Anthropocenes
HUMAN, INHUMAN, POSTHUMAN

Machado, I. J. d. R., & Nikolaou, S. (2026). The (Ambiguous) Life of Metals: Chemistry, Metals, and Agency Perspectives. *Anthropocenes – Human, Inhuman, Posthuman*, 7(1): 1. DOI: https://doi.org/10.16997/ahip.1830

RESEARCH

The (Ambiguous) Life of Metals: Chemistry, Metals, and Agency Perspectives

Igor José de Renó Machado* and Sofia Nikolaou†

This paper explores the concept of the agency of metals from an anthropological perspective of chemists working in their laboratories. It delves into the ideas of molecules' behaviours and how they can be interpreted as actants. The paper argues that the relationship between living beings and non-living entities can be surprising from a chemist's perspective and that metals in their various forms, like living beings, are often seen as having behaviours. We also discuss how the behaviour of certain metals is an essential part of life and how the relationship between metals and living beings varies with the levels and scale of analysis. Overall, this paper provides insights into the actancy of metals and their relationship with living beings from the perspective of chemists. Through examples from laboratory experience and teaching chemistry, the paper aims to contribute to the ongoing discussion about the actancy and life of metals.

Keywords: chemistry; metals; agency; anthropology of science; life

Introduction

How can we interpret the actancy[1] and, eventually, the life of metals, following, for example, the laboratories of chemists? From a recurring point of view in these laboratories, molecules have 'behaviours'. These behaviours are seen even as agencies, although without apprehension of consciousness or 'animation'. Therefore, supposedly inanimate substances can have actancy in these scientific research contexts because they have anthropomorphised behaviours. Looking at the relationship between living beings and non-living from the point of view of chemistry confuses our ways of seeing processes.

In this sense, metal,[2] while not a living being, exhibits behaviours similar to those of living beings. Moreover, when we enter the molecular scale and the reflective perspective of chemistry, the opposition between living beings and non-living entities may not make as much sense. The behaviour of metals plays an essential part in planetary life, indicating that the relationship between metals and living beings is very relative to the levels and scale of the analysis. In other words, given a specific scale, there is no difference, and what happens to the metal is an integral part of the specific behaviours of a living being's organism. Based on ex post facto anthropological research (Machado 2019; Machado 2023), we present examples from an inorganic chemistry laboratory and teaching chemistry experiences to discuss the above issues.

According to Almeida (2021), we need to overcome the contrast between radical relativism and scientific naturalism by reaching an agreement that acknowledges both the truth of the scientific consensus and the multiplicity of non-white worlds. Almeida speaks of an agreement between global and local sciences, admitting that local (ontological) sciences are not variations or encompassments of global sciences. Distinct and irreconcilable theories (or cosmogonies) can account for the same things (pragmatic truths) in specific contexts. Thus, multiple worlds can emerge from the same truth (facts, substances, processes). We are dealing with a specific ontology, which Almeida calls 'scientific realism'. The 'pragmatic truth' refers to the place of a metal in the molecular world.

Chemistry and Anthropology

Chemistry is not a very popular subject in anthropology, even for the anthropology focused on studying the sciences. Generally, chemistry topics appear in anthropological literature through Science and Technology Studies (STS), in which they feature prominently, although always in a lower position than physics. In this field, a common theme is the question of chemists' research strategies and their recourse to 'inscribers' (Latour 1990), which are less common in physical science. Chemists used paper-based tools to produce data (before computing became accessible) and three-dimensional models to represent chemical structures. This practice has fascinated researchers in the STS, even though three-dimensional computer simulations have replaced three-dimensional artefacts. This procedure reduces the material representations to the two dimensions of the computer screen, implying a new round of artifices that simulate three-dimensionality (Francoeur 2001).

* Department of Social Sciences, Federal University of São Carlos (UFSCar), BR

† Department of Chemistry, FFCLRP, University of São Paulo (USP), BR

Corresponding author: Igor José de Renó Machado (igor@ufscar.br)

On the other hand, physics and chemistry share the characteristic of the successive production of new acting entities—such as particles smaller than the atom—an unavoidable reference in STS (Stengers 1996; Woolgar & Latour 1997). The sociotechnical process of mutual production between new entities, the paraphernalia of new devices on variable scales, and the researchers themselves is fundamental in organising reflections on the forms of action and existence of science in the contemporary world. Even the capacity of chemistry to imagine and describe entities that 'do not exist'.[3] At the same time, the field of STS has been reflecting on how to make them actors in a sociotechnical network (Ramberg 2001).

The question of the three-dimensional strategy of analysing chemical structures used repeatedly by chemists has attracted the attention of anthropologists. Myers (2008), for example, produced a study on crystallographers and their three-dimensional models of proteins constructed using X-ray diffraction techniques. What draws the attention of Myers (2008), Ramberg (2001), and Francoeur (2001) are chemists' learning strategies and imagination, who, when analysing the three-dimensional structures of molecules, transfer realities from the world of 'paper' (graphs and equations) to a world in three dimensions. In Myers' case, what is emphasised is a bodily representation of the structures drawn on the computer, implying what she calls the 'embodiment' of the research technique in a bodily representation technique that is taught unconsciously in laboratories. These bodily representations would be essential in understanding the structures under investigation.[4] Myers presents the possibility of a connection between the chemists' bodies and the animation they imagine happening in the molecules of the proteins analysed in the laboratory studied: that is, the actance of proteins is embodied by chemists in the ways they talk about and teach their own research. The possibility of this passage, from molecule to body, is in itself a way of imagining the life of molecular structures.

Although this is an essential topic in this small field of study, we consider it less relevant given another dimension that Myers herself indicates when transcribing the speech of a chemist: 'seeing what the structure is saying is difficult' (Myers 2008: 165), or even, 'you have to enter the structure to understand it' (idem.: 187). These two passages give an idea of what interests us here: the recurrently expressed idea that structures are living entities, acting beings that, in a way, think, since to understand them, the researcher has to "enter the structure" in the sense of thinking like them. This sphere of chemical practice inscribes an action in these chemical structures. When we analyse the interactions between metal and living beings or the role of metal within living beings, we are intrigued by what could be perceived as a form of molecular animism.

Anthropologists analyse chemistry alongside other issues, especially the Anthropocene and its production of substances that radically affect the general environment or the health of humans and nonhumans. A relevant dimension in these studies is the notion of pharmakon, which Stengers (1996) took up and was explored by Kirksey (2017) and Shapiro and Kirksey (2017). Pharmakon is a substance that can be both a poison and a cure, in the Greek sense, from which our idea of a 'drug' is derived. Using pharmakon, Kirksey explored the limits of substances used in chemotherapy, from the industrial complexes of production to the practices of care applied to people with cancer. She highlights that the same companies that manufacture drugs to cure a particular ailment are also responsible for producing substances that lead to the development of cancers.

In these cases, the focus is also on what the drugs do to the body (such as cisplatin), thus also moving towards the 'embodiment' of these drugs. From a phenomenological point of view, the focus is on the effects of this sociotechnical network of pharmakon on the body, with changes in the physical senses. However, this field is embarking on a 'chemo-ethnographical' vision that goes beyond the body towards the sociotechnical networks that produce actants, or things—from Ingold's (2012) perspective—by analysing chemical substances, which are usually toxic and produce new realities of destruction and desolation in the Anthropocene. Like in Tsing's work (2015), these chemo-ethnographers analyse the emerging conditions of chemo-social lives. Thus, anthropologists are following new chemical species (reagents, enzymes, and many others) as they produce new ontologies, entities, and agents that emerge from molecular interactions in these new pharmakons of the capitalist world. Scholars like Roberts (2010) and Pandian (2016) have analysed the unintended consequences of producing new toxic realities, which can pollute water with pesticides and medicines.

One of the implications of this perspective, which concerns us here, is a discussion of 'substance'" and how it implies, at the molecular levels that interest us, complexities, frictions, and unpredictability. Bennett (2010: 117) discusses the nature of these substances' life and states that 'in a sense, everything is alive', even if in other dimensions and propensities. The existence of these other forms can be analysed by chemo-ethnography (Povinelli 2016).

Determining what life is or is not and how each of these dimensions converts into the other is remodelled by the perspective of pursuing chemical substances in the contemporary world. Authors such as Thacker (2005) and Abrahamsson et al. (2015) highlight how this analysis of substances in the capitalist world challenges the usual social imaginary, leading to an idea of matter (substance) concerning these sociotechnical universes. Sometimes living, sometimes dead, sometimes neither, sometimes lethal, sometimes remedies, sometimes transformations, sometimes decompositions, sometimes indecomposable compounds, sometimes producers of devastation, sometimes supporting new and unexpected communities. These processes are, in turn, reconfiguring our conditions for existing, knowing, and living in society.

Our goal, based on some examples of chemistry knowledge and its substances, is to understand the dimension of existence—based on the understanding of chemistry—of these substances in the production of life in our usual sense (that is, as organic animal species, we are alive). Considering the different scales and understanding molecular substances as actants, as chemists do, our understanding of life and nonlife will be scrambled. As Shapiro and Kirksey state:

> Considering the full spectrum of dynamics among chemical species – processes of persistence, decay, ionisation, combustion, and sublimation, to name a few – requires moving beyond the bios/Thanatos divide and gazing into the realm of nonlife. (Shapiro & Kirksey 2017: 486)

The proposal here is not precisely chemo-ethnography in the sense of following substances ethnographically (and the worlds they produce). However, it has something similar in thinking about the different scales and complexities of the living entities, the non-living, and 'things beyond'.[5] However, we push beyond traditional proposals for the anthropology of laboratories by thinking about how chemists think about the substances that emerge from their benches and apparatus.

Metals on Other Scales

Now, we will investigate how chemists refer to metals at the molecular level (and other adjacent levels, such as proteins and cells). The following narrative is a discourse by chemistry practitioners on some basic knowledge about the role of metals in the body. We will use this narrative in two senses: one refers to the specific content of chemistry's scientific knowledge or to a chemical cosmology of how the molecular world functions; the other refers to the form of the discourse as an indication of how, in this cosmology, the shuffle between the living entities and the non-living is complex.

Analysing the form is an ex post facto ethnography. Based on 20 years of one of the author's laboratory experience, an ex post facto perspective (Machado 2019) discusses the possibility of constructing ethnographies after the fact (ex post facto), organised by memory—that is, the idea that it is possible to transform an event or series of events experienced in an ex-post ethnographic field. This perspective implies that during the event, it was not known that it was a period of ethnographic fieldwork, and only memory reconstructs the events and facts as an ex post facto ethnography. Thus, this paper's data come from our experience and memory, transformed into an ex post facto ethnography (Machado 2019). It implies that the language of the description of chemical phenomena is an indication of the cosmologies implicit (or unconscious) in this specific scientific practice. Therefore, although all chemists will talk about the behaviour of molecules and how they 'act' and do things such as 'move arms', 'pull things', 'pilot', and 'carry things', not all of them will assume that these entities are, in some sense, alive. However, many would have doubts. In addition, many would say that they are alive in specific contexts and not in others. We will return to this in the following discussion. What follows next is a typical chemist's account of the place of metals in the production of life. This narrative was constructed from an ex post facto anthropology of experiences in chemistry classrooms and inorganic chemistry laboratories.

These examples are not just instances of how chemistry is taught in classrooms and laboratories, but they are carefully chosen to highlight the ambiguities that arise in understanding the life of metals. We present these examples as a textbook narrative to show how future chemists are introduced to these ambiguities. The anthropological implication of these examples is to provoke thought about how the training of chemists can lead to an ambiguous understanding of the life of metals, a theme that permeates their professional experience.

To enter the world of metal chemistry, we first need to briefly discuss how we use the ideas of 'agency' and 'actancy'. Latour defends the most traditional perspective in the STS field, circumscribed in the notion of an actant. An actant is a source of action that can be both human and nonhuman. It has efficacy and can do things, produce differences, have effects, and alter the course of events (Latour 2019). Following Latour's point of view that there is little room for the invisible in science (which would be restricted to a mode of existence of illusions and ghosts), we can see in the chemists' subjective perspectives about the action of metal a parallel to the ghostly mode of existence, right at the centre of the science of the smallest things. This subjectivity brings us to the essential ambiguity we want to explore in this text: that metal appears as a living being (with agency) for chemists at certain moments. At the same time, this life of metals is ambiguous because it does not extend to all situations and realities of metal as a substance. Rather than resolving a dilemma, we want to show that exposing this ambiguity tells us something about the perspective of life or nonlife in contemporary science.

In this article, we consistently use two notions of 'living'. The first refers to things that we generally, in common sense, consider to be alive, such as beings with biological bodies. This is what we call living beings. The second notion, 'living entities', refers to things that can have action and active participation in the world but for which we do not imagine any conscious agency. We use these two categories as an explanatory resource throughout the text. In the end, we will scramble the ideas that relate to actancy, living, and non-living entities, based on the praxis of chemists, with the help of Bennett's (2010) concept of vibrant matter.

The ex post facto narrative we will present below is not just a storytelling device but a powerful tool for capturing the subjectivity of chemists in action. It establishes a connection with Latour's (2007) methodology of phenomenological reduction, which suggests that we can suspend static notions about the world to analyse the relationships between human and nonhuman actors when trying to understand the constitution of reality. This narrative allows us to explore more carefully the complex relationship between the actions of different elements in a social or sociotechnical network. We will see that the narrative implies a doubt about the notion of agency, which we will return to at the end of the article. We reserve the term agency for actions we presuppose that the actors are previously aware of, like the actions of humans. Actancy refers to actions that do not presuppose consciousness. In the case of chemists, we will see that the metal sometimes seems to have agency, at others, only actancy.

The chemical cosmology of metals

In chemistry, it is argued that at least 10 metals are essential to life and that another 40, including radioactive elements, make up the formulation of medicines and contrast agents for diagnostic procedures (Anthony et al. 2020; Barry & Sadler 2014; Jomova et al 2022; Zoroddu et al. 2019). Metal compounds can also interact with biomolecules such as proteins, lipids, enzymes, and DNA by interfering with various metabolic processes.[6] These interactions can alter the biological functions of biomolecules or determine the pharmacokinetic and pharmacodynamic behaviour of metal compounds. These two major areas focus on mobility, transport, and storage behaviour (pharmacokinetics) and how drugs act (pharmacodynamics), including drugs containing metals in their composition.

Beyond the specialised public (chemists, pharmacists, pharmacologists), most metallic elements and their compounds are not even recognised as metals. When recognised as such, they are associated with dead things or things that are toxic, aggressive, and harmful to life. Some compounds containing metals in their composition are toxic indeed. A typical example is the metal mercury (Passos & Mergler 2008). Interestingly, one of the most toxic chemical species with mercury in its composition is called 'dImethyl mercury', in which mercury is not in its metallic state, but it is an organic, fat-soluble molecule that accumulates in our bodies.

Some materials, such as iron, zinc, copper, and nickel, are easily identified as metals. Others, not so much. Sodium and potassium, widely known from discussions about their role in diets, high blood pressure, etc., are metals. There is some confusion about the different ways in which a chemical element[7] occurs. This aspect would be irrelevant to this discussion, except that this confusion can lead one not to recognise the good or bad occurrences of metals concerning life. Take sodium as an example because it is familiar to us. Although metal, it occurs in our diet as a salt,[8] sodium chloride or table salt. In the form of salt, it mediates biological processes such as the active transport of substances into and out of cells, but it can also trigger high blood pressure if its intake is excessive (Rayner-Canham & Overton 2003).

Establishing antagonistic pairs of metal manifestations in dead and living beings is also easy. For example, copper is the electric current conductor metal in the wires of our homes. On the other hand, it is found in the composition of proteins called superoxide dismutases (SODs) that combat oxidative stress[9] in our bodies (Ferreira et al. 2000). In both contexts, it works well due to the very same capacity to transfer electrons. Attributes such as size and shape are also determinants of the chemical and biological behaviour of metal compounds, and the consistency of the behaviours determined by these qualities allows trained chemists, in this case, to plan and obtain desirable actions from these materials.

However, why are metals mainly unknown to people, only known in specific contexts, or even recognised for their deleterious effects, more strongly associated with death (or the absence of life) than with positive aspects? The Periodic Table, the structure that organises and represents all the known chemical elements, shows that out of 118 elements, seven are classified as semi-metals, 19 as non-metals, and all the rest are metals. In other words, more than three-quarters of the known elements are metals. If that is the case, why is all this matter predominantly unknown to us?

In contrast, non-metallic elements, primarily carbon, hydrogen, oxygen, nitrogen, and phosphorus, are always associated with life within the so-called organic chemistry. Note the name: organic. Perhaps because of the name or, on the contrary, because the name originates in perception, matter made up of this other group of chemical elements is associated with 'life'.

A clue to establishing this situation is the various ways metals manifest themselves in matter. It must occur in its electrically neutral form to behave as a metal. An iron bar, for example, comprises metallic iron, i.e., Fe^0 (iron zero). However, all metals take on electrically charged forms. When charged, they combine in highly varied ways with countless other materials, thus giving rise to countless new substances. We are predominantly ignorant of these other substances that contain metals. Metallic iron becomes charged when it combines with oxygen in the air in the process of corrosion, giving rise to rust, which is perfectly familiar to us. It is more difficult to identify that table salt, which we eat daily and are so concerned about because of its so-called 'sodium content', contains a metallic element (in this case, sodium).

Iron, life, and nonlife

Concerning the essentiality of metals for life, for example, our body recognises iron as 'so' essential that it does not have a specific mechanism for its excretion but has an exclusive protein machinery that aims to use, transport, and store it. Given its essentiality, our body understands that, in excess intake, iron cannot be wasted and, therefore, stores it. A marked imbalance in its concentration or some metabolic disorder disrupts the physiological processes regulating the balanced use of iron to maintain life, and it begins to play a harmful role (Milto et al. 2016).

The reversible reaction[10] of iron binding to oxygen forms the basis of our breathing. In the lungs, a protein called haemoglobin captures molecules of $O_2(g)$ ('gaseous molecular oxygen' or simply 'oxygen'). In the other tissues of our body, especially the muscles, it releases oxygen to another protein, myoglobin. Both haemoglobin and myoglobin are iron proteins, and the slight difference in acidity[11] between the lungs and muscles regulates the different affinities of iron for oxygen. The iron in haemoglobin has a high affinity for oxygen due to the physiological acidity of the lungs. This affinity is reduced due to the acidity of the muscles (slightly more acidic), in which the iron in myoglobin has a greater affinity for oxygen and is, therefore, able to capture it (Toma 2015). In other words, the metal iron fundamentally acts in the transport of oxygen from the organ where it is captured by our body (lungs) to the places where oxygen needs to be utilised (other tissues). To do this, iron needs to circulate.

To fulfil its role, iron, assimilated from what we eat, is involved in a complex chain of actions mediated by the so-called iron proteins. These actions happen because the metal iron does not circulate freely in the body in its two common forms: Fe^{3+} (it reads as 'iron-three') and Fe^{2+} (it reads as 'iron-two'). It is ingested predominantly in the form of iron-three and, in this form, circulates in the body but is unable to enter cells. Inside cells, iron must exist in the form of iron-two to circulate.

Iron-two is transformed into iron-three by a protein called ceruloplasmin. In this form, iron has more affinity for an enzyme called transferrin, which, as the name suggests, captures and transports iron out of cells and takes it to places in the body where it is needed. Any surplus iron is, in turn, stored in the form of iron-three in proteins called ferritins. Haemoglobin incorporates iron in the form of iron-two, which is essential for breathing. In the reverse transformation (iron-three to iron-two), the body uses the famous ascorbic acid, which is the chemical name for vitamin C. Over a day, 40 mg of iron is estimated to be transported by transferring to the bone marrow, which synthesises haemoglobin. Approximately 6 mg is stored in ferritins.

Iron depends on the actions of a series of proteins that often contain other metals in their structure to carry out their actions (Yu et al. 2014). For example, one of the enzymes responsible for iron-two/iron-three transformation, ceruloplasmin, contains six Cu^{2+} ions ('copper-two') in its structure.[12] This ballet between iron-three and iron-two is an organism's strategy so that the molecules that perform specific functions (proteins and metalloproteins) can recognise a species for which they have greater chemical affinity and correctly transport, store, or transform it. We have proteins in our bodies that operate as trains, shelves, and reactors, all made up of molecules that mostly contain metals.

In addition to the question of the structural constitution (iron-two/iron-three, a notation that refers specifically to the number of electrons in a metal atom), the shape and size of their different manifestations also matter for executing a specific action. In other words, the three-dimensional aspect, the object with which metals and their compounds are identified, also determines their action. The haemoglobin protein contains four iron-haem groups, each capable of binding to an oxygen molecule concertedly. An iron-haeme group is a portion of the protein with the shape and planarity of a square, with iron-two in the centre. However, due to its size, it cannot fit between the four binding atoms of the haeme centre (atoms of the haeme group itself that make a chemical bond with the iron-two). It is displaced from this plane by approximately 0.040 nanometers (1 nanometer = 10^{-9} meters). This iron also has a fifth chemical bond with a group called imidazole, which acts as an arm linking one haeme group to another. When an iron-two, outside the spatial plane of the haeme group, binds to an oxygen molecule, the chemical effects of this bond decrease its size. Once smaller, this oxygen-bound iron-two moiety fits into the plane of the haeme group, displacing the imidazole arm. This movement works (literally) like a tug, signalling to the second haeme group that it is time for it to bind to a second oxygen molecule, and so on. Chemically speaking, the geometry of the free and oxygen-bound iron-haeme complexes changes, which promotes a movement essential for carrying out the function of haemoglobin.

Zinc and DNA

Zinc, a known metal, is a constituent of a family of proteins called 'zinc fingers' (Cassandri et al. 2017; Toma 2015). Zinc fingers are genetic transcription factors that occur widely in various types of organisms and are the most prominent family of transcription factors in the human genome. These proteins can be described as pilots that guide other larger proteins (the RNA synthases) to specific DNA regions.

Because they have their own characteristic amino acid sequence and chemical affinity, zinc fingers recognise specific points on the DNA to which they direct RNA synthases. The origin of the name zinc finger is not clear. However, this name could be related to the protein's shape and action. The most widely accepted explanation bases its argument on the shape. These 'motifs', common in different contexts, are small proteins that, in technical language, have a secondary structure comprising two beta-sheet, an alpha-helix and a fraction of the random-coil structure. The beta-sheets and the alpha-helix fold and assume parallel positions by binding amino acids to the metal zinc in the form of zinc-two (chemical notation Zn^{2+}). From this folding, the random-coil structural fraction of the protein takes on a 'tubular' shape reminiscent of a finger. Some authors, however, suggest that the term is related to the fact that to translate the sequence of nitrogenous bases encoded in DNA into the right sequence of amino acids in a protein, the zinc-finger proteins need to 'open up', 'tinker with', or 'finger' the three-dimensional structure of the DNA.

Pharmakon metals

Generally, we have the notion that 'chemical compounds' are toxic and harmful. Indeed, many are. However, we must not forget that chemical compounds comprise all existing matter. In the case of metals, this is no different. Many metals are used to treat diseases. As is true for conventional drugs (organic molecules), the dose matters concerning the therapeutic function versus the capacity for intoxication that a metal-containing molecule can present. Therefore, metals are involved in processes closely linked to life and in their support by exercising therapeutic functions, such as cancer treatment (Banerjee & Banerjee 2022).

Platinum, a noble, expensive, and relatively scarce metal, has been used since the second half of the last century to treat various types of cancer, including prostate, testicular, and ovarian cancers, among others. The drug of choice for chemotherapy treatment of some cancer types is called cis-platin. This molecule contains platinum in the form of Pt^{2+} (i.e., 'platinum-two'), and its shape is precisely that of a square with the platinum at the centre, with the planes above and below the molecule completely unhindered. In addition to this characteristic, the cis-platin molecule (as the name suggests by the use of the term 'cis') contains two identical and labile chemical groups on two adjacent vertices of the square, which in chemistry means that these groups are weakly bound to the metal and can therefore be easily replaced. Because of these two characteristics, shape and lability, cis-platin has an antitumour effect.

The square shape and the occurrence of platinum as platinum-two and not as platinum-zero or platinum-four (the other two accessible forms of platinum) are determinants of the lability of the groups in the cis position. The possibility of exchanging these chemical groups in the cis-platin molecule allows it to chemically bind to DNA. Once bound, the molecule prevents proper DNA replication and transcription, killing the tumour cells. What is wrong with this scheme? Cis-platin has the same effect (to varying degrees) on healthy cells, making it a drug with many side effects.

In contrast, there are also molecules containing ruthenium. This lesser-known metal has chemical qualities different from platinum and, precisely for this reason, can also fight some types of cancer. Ruthenium compounds are usually not square but have a so-called octahedral geometry, with six vertices and the centre occupied by a ruthenium-two or a ruthenium-three ion. In addition to having no free spaces above or below the metal, ruthenium-two compounds are less labile than platinum-two compounds, and ruthenium-three compounds are predominantly inert. In other words, shape and labile/inert behaviour are different.

Interestingly, with their opposite chemical behaviour, ruthenium compounds are generally unable, as far as it is known, to enter the cell nucleus and access its DNA as their predominant mechanism of action. Researchers have well-documented that ruthenium compounds do not always directly[13] target primary tumours, unlike cis-platin. On the other hand, ruthenium compounds can perform a motor action: they bind to some membrane proteins and alter the mobility of the cells to which they bind. Researchers have linked this intrinsic capacity to the fact that ruthenium compounds act preferentially on metastatic tumours, unlike platinum compounds. In other words, they prevent cancer from spreading throughout an organism by interfering with cancer-cell mobility. This behaviour, among others, has driven research into this metal for its use as a medicine.

Implications of Chemical Cosmology

As we have seen above, there are two paths to follow in analysing the place of metal in the universe through chemistry: scientific discourse and scientific practice, on the one hand, and the discourse about it on the other. We will see that at the confluence of the two, a *hesitation* emerges that destabilises certain hegemonic conceptions of 'living being' and 'non-living', almost like a fracture in what Povinelli (2016: 4) calls 'geontopower': 'rather a set of discourse, affects, and tactics used in late liberalism to maintain or shape the coming relationship of the distinction between Life and Nonlife'.

In Povinelli's reading, geontopower has surpassed Foucault's idea of biopower in contemporary capitalism because the latter concept can no longer explain contemporary power formations. For our purposes here, it is enough to emphasise that this idea is hegemonic in contemporary global capitalism and determines our imaginary of what is or is not alive. This hegemonic form is inhabited by figures and metaphors that the author explores to make her point. We are interested in the figure of the 'carbon imaginary', or the idea that life only occurs in 'existents' (or 'actors' or 'things') based on carbon (the chemical substance). These would be beings that are born, grow, reproduce, and die.[14]

The author chooses the term 'existents' precisely to get away from the imagery of carbon, advocating that other things, beings, organisms, and substances can be seen from other angles. In the scenario of the Anthropocene and the climate crisis, the distinctions between life and nonlife have become less evident. Trying to think about the multiplicity of ontologies and, therefore, of imaginations about 'existing', the author criticises 'geontopower'. Povinelli emphasises that science produces a mixture of life and nonlife:

> The same techniques that allow the natural sciences to distinguish between categories of life also demonstrate not merely the interdependent entanglements of Life and Nonlife but the irrelevance of their separation. Animals and minerals, plants and animals, and photoautotrophs and chemoheterotrophs are extimates – each is external to the other only if the scale of our perception is confined to the skin, to a set of epidermal enclosures. (Povinelli 2016: 42)

The way to think about the interpenetration between life and nonlife is precisely by resorting to scale: changes in scale end up challenging the imaginary of carbon. Returning to our example from the previous section, we see that the scientific discourse of chemistry is constructed primarily from a radical change of scale, entering the universe of the incredibly small (up to the uncertainties of the quantum world).

Thus, the description of iron elucidates that it *acts* in human respiration, *capturing* oxygen from the air we breathe in specific proteins, *being carried* around our body by others, and then *released* in different parts by yet other proteins. We also analyse the different forms that iron takes in the body depending on the scale at which we look (whether as a loose chemical species or as part of proteins, outside or inside cells, all these different size scales). All the variations in iron in the body, which change according to the number of electrons it carries at each stage of its various journeys, indicate that iron *is doing* things that keep us alive. The tiny 0.040-nanometre slope of iron in haemoglobin is single-handedly responsible for the possibility of breathing.

The action of an 'existent'—or 'actants', in Latour or Bennet's words (2010: 112–113), or Ingold's 'things' (2012)—on a nanometre scale is responsible for the possibility of existence from the perspective of another existent, a human delimited by the contours of its 'last membrane', our skin. Moreover, between these two scales, there are an infinite number of scales on which different existents operate in a human body regularly and, according to carbon's imagery, keep it alive. However, are these other existents alive? Are they living entities? When operating within our organism, is iron a living entity, or is it a non-living one operating to maintain the life of what we consider to be genuinely alive (the body, the being of carbon)?

Looking at the other metals we mentioned earlier, we could extend our reflections: Is platinum mechanically introduced into the human body to fight cancer (an existent in itself that struggles to exist against the body that circumscribes it), a non-living existent that acts and allies itself with the organism in the struggle for life, or is it a living entity existent that makes its agendas within a context in which it is placed, attacking tumour cells and healthy cells indiscriminately? Is ruthenium a lifeless substance that works as a body transit agent, blocking cancer cell circulation and preventing metastasis? Or is it a substance that acts according to its chemical nature, combining with other related substances? Does zinc, in its DNA transcription actions, which are fundamental for carrying out various functions in the body, carry out a plan, play a code, and produce an activity characteristic of a living being? Or is it a molecular machine that, in its nonlife, operates processes that make life possible on other scales?

The nature of the practice of chemists, who work on very different scales, produces a shuffling of the notion of life and nonlife. If someone asks a chemist whether iron is alive in human respiration, the answer may be 'yes'. Or a 'no' or a 'maybe'. However, the answer will always come after a *hesitation*. This hesitation results from a fracture that the practice of chemistry introduces into the geontopower and imaginary of carbon. Operating on scales where carbon organisms can only be a context of existence, what happens in these contexts looks like a deliberate action (agency). Iron certainly seems alive. However, the hesitation comes precisely from the hegemonic power of the separation between living beings and non-living that geontopower establishes.

This hesitation between the everyday practical experience of chemistry and the hegemonic cosmology of geontopower allows us to understand the second part of the equation we promised in the previous section: the discourse about what happens on these nanometre scales is completely animistic. Chemists narrate everything molecules do in terms of action, such as making, transporting, pulling, removing, and stealing. All these actions are narrated from a perspective in which the 'existents' act *consciously* in a particular dimension.

This anthropomorphisation of the nanometric life of molecules is not a mere accident or even a vice of language; it is a radical effect of the practical experience of chemistry at other scales. Everything occurs there in an apprehension that existents are carrying out actions that scientists must unravel. The way chemists narrate these molecules is an unconscious expression of the confusion that life and nonlife acquire on this scale. Is iron alive? Wait for a second of *hesitation*: it may be or not.

In the scientific practice of chemistry, this hesitation can be tamed by the imaginary of carbon and its rigid determinations of life and nonlife. This fracture can occur frequently to avoid the anthropomorphisation of molecules, as often occurs in master's and doctoral courses. However, the ways of narrating the practice and the scientific-cosmological knowledge itself derived from this practice, as we saw in the previous section, are thoroughly impregnated with a conception of the life of molecules, which muddles the established divisions and always causes this hesitation, which unites scientific knowledge and a nonconscious idea of these molecular existents as living entities.

It is intriguing to consider that even in the realm of philosophy of science, the concept of entity can be broadened to include atoms, as in Whitehead's philosophy (Armour 2010: 932–933). Whitehead's notion of system (entity as system) offers a compelling way to transcend the boundaries that science sets between life and nonlife. This perspective, however, is intertwined with Whitehead's theological viewpoint, where he posits that 'everything that exists has feelings' (idem., 2010: 938). Thinking along the lines of Whitehead, it is not a stretch to envision the 'life' of metals. Whitehead's entities, such as metals, 'inherit previous circumstances by "deciding" to persevere, in a new way, in being' (Latour 1995: 14).

Hartshorne, one of Whitehead's disciples, taking processualism further, argued that everything has an 'agentic reality' (Oppermann 2017: 284) based on what he called 'inherent creativity'. It would be an idea that all material entities would produce transformations (which he defined from his concept of creativity). Thus, the idea that metals at atomic levels can be 'alive', as happens here in the discourse of chemists, is a discussion that ran throughout the 20th century, especially in philosophy. Inspired by Whitehead, the process philosophy indicated this possibility based on a metaphysics in which God, Creativity, or other definitions of a general force animated all matter. Hartshorne imagined that any entity possessed some degree of memory. This perspective influenced Latour's (2007) actor-network theory, especially in the dimension of the imbrication between entities.[15] New materialism is also influenced by these perspectives (as in ecocriticism, for example), imagining an agency for all matter, treated as a 'narrative' agency. This perspective derives from what Cobb called the 'dynamic world of interrelated activities' (1988: 109), in other words, from a notion of agency marked by the correlation between entities and not by the idea of consciousness. Thus, 'If agency functions this way, it must be composed of multiple interacting entities including the most elementary units of matter that experience the world in various degrees of creative becoming' (Oppermann 2017: 288).

Nevertheless, these perspectives support Colebrook's criticism of Latour, who, in her view, ultimately articulates his argument around an idea that leads to the conception that humans are separate and isolated entities (the 'we' of 'we have never been modern'). For Colebrook, agency emerges from a broad web of relationships of which humans are only a part (Colebrook 2017, Van den Berg 2016).[16] What chemists are doing, in our analysis, by hesitating between the life and death of metals, is, from this perspective, also questioning which 'we' serves as the reference point for examining the molecular world.

These metaphysical perspectives, therefore, do not propose that matter, such as atoms, possesses consciousness, but rather some form of 'experience'. Our narrative here is not metaphysical. Beyond the actancy of these materials (which is referred to by different names in these philosophies, including various conceptions of 'agency'), we are ethnographically exploring the capacity of chemists to consider metals as agents with consciousness, a concept we term 'chemical animism', akin to other anthropological narratives about animism (Descola 2014). This possibility is often dismissed by a geontopower who views it as a misleading 'anthropomorphisation'. However, our focus is on revealing fractures in the geontopower based on the *hesitations* and *ambiguities* of chemists in their cosmologies about the matter. In essence, within the scientific discourse on matter, uncertainties exist about the relationship between living and non-living entities that challenge the dominant effect of geontopower.

Final Considerations

According to Bennett (2010), modernity presupposes the passivity of things, which is seen as inert. In contrast, she advocates a 'vibrant matter' in which things have a certain vitality:

> By "vitality", I mean the capacity of things – edibles, commodities, storms, metals – not only to impede or block the will and designs of humans but also to act as quasi-agents or forces with trajectories, propensities, or tendencies of their own. (Bennett 2010: VII)

Things are actants, a category she takes from Latour to defend a radical form of the 'actancy' of things. Bennett's concept of actancy, which includes 'quasi-agency', significantly extends Latour's ideas. This perspective proposes to view human and nonhuman actors on a more horizontal plane than usual, a concept we have explored in this text. Bennett's actancy, therefore, is a form of 'quasi-agency'. We further our exploration of Bennett's argument by claiming that the cosmology of chemists produces an ambiguity that allows us to see metals as alive at certain moments, as bearers of agency, although this idea generates doubts at other times. Thus, we underscore the agency of nonhuman things, in this case, metals, and the relevance of this discussion in our academic discourse.[17]

However, to reinforce this argument, we also explored other scales, specifically physical scales. Other authors use different time scales, such as the case cited by De Landa (2021): In an incredibly extended time perspective of millions of years, we would see that soft living beings (without rigid structures) predominated until 5000 million years ago. At some point, certain conglomerates of life underwent mineralisation, and a new mineral form emerged within the soft bodies: bones. It is as if minerals used living tissue to spread around the world. Therefore, in the long term, minerals can be seen as the active power, and beings with bones (including humans) can serve as a product of this activity.

Thus, testing other scales, characteristic par excellence of chemical science, opens up gaps or fractures in modern thought's static conceptions of life and death (Povinelli's geontopower or Ingold's hylemorphism). It is interesting to put chemistry at the centre of the debate regarding its critical potential for hegemonic conceptions to see the *hesitation and ambiguity* it produces. On the other hand, chemical science itself, captured by the capitalist industry, is responsible for the proliferation of actants in our world by producing new entities (all with a pharmakon character), such as medicines, agrotoxins, various polymers, and gases of all kinds, that are responsible for shaping a world (Gaia) affected by humans on unprecedented scales (Anthropocene).

Today, fish change sex in certain places due to water contamination by the human use of contraceptives, which are excreted in urine (Tyler, Stumper & Jobling 1997), and the excretion of methamphetamines by humans in aquatic beds produces populations of addicted fish (Horký et al. 2021). These new 'assemblages' connecting human and nonhuman forms considered alive with forms of matter seen as inert are characteristic of the Anthropocene, causing unpredictable effects. However, a consistent part of these effects is the transformation of Gaia into a reality that is increasingly hostile to humans (and thousands of other species).

Considering the vitality of supposedly inert things, such as metals, can indicate a less invasive way of dealing with them. While everything is inert and dead, everything is available to humans for transformation. Considering the vitality of things from a political point of view, we can call into question this state of affairs, governed by geontopolitics, which disposes of the world and its existents in favour of the political-economic projects of liberal capitalism. As Bennett states:

> Why advocate the vitality of matter? Because my hunch is that the image of dead or thoroughly instrumentalised matter feeds human hubris and our earth-destroying fantasies of conquest and consumption. It does so by preventing us from detecting (seeing, hearing, smelling, tasting, feeling) a fuller range of the nonhuman powers circulating around and within human bodies. (Bennett 2010: IX)

This paper, following the knowledge produced by chemists and the way they relate to it—the way that the discourse on this practice denounces—sought to investigate the vitality of metals within human bodies. We saw that everything in the chemistry ontology points to the life of metals within our bodies. In addition, vitality intrinsic to the substances themselves is not coordinated by a vital principle external to the substances (such as a soul or creativity).

We ask chemists if iron outside the body is alive. The answer tends to be 'no'. In an iron rod, this substance would be dead. Dead in contrast to the same substance inside the body, where it seems alive because it does thousands of things in a hectic daily life. The contrast is encompassed by the hegemonic living entities/non-living contrast of a human scale: iron does things and lives inside a living body. Inside a 'dead thing', even if the iron does things, it is dead (the iron continues to exchange electrons with the world, rusting). This perspective, which encompasses the human scale, generates *hesitation and* *ambiguity* that did not exist on the nanometre scale. We then ask the chemists about the iron that leaks out of the body when we bleed: Is it any different from the iron that was inside the body? Does it die when we bleed? The answer is a *hesitation* and a 'no'. The iron remains the same, doing the same things: two questions and two contradictory answers. Alive and not alive, the metal is the *hesitation and ambiguity* of chemistry.

Notes

1 Actancy is the quality of an actant (Latour 2019), which we will discuss below.

2 The notion of metal we use here does not refer to the cyborg theory (Haraway 2006), but rather to the image of metals as chemical substances inside and outside the human body.

3 For example, this happens in computer simulations of molecular structures created by theoretical chemists.

4 For more discussion on the issue of three-dimensional models, see De Chadarevian and Hopwood (2004) and Daston (2012).

5 Or what other authors call more often 'worlds that are more than human' (Bellacas 2017; De la Cadena 2010).

6 A set of transformations mediated by proteins, metallated or not, which results in the synthesis of new substances or the degradation of existing ones in a living organism.

7 The term 'chemical element' is defined as 'A pure chemical substance composed of atoms with the same number of protons in the atomic nucleus' according to the International Union of Pure and Applied Chemistry (IUPAC Gold Book, https://goldbook.iupac.org/). Chemical elements are then subdivided into three major groups: metals, semi-metals, and non-metals.

8 In chemistry, salts are compounds formed by a cation of a metallic element and an anion of a non-metallic element. Cations are chemical elements that have lost electrons and are therefore positively charged, whereas anions are chemical elements that have gained electrons and are therefore negatively charged.

9 Adverse effects occurring when the generation of reactive oxygen species (ROS) in a system exceeds the system's ability to neutralise and eliminate them; excess ROS can damage a cell's lipids, protein, and DNA (IUPAC Gold Book, https://goldbook.iupac.org/).

10 A chemical reaction that, in given conditions, can go forward and also backwards.

11 It refers to how acid a tissue, or solution, etc., is. The acidity relates to the amount of acids or, in chemical terms, to low values of pH.

12 Ceruloplasmin**:** A copper-two site binds and transforms iron-two into iron-three, reducing itself to copper-one. This copper-one transfers this electron to other copper sites. After the successive transfer of four electrons, these copper sites bind to an oxygen molecule, which is reduced, restoring the original copper-two ions and producing two water molecules.

13 The word 'directly' is essential because there are other types of action than the one we have illustrated. Therefore, there are ruthenium compounds that act on tumours/primary lesions, although NOT directly, but through stimulation by light.

14 It should be noted that Povinelli's statements pertain to the ethnography of specific Aboriginal communities in Australia. In contrast, this text aims to consider the concept of metals through the lens of chemists. This shift from one context to another, however, is mediated by different notions of life and death, of what is alive and what acts upon the world. By understanding chemical knowledge as a contemporary cosmology, it is possible to weave these connections, even though the contexts are very different. This stance derives from an anthropological perspective that was structured around comparisons between native knowledge and that produced by capitalist society, as in the works of Strathern (1992, 2016), something that Viveiros de Castro called 'controlled equivocation' (2004).

15 Latour's perspectives on the inanimate have been questioned, among other things, for his notion of agency without intention. Authors such as Swyngedouw and Ernstson (2018), Clark and Yusoff (2017), Yusoff (2018), and Vorhölter (2024) point out that neo-materialist perspectives tend to erase colonial histories of violence and extraction, as well as obscure power differences and asymmetries in processes such as climate change. However, Vorholter (idem.: 11) highlights the difference between more politicised perspectives and more attuned to notions of entanglement between humans and nonhumans, such as those of Bennett. Pellizzoni, for example, highlights how this emphasis on nonhuman agency ultimately generates a 'Politics of ontology inbuilt in the neoliberalisation of nature' (Pellizzoni 2015: 8). Here, we adopt a perspective similar to Bennett's, since we are ultimately arguing that recognising the agency of nonhumans can imply a critique of contemporary capitalism. Talking about the action of metals does not imply disregarding the oppressions of colonialism/capitalism.

16 Swingedouw and Ernstson (2018) point out that this 'modernist' separation between us and them is present in the works of Haraway, Morton, Latour, Tsing, Stengers, and other authors relevant to the theme of the Anthropocene. One of the risks of this perspective would be to erase the internal struggles that characterise, precede, and postdate the Anthropocene, thereby depoliticising the topic. For the authors, 'Our key point here, while recognising crucial distinctions between different thinkers, is that symmetrical relational ontologies have not only served as a common foundation for a fundamental rethinking of socio-environmental issues, but that they also stand as a guarantee for post-capitalist politics.' (idem., 2018: 12). The same authors point out, however, that Povinelli and Bennett, central to our argument here, lean towards analyses that are less problematic.

17 We could discuss the body and metals further here, following Sparrow's (2015) discussion of metals and Mishima's body (in his autobiography) and Deleuze and Guattari's notion of the machinic process, but that's a task for another text.

Competing Interests

The authors have no competing interests to declare.

References

Abrahamsson, S., et al. (2015). Living with Omega-3: New Materialism and Enduring Concerns. *Environment and Planning D: Society and Space*, *33*(1), 4–19. https://doi.org/10.1068/d14086p

Almeida, M. W. B. (2021). Anarquismo ontológico e verdade no Antropoceno. *Ilha Revista de Antropologia*, *23*(1), 10–29. https://doi.org/10.5007/2175-8034.2021.e78405

Anthony, E. J., et al. (2020). Metallodrugs Are Unique: Opportunities and Challenges of Discovery and Development. *Chemical Science*, *11*(48), 12888–12917. https://doi.org/10.1039/D0SC04082G

Armour, L. (2010). Looking for Whitehead. *British Journal for the History of Philosophy*, *18*(5), 925–939. https://doi.org/10.1080/09608788.2010.524768

Banerjee, S., & **Banerjee, S.** (2022). Metal-Based Complexes as Potential Anti-Cancer Agents. *Anti-Cancer Agents in Medicinal Chemistry*, *22*(15), 2684–2707. https://doi.org/10.2174/1871520622666220331085144

Barry, N. P. E., & **Sadler, P. J.** (2014). 100 Years of Metal Coordination Chemistry: From Alfred Werner to Anticancer Metallodrugs. *Pure and Applied Chemistry, 86*(12), 1897–1910. https://doi.org/10.1515/pac-2014-0504

Bennett, J. (2010). *Vibrant Matter: A Political Ecology of Things*. Durham: Duke University Press. https://doi.org/10.1215/9780822391623

Cassandri, M., et al. (2017). Zinc-Finger Proteins in Health and Disease. *Cell Death Discovery, 3*(1), 1–12. https://doi.org/10.1038/cddiscovery.2017.71

Clark, N., & **Yusoff, K.** (2017). Geosocial Formations and the Anthropocene. *Theory, Culture & Society*, *34*(2–3), 3–23. https://doi.org/10.1177/0263276416688946

Cobb, J. B., Jr. (1988). Ecology, Science and Religion: Toward a Postmodern Worldview. In D. R. Griffin (Ed.), *The Reenchantment of Science: Postmodern Proposals* (pp. 99–113). New York: State University of New York Press.

Colebrook, C. (2017). We Have Always Been Post-Anthropocene: The Anthropocene Counterfactual (pp. 1–20). In R. Grusin (Ed.), *Anthropocene Feminism*. Minneapolis: University of Minnesota Press.

Daston, L. (2012). The glass flowers. In A. Jahn (Ed.), *Em Regula Dettwiler–It's my Nature* (pp. 73–75). Freiburg: modo Verlag.

De Chadarevian, S., & **Hopwood, N.** (2004). *Models: The Third Dimension of Science*. Redwood City: Stanford University Press. https://doi.org/10.1515/9781503618992

De la Cadena, M. (2010). Indigenous Cosmopolitics in the Andes: Conceptual Reflections Beyond 'Politics'. *Cultural Anthropology, 25*(2), 334–370. https://doi.org/10.1111/j.1548-1360.2010.01061.x

De Landa, M. (2021). *A Thousand Years of Nonlinear History*. Princeton, NJ: Princeton University Press. https://doi.org/10.2307/j.ctv1qgnqhr

Descola, P. (2014). Beyond nature and culture. In Harvey, G. (Ed.), *The Handbook of Contemporary Animism* (pp. 77–91). London: Routledge.

Ferreira, A. M. C., et al. (2000). Mimics of Copper Proteins: Structural and Functional Aspect. *Anais Da Academia Brasileira de Ciências, 72*(1), 51–57. https://doi.org/10.1590/s0001-37652000000100007

Francoeur, E. (2001). Molecular models and the articulation of structural constraints in chemistry. In U. Klein (Ed.), *Tools and Modes of Representation in the Laboratory Sciences* (pp. 95–118). Berlin: Springer Science, Business Media. https://doi.org/10.1007/978-94-015-9737-1_7

Haraway, D. (2006). A cyborg manifesto: science, technology, and socialist-feminism in the late twentieth century. In S. Stryker & S. Whittle (Eds.), *The Transgender Studies Reader* (pp. 103–118). London: Routledge.

Horký, P., et al. (2021). Methamphetamine Pollution Elicits Addiction in Wild Fish. *Journal of Experimental Biology, 224*(13), jeb242145. https://doi.org/10.1242/jeb.242145

Ingold, T. (2012). Trazendo as coisas de volta à vida: emaranhados criativos num mundo de materiais. *Horizontes antropológicos, 18*, 25–44. https://doi.org/10.1590/S0104-71832012000100002

Jomova, K., et al. (2022). Essential Metals in Health and Disease. *Chemico-Biological Interactions*, *367*, 110173. https://doi.org/10.1016/j.cbi.2022.110173

Kirksey, E. (2017). Caring as Chemo-Ethnographic Method. *Society for Cultural Anthropology*. https://culanth.org/fieldsights/caring-as-chemo-ethnographic-method.

Latour, B. (1990). Drawing things together. In M. Lynch (Ed.), *Representation in Scientific Practice* (pp. 19–68). Cambridge, MA: MIT Press.

Latour, B. (1995). Os objetos têm história? Encontro de Pasteur com Whitehead num banho de ácido láctico. *História, Ciências, Saúde*, *2*(1), 07–26. https://doi.org/10.1590/S0104-59701995000200002

Latour, B. (2007). *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford: Oxford University Press.

Latour, B. (2019). *Políticas da natureza: como associar as ciências à democracia*. São Paulo: Editora unesp.

Machado, I. J. R. (2019). Ethnographic Life: Method for an Ex Post Facto Anthropology. *Anthropologica, 61*(2), 345–351. https://doi.org/10.3138/anth.2018-0071.r2

Machado, I. J. R. (2023). *A memória como campo etnográfico: antropologia ex post facto*. Rio de Janeiro: Papéis Selvagens.

Milto, I. V., et al. (2016). Molecular and Cellular Bases of Iron Metabolism in Humans. *Biochemistry (Moscow), 81*, 549–564. https://doi.org/10.1134/S0006297916060018

Myers, N. (2008). Molecular Embodiments and the Body-Work of Modeling in Protein Crystallography. *Social Studies of Science, 38*(2), 163–199. https://doi.org/10.1177/0306312707082969

Oppermann, S. (2017). Nature's Narrative Agencies as Compound Individuals. *Neohelicon*, *44*, 283–295. https://doi.org/10.1007/s11059-017-0394-9

Pandian, A. (2016). Plastic. Theorising the Contemporary. *Fieldsights* 21 (January). https://culanth.org/fieldsights/plastic

Passos, C. J. S., & **Mergler, D.** (2008). Exposição humana ao mercúrio e efeitos adversos à saúde na Amazônia: uma revisão. *Cadernos de Saúde Pública, 24*, s503–s520. https://doi.org/10.1590/S0102-311X2008001600004

Pellizzoni, L. (2015). *Ontological Politics in a Disposable World: The New Mastery of Nature*. Farnham: Ashgate. https://doi.org/10.4324/9781315598925

Povinelli, E. A. (2016). *Geontologies: A Requiem to Late Liberalism*. Durham, NC: Duke University Press. https://doi.org/10.1515/9780822373810

Ramberg, P. J. (2001). Paper tools and fictional worlds: predictions, synthesis and auxiliary hypotheses in chemistry. In U. Klein (Ed.), *Tools and Modes of Representation in the Laboratory Sciences* (pp. 61–79). Berlin: Springer Science, Business Media. https://doi.org/10.1007/978-94-015-9737-1_5

Rayner-Canham, G., & **Overton, T.** (2003). *Descriptive Inorganic Chemistry*. New York: Macmillan.

Roberts, J. A. (2010). Reflections of an Unrepentant Plastiphobe: Plasticity and the STS Life. *Science as Culture, 19*(1), 101–120. https://doi.org/10.1080/09505430903557916

Shapiro, N., & **Kirksey, E.** (2017). Chemo-Ethnography: An Introduction. *Cultural Anthropology, 32*(4), 481–493. https://doi.org/10.14506/ca32.4.01

Sparrow, T. (2015). *Plastic Bodies: Rebuilding Sensation After Phenomenology*. London: Open Humanities Press. https://doi.org/10.26530/OAPEN_530970

Stengers, I. (1996). *Cosmopolitiques I. La Guerre des Sciences*. Paris: La Découverte; Le Plessis-Robinson (Essonne): Synthélabo.

Strathern, M. (1992). *Reproducing the Future: Anthropology, Kinship, and the New Reproductive Technologies*. Manchester: Manchester University Press.

Strathern, M. (2016). The Patent and the Malanggan. *Theory, Culture & Society*, *18*(4), 1–26. https://doi.org/10.1177/02632760122051850 (Original work published 2001)

Thacker, E. (2005). Biophilosophy for the Twenty-First Century. *Ctheory.net*, 6. https://journals.uvic.ca/index.php/ctheory/article/view/14452/5294

Toma, H. E. (2015). *Química bioinorgânica e ambiental* (Vol. 5). São Paulo: Editora Blucher.

Tsing, A. L. (2015). *The Mushroom at the End of the World*. Princeton, NJ: Princeton University Press.

Tyler, C., Stumper, J., & **Jobling, S.** (1997). Environmental Oestrogens and Sexual Development in Fish. *Freshwater Forum, 5*(3), 154–157.

Van den Berg, K. (2016). Never Modern, Never Human, Always Post-Anthropocene? Latour, Haraway and Colebrook: Assembling Conversations (as) Becoming Knowledge. *Pulse: The Journal of Science and Culture*, *4*(1), 44–56.

Viveiros de Castro, E. (2004). Perspectival Anthropology and the Method of Controlled Equivocation. *Tipití: Journal of the Society for the Anthropology of Lowland South America*, *2*(1), Art. 1. Available at: https://digitalcommons.trinity.edu/tipiti/vol2/iss1/1

Vorhölter, J. (2024). "Agency". In R. Cantave (Ed.), *The Open Encyclopedia of Anthropology*. Cambridge: University of Cambridge. https://doi.org/10.29164/24agency

Woolgar, S., & **Latour, B.** (1997). *A vida de laboratório*. Rio de Janeiro: Relume-Dumará.

Yu, F., et al. (2014). Protein Design: Toward Functional Metalloenzymes. *Chemical Reviews, 114*(7), 3495–3578. https://doi.org/10.1021/cr400458x

Yusoff, K. (2018). *A Billion Black Anthropocenes or None*. Minneapolis, MN: University of Minnesota Press. https://doi.org/10.5749/9781452962054

Zoroddu, M. A., et al. (2019). The Essential Metals for Humans: A Brief Overview. *Journal of Inorganic Biochemistry, 195*, 120–129. https://doi.org/10.1016/j.jinorgbio.2019.03.013

How to cite this article: Machado, I. J. d. R., & Nikolaou, S. (2026). The (Ambiguous) Life of Metals: Chemistry, Metals, and Agency Perspectives. *Anthropocenes – Human, Inhuman, Posthuman*, 7(1): 1. DOI: https://doi.org/10.16997/ahip.1830

Submitted: 07 March 2025 **Accepted:** 09 January 2026 **Published:** 13 March 2026

Anthropocenes – Human, Inhuman, Posthuman is a peer-reviewed open access journal published by University of Westminster Press.