was not yet an Anthropocenic thinker, his diagnostics of the present must be updated (on the basis of his dialectical method). Two key insights seem highly relevant in this respect: Hegel's view of planet Earth as a systemic whole and Hegel's views concerning the "end" of natural evolution.

Planet Earth as a Terrestrial Organism

According to Hegel, our planetary environment constitutes an "elementary, meteorological process" (1830/1986b, § 286). Whereas planet Earth once began as a geosphere (a terrestrial system, an interactive accumulation of inorganic chemical processes), life emerged, eventually giving rise to a global meteorological process (a global ecosystem, in contemporary terms). This view resulted from Hegel's critical assessment of the discrepancies between the insights produced by laboratory research and the real, meteorological processes in outdoors nature, which seemed too complex to be comprehended in laboratory terms (Zwart, 2017b). Initially, modern technoscience studies causal relationships in isolation, probing the pressure, temperature or composition of air and water with the help of laboratory devices (barometers, hygrometers, etc.) to establish causal relationships. Yet, in the real atmosphere, such laboratory equipment is absent, Hegel argues, and laboratory knowledge cannot be meaningfully extrapolated into nature as a whole. It is the conviction of modern experimental science that what happens outdoors (in the open) should concur with processes that are studied under controlled laboratory

circumstances, but that is a mistake, as laboratory work consistently fails to replicate meteorological processes. According to Hegel, this is due to the fact that these research practices do not really regard atmospheric phenomena as moments *of a whole*, as aspects of a comprehensive planetary process, in which planet Earth as such is involved as the "universal individual" (*das allgemeine Individuum*, 1830/1986b, p. 155), with a metabolism of its own. Science aims to differentiate this whole into a limited set of particular causal relationships, but by so doing it proves unable to realise its goal. The reductionist obsession is nonetheless important because all these (finite, particular) experiments eventually culminate in one crucial *experience* (which is the ultimate *truth* of laboratory science), namely that planet Earth must be regarded as a complex, infinite *process*, a terrestrial *whole*, – an insight which reveals the one-sidedness of the reductionist premises on which laboratory research builds. In order to really *understand* nature, science must develop a much more holistic meteorological approach. In schema:

Nature in general as φύσις (M_1) → Nature as a set of causal relationships (technoscientific reductionism as the negation of the primordial whole: M_2) → the awareness that nature constitutes an atmosphere, a meteorological process (the terrestrial system as the ultimate *truth* of technoscientific reductionism: M_3).

Present-day meteorology and climate research, relying on big data and systemic modelling, may actually embody this "holistic turn" (M_3) promoted by Hegel (Zwart, 2017b). Technoscience is studying the metabolism of Earth as such. With the help of *in silico* programs, the complex dynamics of weather and climate are monitored. Precisely at this point, however, something has dramatically changed. Precisely in the context of these powerful research practices, a disconcerting truth is revealed, namely that we are no longer facing an "elementary" process. Geochemistry is irrevocably tainted by human influence, so that human activity *itself* became a decisive, "elementary" factor. In contemporary climate research, technoscience monitors its own disruptive global impact.

Although Hegel urges us to see the planet as an individual whole, he essentially sees Earth as a petrified being, a gigantic, spheroid amalgam of crystals and brittle, not *really* a living organism. As he phrases it, planet Earth is *implicitly* alive: the ground and soil of life as such. On the planetary level, the general terrestrial process remains a meteorological process (1830/1986b, p. 289), the comprehensive result of a plethora of finite, physical and chemical processes. Whereas other substances are dissolved, Earth as such cannot be consumed, but continuous to persist. Therefore, the chemistry of planet Earth (terrestrial nature) is "meteorology" (p. 291), the inorganic geochemistry of nature as a whole. Hegel sees Earth as a frame of life, even as an "individual", but the earthly super-individual lacks self-awareness. It is a paralysed, frozen, petrified form of life (§ 337). Still, Earth must be conceived as a totality. Its global process is perennial.

In the chemical processes actually taking place on this planet, Hegel discerns a "semblance" of life (§ 335). Life is the "truth" of the chemical process (Hösle, 1987). An *implicit* vivacity is at work in planetary existence, but it realises itself in

something else, namely in the living organisms which are sustained by the earthly system. In contrast to a (finite, inorganic) chemical process, organisms are described by Hegel as self-sustaining processes (§ 336). Whereas inorganic substances are continuously exposed to transformative pressures, living beings (exposed to similar external dangers, to "negating otherness") prove able to endure the tension, so that they persevere, and even reproduce themselves. Hegel conceives the transition from inorganic to organic nature as one from prose to poetry (§ 336Z), for while chemical processes take place continuously in multiple directions, life is self-contained. Planet Earth on the other hand is not an organism, and does not reproduce itself, but nonetheless sustains herself (§ 339).

Hegel sees excrements and waste products of living beings as symptoms of error (§ 365; Kingston, 2013), indicating a lack of adjustment between self and other, organism and environment, as food is only partly digestible. In excrements, the metabolism of life becomes chemistry again, as organic by-products, bound to decay. Although Hegel was unaware of course of current insights concerning the active role of the microbiome as our extimate organ, Hegel emphasises that excrements are a *product*: they are not mere negativity, mere waste (i.e. useless indigestible material) because, in the course of the process of digestion, the organism adds to it and actively expels it. Everything is a syllogism, and this also applies to digestion and defecation: food (M_1) is digested (M_2), a process of biochemical diremption, where bodily fluids trigger nutrition to decompose, so that food is negated and annihilated, but the end result (faeces) is a product as well, a combination of remnants and additives (M_3). On the collective level, excrements are part of the metabolism between human culture and the global environment. Seen from this perspective, global disruptive pollution is a symptom of systemic error, signalling the non-sustainability of the current global economy.

Again, although Hegel himself was not yet a thinker of the Anthropocene, his dialectics helps us to articulate what is currently at stake. Under anthropocenic conditions, the earthly process *as such* can no longer be regarded as infinite or self-contained. The ground and soil of life can no longer be taken for granted and may even be made uninhabitable. This awareness entails a planetary form of self-awareness, in the form of the global Anthropocene-debate. As if, in the face of the possibility of annihilation, Earth finally becomes a planetary "subject" (albeit as yet incapable of concerted action). And precisely at this moment, the option of planetary self-reproduction emerges, namely the idea of transplanting terrestrial life to other planets, whose surfaces and atmospheres may now become infected with life (once Earth has been exhausted and "consumed"); for instance, by *terraforming Mars*.[13]

[13] This line of thinking will be taken up in Chap. 7, devoted to the dialectic phenomenology of Teilhard de Chardin.

Hegel and the End of Evolution

Although natural evolution continues to evolve, at its own (imperceptibly slow) pace, the history of life as we know it has reached its completion in the sense that, from now on, Darwinian evolution will be eclipsed by the imminent Cambrian explosion of neo-life forms: the assembly-line production of new, human-made organisms, at an astonishingly high speed, reflecting the era of the technical reproducibility of life: a "negation" of natural evolution, a reassembly of life forms at a higher level of aggregation. Viruses are the exception, evolving continuously and at a high pace, but the current discussion whether the COVID-19 virus spread via a "wet" animal market or leaked from a laboratory, is nonetheless symptomatic of this trend (Andersen et al., 2020; Zwart, 2020a).

This may shed a fresh light on Hegel's highly controversial (Wandschneider, 2002; Houlgate, 2005) views on evolution. Hegel sees the successive geological formations disclosed by modern research as evidence of the "massive changes" and "tremendous revolutions" that must have occurred in a distant geological past (1830/1986b, § 339). Yet, for Hegel, these processes have now come to a stand-still more or less, and he explicitly rejects the idea of an on-going evolution of species. He even regards fossils (notably shells discovered in older geological stratums) as petrified remnants of faltered natural experiments: the debris of previous efforts of nature to forge organic forms (p. 359). Elsewhere (§ 367), however, Hegel explicitly acknowledges that organisms (both as individuals and as species) adapt themselves to external environmental circumstances (both biotic and abiotic), so that the original type may be modified in various directions. In other words, he acknowledges the plasticity of life (Malabou, 1996/2005) in response to environmental pressures.

Hegel's views on evolution are both remarkable and self-contradictory. Remarkable because nothing in his philosophy seems to justify an outright *rejection* of the idea of the evolution of species (Houlgate, 2005). Rather, evolutionary thinking seems quite compatible with his idea of life (Hösle, 1987). It is also self-contradictory, for why should Hegel endorse dramatic geological "revolutions" while explicitly discarding evolution in the realm of living beings? The idea of evolution also concurs with Hegel's views on the origin of life. For Hegel, there is already a glimpse of vitality in chemical processes (Hegel, 1830/1986b, § 335 Z; Ferrini, 2011, p. 208) and the move from chemistry to biochemistry (to the metabolism of life, as self-sustaining biochemical hypercycles) is already implicitly present in prebiotic chemistry. Life, according to Hegel, is a self-renewing chemical process made perennial (Zwart, 2020a, p. 372). Once, according to Hegel, the Earth was in a state where no living things but only chemical processes existed (Hegel, 1830/1986b, § 339 Z, p. 349). Here, life suddenly emerged, as if the whole planet became fertilised with life, and micro-organisms, infusoria ("Infusionstierchen", p. 363), as punctiform maritime vitality arose, through *generatio aequivoca* (§ 341).

Hegel's arguments gain an unexpected coherence, however, when reconsidered from an anthropocenic perspective. Whereas (slow) geological (abiotic) change and Darwinian (biotic) evolution has taken place in the past, in the present situation

these processes are eclipsed and overtaken by the global impact of technoscience. Darwinian evolution may continue, in its own super-indolent pace, but will increasingly be overshadowed by the rapid and dramatic transformations unleashed (directly and indirectly) by modern technoscience, so that Darwinian evolution *de facto* becomes increasingly irrelevant. Compared to the extremely high pace of self-directed, technology-driven processes of selection, extinction, migration, adaptation and even creation (the production of neo-life by synthetic biology, fuelled by the anthropocenic transition), natural random evolution becomes something marginal (with the exception of viral evolution perhaps). In other words, the anthropocenic present basically represents the "end" of (Darwinian) evolution: the end of *natural* history, not in the sense that this type of change no longer happens at all, but in the sense that its impact is dwarfed by the much more immediate and dramatic impact of anthropocenic processes unleashed by technoscience, – ranging from pollution, climate change and ecological disruption up to synthetic biology, biological enhancement and the production of neo-life –, which irrevocably affect the present conditions and future prospects of life on Earth.

This also concurs with the finale of Hegel's philosophy of nature, where he states that the spirit increasingly recognises itself in nature (1830/1986b, § 376). Via technoscience the spirit incessantly absorbs the processes of nature it uncovers, sublating them into something which is rational, technological and artificial (denaturalising the technologies and processes of nature, resulting in bio-technical and techno-natural hybridisation). Moreover, while there is recalcitrance at work in nature when it comes to realising its own possibilities and concepts, the spirit (in the form of technoscience) may now attempt to break this cycle of natural "inadequacies" (the violence, suffering, waste, etc. entailed in natural existence) by self-consciously bringing forth what is implicitly inherent, but not actually realised by nature: a drastic enhancement ("sublation") of nature. As indicated, this line of thinking will be taken up in Chap. 7, where we discuss the dialectic phenomenology of Teilhard de Chardin.

Dialectics of Technoscience

Hegel's logic also applies to the practice of studying Hegel. Hegel's oeuvre represents the point of departure, the groundwork (the first moment), but it is not a *creatio ex nihilo*, of course. Rather, it is a product (the outcome of a syllogism) in its own right. For Hegel himself, Aristotle constituted the groundwork, with the scientific revolution as the anti-Aristotelian "negation", triggering a response (inciting a negation of the negation). What Hegel, as a modern Aristotle, aimed to achieve, was to supersede the contradiction by fleshing out that Aristotelian dialectics actually concurs with modern science: that both moments are direly in need of (and will significantly benefit from) this mutual exposure. This, one could argue, is the basic objective of Hegel's oeuvre. It is not an effort to overcome or complete the work of Kant (Pippin, 1989, 2019) or Fichte (Beiser, 2005), but rather to achieve what

Aristotle had done for ancient thinking: coming to terms with modern history, politics, technoscience and art in a profoundly philosophical manner.

If we take Hegel as commencement, as source material (first moment), the second moment is represented by Hegel studies. Hegel scholars (epigones) and Hegel critics produced and continue to produce an immense discourse which inevitably diffracts into particular schools and fashions (the moment of diremption). We notice a basic contradiction here, however. Hegel himself was not a Hegel scholar at all (nor a Kant or Fichte scholar, as for him, author studies constituted a "moment" within a more ambitious program). In sharp contrast to Hegel studies scholarship, Hegel's own work was not exegetic at all. Rather, what he aimed to achieve was: developing a logical system to address the political, technoscientific and spiritual challenges of the modern epoch. Although this involved a careful reading of previous philosophical oeuvres, this was not an end in itself. Rather, the aim was to extract conceptual building blocks from previous efforts, highlighting their inconsistencies, in order to produce a consistent philosophical system (a diamond net) which allows us to put philosophy on a scientific footing (like Lavoisier had done for chemistry), through the development of a dialectical methodology and nomenclature.

In other words, although Hegel scholarship is important in its own right, it yearns for and prepares the ground for something else, namely a philosophical practice more in line with Hegel's own ambition: seeing dialectics as a philosophical assessment of the present, a dialectics of techno-politics and technoscience. Whereas Hegel studies meticulously compare Hegel's work with previous oeuvres (Schelling, Fichte, Kant, Spinoza, etc.), a dialectics of technoscience aims to live up to Hegel's own understanding of what philosophy is and should be, a critical confrontation with the contemporary world of techno-politics and technoscience. From a Hegelian perspective, dialectics of technoscience is not "applied" philosophy, it is *philosophy*, in the genuine sense of the term.

Although Hegel is not generally considered a philosopher of technology (Hubig, 2000), if we follow the inherent logic of his thinking, a dialectics of technology or technoscience is the inevitable next step, as Natalia Juchniewicz (2014, 2018) convincingly argued. The first Hegelian to develop a philosophy of technology was Ernst Kapp (1877/2015), a German émigré who took Hegel's *Werke* with him to the Texan plains. His *Grundlinien einer Philosophie der Technik* ("Elements of a Philosophy of Technology") elaborate Hegel's outlines and constitute a synthesis, so that Hegel's grounding work (M_1), via the exposure to the experience of emigration to the New World (M_2), resulted in one of the first modern treatises on the philosophy of technology: Kapp's monograph as concrete product (M_3) and as a synthesis of the author's exposure to Hegel (as a German gymnasium professor) and his subsequent exposure to hands-on rural labour in Texas (Maye & Scholz, 2015, p. 8).

For Kapp, technology is the self-externalisation of the spirit. The starting point of his philosophy of technology is indeed remarkably similar to Hegel's philosophy of spirit (the third part of the Encyclopaedia: Hegel, 1830/1986c). According to Kapp, implicitly citing Hegel, the basic objective of a history of technology is

self-knowledge (Kapp, p. 17; cf. Hegel § 377). We study technology to know ourselves, and to understand history as the self-realisation of human culture. The spirit is not something merely spiritual (cf. Hegel: "kein Seelending"), but *activity*, and intimately connected with the body and the material world (Hegel, 1830/1986c, § 378 Z, p. 12). Tools are externalisation of the spirit, projections of organs into the outside world, transforming matter into extended organs, allowing us to interact with and grasp the natural world with more strength, dexterity and precision. The human hand plays a threefold role, Kapp argues (p. 51): it is an instrument as such, but it also provides a model for other tools and artefacts (a hammer resembles a fist, etc.). Finally, it is the tool or instrument which allows us to produce these other tools and instruments. It is by transforming the world that we become ourselves, that we realise our concept. We humans are self-made, and the history of technology is the realisation of self-consciousness.

According to Hegel, technology co-evolved with human labour and the first mode of labour was compulsory work, choosing life over the risk of death, the obligation to work for the Lord or Master in the context of an agricultural ambiance (Hegel, 1807/1986; Juchniewicz, 2014). The ground for these ideas, elaborated in *Phenomenology of the Spirit*, notably the dialectic of Master and Servant, was prepared in unpublished fragments, written during Hegel's Jena years. Agricultural and horticultural labour are *mechanical*, Hegel argues, in a fragment written in Jena in 1802/1803 and known as *System der Sittlichkeit*, compelling plants to produce biomaterials, while the taming of animals entailed a combination of compulsion and trust. The next stage is *chemical* labour (metallurgy, ceramics, etc.). The middle term (the mediation) between subject and object is the tool (the hammer, the furnace, etc.): itself a product (the materialisation of a concept: consciousness transformed into a thing), but also, as Hegel phrases it, the persistent "norm" of labour, because the handling of such tools requires significant skill. Thus, we may distinguish mechanical, chemical and biological tools (e.g. ploughs, fertilisers and yeast respectively). The attitude of artisans towards their tools is one of veneration, Hegel notices, while the workers' attitude towards their products is desire held in check. The most important product of technology, however, is a new mode of human existence, as the Servant becomes a highly skilled artisan, while labour becomes a social activity (craftmanship). Subsequently, labour is replaced by, or outsourced to, machines.

We notice this same dialectic in technoscientific labour (i.e. knowledge production). The initial researcher is a Servant, for instance a scribe, labouring for a lord or master (as a palace scribe, a monk, etc.). In the course of history, however, knowledge workers produce sophisticated contrivances (which not only serve as intermediaries between subject and object, but also set *norms* in terms of precision, accuracy and craftmanship for the research practice involved), while these individuals transform themselves into skilled artisans of knowledge. The menial aspects of research tend to be out-sourced to machines (alienation), although one could argue that in the era of technoscience, this not only applies to the monotonous handiwork of science, but to brain work as well: to thinking as such (Habermas, 1968/1973), so that humans eventually become mere operators, highly dependent on their equipment.

They themselves increasingly become components within complicated networks of machines: "living accessories" in a machine park.

In line with Hegel's logic, three modes of machines emerge in the course of the history of knowledge. First of all, mechanical machines (clockworks, weighing scales, etc.) which function in a quantitative manner (dissecting the world, parcelling out quantities). The next step is the chemical machine (electrolysis machinery, for instance), where quality and proportion become increasingly important. And the third step is a biological machine (e.g. *Caenorhabditis elegans* or nude mice as animal models) where the organism's inherent goal-oriented (teleological) behaviour is exploited for research. The final step are the intelligent machines currently emerging, from advanced computers up to synthetic cells, especially developed for research. In other words, we notice a gradual displacement from labouring bodies via mechanical machines to sophisticated technoscientific hybrids. In technoscientific research we see the *Geist* at work, sublating the subject-object divide (posited by Descartes, Kant, Mach and many others) through practical and intellectual activities (Juchniewicz, 2018) in the context of an institutionalised practice, while planet Earth (a geosphere which at a certain point gave rise to a biosphere) currently develops into a noosphere (a technoscientific global web; cf. Chap. 7).

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