Chapter 3
Dialectical Materialism

Introduction

Although Karl Marx and Friedrich Engels strictly speaking never used the term, "dialectical materialism" refers to the philosophy of science and nature developed in (and on the basis of) their writings, emphasising the pivotal role of real-world socio-economic conditions (e.g. labour, class struggle, technological developments).[1] As indicated by their correspondence (Marx & Engels, 1983), their collaboration represented a unique intellectual partnership which began in Paris in 1844 and continued after Marx's death, when Engels took care of Marx's legacy, notably the sprawling mass of manuscripts which he managed to transform into Volume II and III of *Capital*. While their joint effort (resulting in no less than 44 volumes of collected writings known as the *Marx Engels Werke*, published by Dietz Verlag Berlin) began as co-authorship, they eventually decided on a division of labour (with Marx focussing on *Capital*), although reading, reviewing, commenting on and contributing to each other's writings remained an important part of their research practice. As a result of this division of labour, while Marx focussed on political economy, Engels dedicated himself to elaborating a dialectical materialist philosophy of nature and the natural sciences, resulting in works such as the *Anti-Dühring* and his unfinished *Dialectics of Nature* (published posthumously), although Engels (a voracious intellectual) wrote and published on may other topics as well, so that his output can be regarded as a dialectical materialist encyclopaedia in fragments. Again, although I will start with an *exposition* of dialectical materialism, my aim is not to contribute to scholarly discussions *on* dialectical materialism. My focus is on the *how* and *now*,

[1] The term "dialectical materialism" was coined by Joseph Dietzgen in *Das Wesen der menschlichen Kopfarbeit* [The nature of human brainwork] as a form of dialectics which allegedly superseded Hegel's version, which had become "reactionary" (Dietzgen, 1869/1961), – Georgi Plekhanov and Karl Kautsky are often mentioned as early adopters of the term.

H. Zwart, *Continental Philosophy of Technoscience*, Philosophy of Engineering and Technology 38, https://doi.org/10.1007/978-3-030-84570-4_3

and my aim is to explore how to *practice* dialectical materialism of technoscience today (cf. Žižek, 2014/2015, p. 1; Hamza, 2016, p. 163).

The precise relationship between Hegel's dialectics and dialectical materialism (Marxist dialectics) is a controversial issue. Marx and Engels famously presented their collaborative oeuvre as an *Umstülpung* (reversal or inversion) of Hegel's dialectic. They saw history not as the self-realisation of ideas, but as driven by material and socio-economic factors, so that consciousness ("*Bewusstsein*") is determined by socio-economics existence ("*Sein*"). In his *Epilogue* to *Capital* (Volume I), Marx indicates that, for Hegel, thinking functioned as the "demiurge" of reality, so that the real world was seen as a phenomenological realisation of primal ideas (1867/1979b, p. 27). His own version of dialectics, Marx argues, entails a demystification of Hegelian dialectics. Yet, dialectics as such remains the point of departure, if only because, as Marx phrases it, Hegel's idealistic inclinations by no means prevented him from presenting dialectics in a remarkably comprehensive and conscious manner (p. 27), giving rise to a philosophy which is inherently critical and revolutionary, even anticipating bourgeois society's inevitable negation and decline (p. 28). Still, dialectical idealism has to be transformed ("umstülpen", p. 27) into a more scientific version (dialectical materialism), which sees consciousness (ethical ideals, religious views, legal norms, etc.) as a psychic *translation* (p. 27) of material, socio-economic conditions.

This immense undertaking of reversing Hegelian dialectics into (what later came to be known as) dialectical materialism, while at the same time bringing dialectics on a par with contemporary developments during the second half of the nineteenth century, remained unfinished (notwithstanding the 44 volumes of writing which Marx and Engels managed to produce). This basically means that dialectical materialism should not be seen as a complete whole, but as a *program for research*, i.e. as an unfinished, organic body of textual materials, awaiting further development and elaboration by new generations of scholars. This also applies to Hegel's own oeuvre, of course, for notwithstanding the fact that Hegel presented his thinking as an encyclopaedic system, his oeuvre is evidently "work in progress". Hegel's death interrupted an (interminable) process of continuous revisions and expansions.

Thus, the collaborative oeuvre of Marx and Engels is both a continuation and a subversion of Hegel's paradigmatic effort, both critical of and dependent on Hegel. Hegel's philosophy of history was replaced by "historical materialism", while Hegel's rudimentary reflections on labour, political economy and the role of machines (e.g. in the *Philosophy of Right* as well as in some early manuscripts written in Jena) dramatically expanded into Marx's impressive political-economical volumes. While Engels' *Dialectics of Nature* sublated (i.e. both leaned on and updated) Hegel's *Philosophy of Nature*, the *Anti-Dühring* (in combination with multiple other texts on various topics) may be regarded as fragments of a dialectical materialist version of Hegel's *Encyclopaedia*.

Engels was a remarkably prolific writer. Besides journalism, political pamphlets and an (astonishingly extensive) correspondence, his publications and manuscripts cover a broad spectrum of fields, in accordance with his encyclopaedic mindset: from the humanities (German literary studies, linguistics, language studies and philology, philosophy and philosophical criticism, palaeoanthropology, ancient history, medieval history, military history, modern history, theology and early Christianity) via the social sciences (sociology, economy, geography, cultural anthropology, legal studies, gender studies, parapsychology) up to the natural sciences (mathematics, physics, chemistry, biology and ecology). What all dialecticians (Aristotle, Aquinas, Hegel, Marx, Engels, etc.) have in common is that they see their work not as a specific discipline, but as a *Gesamtwissenschaft*. Marx and Engels aspired to achieve what Aristotle managed to bring about in Ancient Greece and Hegel in Germany. Seen from this perspective, Engels's kaleidoscopic output can indeed be considered as building blocks for an unfinished dialectical materialist encyclopaedia, addressing and assessing all existing research fields.

On the other hand, while Hegel's *Logic* was a substantial part of his oeuvre (consisting of two versions, spread over three volumes), it is precisely this part which seems underdeveloped in the writings of Marx and Engels. Louis Althusser has argued that, fully absorbed in his political-economical and historical materialist writings, Marx never managed to produce a dialectic (or *Logic*) of his own. And this is a problem notably because Marx and Engels never fully developed their methodology, although their way of working is evident in their writings. When it comes to *practicing dialectical materialism today*, we may follow and extrapolate their examples, but without the guidance that would have been provided by a logical or methodological manual. Marx and Engels develop their methodology *along the way*, and we must familiarise ourselves with it by reading their work, preferably all of it.

Although Marx and Engels continued to read an discuss "old Hegel", notably his *Logic* (as indicated in their correspondence), Marx himself never found or took the time to write a Marxist version of Hegel's *Logic*, Althusser argues, although the outlines of a Marxist philosophical practice are nonetheless available. According to Althusser, they can notably be found in the prefaces and epilogues accompanying Marx's major scientific publications, such as *Contribution to the Critique of Political Economy* (published in 1859) and *Capital,* Volume I (published in 1867). These textual materials can be said to contain Marx's "discourse on method", albeit in a fragmented manner. Below, these documents (fragments of a dialectical materialist "logic") are listed:

- Karl Marx (1859/1961a): *Vorwort* (Preface) – Zur Kritik der politischen Ökonomie (*A Contribution to the Critique of Political Economy*) – published 1859 [Karl Marx – Friedrich Engels – Werke Band 13, pp. 7–14]
- Karl Marx (1857/1961, 1939/1983): *Einleitung* (Introduction) – Zur Kritik der politischen Ökonomie (*A Contribution to the Critique of Political Economy*)/*Grundrisse der Kritik er politischen Ökonomie* (Foundations of the Critique of Political Economy) – written in 1857, published posthumously [Karl Marx – Friedrich Engels – Werke Band 13, pp. 615–644; Karl Marx – Friedrich Engels – Werke Band 42, pp. 19–45]

- Karl Marx (1867/1979a): *Vorwort* (Preface) – Das Kapital: Kritik der Politischen Ökonomie, Erster Band (*Capital: a Critique of Political Economy, Volume I*) – published in 1867 (Karl Marx – Friedrich Engels – Werke Band 23, pp. 11–17)
- Karl Marx (1867/1979b): *Nachwort zur zweiten Auflage* (Epilogue) – Das Kapital (*Capital*) – published in 1867 (Karl Marx – Friedrich Engels – Werke Band 23, pp. 18–28).
- Friedrich Engels (1893/1977): *Vorwort* (Preface) – Das Kapital: Kritik der Politischen Ökonomie, Zweiter Band (*Capital: a Critique of Political Economy, Volume II*) – published in 1893 (Karl Marx – Friedrich Engels – Werke Band 24, pp. 7–27).

Thus, the *Umstülpung* of Hegel's dialectics also means that what had remained underdeveloped in Hegel (e.g. political economy) was significantly expanded by Marx and Engels and what was substantially developed by Hegel (e.g. his *Logic*) was left unfinished or was pushed into the margins in the writings of Marx and Engels. For a quick comparative analysis (a comparative anatomy) of their oeuvres, the following table may serve as outline:

Hegelian dialectics →	**Dialectical materialism** (*Umstülpung*)
Philosophy of history →	Historical materialism
Logic →	Prefaces and epilogues
Philosophy of nature →	Dialectics of nature (Engels)
Philosophy of right →	Political economy (Marx)
Encyclopaedia →	Anti-Dühring and multiple additional fragments on various topics (notably Engels)

Thus, although in the case of Marx and Engels a *Logic* (outlining the dialectical method) is only marginally present, their methodology can nonetheless be extracted from their work, especially from these satellite documents, indicating a rupture with Hegel while at the same time providing a methodological bridge between Hegelian dialectics (Hegel's method) and dialectical materialism (Marxism as a methodological research practice). This method of Marx and Engels, moreover, is not frozen into a rigid protocol, but remains a vibrant program and practice of research, something to be further developed *along the way*. The fragments listed above can be considered as a Marxist "discourse on method", providing a first indication as to how dialectical materialism can be practiced today. Special attention will be given to the question how to extrapolate this method into a dialectics of technoscience.

Fragments on Method

In his *Preface* to the first edition of *Das Kapital*, Marx explicitly compares his research in political economy with life sciences research. In both cases, Marx argues, the organic whole (e.g. society at large, or the biological organism as such) proves a more readily accessible target of inquiry than the basic components (commodities and living cells, respectively). Therefore, the physiology of living bodies precedes the biochemistry and microscopic anatomy of living cells, – in accordance, we could add, with Hegel's syllogism, which likewise progresses from the general, i.e. organisms (M_1) via the particular (differentiated components: M_2) to the concrete cell (M_3). In other words, Marx draws an analogy between social formations and organisms (the general) as well as between commodities and cells (the concrete; Marx, 1867/1979a, p. 12). Research starts with life or society in general (e.g. the social organism), while the biological cell, as a focus of technoscience, is already a *product* of technoscientific activity, never a given.

Moreover, Marx argues that, whereas scientists conduct laboratory experiments under particular (controlled) circumstances, with the help of optical instruments or chemical agents (studying phenomena in their "normality", that is: undisturbed by fluctuating circumstances, p. 12), political economy (the study of the evolution of socio-economic formations) can better be compared to natural history. Both fields of research adopt a systemic perspective, studying society outdoors under real life circumstances (in Manchester or London for instance). In other words, political economy, as it had developed when Marx began his research, was comparable to natural history as it had developed in the nineteenth century, before the scientific revolution transformed it into biology as real, laboratory science (cell physiology, microbiology, experimental research etc.). The scientific approach adopted by Marx focusses on basic components (commodities), comparable to cell physiology in biology. Again, we notice how closely Marx follows Hegel's dialectical syllogism, indicating how the focus of research shifts from the general (natural history as an empirical field) via the particular (laboratory research) towards the concrete (commodities, cells).

In the *Epilogue* to the second edition of *Capital* (Volume I), Marx returns to the issue of method, pointing out that his method has been poorly understood (1867/1979b; p. 25). Dialectics is a rigorous science, he claims, demonstrating how human consciousness ("*Bewusstsein*") is determined by socio-economics existence ("*Sein*"), rather than vice versa. Dialectics is the systematic study of the origin, existence, development and decline of social formations (as "social organisms"). In other words, the development of a comprehensive view is not the starting point (as in traditional metaphysics) but the result, while the understanding of the *phenomena* of consciousness requires a thorough grasp of (what could be referred to as) the *noumenal* dimension, the dynamics of microscopic components (in political economics: the dialectics of commodities).

Capital (Volume I) is presented as the continuation (p. 11) of *Contribution to the Critique of Political Economy*, published in 1859 (the year in which Darwin published his *On the Origin of Species*). In his *Preface* to this preparatory volume (sometimes referred to as "*Capital, Volume Zero*"), Marx (1859/1961) likewise describes his method as a socio-economic "anatomy" (p. 8) of modern society. Marx also explains how, after migrating to London in 1850, the British Museum provided him with the perfect observatory or platform: a perfect vantage-point from where to observe and analyse bourgeois society in a systematic manner, focussing on particular disruptive events, such as the discovery of gold in California, Australia and Alaska (1859/1961, p. 10). Rather than functioning as an observatory in the empirical sense, however, the British Museum provided him with an enormous amount of written materials assembled there, which he subjected to his "symptomatic" reading practice, as Althusser would later phrase it, focussing on the gaps and contradictions: on the unsaid. Marx also again explains how Hegelian dialectics is subjected to a reversal by emphasising that consciousness ("*Bewusstsein*") is determined by our mode of being ("*Sein*"), by the evolving modes of production. A particular social formation originates and thrives, until it exhausts the material conditions of its own existence. Moreover, humanity inevitably sets itself only such tasks as it is able to solve, and certain problems arise only when the material conditions for their solution are already present.

It is tempting to apply these insights to technoscientific research, i.e. to contemporary processes of knowledge production. From a Marxist perspective, scientific discourse is determined by the *modes* of knowledge production: the social organisation or research, the technologies in place, rather than vice versa, while normal discourse addresses those question that are solvable under existing conditions, in principle at least, until the existing mode of knowledge production has effectively exhausted its own resources. In that case, a scientific crisis is inevitable, until the outdated and inhibiting mode of knowledge production is replaced by a new technoscientific regime. Also, science commences with a critical analysis of existing discourse (M_1), whose latent tensions and contradiction provide an impetus to critical inquiry, a process of *Zerlegung* (M_2), eventually giving rise to a set of validated concepts (M_3), enabling the development of a *scientific* approach.

Another core text for understanding the methodology of Marxism is the (initially retracted and posthumously published) *Introduction* to Marx's *Contribution to the Critique of Political Economy*, which also serves as introduction to the *Grundrisse*, dating from the same period. As a result, two versions of this *Introduction* were incorporated in the *Marx Engels Werke*: one in volume 13 (1857/1961) and one in volume 42 (1939/1983). In this *Introduction*, Marx (1857/1961, 1939/1983) points out how bourgeois political economy is grounded in a mythology of origins, considering individual (entrepreneurial) hunters and gatherers as point of departure. For Marx, this is the political economy version of the Robinsonade: a bourgeois literary motif (also recognisable in the history of technoscience, as the myth of the lone scientific genius, working in splendid isolation, or in the image of the technoscientific entrepreneur, entitled to appropriate the results of what in reality stems from collective efforts). The gestalt of the modern autonomous individual – the *outcome* or product, genealogically speaking, of a long and extended socio-economic history – is mistaken for its starting point. In pre-historic societies, individuals were dependent rather than independent, and rural communists rather than bourgeois entrepreneurs. Since time immemorial, production and reproduction were collective endeavours.

Moreover, Marx presents the coming-into-being of human society as a dialectical process: a dialectic of production and consumption (1939/1983, p. 25 ff.). Production commences a process that is finalised by consumption as its end, while both are mediated by distribution and exchange. In other words, Marx argues, production and consumption constitute a *syllogism*, in the Hegelian sense of the term: interconnecting the *general* form of production (A) via *particular* forms of distribution and exchange (B) with *concrete* instances of consumption (E). Moreover, it entails an interpenetration of opposites, in the sense that production is also consumption, and consumption also production. Production is consumption ("productive consumption") because it consumes its resources and wears out its means of production. And consumption is also production in the sense that the consumption of food, for instance, produces and sustains life. In production, the producers objectify themselves, while in consumption the product becomes personified. Production reaches its end in consumption so that, without consumption, there would be no production. Dialectically speaking, consumption *produces* production. It is only in consumption that the product really becomes a product, while consumption drives the development of new products. Consumers produce these products, provoke them into existence, by subjectively envisioning and practically consuming them. On the other hand, no consumption without production, so that the mode of consumption is determined by the mode of production. Indeed, the production process generates its own consumers. This is a telling example of how Marx continues to employ the basic logic of Hegelian dialectics: production inevitably passing over into consumption as its opposite, and vice versa, while at the same time materialising it (connecting it with the material conditions of human existence).

The third part of the *Introduction* presents an outline of Marx's method (1939/1983, p. 34 ff.). Two pathways are open to us, Marx argues, two methods in the literal, etymological sense. The first pathway ("*der erste Weg*", p. 35, 632) is the one adopted by mainstream political economists. They start from something general, a living totality (e.g. the population inhabiting a particular country) and set to work to analyse it in terms of categories and concepts. The method of science, however, moves in the opposite direction, backwards as it were, and this is the way of thinking ("Weg des Denkens", p. 35, 632), from concepts to the real. Scientific research for Marx is an *appropriation* of the real. Thus, a syllogism emerges. Marx's method begins as discourse analysis: subjecting established discourse (as source material) to a procedure known as symptomatic reading, focussing on the "symptoms", i.e. the contradictions, and resulting in a set of critical concepts. With the help of these concepts, Marx sets out to analyse real processes of production, circulation and consumption. While Hegel conceives the real as a product of ideas, Marx sees modes of knowledge production as materialisations of ideas, which subsequently appropriate and process the real. This, according to Marx, is the method (the pathway) of thinking.

Before zooming in on Friedrich Engels' effort to develop a full-fledged materialist dialectics of nature, I will first present an example of what a Marxist view on technoscience amounts to, namely by discussing the history of astronomy written by Anton Pannekoek (1951/1961), a prominent practicing astronomer, but also a prominent Marxist.

Anton Pannekoek: A Marxist View on the History of Astronomy

My first concrete exposition of a dialectical materialist approach to technoscience starts at the beginning as it were, highlighting the research field to which Hegel devoted his doctoral dissertation in Jena (entitled *De Orbitis Planetarum*), namely astronomy. Marxist scientists were active in life sciences research (Bernal, Haldane, etc.) but in astronomy as well, and Anton Pannekoek (1873–1960) is a telling example, as a prominent practicing astronomer who was also a prominent Marxist. As an astronomer, he studied the statistical distribution of stars in the Milky Way and became founding director of the *Anton Pannekoek Institute for Astronomy* (Tai, 2017; Tai et al., 2019). As a Marxist, he was an international representative of council communism and author of several books and brochures. Finally, in 1951, he authored a history of astronomy as a research field (Pannekoek, 1951/1961). From the 1910s onwards, he kept his socialist activities and his scientific career at a distance, and even ended up writing two separate autobiographies: one focusing on his involvement in the communist movement, the other discussing his scientific research (Pannekoek, 1982; Tai et al., 2019, p. 9). Thus, his astronomical publications on the one hand and his Marxist publications on the other evolved as two parallel series (as if written by two different authors, apparently quite independent from each other). In fact, his oeuvre is a syllogism. Initially, both Marxism and astronomy were part of his efforts to come to terms with the real in a rational manner, building on the conviction that both the natural and the social real are rational. Subsequently, astronomy and Marxism evolved as separate oeuvres, carefully segregated from one another. Finally, however, both strands of writing converged into his history of astronomy, written towards the end of his life and published in 1951, wherein the duality is finally sublated. In Pannekoek's *History*, astronomy is presented as the first science, not only in the chronological sense of the term, but also in the sense that astronomy grounds and reflects the way we conceive the world as such.

From the outset Pannekoek emphasises how astronomy ("Bewusstsein") is connected with modes of production and ways of living ("Sein"). His *History* begins with the astronomy of Polynesian ocean travellers, for whom astronomy provided a celestial compass on their remarkable journeys across the Pacific, until their autochthonous (indigenous) knowledge fell victim to what is currently known as "epistemicide": the systematic eradication of non-Western knowledge systems, as a result of their contact with Western imperialism. This confirms the dialectical view that knowledge never begins with a blank slate (to be filled with observations: "induction"), nor as a Robinsonade. Rather, astronomy begins as appropriation and elimination, with *loss* of knowledge, as existing knowledge practices are exposed to the negativity of a new set of principles, a new relentless logic, supported by a socio-economic power regime.

Subsequently, Pannekoek describes the early history of astronomy as a collision (a battlefield) between nomad knowledge and agricultural knowledge. He explains that, whereas nomads were primarily focussed on the moon (employing moon calendars as a first astronomical moment), agricultural societies are oriented towards the sun, and therefore bent to produce solar calendars. This resulted in the first big challenge of astronomy: how to *overcome* the incompatibility of moon and solar calendars, a *real disparity*, as Žižek (2016/2019) would later call it. This disparity cannot be completely solved and continues to leave its symptomatic traces in calendars even today. The result was a calendar dominated by the solar principle, but incorporating the lunar cycle as a sublated moment. Astronomy (i.e. the production of reliable calendars) initially developed as a priestly science, and observance of celestial phenomena was considered a religious vocation. The calendar was the result of the movements of two celestial deities, a diurnal and a nocturnal one. Thus, as Pannekoek points out, astronomy developed in close interaction with socio-economic conditions, e.g. the dominance of agriculture as a result of the Neolithic Revolution (1951/1961, p. 31).

Agriculture gave rise to large-scale political entities (kingdoms), moreover, so that another function became increasingly important, namely the apparent correlation between earthly and celestial phenomena. Palace politics and policies of expansion resulted in a need to foresee the future, an ability to read the omens, in preparation of large enterprises. Thus, Assyrian astrology emerged, considering celestial phenomena as signs, conveying decipherable messages. Science, Pannekoek argues, is fostered by practical human activity (p. 85) and he discards the opposite idea, namely that science evolves from leisure (as a privilege of the elite stratum). Although Plato's astronomic insights, for instance, can indeed be regarded as an expression of the mode of thinking of the Athenian elite, who ruled over large numbers of artisans and slaves, this actually proved an epistemological obstacle, because these Athenian masters looked down upon manual work with utter disdain, as something dishonourable (p. 101), which was precisely the main reason why exact experimental natural sciences never developed in antiquity. Platonic astronomy involved a conscious withdrawal from practical experience, resulting in the idea of the universe as a perfect globe where only circular motion is admissible. Aristotle, who emphasised the importance of careful observation, deviated from this trend, and Hellenistic astronomy, practiced in Alexandria, already relied on the use instruments, allowing Eratosthenes to determine the size of the earth with the help of a gnomon (a practical instrument, a vertical stick casting a measurable shadow). Whereas in Assyria and Babylon astrology had been the privilege of monarchs, in the Roman Empire, horoscopes became democratised and were adopted by virtually everybody as a decision-making tool. Subsequently, during the medieval period, Arabian astronomy produced astronomical instruments of great artistic skill, again primarily designed for practical astrological purposes.

In occidental modernity, instruments evolving from concrete practice likewise played a decisive role, Pannekoek argues. The scientific revolution, which began in astronomy, resulted from the development of new technical instruments produced in workshops by artisans, such as the cross-staff and the telescope. The ancient (Platonic) conviction that the world is *spherical* (the first moment as it were), was still very much alive in the work of Copernicus, but was now challenged by technology-based observation. Pure (withdrawn, detached) reason refuses to accept irregularities, but anomalies and contradictions quickly began to accumulate (the second moment). For astronomical computing, Greek and Roman number systems proved highly impracticable (and not only for making astronomical calculations, but also for other arithmetic practices such as book-keeping). This obstacle was superseded by the introduction of Arabic numbers in combination with other computational tools such as logarithmic scales (John Napier) and decimal fractions (Simon Stevin). Modern astronomy (M_3) resulted from this combination of precise observation and advanced computation.

Tycho Brahe's work exemplified the importance of measuring instruments, resulting in his pupil Kepler's insight that the orbit of planets is elliptic: the third moment, dialectically speaking, restoring mathematical harmony and order (after the logic of circular movement had been negated), and converging advanced artisanal contrivances with advanced mathematics. Thus, dialectically speaking, the solar system represents a concrete reconciliation of mathematical order and empirical evidence on a higher level of complexity, through a combination of technical, observational and computational skills.

The fabrication and systematic use of instruments such as quadrants and sextants became a condition sine qua non for producing accurate, computationable data. At the same time, astronomy was highly dependent on the "benevolence" (i.e. financial support) of monarchs and princes, who provided funding for developing the necessary infra-structure, as exemplified by Tycho Brahe's Uraniborg observatory: a fascinating early modern example of the drive towards scientific upscaling (Uraniborg = the city of Urania, the Muse of astronomy). The monarch expected something in return, however: a confirmation of the heavens as a harmonious whole, a celestial template which the sublunary, political world ought to mimic, revolving around the monarch (*le soleil, c'est moi*). But the monarch also expected something else, namely prognostications. God did not create His heavenly scenery without a purpose, and the celestial machine was a wonderful device, available for consultation, providing a political compass. In a famous illustration we see Tycho Brahe as a homunculus inside his observatory, handling his contrivances. Paradoxically, he was the last of the naked-eye astronomers and refused to use a telescope. This praise for the human eye as a "perfect" organ was perhaps a desperate attempt to preserve his autonomy, a refusal to become a mere accessory of this giant machine (exemplifying the machinery of absolutism).

Gradually, however, scientists increased their independence by fabricating their own tools and by conducting experiments with self-made contrivances, as in the case of Christiaan Huygens, who was quite dexterous, not only in building accurate pendulums, but also in grinding lenses for telescopes (cf. Aldersey-Williams, 2020), while Newton constructed a metallic mirror. Menial workmanship became a crucial requirement for constructing and optimising astronomical equipment. Together with clocks, telescopes and other instruments, the calculus was developed as a computational tool. These developments gave rise to the mechanical view of the universe: the solar system as a rotating machine (exemplifying the mechanical machine as the concrete universal of modern thinking).

The industrial revolution unleashed a rapid advance of precision technology, thereby transforming astronomy from a pursuit practiced by individuals into a collective, large-scale enterprise. Capitalism produced ingenious precision machines, and Pannekoek explicitly mentions the Carl-Zeiss Werke in Jena, for instance, as an industrial producer of high-precision equipment. The rise of big industry created the technical basis for a rapid expansion, not only of capitalism as such, but also of astronomy, where astronomers became highly skilled brain workers. Every instrument is made twice, Pannekoek argues, by two different types of brain workers, the first time in an industrial setting, but subsequently also by practicing astronomers themselves, who continuously have to optimise and improve their means of knowledge production (p. 325). The initial, standardised apparatus (M_1) is challenges and affected by particular outdoors circumstances (M_2) and optimised / adapted by practitioners (M_3).

The ideal of a harmonious cosmos gave way to a new ideal, namely that of extremely precise measurement, through optimised instruments and rigid working methods. This ideal inevitably encountered challenges, however. Every time extreme accuracy seemed to be within reach, new frustrations emerged in the form of deviations, irregularities and fluctuations caused by unknown sources of error. Eventually, the most important source of error proved to be human observers themselves. Thus, an important *experience* emerged. On closer inspection, *every* human observer is in error, and with increased training, personal error does not become smaller, it only becomes more constant. Research inescapably suffers from systematic error, caused by various sources of variation, including atmospheric diffraction. Although machines were designed in such a way that the role and influence of individual observers was marginalised, the crisis was also addressed in a different manner, namely through the invention of statistics. Rather than trying to eliminate the error completely, the *inevitability of error* was *incorporated into* the methodology of measurement as such (i.e. sublated), as a containable component, namely by calculating averages of large numbers of equivalent measurements made by large numbers of observers, so that, at a higher level of comprehension, sufficient accuracy could be attained, and deviations could be superseded. It also implied that science became a *collective* enterprise, conducted by professional research teams employed at big observatories. Big machines gave rise to big science, involving large numbers of trained researchers producing masses of observational data. Industrial machines combined great size with detailed precision, and human observers became homunculi as it were, positioned inside huge steel mammoth machines, directing the motions of such machines merely by pressing buttons. Indeed, electronic control of gigantic instruments became the material basis of modern astronomy (p. 338).

In the final chapters of his *History*, Pannekoek describes another dialectical process, namely the convergence of astronomy and astrophysics, i.e. a new form of science which studies the world of elementary particles both at a very small and at an immensely large scale, thereby opening up the noumenal dimension of stars and atoms, of energy and matter. The focus shifts from how heavenly phenomena appear to the eye towards their composition and structure in terms of subatomic particles and nuclear radiation (the noumenal dimension). Initially, stars and planets had been regarded as deities, as animated “luminaries”. In early modern science (the second moment), celestial bodies were seen from a deterministic perspective, as lifeless passive “objects”, whose movements were completely determined by external forces and factors. An ontological divide was introduced, between inorganic and organic nature, as stars, planets and comets were considered lifeless and inorganic. From a dialectical perspective, such an opposition, such a binary mode of thinking (living versus non-living, organic versus inorganic, phenomenal versus noumenal, etc.) is unsustainable in the end. Hegel already raised the question when and how chemical processes become life and for Pannekoek this also applied to the chemistry of stars and other celestial entities such as nebulae. In the early twentieth century, the convergence of astronomy and astrophysics resulted in an evolutionary conception of the universe. Stars are alive: they are born, evolve and age. Both stellar objects and living organisms are part of the great universal cycle of transformation of matter and energy, of growth and decay, or positive and negative entropy, i.e. the Hegelian concept of a cycle of cycles. Research into the inner, noumenal, subatomic constitution of stars revealed their life-history (p. 494), which is not endless repetition, but evolutionary development of stellar individuals and species. Life is progressive change, from the primary substance of primal matter (protons) up to the macro-molecules of earthly life.[2] In short, for astronomers and astrophysicists, all the world is energy, in the dialectical sense of ἐνέργεια: continuous motion, activity, growth and change. Whereas for Kant as a bourgeois thinker mind and spirit are considered as separate realms (Pannekoek, 1901), dialectics reveals that the methods of natural science can be applied to human history as well, seeing the world as a constellation of processes, rather than things. This is exactly the core problematic of Friedrich Engels’ dialectics of nature.

Friedrich Engels and the Technoscientific Reproducibility of Life

As a result of their division of labour, while Marx focussed on the social sciences (political economy), Friedrich Engels developed his dialectical assessment of technoscience in treatises such as *Anti-Dühring* and *Dialectics of Nature*, resulting from

[2] This line of thinking was taken up by another dialectical thinker, Teilhard de Chardin (Chap. 7).

his fascination with the natural sciences, in combination with his resurging interest in the work of "old Hegel".

According to Engels, the three most important revolutionary developments in nineteenth-century science were (a) thermodynamics, (b) the theory of evolution and (c) the physiology of the cell. Rather than specific research topics, these three breakthroughs entailed a comprehensive dialectical view on nature. Thermodynamics addresses the relationship between energy, movement and force, seeing nature as ἐνέργεια, as being-at-work, with energy transforming from one form into another, eventually giving rise to the concept of entropy and its negation: "negative entropy", i.e. life (the tendency to develop and maintain high levels of complexity and to resist disorder for extended periods of time). Evolution entails the idea of an inherent conflict within every living entity (e.g. between nature and nurture, genome and environment, sensitivity and immunisation, between adaptation to and modification of the environment, etc.), giving momentum to growth and development (Duran-Novoa et al., 2011; Vincent, 2016). Dialectics is the philosophy of how evolution operates, and evolution theory is itself a dialectical phenomenon: a research program which continues to develop (spiralling between gradualism and catastrophism, quantitative and qualitative change), resulting a comprehensive understanding of the origin and future of life. Last but not least, cell research addressed the basic metabolism of life as such, because the cell is the basic structural and functional unit of all organisms, the *concrete universal* of life, so that cell research culminates in the question "What is life?"

Against this backdrop, Engels became especially interested in what he saw as the molecular (noumenal) essence of life, namely proteins or, more specifically, albumin (*Eiweiß*), seeing life as the mode of existence of living substances. I will begin with a short recap of Hegelian dialectics, focussing on those aspects that are most crucial for developing a dialectical materialist understanding of contemporary technoscience. Subsequently, the outlines of a dialectical materialist understanding of technoscience as a research practice will be fleshed out, building on Engels, but also on later (scientific) authors who were inspired by his writings, e.g. life scientists such as Haldane, Needham and Bernal. Next, I will consider the criticism raised against Engels's dialectics by some twentieth-century Marxists. And finally, I will flesh out a dialectical diagnostic of contemporary technoscience, shifting the focus from artificial albumin as "living matter" (as *discussed* by Engels) to contemporary research on synthetic cells (as *anticipated* by Engels). Engels' view on the technoscientific reproducibility of life will therefore serve as case material for practicing dialectics of technoscience today.

Dialectics of Science and Nature as a Research Program

Friedrich Engels developed his dialectics of science and nature in his correspondence with Karl Marx, but more systematically in his *Anti-Dühring* (1878/1962) and in *Dialectics of Nature* (1925/1962a), a collection of notes and manuscripts which he left unfinished. Dialectics, for Engels, is the science of the laws of motion and development of nature, society and thought (1878/1962, p. 11, 132). The Marx-Engels correspondence (1983) served as a dialectical laboratory where important scientific developments were quite regularly discussed. These epistolary exchanges addressed a broad range of scientific topics, from Justus von Liebig's and James Johnston's work on organic and agricultural chemistry via Darwin's *The Origin of Species* up to John Tyndall's experiments on light scattering.

Engels began his dialectical analyses of science in the late 1850s, building in the work of Hegel. In a letter to Karl Marx (July 14, 1858), he announces his intention to reread Hegel to find out to what extent the latter anticipated recent progress made in the natural sciences, notably in physiology (e.g. cell biology) and chemistry. In this letter, Engels already outlines how he sees the cell as the Hegelian being-in-itself and the living organism as the realisation of the "idea" of life, while comparative physiology demonstrates how quantitative changes give rise to qualitative leaps (Marx & Engels, 1983 II, p. 326). Unfortunately, Engels' extensive research efforts were significantly hampered by competing time-consuming activities, not only his professional work at the offices of Ermen & Engels in Manchester, but also the posthumous editing of Volumes II and III of Marx' *Capital* (Hunt, 2009). The question addressed in this chapter is, to what extent Engels's dialectical views are still relevant for addressing recent developments in contemporary technoscience. My objective is to update dialectical materialism by raising a question comparable to the one addressed by Engels in the nineteenth century, namely: how to assess contemporary technoscience from a dialectical perspective? What would a dialectics of contemporary life sciences research amount to? How to *practice* dialectics of science and nature *today*?

Engels's dialectics of science and nature (as a research program) resulted in four core texts:

- *Dialectics of nature*, a collection of manuscripts written between 1876 and 1878 and published posthumously in 1925 (Engels, 1925/1962a)
- The Marxist classic *The Anti-Dühring* (*Herrn Eugen Dührings Umwälzung der Wissenschaft*) dating from the same period, written between 1876 and 1878 and published in 1878, after having been serialised in the German socialist periodical *Vorwärts* (Engels, 1878/1962).
- *Socialism: utopian and scientific* (*Die Entwicklung des Sozialismus von der Utopie zur Wissenschaft*), first published in 1880 and based on excerpts from the Anti-Dühring (Engels, 1880/1962).
- *Ludwig Feuerbach and the End of Classical German Philosophy*, written 1886 and published the same year (Engels, 1886/1962).

These documents reflect at least two over-arching trends in Engels's scholarly activities. First of all, his return to and resurging interest in the work of "old Hegel",[3] the

[3]A phrase used by Marx and Engels in their correspondence, cf. Engels's letter to Marx of December 3, 1851 and Marx's letters to Engels of August 19, 1965 and March 25, 1868 (Marx &

philosophical hero of his youth, from the late 1850s onwards, a development which concurred with a similar "return to Hegel" in Marx.[4] Secondly, a growing interest in the quickly progressing natural sciences,[5] an interest which he, again, shared with Marx during this same period, although whereas the latter predominantly focussed on fields such as agricultural chemistry (Justus von Liebig, James Johnston, Henry Carey) and mathematics (as reflected by his extensive notebooks on differential calculus),[6] Engels mainly occupied himself with physics, (organic and inorganic) chemistry and biology.[7]

In the writings listed above, Engels aspired to come to terms with what he considered as the three decisive scientific discoveries of the nineteenth century (Engels, 1886/1962, p. 294), namely: (a) the discovery of the laws of thermodynamics (conservation of energy and increase of entropy); (b) the theory of evolution; and (c) the discovery of the structure and function of the cell. All three discoveries revolve around the question of life, as we have seen. The cell is the basic structural unit of living entities: the prototypical realisation of the idea of life as such. As to thermodynamics, one could argue that, dialectically speaking, whilst the first law represents conservation as the *first* dialectical moment (M_1), which is *negated* by entropy (conceived as *negativity*, i.e. as the *second* dialectical moment, M_2), then life (more concretely: a microbe or a living cell) represents the *negation of the negation*: the third dialectical moment (M_3). Indeed, life is "negative entropy", as Erwin Schrödinger phrased it (Schrödinger, 1944/1967; cf. Zwart, 2013) to capture the astonishing ability of living systems to maintain and reproduce high levels of complexity, and to withstand environmental entropic pressures for extended periods of time. Finally, the theory of evolution represents the *historical* dimension of life, urging us to see life as something which is perpetually in flux and continuously changing.

In the context of these research activities, Engels devoted special attention to what he saw as the molecular or *noumenal* essence of life, namely proteins or, more

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Engels, 1983 I, p. 292; II, p. 289; IV, p. 34). Also in his letter to Albert Lange (29.3.1865) Engels confesses his "deep feeling of piety and devotion for the titanic old fellow".

[4] See for instance Marx & Engels, 1983 II, p. 275, 326. Marx used Hegel's dialectical logic as a scaffold for designing the structure of *Das Kapital* (Marx & Engels, 1983 III, 393–402; Arthur, 2004).

[5] In his correspondence with Engels, Marx underscored the socio-economic importance of the scientific work of, for instance, Humphry Davy and Justus von Liebig (cf. Bernal, 1936).

[6] Hegel was already dissatisfied with the conceptual vagueness of the calculus. Are differentials *dy, dx* finite quantities, are they zero, do they represent an intermediate state between being and nothing, so that vanishing is their truth? This vagueness symptomatically reflects the tension between the continuous and the discrete, between physical movement and mathematical symbols. Differentials seemed chimeric, minimal magnitudes, caught at the moment of their disappearance. The impact of Marx's work was limited due his insufficient awareness of the developments concerning the calculus in the nineteenth century (Kennedy, 1977).

[7] Engels intensely acquainted himself with the natural science after stepping down from commerce and moving from Manchester to London, where he went through process of re-education in mathematics and natural science: a thorough scientific "moulting" ("Mauserung", 1878/1962, p. 11; Hunt, 2009, p. 288). An important influence was the "red" chemist Carl Schorlemmer (1879), a close friend of both Marx and Engels (Benfey & Travis, 1992).

specifically, albumin (*Eiweiß*). As will be discussed in more detail below, Engels basically saw life as the mode of existence of proteins. Whereas abiotic, inorganic entities are damaged and destroyed by entropic metabolism, in living entities metabolism is incorporated and transformed into sustainable biochemical processes. Engels' thoughts about proteins and cells evidently built on Hegel's philosophy of nature, notably the latter's dialectical analysis of the chemical process (Hegel, 1830/1986, § 326 Z, p. 292; § 335 Z, p. 333) where he argues that the chemical process is an analogue of life in the sense that, if the chemical process would continue spontaneously, it would be life.[8] Indeed, there is a glimpse of vitality in the chemical process (Hegel, 1830/1986, § 335 Z; Ferrini, 2011, p. 208), but contrary to inorganic chemical processes, which do not renew or reproduce themselves on their own accord, Hegel argues, life is a self-renewing chemical process made perennial.

Last but not least, Engels already predicted that, one day, scientists will be able to produce proteins artificially (*in vitro*) in their laboratories. And if they succeed in doing so, he argued, these artificial proteins will undoubtedly exhibit the phenomena of life (e.g. organic metabolism), however weak and short-lived these may be.[9] In other words, Engels anticipated (on various occasions) the creation of artificial life in the laboratory as the inevitably "end" (dialectically speaking) of modern biochemical research.

Precisely this latter development is currently evolving from "utopia" to "science", as Engels once phrased it (1880/1962). For indeed, at this very moment, scientific research consortia are trying to build synthetic cells in man-made laboratories. As a (dialectically inspired) philosopher of science, I myself happen to be actively involved (as a principal investigator) in one of these projects, namely the BaSyC project, an acronym which stands for *Building a Synthetic Cell*.[10] As indicated above, the question addressed in this chapter is, to what extent Engels's dialectical views are still relevant today, notably for philosophers who aim to come to terms with the conceptual implications and socio-cultural consequences of synthetic cell research, as a high-profile, trans-disciplinary and cutting-edge area of inquiry (Zwart 2017). I intend to revivify dialectical materialism as a philosophical methodology by raising a question comparable to the one addressed by Engels in the nineteenth century, namely: how to assess contemporary cell research from a dialectical perspective? What would a dialectical assessment of contemporary life sciences research amount to? How to *practice* dialectics of science and nature *today*?

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[8] "Der chemische Prozess ist so ein Analogon des Lebens. Könnte er sich durch sich selbst fortsetzen, so wäre er das Leben; daher liegt es nahe, des Leben chemisch zu fassen" (Hegel, 1830/1986, § 326 Z, p. 292); "Wenn die Produkte des chemischen Prozesses selbst wieder die Tätigkeit anfingen, so wären sie das Leben. Das Leben ist insofern ein perennierend gemachter chemischer Prozess" (§ 335, p. 333).

[9] "Wenn es je gelingt, Eiweißkörper chemisch darzustellen, so werden sie unbedingt Lebenserscheinungen zeigen, Stoffwechsel vollziehen, wenn auch noch so schwach und kurzlebig" (Engels, 1925/1962a, p. 560).

[10] http://www.basyc.nl

Assessing the relevance of Engels's writings for contemporary philosophy of technoscience proves a challenging issue, first of all because his "dialectics of nature" became a highly controversial endeavour, especially within Marxist discourse itself (Sheehan, 1985/2017; Kangal, 2019). A relatively large number of Marxist scholars explicitly dismissed it, often favouring a Mach-like or neo-Kantian approach to science instead. Therefore, the multiple controversies raised by Engels' writings up to this day cannot be ignored.[11] Moreover, Engels developed and published his ideas during the 1870s and 1880s, and the life sciences evidently experienced a series of dramatic revolutionary transitions since then. Therefore, rather than "applying" Engels' views, these sections will amount to an exercise in *extrapolation*. Although I will start with the question how Engels himself used dialectics to analyse scientific research concerning the phenomena of life during his own era, the core question will be the one already brought forward above, namely: how to be a dialectical philosopher of natural science or technoscience *today*? What would a contemporary dialectics of nature, focussing on synthetic cells (as a symptomatic case study, reflecting broader technoscientific trends) amount to?

The structure of the remainder of this chapter is as follows. I will begin with a short recapitulation of Hegelian dialectics, focussing on those aspects that are most crucial for developing a dialectical materialist understanding of contemporary technoscience. Subsequently, the outlines of a dialectical materialist understanding of technoscience as a research practice will be fleshed out, building on Engels, but also on later (scientific) authors who were inspired by his writings, e.g. life scientists such as Haldane and Bernal. Next, I will consider the criticism raised against Engels' dialectics by some twentieth century Marxists. And finally, I will flesh out a dialectical diagnostic of contemporary technoscience, shifting the focus from artificial albumin as "living matter" (as *discussed* by Engels) to contemporary research on synthetic cells (as *anticipated* by Engels).

[11] "Engels was at the root of whatever was wrong with Marxism. With few exceptions, the argument against Engels had now become a virtual orthodoxy, perhaps best summarised in Norman Levine's *The Tragic Deception: Marx contra Engels* (1957)" (Rees, 1994). Besides the many Marxist authors who vehemently criticised Engels, there are many others who systematically ignore him. In Slavoj *Žižek's Less than nothing: Hegel and the shadow of dialectical materialism* (2012/2013), for instance, Engels is not even mentioned, while in *Absolute recoil: towards a new foundation of dialectical materialism*, his name appears only once, in a quotation borrowed from Lenin (Žižek, 2014/2015, p. 1), although some phrases may implicitly refer to Engels, such as the remark that the idea of a tension or contradiction between Hegel's dialectical method and Hegel's system – discussed below – is "ridiculous" (2012/2013, p. 195). Supporters of Engels (Bernal, Haldane, Levins and Lewontin, etc.) often have a scientific background. Rather than "applying" dialectics to physics or biology, they adopted dialectics as their scientific method, acknowledging that science is inherently dialectical (Royle, 2014).

Engels' Dialectical Materialist Rereading of Hegel

As Hegel explains in the Introduction (*Einführung*) of his *Phenomenology of the Spirit* (Hegel, 1807/1986): whereas the sciences study natural phenomena (natural processes and entities), thereby developing a (fragmented and partial) phenomenology of nature, philosophy is the science of science: a *phenomenology of scientific experiences*. Hegel develops a systematic and comprehensive perspective on nature by discerning a dialectical unfolding in the interactions of scientific subjects (researchers) with their scientific objects (natural processes and entities). As explained in Chap. 2, while science is about knowing or understanding natural objects, philosophy aims to understand the process of knowing as such. It is a critical assessment of the ways in which particular forms of knowledge, emerging at particular moments in history, allow nature to reveal itself. Dialectics is the systematic exposition of scientific research practices as they appear on the scene, tracing the journey of consciousness passing through various configurations or stations of knowledge towards more comprehensive forms of understanding. Thus, dialectics entails *knowing about knowing*: a phenomenology of scientific experience.

Dialectically speaking, moreover, science (as a methodological, self-critical endeavour aspiring to come to terms with nature) is inherently dialectical, even if practicing scientists themselves are not always aware of this, because it relentlessly challenges, contradicts and eliminates its own results, in order to reach a more comprehensive level of understanding. Science is never satisfied with its own outcomes. It is a zealous, unhalting process which finds no satisfaction in existing forms of knowledge but is driven by an inherent unrest, continuously disturbing and spoiling its own satisfaction: a relentless drive to move farther. Existing science is rational, certainly, but this does not mean that scientists are already there, for what is rational about science is first and foremost the scientific method. Dialectically speaking, science is not a collection of facts and insights, but a *process*, a practical endeavour, a *praxis*, whose actual results will only remain temporarily valid. Even the most robust insights will be challenged sooner or later by new findings, – spurred on by technological innovations, as Engels will later emphasise. Science progresses through stages and, although all these stages are necessary and inevitable as such, none of them is final. From a dialectical perspective, scientific knowledge production is a process of becoming, continuously unfolding. All existing knowledge forms will evaporate sooner or later, but the rationality and necessity of this (seemingly haphazard) dynamics can be dialectically grasped.

At the same time, dialectics acknowledges a stabilising tendency in science, namely the tendency to integrate multiple partial knowledge fragments into a coherent, encyclopaedical *system.* Therefore, two apparently juxtaposed dimensions can be discerned: on the one hand the drive towards a theoretical processing and systematic assembling of available research results, and on the other hand the impetus (no less forceful) to challenge, negate, overcome and defreeze these integrative efforts, seeing current knowledge systems as temporary episodes. This tension is also discernible in the edifice of Hegel's own oeuvre (Engels, 1886/1962), which on the one hand strives to develop a comprehensive and encyclopaedic *system* of knowledge (the "conservative" dimension) while this system is at the same time challenged and negated by the dialectic *method* itself (the "progressive" dimension).

Whereas the scientific revolution continues to unfold, outdated insights become spectres and sediments of knowledge, as living science continues to progress farther. Sooner or later, all forms of knowledge will be negated, sublated and transformed. As Engels phrases it, dialectics is not only a phenomenology, but also a "palaeontology" of knowledge (1886/1962, p. 269), seeing the present as the temporal outcome of a long history,[12] about to give way to newly emerging and proliferating landscapes of research. The Hegelian claim that "*all* that is *real* is *rational"* applies to science insofar as existing theories are exemplifications of the scientific method. Yet, sooner or later, their validity will be undermined, they will be exposed as misguided, or only partially reasonable, and therefore unreal (bound to become mere history). Indeed, *all* that comes to be, deserves to perish wretchedly (Engels, 1886/1962, p. 267), as Mephistopheles already proclaimed, and this also applies to science. For Engels, even Hegel's own impressive encyclopaedic system was but a temporary edifice. Sooner or later, it will become a monument of the past, while science as a dialectical praxis continues to unfold, by overcoming the next crisis.

Dialectics is a method of thinking which starts from the awareness that *thinking itself* is subject to a process of becoming. This evidently also applies to dialectics, so that the dialectical method is not a static, but a dynamical procedure which must continuously be refined and transformed. By implication, Engels's version of dialectics, although building on Hegel, at the same time aims to transform and enhance it, to assure that dialectics remains up to its task of effectively addressing the challenges of the dawning era. This requires a thorough understanding of Hegel's thinking, for dialectical materialism is a transformation *from within*. The force of dialectics consists precisely in this creative tension or interaction between the system-building trend (the systematic effort to preserve existing knowledge fragments by developing them it into a consistent, comprehensive view) and the dialectical method (the awareness that this edifice of knowledge itself is constantly under pressure and besieged by emerging disruptive developments).

Hegel's prediction about the end of philosophy was correct, Engels argues, in the sense that modern science will indeed abolish philosophy. Philosophy must and will resurge, however, albeit no longer as a separate field (practiced at a safe distance from the turmoil of active scientific research), but as philosophy *in* science, sublated by and preserved as an *inherent* self-reflective dimension of the scientific enterprise (1878/1962, p. 129). Philosophers should be self-consciously *there* where science happens.[13] For Engels, philosophy is a dialectical and critical reflection on the dynamics of scientific research as such. If we see traditional philosophical

[12] Cf. Hegel: "Vor der Wissenschaft liegt der reiche Inhalt, den Jahrhunderte und Jahrtausende der erkennenden Tätigkeit vor sich gebracht haben" (1830/1986, p. 28)

[13] Cf. Hegel: "Das Prinzip der Erfahrung enthält die unendlich wichtige Bestimmung, dass … der Mensch selbst dabei sein müsse… Er muss selbst dabei sein … mit seinem wesentlichen Selbstbewusstsein" (1830/1986, § 7, p. 49).

contemplation as the first moment of the knowledge production process (M_1), which was negated, disrupted and marginalised ("dethroned") by modern scientific research (M_2), the end result will be a negation of the negation: a resurgence of philosophical reflection, but now as an inherent dimension of scientific praxis (M_3). The science-philosophy divide will become sublated, allowing philosophy to become more relevant and up-to-date, while science becomes more comprehensive and advanced (cf. Bernal, 1937). Our current world-view materialises in technoscientific research, while research feeds and transforms our emerging worldview.

This is also the basic message conveyed by Hegel's dialectic of Master and Servant as we have seen. The Master (initially in control) represents philosophy-as-contemplation, producing abstract *universal* knowledge, in contrast with the hands-on experiences of the Servant. Eventually, however, the practical knowledge concerning *particular* aspects of nature produced by Servants (in an interactive, experimental manner, through research-as-praxis) will prove much more powerful and effective than the lofty contemplations of the Master who, instead of transforming nature, develops a more passive form of contemplation: a worldview. Thus, the initial supremacy of the Master will by subverted by the practical and transformative know-how of the Servant, who actively puts an end to his "bondage" ("Knechtschaft") via epistemic emancipation (Engels, 1925/1962a, p. 480). Dialectically speaking, empirical science represents the emancipation of the labouring Servant vis-à-vis abstract contemplation (as a privileged but unworldly form of *otium*). Servants explore and interact with nature more directly, through their experimental work, developing powerful tools to effectively manipulate *concrete* natural objects, both inside and outside their laboratories. In terms of Hegel's logic, this development reflects the dialectical unfolding from abstract universal knowledge (*das Allgemeine*, A), via experimental exploration of particular aspects of nature (*das Besondere*, B), towards the creation and modification of concrete entities (*Einzelheit*, E), as materialisations of the technoscientific approach to life.

Dialectics of Science and Nature

As indicated, Engels's aim was to update Hegelian dialectics by focussing on the practical and material aspects of technoscientific research. The dialectics of science and nature which results from this, still builds on Hegelian dialectics, whose great merit had been to see the world (natural, historical as well as intellectual) as a process.[14] Yet, in contrast to Hegel, dialectical materialism stresses the hands-on, interactive dimension of human thinking, the *technicity* of science, up to the point of acknowledging that science inevitably evolves into *technoscience*, – even though he doesn't literally use this term. In Engels's writings on scientific inquiry, there is a

[14] Engels explicitly praises "Hegels System, worin zum ersten Mal – und das ist sein großes Verdienst – die ganze natürliche, geschichtliche und geistige Welt als ein Prozess [begriffen wird]" (1880/1962, p. 206).

consistent emphasis on experimental praxis and on the disclosing and transformative role of scientific and industrial contrivances and instruments.[15]

Dialectical materialism endorses Hegel's claim that the laws of dialectics not only apply to technoscience, but also to nature as such. The natural sciences are inherently dialectical because dialectics represents the *subjective* analogue of the *objective* dialectics at work in nature (Engels, 1925/1962a, p. 331; cf. Schweiger, 2011, p. 28). In other words, dialectics applies both to the subject pole (technoscience) and to the object pole (nature) of the knowledge production process. At the subject pole, the emphasis is on technoscientific research as a form of *labour* (Lefèvre, 2005), as a technological *praxis* as we have seen, highly dependent on advanced *means of knowledge production* such as microscopes, telescopes and spectroscopes. At the object pole, the emphasis is on movement, as life itself evolves via conflict and contradiction towards higher levels of complexity. Science continuously develops: gradually, but also via dramatic leaps (when quantitative accumulative growth enables qualitative change and disruptive transition). Motion is the mode of existence of matter in general and of living matter in particular, and this applies both to chronic motion (metabolism) and to diachronic motion (evolution).

Engels' most famous work in this area is the Marxist classic *Anti-Dühring* (1878/1962). As Engels himself points out, what began as a polemical essay quickly evolved into an extended "positive" (p. 6, 8) exposition of the dialectical method, applying it not only to history and economics, but also to science and nature. The *science* pole and the *nature* pole (the subject and the object pole) should not be seen as compartmentalised from each other, but rather as inevitably *interpenetrating* each other, for while science allows the natural world to appear in a certain manner, the objects of research challenge researchers to develop their contrivances and approaches in a certain direction.

In 1877, in a letter to Franz Wiede, Engels wrote that, as soon as he had finished with criticising Dühring, he would concentrate all his energies on a larger work that he had planned for years, in order to demonstrate that the laws of dialectics apply both to human society and to nature (Griese & Pawelzig, 1986). This immense project combined a rereading of Hegel with an intensive journey of exploration through the evolving natural sciences, both theoretically and practically (e.g. in chemical industry), resulting in a thorough intellectual "moulting". Engels worked on it from 1873 up to 1882, resulting in almost 200 textual fragments and addressing three key issues from a dialectical perspective: the dialectical *history* of the natural sciences, the dialectical *logic* of scientific inquiry, and a criticism of one-sided (i.e. undialectical) scientific positions. Thus, he aimed to overcome both bourgeois metaphysics

[15] This evidently contradicts the views of Lukács who proclaimed that "Engels' deepest misunderstanding consists in his belief that the behaviour of industry and scientific experiment constitutes praxis in the dialectical, philosophical sense. In fact, scientific experiment is contemplation at its purest" (1923/1971, p. 132). Due to lack of proximity, Lukács misunderstands the basic logic of experimental laboratory research, a practice which, as Claude Bernard explains, combines theoretical contemplation (θεωρία) with hands-on, manual modification (πρᾶξις): in laboratory practice "il serait impossible de séparer ces deux choses: la tête et la main" (Bernard, 1966, p. 27).

(thinking in terms of dichotomies, e.g. humans versus nature, mind versus matter, etc.) and scientific empiricism (i.e. the neglect of theoretical thinking), and to replace it with a dialectical approach, emphasising the continuous interaction between science and society, theory and practice, experiments and reflection, heredity and environment, etc. and the alternation of quantitative (evolutionary) and qualitative (revolutionary) change.

As Hegel already argued, dialectical laws can be discerned both in scientific experiences concerning nature (the subject-pole of the knowledge production process) and in nature as such (the object pole, where countless instances of contradiction and sublation can be pointed out). The chemical process as such, for instance, is an inherently dialectical process (Hegel, 1830/1986, § 326 ff.; 1831/1986). Basically, Engels aims to demonstrate that scientific research is an *inherently dialectical* endeavour that will significantly benefit from the *conscious* and *systematic* application of dialectical insights and methods. His aim was to save dialectics by rescuing it from the constraints of bourgeois idealism, transporting it to the realm of natural science instead (1878/1962, p. 10). Dialectics will allow science to emancipate itself: from the dogmas of traditional metaphysics (frozen into scientific concepts), but also from the scientific tendency towards fragmentation and empiricism, at the expense of genuine insight (1878/1962, p. 14).

According to Engels, again explicitly building on Hegel, three basic dialectical laws can be distinguished (1925/1962a, p. 348): (a) the law of the transformation of quantity into quality and *vice versa*; (b) the law of the interpenetration of opposites; and (c) the law of the negation of the negation. Engels' exemplifications of the first law are borrowed directly from Hegel's work. Increasing or decreasing the temperature of water, for instance, is an incremental, quantitative change, Engels explains, until a point is reached at which water suddenly becomes transformed into steam or ice: a qualitative transition (1878/1962, p. 118). Another example he often uses are carbon compounds, where the addition of elementary components (C, H, O) to a particular compound will bring about qualitative change (p. 119). Whilst a certain amount of carbon dioxide is a necessity for life, too much of it transforms it into a poison, and so on.

As to the second law, multiple examples have already been given, such as the interaction between subject and object. Natural science is a relentless productive interaction between science and nature. Technological research practices allow natural objects to emerge, while the object of research (say, a living cell) determines the tools, approaches, mind-set and intentionality of the laboratory subject. Another example is the opposition between heredity and environment (between nature and nurture). Dialectically speaking, it would be one-sided to understand living organisms solely in terms of heredity or genetics (claiming that organisms *are* their DNA, their genomes), but it would likewise be one-sided to see them solely as products of their environment (claiming that organisms *are* the product of environmental factors).[16] Rather, life results from the constant interaction and interpenetration of

[16] The latter position would later (quite un-dialectically) be defended by Trofim Lysenko.

both dimensions (heredity and adaptation). Likewise, in chemistry, analysis and synthesis are often regarded as opposites (as processes moving in juxtaposed directions) but in actual laboratory practice, the one is highly dependent on the other, as synthesis (recombination) presupposes analysis (*Zerlegung*) and vice versa.

Also the third dialectical principle (the negation of the negation) was discussed earlier. A dialectical process starts from an initial situation or first moment (M_1), for instance: the rural communism practiced by self-sufficient villages in the pre-industrial past (Engels, 1880/1962, p. 2015). As Marx explained in *Capital*, the rise of capitalism obliterated this rural world, so that farmers were expropriated and forced to migrate into urban areas as battle zones, where a Darwinian struggle for existence raged (Engels, 1880/1962, p. 216): a process which represented the second moment, of negativity and disruption (M_2). It involved, among other things, a separation (estrangement) of production and consumption, as food products were no longer produced collectively by consumers themselves (in villages), but in factories, as commodities, so that consumers from now on had to buy these food products (e.g. industrially produced bread, beer, canned meat, etc.) on the market (Zwart, 2000). Traditional agricultural and artisanal know-how was replaced by scientific knowledge (mathematics, chemistry, logistics, human resource management, etc.) to rationalise and increase the pace and scale of the food production process. Yet, although industrial production *seems* rational, it actually results in anarchy and contradictions (e.g. highly competitive food markets, environmental pollution, waste, social disruption, etc.). Therefore, a third moment (the negation of the negation) becomes inevitable (M_3), which will amount to an expropriation of the expropriators (Engels, 1878/1962, p. 124): the confiscation of the means of production by the working classes and consumers. Scientific knowledge will no longer be the property of the owners (the bourgeoisie), but common knowledge, freely accessible and consciously employed to optimise the agricultural system in terms of equity and sustainability.

A similar dialectics is discernible in nature as such, however. According to Engels, the whole of geology is a series of negated negations (1878/1962, p. 127), as mountain ranges emerge in response to strains in the earth crust, resulting in increased weathering and accumulation of sediments, resulting in new strains etc. (cf. Bernal, 1936; Royle, 2014). But we may also use the development of natural organisms as example, say: a plant. The seed containing the program of life (the "concept" of life; "heredity", M_1) is exposed to a hazardous, entropic environment (the vegetative version of the trauma of birth) which threatens to negate and eliminate this fragile life form (M_2), unless the plant manages to *use* this threatening environment as a resource for growth and protection (the *negation of the negation*), thus growing into an adult form, as the concrete realisation of the *idea*, so that two antagonistic forces (nature and nurture, heredity and environment) are reconciled, functioning complementary to each other. Living entities *need* this dramatic interaction between both components (heredity and environment, nature and nurture) to flourish and thrive. Indeed: they basically *are* (the product of) this interaction.

From Bourgeois Metaphysics to Dialectics of Science

From a dialectical perspective, Engels argues, Hegel must be credited for having developed the dialectical method, understanding both the natural and the cultural world as processes of becoming (1878/1926, p. 22), but he also remained an idealist (p. 23), envisioning history (including the history of science) primarily as a dialectical unfolding of *ideas* which realise themselves in the course of time, in the form of episodes or stages, challenging, negating and sublating each other. In contrast to Hegel, dialectical materialism emphasises that thinking (*Bewusstsein*) is determined by being (*Sein*; Engels, 1878/1962, p. 25). This means that scientific convictions and ideas are shaped *in interaction with* nature, under specific socio-economic conditions, in the context of actual research practices in laboratories and industries. Scientific ideas emerge in particular historical settings: they reflect and materialise the *technicity* of science, i.e. the *means of knowledge production* developed to enable researchers to effectively address practical challenges. Science is a praxis, and scientific research means *practicing* science. It is hard work, involving both intellectual and menial components (both brain-work and active manipulation). The industrial revolution owes much to science, but the reverse is also true: science (notably chemistry) owes much to the industrial revolution and thrived because of it (cf. Lefèvre, 2005). Engels points to the connection between thermodynamics and the use of steam engines, for instance, while telescopes were initially developed for military purposes, but he also sees mathematics as grounded in concrete human activities and bodily practices. For him, mathematics is the product of a long history of active engagement with nature (1878/1962, p. 36). It is only in bourgeois metaphysics that mathematics is conceived as something pure, axiomatic and abstract, so that the idea arises that a line is a point moving through empty space (p. 37), ignoring the grounding of mathematical theory in geodesy and other earthly pursuits. Even mathematical terms like "body" (used for three-dimensional forms, e.g. cube, sphere, etc.) etymologically imply materiality and physicality (p. 38), while the calculus allowed scientists to study processes of continuous change experimentally. It is no coincidence of course that "laboratory" literally means workshop, a locality designed for fabricating knowledge (Zwart, 2019b).

Modern science means: understanding by doing, reflecting a shift (in the history of knowledge) from hands-off (aristocratic) contemplation to hands-on (interactive) experimentation. Bourgeois ideology, however, is hampered by a split consciousness (*Zerrissenheit*), because it separates practical innovation ("applied research") from "pure" science (the science version of aesthetic disinterestedness, of *l'art pour l'art*). This split is connected with a whole series of similar compartmentalisations (between science and society, basic and applied research, intellectual and menial activities, etc.). From a dialectical materialist perspective, however, labour (the use and development of technologies and machines) is a necessary precondition for producing scientific knowledge claims, even allegedly "pure" ones. This already applies to Aristotle, Engels argues, a thoroughly dialectical thinker (1880/1962, p. 202) who combined philosophical speculation with natural history and anatomy (discovery by doing). Although bourgeois consciousness tends to underestimate the importance of (what is denigratingly referred to as) the Middle-Ages, it was during the (late) medieval period that the first industries were created and the first machines were produced, while new instruments became available for experimentation (Engels, 1886/1962, p. 279; 1925/1962a, p. 457, 462), resulting in the collaboration of monastic scholarship and craftmanship (notably instrument making, cf. Pannekoek, 1951/1961; Zilsel, 2003). Moreover, whereas the early modern era (when the bourgeoisie still represented a progressive factor) was a period of revolutionary fervour,[17] during the seventeenth and eighteenth centuries many bourgeois thinkers opted for lofty ("disinterested") contemplation rather than hands-on experimentation, so that in the eighteenth century, genuine dialectical works typically emerged outside philosophy proper (in the writings of Diderot and Rousseau for instance, 1880/1962, p. 202) while it was only in the nineteenth century that the first truly scientific laboratories were created (by Justus von Liebig and others). Bourgeois thinking tends to see nature as a collection of separate entities (things), rather than as a systemic, dynamic and evolving process (p. 203). The question whether something is alive, for instance, is not a matter of Yes or No, Engels argues, for living and dying are complex, protracted processes, so that metaphysical, scientific or legal attempts to discern a clear caesura between the two are bound to falter (p. 204).

The emphasis on praxis not only applies to the context of discovery, but also to the context of validation and justification, moreover. For Engels, the ultimate proof of the validity of knowledge is provided when we are not only able to understand and predict, but also to actively manage, reproduce and recreate natural processes in our laboratories and industries (Engels, 1925/1962a, p. 497). The artificial, technological reproduction of natural processes *in vitro* is the ultimate test of the validity of scientific theories. Rather than positing a divide between thinking and being, or between theory and practice, the starting point of dialectical materialism is the unity of theory and praxis brought about by experimentation, putting theories to the test experimentally, and further developing them through experimental trials. Indeed, conducting an experiment means using nature to put our concepts to the test, revealing how nature itself likewise unfolds in accordance with dialectical patterns.[18] Science is not a body of knowledge, but first and foremost a practical endeavour, a systematic interaction with the unfolding environment. The subject and the object pole of the knowledge production system interpenetrate each other via the means of knowledge production: scientific instruments handled by scientists which allow the

[17] Again, Engels discerns a dialectical process here: the medieval period sets in with the fall of Rome and the elevation of Constantinople (M_1), but is itself eliminated/negated during the fall of Constantinople (the moment of negativity: M_2) which, paradoxically perhaps, unleashes a return to Greek philosophy and science in Western Europe: the Renaissance as negation of the negation (M_3).

[18] "Die Natur ist die Probe auf die Dialektik, und wir müssen es der modernen Naturwissenschaft nachsagen, dass sie für diese Probe äußerst reichliches, sich täglich häufendes Material geliefert und damit bewiesen hat, dass es in der Natur, in letzter Instanz, dialektisch hergeht … dass sie eine wirkliche Geschichte durchmacht" (1878/1926, p. 22; 1880/1962, p. 205).

world to appear in a certain manner, as modifiable molecules and organisms for instance, and this allows researchers to produce *reproducible* knowledge. From a dialectical materialist perspective, there is no divide but rather continuity between laboratories and factories, as well as between universities and industries, and the concept of pure knowledge is a bourgeois fiction. Even logical categories do not exist as pure axiomatic mental entities but rather as ideas that realise and optimise themselves in practice.

Whereas bourgeois metaphysics is imprisoned in mental activities (thinking, consciousness, ego-centric meditations, the mind-body problem), the technicity of technoscience opens up the noumenal dimension of nature: the basic molecular processes of life, energy and matter. And contrary to what bourgeois authors (including Eugen Dühring) claim, thinking is not something we do as individuals. Rather, for Engels, thinking relies on what nowadays would be referred to as distributed intelligence: it is a collective activity involving millions of individuals, dispersed through space and time (Engels, 1878/1962, p. 80). Constricted ideas produced by single, isolated individuals should be regarded with critical suspicion. At the subject pole, dialectics studies the dialectical unfolding of research programs, which inevitably constitutes a tale of tensions, anomalies and contradictions, where existing knowledge systems (displaying the tendency to freeze into certain modes of thinking), are disrupted and pushed forward by the development of even more powerful and precise machines, whose ground-breaking discoveries may enforce dramatic revisions of dominant ideas (Engels, 1878/1962, p. 82). And at the object pole, dialectics allows us to see nature not as a series of chance events, but as processes in which dialectical laws are at work and dialectical patterns can be discerned (Engels, 1878/1926, p. 11).

Contrary to the splendid isolation propagated by bourgeois metaphysics, Engels contends, philosophy should no longer be considered a separate field standing apart from science (1878/1962, p. 24; 1880/1962, p. 207). Rather, philosophy should be practiced as an integrated endeavour. “Pure” philosophy has become irrelevant and futile. The end of (bourgeois) philosophy is at the same time a new beginning, however. Similar to how social philosophy should be practiced in close connection with political activity, the philosophy of science and nature should likewise be practiced in close interaction with actual research endeavours, fostering the further development of the dialectical method. Philosophy of science should become philosophy *in* science, using the dialectical method to bring the dynamics of scientific progress to the fore. And again, modern science is not only a dialectical process itself, but also reveals the dialectical logic inherent in the natural processes it studies.

Dialectically speaking, three moments can be distinguished in the history of thinking. During the initial situation (M_1, exemplified by Plato and others), philosophy was seen as contemplation, far removed from practical interaction with nature. This is reflected in the Platonic view of nature as perfectly harmonious and balanced, a view which must have been quite at odds with the experiences of artisanal and agricultural labourers of ancient societies, working hard to mould and domesticate nature in a hands-on manner (Zwart, 2009). During the scientific and industrial revolutions of the nineteenth century, however, philosophy seemed to be *negated* (dethroned and marginalised) by science and technology (M_2). As a third moment, dialectics represents a reconciliation in the sense that it reveals how science unfolds in a dialectical manner by disclosing the dialectical processes at work in nature. The opposition between science and philosophy is sublated as dialectical materialism becomes dedicated to the task of revealing and critically assessing the metaphysics that is unconsciously at work in scientific research. And this reconciliation represents the dialectical "end" of a long history of estrangement (Engels, 1878/1926, p. 14).

In ancient Greece (M_1), many Greek thinkers already were materialists and dialecticians (1878/1926, p. 14) and even in modern history many examples of "spontaneous" dialecticians can be found.[19] Overall, however, bourgeois metaphysics[20] (represented for instance by British idealism, e.g. Berkeley, Hume, etc.) tended towards negating materialism and dialectics (M_2). The existence of an external material world was put into question by idealism and solipsism, while nature was seen as completely deterministic: a world in which nothing (nothing spontaneous or unpredictable) could ever happen. Moreover, bourgeois thinking posited a series of insurmountable divides, between subject (the ego of solipsism) and object (the thing-in-itself), between society and nature, between *is* and *ought*, between fact and value, between social science and natural science, etc. This position is now itself negated by dialectical materialism, which represents a return of materialism, not in the ancient contemplative sense, but informed by two millennia of research (1878/1962, p. 129), including the most recent and advanced scientific insights. This dialectical negation of the negation (M_3) will transcend the dichotomies of bourgeois metaphysics, resulting in a reconciliation, of social science and natural science for instance, so that scientists become conscious of the social dimension of their research as a decidedly *social* practice.[21] Dialectics is itself a science: it is philosophy in the form of a science. Its vocation is to consciously develop the dialectical method, but in dialogue and interaction with scientific research practices: discerning, articulating and addressing the dialectical processes at work *in* science.

A similar view was developed by British Marxist Christopher Caudwell (1939/2017), who saw the cleavage between theory and practice (between basic and applied research) as the signature characteristic of "bourgeois" epistemology: ceasing to be interested in matter, while becoming exclusively concerned with the mind

[19] Engels mentions Jean-Jacques Rousseau, for instance (1878/1926, p. 19), who posits an original natural position (M_1) which is negated by the estrangement of modern society (M_2), but bound to resurge on a higher level of social complexity in a future society where the opposition between nature and culture is sublated (M_3).

[20] This label refers to a mode of thinking which sees the world in terms of dichotomies and opposites, e.g. subject versus object, society versus nature, *is* versus *ought*, etc., and in terms of fixed, separate things (or even things-in-themselves) rather than in terms of processes of relentless interactive change.

[21] Cf. Bernal (1937): in contrast with determinism, dialectical materialism explains the emergence of radical new things in nature, such as life and human society, while at the same time showing how science is part of social and historical development, also as a source for generating scientific questions, fostering scientific innovation and discovery.

and with subjective, phenomenal reality (1939/2017, p. 30), while science, on the other hand, became increasingly impersonal. According to Caudwell, during the bourgeois period, while technoscientific practice became increasingly specialised and empirical, theory became increasingly abstract and diffuse, resulting in an amalgam of reductionism and mysticism. Under the sway of bourgeois thinking, while physicists concentrated on matter, philosophers were exclusively concerned with the mind. Thus, the subject-object relationship became the most pressing problem of bourgeois philosophy, closely related to the question whether the external, material world exists at all. Both the object and the subject were stripped of their qualities. The subject vanished (only phenomena and experience existed, p. 63), while the object became the unknowable thing-in-itself, ceasing to exist. This philosophy of contemplation became increasingly estranged from the working masses who actively worked with machines (either in laboratories or in industries). Philosophy lacked the experience of active interaction and struggle with material objectivity, so that philosophy became a marginalised theoretical reserve. Subjectivity likewise eroded as the observer (as a concrete subject) became eliminated (p. 46). Dialectical materialism, Caudwell argued, must supersede bourgeois thinking by rediscovering both the subject (as a brain-worker, operating machines) and the noumenal object (made accessible via technological advances), so that philosophical consciousness becomes restored to activity.

For Engels, this effort to supersede bourgeois metaphysics was part of a historical unfolding which affected both the subject and the object pole of the knowledge production process. As to the object pole: during the initial situation, in ancient Greece (M_1), the focus was on nature in general, on being as a whole, on abstract, general, universal ideas about nature (*Allgemeinheit*, A; Hegel, 1830/1986, p. 57). This holistic view was negated by the *negativity* of modern empirical science (M_2), which amounted to a breaking down, an analysis (*Zerlegung*) of natural phenomena into *particular* components (*Besonderheit*, B). The negation of the negation (M_3), entails a return to the whole in the form of a *systemic* and converging approach, but now on a higher level of comprehension and understanding, focussing on concrete entities which exemplify nature or life as such, e.g. the cell (*Einzelheit*, E). Thus, initial general insights inevitably give way to divergence and contradiction (*Entzweiung*), but these are sublated by a third moment, a return (*Zurückführung*) to concrete convergence (*Einigkeit*) (Hegel, 1830/1986, p. 88).

Dialectical Materialism Versus Bourgeois Epistemology in Twentieth Century Marxism

From the 1920s onwards, Engels's dialectics of science and nature became a controversial endeavour and Engels's project has remained the target of substantial polemics ever since, notably in Marxist circles, and notably among authors who aim to restore "pure" Marxism by cleansing it of what they see as contaminations. The dialectics of nature debate was ignited by prominent authors such as György Lukács and Jean-Paul Sartre[22] (Sheehan, 1985/2017; Sim, 2000, p. 132; Kangal, 2019) and eventually became a "polemical battlefield" (Kangal, 2019), giving rise to a whole "mountain of literature" (Sheehan, 1985/2017, p. 54). Notably Lukács aimed to discredit "the banalities of Engels's version of dialectical materialism" (Feenberg, 2017, p. 111), limiting the dialectical method "to social issues, while leaving the natural scientists to carry on as before" (p. 120). Lukács and his followers saw the very idea of a dialectics of nature as mistaken, stemming from a "retreat to Hegel", and allegedly in "opposition" to Marx (Lukács, 1978, p. 110).[23] According to Lukács, "the misunderstandings that arise from Engels' account of dialectics can in the main be put down to the fact that Engels – following Hegel's mistaken lead – extended the dialectical method to apply also to nature" (1923/1971, p. 24). Dialectics of nature was allegedly "non-Marxian", he and others maintained (Burman, 2018).

These efforts to posit a cesura between Marx and Engels are contradicted by a juxtaposed strand of publications, less visible and less vocal perhaps, but based on a more careful reading I would argue, which emphasise continuity between Marx and Engels, notwithstanding their "division of labour" (i.e. Marx's decision to focus on political economy), both with regard to their intense rereading of Hegel and concerning the endorsement of a dialectics of nature. Both in his writings (including *Capital*) and in his correspondence with Engels, Marx stated his conviction that dialectics, including Hegel's discovery of the law of transformation from quantitative into qualitative change, is attested by history and the natural sciences alike (cf. Marx's letter to Engels, 22 June 1867; MECW 42, p. 385; Stanley, 1991; Griese & Pawelzig, 1995), while in *Capital* he refers to chemistry, for instance, to explain dialectics.[24] While there is no evidence that Marx disagreed with Engels's project, there is plenty of evidence to the contrary (Royle, 2014; Hundt, 2014; Blackledge, 2017). The claim that Marx "did not share" Engels' interest in the natural sciences (Thomas, 2008, p. 1) is evidently mistaken, and the suggestion that Marx (unlike Engels) would adhere to endorsing a humanity vs. nature dualism is misguided,

[22] On December 7, 1961, Jean-Paul Sartre participated in a famous debate in Paris before a large audience (Sartre et al., 1962) to criticize Engels and defend the thesis that the laws of dialectics only apply to mental and social processes, so that there can be no such thing as a dialectics of nature. In *Critique of Dialectical Reason*, however, Sartre had argued that organisms negate their negations, and develop dialectically, by rejecting and excreting the disruptive forms of negativity which they themselves engender. Sartre here defines need as the negation of the negation (overcoming the lack which hampers to organism to function), pointing out that also other animals besides humans develop tools to overcome that which opposes their project of integration (Sartre, 1960/2004, p. 83, 85).

[23] In Volume 3 of *The Ontology of Social Being*, however (his unpublished Nachlass as it were), Lukács reconsiders his position, now praising Aristotle's, Hegel's and Engels' dialectical understanding of labour (Lukács, 1980).

[24] Already in his thesis, Marx practiced what he consistently preached, as his thesis already amounted to a close dialectical reading of ancient Greek atomism and a dialectical interpretation of the declination of the atom (Stanley, 1989).

since Marx (like Engels) consistently emphasises the interaction and metabolism between both. And yet, as Kangal phrases it, no other work has been subject to as much conflict and chaos in Marxist scholarship than Engels' *Dialectics of Nature*. It is not my purpose to present a full overview of this debate, of course, but I cannot wholly ignore it either. A dialectical materialist perspective on *contemporary* science must position itself against this turbulent backdrop. Therefore, a concise resume of this debate will be presented, albeit from a dialectical materialist position. As a starting point of the debate, I will use the Marxist classic *Materialism and Empiriocriticism* published by W.I Lenin, a staunch supporter of Engels, in 1908 (Lenin, 1908/1979).

In *Materialism and Empiriocriticism*, Lenin aims to update Engels's dialectics of nature through a polemical review of the theories of Ernst Mach, Richard Avenarius and other "empiriocriticists" (Lenin, 1908/1979). In terms of style and structure, Lenin's book echoes Engels' polemical review of Eugen Dühring's work (1878/1962). The empiriocriticists where progressive authors who aimed to develop a new epistemology (a new theory of human understanding) to replace pre-scientific, "metaphysical" conceptions with science-compatible ones, but Lenin's purpose is to demonstrate that they were much less progressive than they thought, because they actually articulated a bourgeois epistemology.

Empiriocriticists regard "sense data" (i.e. impressions, observations, sensations, affections and the like) as the primary starting point of human knowledge and reject the materialistic ("metaphysical") idea that these impressions are produced in us by material things existing in the outside world, independent of human consciousness. There is *nothing* beyond experience, they argue, no environment without a subject who experiences it. By positing the existence of things beyond sensation, materialism gives rise to an unnecessary duplication ("Verdopplung") of the world (p. 13). The material world posited by materialism is discarded as a mystification. According to Lenin, however, by regarding objectivity as a mere product of human subjectivity (by considering the world as a product of human consciousness), these empiriocriticists "plagiarise" (p. 35) the views of eighteenth-century bourgeois idealist George Berkeley, who already denied the existence of an outside world, considering it an illusion and claiming that *being* equals *being-perceived (Esse est percipi*). Our experiences and sensations are produced in us: not by external things (via our sense organs), Berkeley argued, but by God. In short, according to the empiriocriticists, we only experience experiences ("Wir Empfinden unsere Empfindungen", p. 35), while things are merely seen as "complexes of experiences". The world basically is what I experience ("Die Welt ist meine Empfindung", p. 61). The existence of non-thinking substance outside human consciousness is systematically eliminated (p. 17, 51).

According to Lenin, however, dialectical materialism should hold on to the existence of a material world independent of human consciousness. We experience the existence of external reality primarily by interacting with it, in an active, practical manner, via labour, Lenin argues. Human praxis (labour) is our primary source of experience, and this convinces us that the world out there really exists. At the same time, Lenin is clearly aware of the crisis raging in contemporary physics, due to revolutionary discoveries such as X-rays and radioactivity. The material world (e.g. the atom as a basic material entity) seems to evaporate, to dissolve into radiation. Thus, whilst being aware of the challenge to update dialectical materialism, Lenin nonetheless argues that *materialism* should remain the starting point.

A dialectical unfolding can be discerned in this debate, in which the first moment (M_1) is represented by pre-modern metaphysics (say, Aristotle and his medieval followers: Scholasticism), where the soul is considered to be the form of the body. For Aristotle, a concrete living entity is the realisation of an idea. This mode of thinking was negated during modernity, however. The modern metaphysical position was inaugurated by Descartes who developed a dualistic view – dividing the world into the ego (human consciousness) as a "thinking thing" (*res cogitans*) surrounded by extended things (*res extensa*), thus introducing a compartmentalisation between mind and body, as well as between mind and matter (although Spinoza would subsequently argue that the world is one substance, a thinking and extended whole, with two attributes known to us, namely thought and extension, mind and body). This second moment (M_2) was pushed towards its extreme by Berkeley's solipsism, who dropped the existence of external material reality altogether and solely focussed on his own mind. As Lenin argues, Empiriocriticism can be considered a fin-the-siècle update of this radical bourgeois stance. By claiming that we only have access to the world of sense data, the existence of a material world independent of and predating human consciousness is *negated* and discarded as a metaphysical illusion. We are not entitled to posit the existence of things outside (independent of) human experience. M_2 entails the *negation* of the material dimension of the world.

The challenge, dialectically speaking, is to reach a higher level of comprehension via a *negation of the negation* (M_3), i.e. a position which *negates* and *sublates* both pre-modern metaphysics (M_1) and bourgeois idealism (M_2), thereby *overcoming* both antithetical positions. To do this, we must come to terms with the revolutionary and unsettling insights produced by twentieth-century science. Rather than relapsing into pre-modern metaphysical conceptions, dialectical materialism aims to develop a science-compatible version of materialism. Dialectically speaking it is clear that both opposites or antagonists – both traditional (naive) materialism and idealism – have something in common. They both take the phenomenal world of human experience as their starting point, and the issue at stake is whether or not it is admissible to posit the existence of a material world beyond human consciousness. With the help of powerful mathematics and highly advanced technologies, however, modern science has opened up completely unknown and unimaginable dimensions of the material world, far beyond the confines of human understanding: the extremely small world of molecules, atoms and elementary particles (studied by modern chemistry and quantum physics) and the extremely large world of galaxies evolving in spacetime (studied by astrophysics). It is only by coming to terms with science in both directions (the hyper-small and the hyper-large) that dialectical materialism may develop a "sublated" understanding (a negation of the negation).

To phrase it in contemporary terms: this third position neither opts for traditional materialism (since the material world as we know it from every-day experience, and as it is studied by classical physics, is obliterated and eliminated by quantum physics, molecular life sciences research and astrophysics) nor for idealism or Empiriocriticism (the initial "negation" which is now itself negated by this third position). Contemporary technoscience discloses an unknown world existing beyond the reach of unaided human consciousness and sensitivity, a world which is unimaginable and imperceptible for us, which defies the basic structures of human experience and is only accessible via advanced mathematics and scientific technicity. Lenin's book, one could argue, represents a moment of transition, hovering somewhere between M_2 and M_3. He emphasises (in a polemical manner) the shortcomings of Empiriocriticism, is clearly aware of the need for a third dialectical step, but without really being able to realise this step himself because, unlike later authors such as Haldane and Bernal, he studied this debate in libraries and was not really physically *there* as far as technoscience was concerned.

Dialectically speaking, the second moment represents bourgeois epistemology (M_2). Starting point is the ego, which not only gives rise to an egocentric political philosophy (e.g. an ideology of individual autonomy and social contracts, of original positions and egocentric self-sufficiency, reflected by the Robinson Crusoe theme, etc.), but also to an egocentric epistemology: the idea that the world *is* what *I* experience. While Empiriocriticism is a radical version of this idea, a basic affinity can be discerned with Kantianism and neo-Kantianism as well. Kant had posited the concept of the thing-in-itself (the noumenal dimension of objectivity, beyond the phenomenal realm of human experience) as something which is inaccessible to human understanding (Kant, 1781/1975). Idealism (Empiriocriticism) merely took the final step: if the noumenal thing-in-itself is unreachable, why not get rid of it altogether?

From a dialectical materialism perspective, however, this debate now takes a completely different turn as we are confronted with the results of contemporary technoscience. After the fin-the-siècle scientific revolution (the discovery of the electron, the emergence of quantum physics, of relativity theory, of genetics, of molecular life sciences research, etc.), the noumenal dimension of nature has been effectively revealed with the help of advanced technicity (e.g. contrivances such as elementary particle colliders, radio telescopes, spectroscopy, etc.). Technoscience as a praxis has effectively disclosed the noumenal realm of natural processes and entities (of protons and quarks, of nucleotides and amino acids, etc.). It has opened up the basic molecular structure of life and matter. Our understanding of materiality has been radically transformed and sublated, so that our conception of materiality as such (from Higgs-bosons up to stellar formations) has been uplifted, reaching a higher plane of complexity and comprehension (M_3), and the same applies to our bio-molecular understanding of living systems. In short, although our understanding of matter has dramatically changed since the days of Friedrich Engels, the existence of an external world as such (the core issue of bourgeois metaphysics) is no longer our major concern. It is marginalised into a purely academic quandary, because the noumenal structure of reality has effectively been made intelligible by technoscience as an interactive research praxis, continuously interacting with matter and nature in an experimental manner (high-tech scientific experimentalism as a particular mode of human praxis). Building on Engels, a dialectical materialism perspective would emphasise the role of scientific experimental *labour* in this endeavour, which put an end to futile bourgeois speculations (bourgeois mind games).

Dialectically speaking, although scholars like Lukács claimed to endorse a dialectical view on human society, they reverted to a bourgeois perspective as far as the realm of science and nature was concerned. These scholars worked in libraries rather than laboratories, quite remote from the actual world of scientific research (Sheehan, 1985/2017). Taking Engels as their key source of inspiration, a genuine dialectical materialist perspective on contemporary science was developed by dialectical scientists such as Haldane, Bernal and Needham in the 1930s, in whose writings the tensions between the *library* and the *laboratory* perspective on science and nature were sublated and integrated into a comprehensive, genuinely dialectical view.

In Marxist discourse, however, this endeavour (the development of a dialectics or dialectical materialist view of nature) remained a contested undertaking. Lukács (1923/1971) was probably the first but certainly not the last Marxist scholar who viewed the application of dialectics to nature as problematic (Kangal, 2019, p. 218), arguing that dialectics should be limited to the realms of history and society, as the dynamics of contradiction and antagonism should allegedly be seen as a social, not a natural phenomenon.

Dialectically speaking, however, this is an untenable position, first of all because dialectics urges to move beyond such "bourgeois" oppositions (nature versus society, natural science versus social science, etc.). Moreover, the view of nature opened up by the natural sciences in the twentieth century reveals a remarkably dialectical series of processes, abounding in dialectical antagonisms and contradictions. Novelty emerges in nature because of the internal contradictions and crises of previous states (Bernal, 1937). Organic life (as "negative entropy") is something inherently dialectical, consisting of constantly emerging and resolving biotic processes (Engels, 1878/1962, p. 112). Take for instance the theory of evolution (one of the three key discoveries of the nineteenth century, according to Engels as we have seen) where the debate concerning the question whether nature evolves in a gradual (Darwinian) fashion or in a leap-like fashion (via catastrophes, disruptive transitions, etc.) has been overcome (sublated) by the punctuated equilibrium theory developed by dialectical biologists Stephen Jay Gould and Niles Eldredge (Eldredge & Gould, 1972; Rose, 1997; Gould, 2002, p. 745 ff.; Clark & York, 2005), reconciliating both moments on a higher level of comprehension, arguing that nature (comparable to human society and history) evolves *both* incrementally *and* through radical transitions. Or, to stay closer to the work of Engels, take the development of a natural organism, say a plant. The seed containing the program of life ("heredity", DNA) is exposed to a hazardous, entropic environment which threatens to negate and obliterate this fragile life form, unless the plant manages to *use* its environment as a resource for growth and protection (the *negation of the negation*), so that two antagonistic forces (nature and nurture, genome and environment) eventually complement each other. As was already indicated above, living entities basically *are* this dialectical interaction. The technicity of modern science takes us far beyond the type of experiences provided by our natural sense organs (as products of evolution).

Rather, it opens up the noumenal, molecular "essence" of living systems. But to really and convincingly address this issue, we have to shift our focus towards a concrete dialectical assessment of an actual research practice; which is precisely what the final section of this chapter purports to do.

From Artificial Proteins to Synthetic Cells

Life, according to Engels, is the mode of existence of proteins (*Eiweißkörper*),[25] characterised by the constant self-renewal of the chemical constituents of these proteins, a conception which echoes Hegel's view of life as a self-renewing chemical process made perennial, discussed above. Egg-white (*Eiweiß*) is a term which Engels uses here in its modern chemical-industrial sense, as a general denominator for the larger family of protein substances (1878/1962, p. 76).[26] Wherever we find life, we find proteins and vice versa. Proteins represent *noumenal life* or life "*an sich*", they are the essence of "naked life" (p. 76). The lowest living beings known to us are aggregates of proteins and they already exhibit all the essential phenomena of life: they absorb and appropriate substances from their environment and assimilate them, while other substances disintegrate and are excreted: a process known as metabolism. Non-living bodies also change or become involved in chemical combinations (e.g. metals which oxidise and rust), but they thereby cease to be what they were. In living entities, this constant interaction with the environment (a cause of entropic destruction in non-living bodies) is transformed into a fundamental condition of existence (Engels, 1878/1962, p. 76). As soon as metabolism seizes, they decompose and die. Paradoxically therefore, life is in a constant state of flux, being every moment both itself and something else, as a result of processes which are self-implemented and inherent to life. Hence it follows that, if chemistry ever succeeds in producing proteins artificially from chemical components (Engels, 1878/1962, p. 67, 76), these substances must display phenomena of life (metabolism, growth,

[25] "Leben ist die Daseinsweise der Eiweißkörper" (1878/1962, p. 75). The term *Eiweiß* may be translated either in a general sense (as *protein*), or in a more specific sense, as *albumin*: the type of proteins egg white contains.

[26] "Eiweißkörper im Sinn der modernen Chemie, die unter diesem Namen alle dem gewöhnlichen Eiweiß analog zusammengesetzten Körper, sonst auch Proteinsubstanzen genannt), zusammenfast" (Engels, 1878/1962, p. 76). Proteins are macromolecules consisting of extended chains of amino acids and performing a vast array of functions within organisms. They were first described by the Dutch chemist Gerardus Johannes Mulder in 1838 (Harold, 1951), who discovered that these substances had the same empirical formula ($C_{400}H_{620}N_{100}O_{120}P_1S_1$) (Perrett, 2007). Prior to "protein", which is derived from ancient Greek and means primary (primary substance), other names were used such as "albumins" or "albuminous substances" (*Eiweißkörper*), derived from "albumin" (egg white).

etc.),[27] however weak these may be, provided scientist find out what the right nutrition for such a substance would be.

Engels perceives life from a dialectical position. Initially, we know life from every-day experience and contemplate about it (M_1), but at a certain point, a more active and experimental approach is adopted, so that living entities are taken apart, dismantled and analysed. This analysis (*Zerlegung*) entails an element of violence, resulting in the *obliteration* of living entities, a process which reveals the *negativity* of experimental science (M_2). In order to understand life, scientists systematically destroy (negate) it in their laboratories, in order to find out that living substances, which we know from every-day experience, actually consist of molecular substances called *proteins*, which can be analysed further, so that their chemical composition is revealed. The inevitable third step, dialectically speaking, is the negation of the negation (M_3). Starting from a *general* understanding of life (A), but proceeding on the basis of accumulated knowledge concerning *particular* aspects of life (B), scientists will eventually try to reconstruct living matter (proteins) *in vitro*. The final aim inevitably will be to technologically reproduce proteins: putting the basic components together again to produce something which is a *concrete whole*; – something like an artificial cell, the concrete universal of life (E).

This same line of thinking, developed in *Anti-Dühring*, can also be encountered in *Dialectics of Nature*. In nineteenth-century biology, Engels points out, the discovery of the structure and function of the cell with the help of advanced microscopes revealed that cells indeed constitute the basic realisation of the concept of life. Meanwhile, in chemistry, through complementary processes of analysis and synthesis, scientists not only discovered the basic molecular constituents of living (organic) matter, but were also able to produce organic compounds *in vitro* that hitherto had only been produced in living organism (*in vivo*), starting with urea, thereby bridging the gap (the ontological divide) between inorganic and organic nature, which Kant had considered to be insurmountable (Engels, 1925/1962a, p. 318). And while biochemists are working hard to understand life in their laboratories, palaeontologists disclose immense palaeontological "archives" which one day may help us to understand the origin of life on Earth (p. 322).

As to the subject pole, paleo-anthropologists reveal the crucial role of tool use and labour in the process of anthropogenesis, the coming into being of human societies and the self-formation of humankind (p. 322), starting with the discovery of the transformation of mechanical motion into heat: i.e. the generation of fire by means of friction (Engels, 1925/1962b, p. 106), and eventually arriving at its counterpart: the transformation of heat into movement via steam engines. Humans are self-made, Engels argues, and the most important product of human labour is humanity as such, most notably the human hand (1925/1962b, p. 445), which coevolved with the human brain (p. 232). Technoscientific research itself still exemplifies this formative interaction between the human hand (active experimental

[27] "Und daraus folgt, dass, wenn es der Chemie jemals gelingen wird, Eiweiß künstliche herzustellen, dies Eiweiß Lebenserscheinungen zeigen muss" (1878/1962, p. 76).

manipulation), the human brain (the organ of thinking) and the natural environment, in order to produce viable knowledge concerning the natural world, although modern science has of course moved far beyond Palaeolithic conditions by developing a conscious *organisation* of the knowledge production process. Whereas Greek thinkers conceived of nature as a whole, modern research involves an active processing of nature, applying the laws of dialectics, albeit often in an "unconscious" manner. But conscious dialectics would optimise this process and result in a more comprehensive view, provided Hegelian dialectics is turned upside down ("umstülpen", p. 335), transforming it from an idealistic approach (focussed on concepts) into a materialist approach (focussed on how these concepts materialise in concrete research practices, in concrete interactions with life and matter).

In the nineteenth century, science resulted in three decisive discoveries as we have seen: the discovery of the cell, the laws of thermodynamics and evolution (p. 468). One big challenge is still awaiting us, Engels argues: explaining the origin of life out of inorganic nature, but modern chemistry is bound to reach this goal (p. 469).[28] Since the artificial production of urea by Wöhler in 1828, there are in principle no obstacles to progress further towards the production of more complex substances in the laboratory, including proteins (albumen). Once the molecular composition of proteins is known, moreover, scientists will try their hands at producing living protein,[29] so that the chemical process will give way to the process of life and the gap (allegedly insurmountable) between inorganic and organic nature will be bridged (1925/1962a, p. 318, 319). This will affect the subject pole as well, for as soon as chemistry is able to produce proteins, it will become a qualitatively different type of science, namely the science of artificial life (p. 522).

Dialectically speaking, this again represents an unfolding triadic development, from the initial discovery of living cells (M_1), via their chemical analysis (M_2) towards re-synthesis (convergence, *Zurückführung*: M_3). One day, scientists will be able to create life artificially (p. 559), by producing proteins and mimicking metabolic processes. As a result, the basic processes of life will become modifiable in a test-tube. This line of thinking builds on what was already brought forward by "old Hegel" himself, namely that, as soon as the chemical process becomes self-sustainable (becomes metabolism), it becomes life.[30] So-called artificial cells

[28] "Nur eines bleibt noch zu tun: die Entstehung des Lebens aus der unorganischen Natur zu erklären. Das heißt auf der heutigen Stufe der Wissenschaft nichts anderes als: Eiweißkörper aus unorganischen Stoffe herzustellen. Diese Aufgabe rückt die Chemie immer näher" (p. 468/469).

[29] "Sobald die Zusammensetzung der Eiweißkörper einmal bekannt ist, wird [die Chemie] an die Herstellung von lebendigem Eiweiß gehen können" (p. 469); "Gelingt es der Chemie, dies Eiweiß in der Bestimmtheit darzustellen … greift der chemische Prozess über sich selbst hinaus, d.h. er gelangt in ein umfassenderes Gebiet, das des Organismus" (p. 520).

[30] See for instance Hegel's comments about the chemical process in his *Enzyklopädie der philosophischen Wissenschaften II*: "Der chemische Prozess ist so ein Analogon des Lebens. Könnte er sich durch sich selbst fortsetzen, so wäre er das Leben; daher liegt es nahe, des Leben chemisch zu fassen"(§ 326); „Wenn die Produkte des chemischen Prozesses selbst wieder die Tätigkeit anfingen, so wären sie das Leben. Das Leben ist insofern ein perennierend gemachter chemischer Prozess" (§ 335).

created by Moritz Traube in 1864 did not yet represent genuine metabolism, Engels argues, but it did represent a symptomatic step. Once upon a time, environmental conditions on planet Earth must have been such that the first protein aggregates could arise spontaneously and evolve into primeval primitive organisms. And one day, in modern laboratories, such conditions may again be reproduced *in vitro*.[31]

Thus, Engels can be credited for having predicted the emergence of efforts to create artificial life in vitro as an inevitable step, eventually resulting in the creation of synthetic cells, as an important dialectical endpoint (turning-point) in the history of science. He thereby prepared the ground for a dialectical assessment of contemporary technoscience, exemplified by projects committed to building a synthetic cell and similar endeavours. A number of dialectical authors, notably scientists, already contributed to the extrapolation of dialectical materialism to contemporary science, such as for instance J.B.S. Haldane (1938/2016) who is still famous for his contribution to the primordial, prebiotic soup hypothesis, which states that life arose gradually from inorganic molecular building blocks, e.g. amino acids. Building on Engels, he defined a number of methodological principles for a dialectical understanding of scientific research, such as the primacy of practice over theory (seeing research first and foremost as a *praxis*, a systematic experimental interaction with nature, building on the conviction that knowledge claims should be tested and validated *in practice*). Another principle is that nature should not be considered as a collection of things, but rather as a series of processes. Science is about change and relies on technological contrivances to study these transformative processes with due exactness and precision. Moreover, science itself progresses in a dialectical manner as well, via the negation and obliteration of existing viewpoints. Currently (in the 1930s), Haldane argued, science is bridging the gap between inorganic and organic nature, between chemistry and biology, for instance via the study of viruses: entities which consist of pure nucleic acid (the noumenal essence of life *as such*) contained in a protein capsule. The metabolic processes of life consist of anabolism and catabolism, of building up and breaking down, as opposites which actually must be seen as complementary and as part of the living cell as a concrete, comprehensive whole. And now that the basic constituents of living systems are being explored, the question arises: how to put Humpty Dumpty together again (p. 98)? Increasingly, partial components of living systems will prove replaceable, even in the case of humans, whose organs may one day be replaced by artificial substitutes (a practice currently known as tissue engineering). Genes are beautiful exemplifications of the dialectics (the creative antagonisms) in nature, Haldane argues, containing a program which is constantly trying to adapt to the environment and vice versa, so that the program may optimally function in a thriving living being. Contrary to genetic determinism, dialectics sees organisms not merely as passive objects, but as active subjects or agents of evolution, adapting to and at the same time modifying their environment. Plant roots and rhizomes change the structure and composition of the

[31] This idea, the spontaneous origin of life from inorganic matter (*generatio aequivoca*), is also discussed by Marx and Engels in their correspondence (1983 III, p. 339, 437). J.B.S Haldane and Alexander Oparin later developed this idea into the Oparin-Haldane hypothesis.

soil, and networks of interacting living things (the biosphere) changed the planet on a spectacular scale, altering the atmosphere irreversibly by adding oxygen (cf. Levins & Lewontin, 1985; Royle, 2014). Neither organism nor environment can be understood without reference to the other (Royle, 2014, p. 103). They alternately perform the role of agent (A), other (O) and product (P) in dialectical cycles (as explained in Hegel's analysis of the chemical process, above).[32]

This reflects a dialectical dynamic. Initially, living entities are seen as stable, balanced wholes (M_1) and the phenomena of life are addressed on a general or *universal* level. Aristotle, for instance, is interested in life as such, in the conceptual understanding of life (*das Allgemeine*: A), although in his anatomical research he began to introduce rudimentary differentiations between particular groups of species (e.g. animals with lungs versus animals with gills). Modern scientific analysis focusses on *particular* processes and dimensions, such as, for instance, heredity or the environment (*das Besondere*: B). Here, multiple antagonistic factors and forces are actually at work: productive tensions between heredity and environment, anabolism and catabolism, growth and equilibrium, etc. (M_2). Finally, we will come to understand how these antagonisms converge into concrete living entities such as living cells, functioning and maintaining high levels of complexity as concrete unities (M_3). Thus, the living cell is the *concrete* realisation of the idea of life (*Einzelheit*: E). And to really understand the living cell, one final step has to be made, namely the technical reproduction of a minimal or artificial cell *in vitro*.

This same idea is further developed by Friedrich Engels in his treatise *Ludwig Feuerbach and the End of Classical German Philosophy* (1886/1962). Again, he argues that bourgeois metaphysical convictions, such as the idea of an insurmountable gap between subject and object, between phenomenal experiences and things-in-themselves, between living and non-living entities, between organic and inorganic nature, etc. must be overcome by experimental labour in laboratories and industries: by science as praxis. Indeed: the ultimate validation of the dialectical materialist conception of natural processes can be achieved by actively reproducing biotic organic entities ourselves, in laboratories and factories. That would finally put an end to the Kantian "thing in itself."[33] Biochemical substances remain "things in

[32] For Joseph Needham, a biochemist and historian of science, specialised in science history in China, dialectics applied both to natural and societal processes. Thus, he emphasised the dialectical nature of natural phenomena such as muscle contraction (Chen, 2019). He saw nature as a series of dialectical syntheses. "From ultimate particle to atom, from atom to molecule, from molecule to colloidal aggregate, from aggregate to living cell, from organ to body, from animal body to social association... Nothing but energy (as we now call matter and motion) and the levels of organisation (or the stabilized dialectical syntheses) at different levels have been required for the building of our world" (Needham, 1943, p. 15). Living organisms and their environment are as inextricably interlaced as science is with society and its history. Indeed, as Needham phrases it, Marx and Engels set "Hegelian dialectic within evolving nature" (1983, p. 15; cf. Nappi & Wark, 2019).

[33] "Wenn wir die Richtigkeit unsrer Auffassung eines Naturvorgangs beweisen können, indem wir ihn selbst machen, ihn aus seinen Bedingungen erzeugen, ihn obendrein unseren Zwecken dienstbar werden lassen, so ist es mit dem Kantschen unfassbaren "Ding an sich" zu Ende. Die im pflan-

themselves" only until biochemistry can artificially produce them, one after the other, because then these processes and substances become things *for us*.[34]

Dialectics also helps us to come to terms with the enigma of the origin of life. Under current terrestrial circumstances, life can no longer emerge spontaneously (*generatio aequivoca* seems no longer possible) because life emerged as a third moment in a dialectical unfolding. Initially, primeval organisms (aggregates of living albumin as Engels phrased it: M_1) emerged, able to withstand their entropic, abiotic, anaerobic environment (M_2) which threatened them with destruction. These budding life forms became increasingly able not only to survive, but also to thrive and to use their primeval environment (now known as the primordial soup) as a resource for development and growth (M_3). In the present situation, biotic, aerobic environments effectively block such a trajectory. Indeed, as Levins and Lewontin phrased it, the primary requirement for the origin of life is now the absence of life (1985, p. 46). Under current circumstances, fragile neo-life requires a gnotobiotic, fully controlled environment, which can only be provided by the purified ambiances of technoscientific laboratories (Zwart, 2019a). Thus, the synthetic cell emerges as the concrete realisation of the *technoscientific* concept of life, and as the reconciliation of self-conscious reason (i.e. technoscience) with the reason (logos) inherent in existing nature.[35]

But precisely this may also prove a weakness. Should the experiment succeed, the initial experience of success will probably be short-lived: a fate which befalls most if not all the triumphs of scientific inquiry. Before long, discontent will set in, in the form of the *experience* that, apparently, we have missed something and that these artificial ("fake") cells fail to fully grasp and reproduce the astounding complexities of living systems, so that the synthetic cell will only prove a temporary station on the long and winding pathway of the dialectical unfolding of scientific consciousness. This *particular* triumph will be negated, but rather than clinging to this *particular* trial (and the – apparently constricted – understanding of life on which it built), technoscience will doubtlessly desire to progress farther. As a positive result, the inevitable experience of *Enttäuschung* will inform and enable the development of even more advanced programs and efforts to realise a negation of this negation in the future.

Ultimately, the dialectical objective (the envisioned *end result*) remains the will to *supersede* the disruptive divergence between technology and nature, thereby making biotechnology sustainable and bio-compatible again. In the course of the industrial revolution, bourgeois technoscience developed into a detrimental

zlichen und tierischen Körper erzeugten chemischen Stoffe blieben solche "Dinge an sich", bis die organische Chemie sie einen nach dem andern darzustellen anfing; damit wurde das "Ding an sich" ein Ding für uns" (Engels, 1886/1962, p. 276).

[34] Cf. Bernal (1937): scientists of today are learning to manipulate life very much as their predecessors learned to manipulate chemical substances, so that life ceases to be a mystery and is becoming a utility.

[35] Cf. Hegel, "den höchsten Endzweck der Wissenschaft [ist] die Versöhnung der selbstbewussten Vernunft mit der seienden Vernunft, mit der Wirklichkeit hervorzubringen" (1830/1986, § 6, p. 47).

technological power of epochal impact, critically affecting the metabolism between human society and the natural environment. Already in early publications, Engels acutely described how in booming cities such as Manchester (1845/1962, p. 237, 250, 254), techno-industrial disruption resulted in miasmic air, hideous smells (p. 259) and polluted puddles (p. 274), such as the river Irk, which had become a narrow, coal-black, foul-smelling stream, filled with refuse and excrements (p. 282, 295), creating optimal conditions for the spread of infectious diseases such as cholera (Zwart, 2019b). While Engels saw cities themselves as complex processes, rather than as entities (Royle, 2014, p. 100), ecological disruption was a decidedly *global* process, and in *Dialectics of Nature* Engels describes, for instance, how Spanish planters in Cuba, by burning down forests in order to plant their profitable coffee trees, caused tropical rainfall to wash away the now unprotected upper stratum of the soil (1925/1962a, p. 455). While during the artisanal agricultural era (M_1) the metabolism between humanity and nature had remained relatively sustainable, the industrial revolution gave rise to an "ecological rift" (Foster, 2000; Foster et al., 2010): to massive processes of disruption (environmental pollution, soil degradation, urbanisation, alienation) which catastrophically aggravated during the current era of globalisation (M_2). These developments fuelled a revival of Marxist approaches to the current ecological crisis (Foster, 2000; Moore, 2016; Royle, 2019), underscoring the detrimental environmental and biological impact of egocentric bourgeois metaphysics on our global economic and ecological system. Now that global disruption (climate change, mass extinction, ecological destruction) is being pushed to its extreme, the challenge is more than ever to supersede the "*Entzweiung*" between technology and nature, between urban and rural, etc., on a higher level of sophistication (M_3).

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