

University of Groningen

Holism and reductionism in biology and ecology

Looijen, Richard

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

1998

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Looijen, R. (1998). *Holism and reductionism in biology and ecology: The mutual dependence of higher and lower level research programmes*. s.n.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

CHAPTER 2

HOLISM AND REDUCTIONISM IN BIOLOGY

2.1 Introduction

"An organism is essentially nothing but a complex set of atoms and molecules". "You cannot just simply reduce an organism to a sack of molecules!"

These two statements form a terse expression of the contradistinction between holism and reductionism in biology. They express different aspects of the contradistinction, and they express several of the confusions and misunderstandings to which the contradistinction is subjected. They raise many questions. For instance, if an organism is nothing but a set of atoms and molecules, what then is the difference between a living organism and a dead one? What is 'essentially'? What is 'reduce'? Is reduction in science an ontological issue (reduction as diminishing or lowering, such as in sales reduction) or an epistemological issue (reduction as a kind of explanation)? The moral indignation expressed by the second statement suggests that one has in mind, incorrectly as I will argue, ontological rather than epistemological reduction. Apart from that, there are methodological questions. For instance, what should we do in order to 'reduce' an organism to a set of atoms and molecules, or, conversely, what should we not do to an organism in order to understand its being and functioning? Even more interesting is the question what we should do to atoms and molecules in order to 'holismize' them to organisms.

The questions and problems to which the holism-reductionism dispute pertains are known as reduction problems. These problems relate on the one hand to different levels of organization in nature and to the hierarchical (part-whole) relationships between them, and on the other hand to the hierarchical relationships (whether alleged or not) between scientific disciplines (see figure 1). Thus, the statement that an organism can be 'reduced' to a collection of atoms and molecules expresses on the one hand something about the ontological, part-whole, relationships between atoms, molecules and organisms and on the other hand something about the epistemological relationships between (a) biology and (b) physics and/or chemistry: the former is assumed to be reducible to the latter. On the other side, the statement that an organism cannot be 'reduced' to a collection of atoms and molecules suggests on the one hand that an organism is 'more than' just a collection of atoms and molecules (for example, it is, among other things, also a collection of cells, tissues and organs) and on the other hand that biology is autonomous with respect to physics and chemistry. These differences in point of view have important consequences with respect to the methodology of research programmes as well: while from the one point of view (reductionism, be it in a moderate form; see below) a more or less strong form of co-operation between biological and physico-chemical research programmes may be pursued, such co-operation may be dismissed from the point of view (radical) holism.

In this book, I will make a strong plea for the importance of holism in biology, but an even stronger plea for the co-operation of holistic and reductionistic research programmes, both within biology and among biology and physico-chemistry. In this chapter I will start by discussing the hierarchical structure of nature that underlies the reduction problem and hence the holism-reductionism dispute in biology. After that, I will provide an overview of the issues at stake and of the various, holistic and reductionistic positions taken with respect to those issues.

2.2 The reduction problem in biology

There are several ways in which the reduction problem in biology can be formulated. One way is by asking the following questions. Are the properties and other attributes of living creatures, their morphology, physiology, behaviour and ecology, totally independent of the physico-chemical parts of which they are composed? Is life, or the complex of properties and processes we call life, 'emergent' with respect to inorganic matter? Or are the morphology, physiology, behaviour and ecology of organisms in some, undoubtedly complex way being determined by structures of molecular and macro-molecular kind?

Another way of formulating the problem is by asking whether the concepts, laws and theories that have been developed for some higher level of organization in biology (for instance, the level of organisms) can be explained by theories that have been developed for some lower level of organization (for instance, the level of organs, tissues or cells, or of the macro-molecules of which they are composed). Put differently, can theories about the 'whole' be reduced to theories about their component parts? And if so, does this mean that eventually all biological concepts, laws and theories can be reduced to physico-chemical ones?

While in the former series of questions the emphasis lies with ontological aspects of the problem, in the latter series it lies with epistemological aspects. The former pertain to relations between different levels of organization in nature, the latter to relations between scientific disciplines. Both are founded upon the hierarchical structure of nature.

2.2.1 The hierarchical structure of nature

In the left-hand side of figure 1 I have pictured the 'classical' hierarchy of levels of organization in nature, which is usually presented in this context. In the right-hand side I have put various scientific disciplines which are more or less associated with a certain level of organization. This part of the figure is neither exhaustive nor fully adequate (for instance, genetics spans all levels from macro-molecules up to populations), but only meant to provide a rough indication of the positions of various disciplines.

In the left-hand side of the figure, the level of organization, and hence the degree of complexity, increases from low to high. At the basis of the hierarchy we find what are presently considered to be the most 'fundamental' 'building blocks' of nature (or of reality): the various quantum particles.⁸ Next come sub-atomic particles, then atoms, molecules and macro-molecules, the domains of classical chemistry, and finally the various domains of biology (including ecology): organelles, cells, tissues, organs, organisms, populations, communities, ecosystems and, at the top of the hierarchy (as far as biology is concerned), nature as a whole: the biosphere. (One may include astronomical levels of organization in this hierarchy but these are of no interest in this book.)

The core idea of this hierarchy is that the entities of higher levels of organization are

⁸Considering the erratic nature and behaviour of these particles, as presented by modern physics, the term 'building block' seems hardly appropriate any more. In fact, the whole idea of physical 'building blocks' has become controversial, for which reason there is presently also a holism-reductionism dispute in physics (Bohm 1980; Davies 1983; Stavenga 1986; see also Capra 1975; Zukav 1979; but also Stenger 1995).

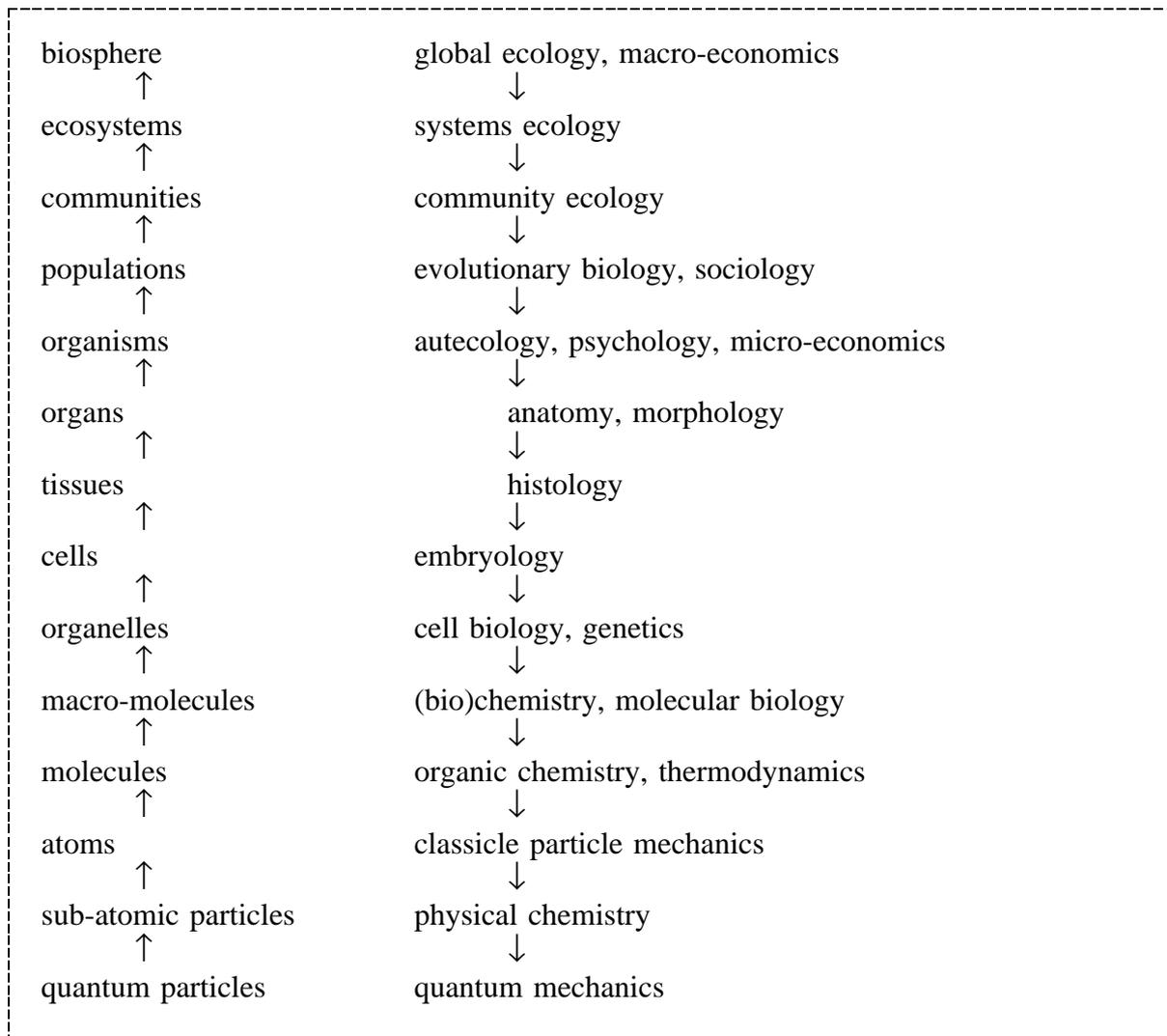


Figure 1: Classical hierarchy of levels of organization in nature, and the associated hierarchy of scientific disciplines.

comprised (exclusively) of entities of lower levels, or conversely, that the entities of lower levels form the (exclusive) components or 'building blocks' of entities of higher levels. Put differently, the entities of higher levels are considered to be 'wholes' which consist of entities of lower levels, the component 'parts'. Thus, between lower and higher levels of organization there are supposed to be 'exhaustive' part-whole relationships. From this hierarchy it becomes immediately apparent that there is not just one reduction problem, but that there are many: between each higher and lower level there is in fact a reduction problem.

In the right-hand side of figure 1 the degree of specificity increases from low to high: at the basis of the hierarchy we find (various disciplines of) physics, which is supposed to be the most 'fundamental' (but see note 8) and universal of all sciences applying to all levels of

Chapter 2

organizations and to all domains of reality⁹; next comes chemistry, applying to (sub-)atomic, molecular and macro-molecular levels of organization, but also to all higher levels¹⁰; then follows biology, encompassing all levels from macro-molecules (molecular biology, molecular genetics) to the biosphere as a whole (global ecology); and at the top of the hierarchy we find the most specific sciences, the human sciences. The latter may be placed at the levels of individual organisms (psychology, micro-economics), populations (sociology) and the biosphere as a whole (macro-economics). However, they are considered the most specific disciplines, because they deal only with our own species, or, as in the case of economics, with our own species in relation to other species and the abiotic world.¹¹

2.2.2 Complex hierarchy

Although this hierarchy may seem, according to present insights, broadly adequate, it is in many respects incorrect or incomplete.

In the first place, although 'higher' (complex, multi-cellular) organisms are composed of organs, organs of tissues and tissues of cells, there are also organisms that consist of only one cell (bacteria and some algae) or of only a group of cells (other algae and some fungi), without having a further structure of tissues and/or organs. There are also 'organisms' that don't even have a cellular structure (viruses). Thus, in figure 1 there should also be a direct line from cells to populations (in so far as these organisms form populations, otherwise the hierarchy ends at this level).

In the second place, there is not a simple hierarchical relationship between organelles and cells. For cells are composed not only of organelles, but also of a cell-wall and cell-plasm. Thus, as the latter are comprised of (complex chains of various types of) macro-molecules, there should be lines from macro-molecules to both organelles, cell walls and cell plasm and there should be lines from these three main components of cells to cells.

In the third place, neither is there a simple hierarchical relationship between, respectively, organisms and organs, organs and tissues, and tissues and cells. For many 'higher' organisms, such as mammals, are composed not only of organs (which are composed of tissues, which are composed of cells), but also of many tissues that do not make up any organ, and of many

⁹Ranging from the domains of quantum mechanics and quantum electrodynamics to those of celestial mechanics and the general theory of relativity.

¹⁰With the arrival of quantum chemistry the distinction between physics and chemistry according to levels of organization or domains of reality, does not seem appropriate any more, except for the domains of celestial mechanics and relativity theory.

¹¹One could call macro-economics the systems ecology or the global ecology of humans (regarding the entire biosphere as an ecosystem), sociology the population ecology of humans, and micro-economics the autecology of humans. In that sense, one could view these human sciences as specific applications of the respective ecological disciplines but they are, of course, more than that, which is why there are reduction problems in these higher sciences too. The same applies to psychology, which could be called the biology of humans but is more than just biology, which is why there is a reduction problem in psychology as well.

cells that do not make up any tissue. Therefore, there should also be lines from both cells and tissues to organisms.

In the fourth place, pending definitions of the terms 'ecosystem' and 'community' (see chapters 8 and 9), the same applies to communities and ecosystems. That is, there is also no simple hierarchical relationship between, respectively, ecosystems and communities, and communities and populations. For, apart from their abiotic components (see below), ecosystems may be composed not only of communities (groups of organisms of different species of plants, animals or micro-organisms), but also of individual organisms (of different species) and of parts or products of individual organisms (leaves, seeds, fruits, faeces). This can be best seen by imagining two actual ecosystems, for instance a grassland ecosystem and a forest ecosystem, occurring next to each other in a landscape. In the grassland ecosystem, communities (of plants, animals or micro-organisms) may occur that do not occur in the forest ecosystem and vice versa. But there may also be species occurring in both ecosystems, such as certain plants or shrubs occurring at the border of both systems, deer or rabbits foraging in both systems, birds flying to and fro, etcetera. Also, several parts or products (leaves, seeds) of organisms belonging to the forest system, but not to the grassland system, may happen to be dropped in the grassland system, and vice versa. This means that both communities and populations and individual organisms may be 'split up' into parts belonging to the grassland ecosystem and parts belonging to the forest ecosystem. And that in turn means that ecosystems may be composed of either communities, populations and individual organisms of different species or parts of communities, populations and individual organisms of different species. Thus, the hierarchical structure of ecosystems is a lot more complicated than is assumed by the simple picture of figure 1. The same applies to communities, but as that is the subject of chapter 9, I will not discuss it here.

In the fifth place, the entire abiotic, macroscopic world is left out of account in figure 1. In this respect, one should think of the abiotic components of ecosystems (soil, air, water, also making up significant parts of the environments of organisms) as well as the abiotic world of human artefacts (which may actually also be seen as abiotic components of ecosystems). Thus, some bifurcations should be added to figure 1 at the physico-chemical levels of organization (atoms, molecules and perhaps macro-molecules) leading to the organic world on the one side and to the inorganic or abiotic world on the other side, and these bifurcations should come together again at the top of the hierarchy, at the level of ecosystems.

Thus, the hierarchical organization of nature (or reality) is not as simple as shown in figure 1. This figure is adequate only in so far as it represents different levels of organization, but when it comes to part-whole relationships the hierarchy is a lot more complicated. Although this does not seem to have dramatic consequences for the relations between sciences (which are complex anyway), it does mean that reduction relations (involving part-whole relationships) are considerably more complicated as well. In figure 2 I suggest a new, more complex hierarchy taking the above considerations into account.

2.3 Epistemological aspects of the problem

In dealing with reduction problems, it is extremely important to distinguish between ontological, epistemological and methodological aspects of these problems.

Ontological aspects relate to the question of what entities, things or substances reality (nature) is assumed to be made up of, what properties are assigned to these things or entities

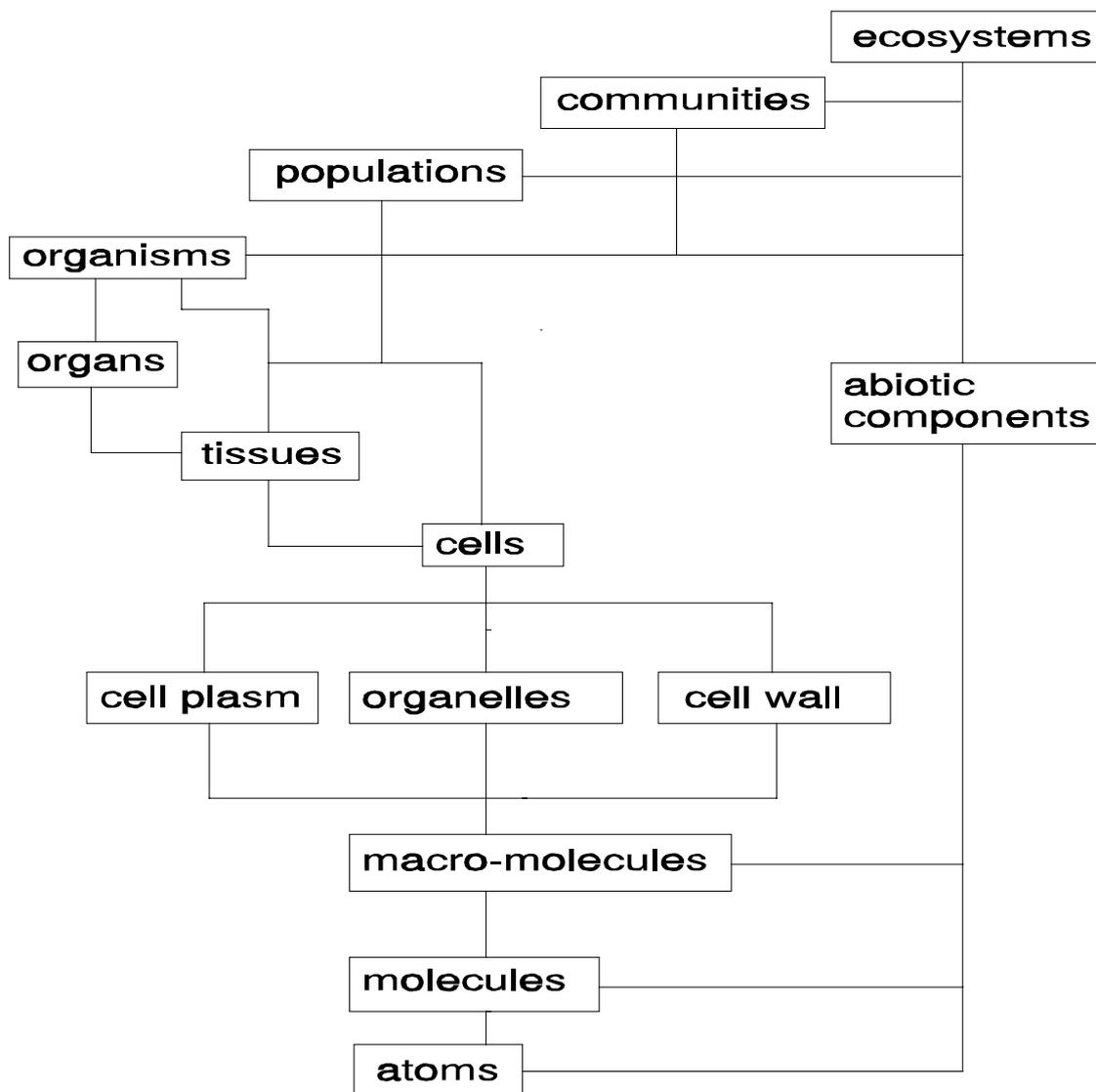


Figure 2: More complex hierarchical structure of nature.

and what relations and functions are assumed to exist between them. Epistemological aspects pertain to our knowledge of reality, to the way this knowledge is embodied in (among other things) theories, and to the logical relations between theories. In particular, they pertain to relations between theories that have been developed for different domains of reality or for different levels of organization. Methodological aspects relate to the ways of acquiring knowledge and to the principles, rules and strategies thereby used. In particular, they relate to the question whether, in order to arrive at a 'proper' knowledge or understanding of a certain level of organization (the level of the whole), we should study the underlying lower levels of organizations (the component parts and interactions between them) or the higher level itself, or possibly its relationships to even higher levels. I will start by discussing epistemological aspects of the problem.

2.3.1 Reduction and the unity of science

The clearest difference between holists and reductionists in biology appears to exist with respect to epistemological aspects of reduction problems. Reductionism, in its extreme or radical form, is the claim that it is possible, if not in practice then in principle, to reduce all the concepts, laws and theories that have been developed for a certain higher level of organization to concepts or theories that have been developed for (a) lower level(s) of organization. Thus, it should be possible, eventually, to reduce biology as a whole to chemistry (and chemistry to physics).

Reductionists share a certain view of the relations between sciences which is known as the unity of science (Oppenheim & Putnam 1958; Causey 1977). This is the view that there are no fundamental, qualitative differences between the various sciences, neither in the objects of investigation nor in the aims and methods of inquiry, and that the various sciences can be ranked according to their domains of investigation in a hierarchy going from the most general and 'fundamental' science (physics) to the highest, most specific ones (the humanities), as pictured, roughly, by figure 1. According to the reduction thesis, the specific concepts, laws and theories of the higher sciences can eventually all be reduced, step by step, to the fundamental theories of physics (see, amongst others, Nagel 1961/82; Smart 1963; Hempel 1965, 1967, Schaffner 1967, 1976, 1993).

2.3.2 Autonomism versus provincialism

Holists, at the other side, maintain that it is impossible, in principle, to reduce theories about higher levels of organization in biology to theories about lower, physico-chemical levels. Put differently, they claim that it is impossible to reduce theories about biological wholes to theories about their physico-chemical parts. Consequently, they maintain that it is impossible to reduce biology as a whole to physico-chemistry. It is particularly in this respect that holists are anti-reductionists (see, amongst others, Ayala 1968, 1974; Beckner 1968, 1974; Polanyi 1968; Campbell 1974; Dobzhansky 1974; Shapere 1974a,b; Thorpe 1974; Mayr 1982, 1988; see also Ruse 1973; Hull 1974; Rosenberg 1985). Holists are also called *autonomists* (Rosenberg 1985), because they defend biology's autonomy with respect to physics and chemistry. In that sense, they don't care about the unity of science. Reductionists, on the other side, are also called *provincialists* (Rosenberg 1985), as they consider biology to be, like chemistry (as well as any other science), a special branch, or province, of physics.

Not surprisingly, outspoken reductionists in biology are molecular biologists, such as Francis Crick (1966) who, together with James Watson, discovered the structure of DNA-molecules, and Jacques Monod (1971, 1974) who became famous for the development (by him and his colleagues) of the theory of allostery (Monod et al. 1963), a theory about the catalytic properties of enzymes and certain other proteins (see chapter 6), and for the development of the operon theory, a theory about certain interactions between small pieces of DNA within a single chromosome. Prominent holists or autonomists in biology are the evolutionary biologists George Simpson (1964), Francisco Ayala (1968, 1974), Theodosius Dobzhansky (1974) and Ernst Mayr (1982, 1988), and the ethologist Jeremy Thorpe (1974). An

Chapter 2

enthusiastic supporter of holism in exoteric¹² circles of biology is the publicist Arthur Koestler (1967, 1980; see also Koestler & Smythies 1969). And finally Johannes Smuts (1927) should be mentioned. Smuts had professionally nothing to do with biology (he was a general of the South African army), but he was obviously interested in biology and other natural sciences. His book, entitled "Holism and evolution", shows a considerable knowledge of the biology, and also the chemistry and physics, of the time. Smuts invented the term 'holism'.

2.4 Ontological aspects

The claims that it is either possible or impossible, 'in principle', to reduce concepts, laws or theories about higher levels of organization to concepts or theories about lower levels, seem in themselves rather unfounded. Even stronger, the claim that it is possible to reduce the whole of biology to physico-chemistry seems at first sight to be a most implausible if not preposterous claim. On the other hand, given the enormous successes of biochemistry and molecular biology, the autonomy thesis of holists doesn't seem to be very plausible either. The question arises, therefore, what arguments both parties have to support their claims. These arguments appear to be partly ontological or metaphysical, and partly methodological. I will start with ontological or metaphysical arguments.

2.4.1 Materialism and causal determinism

As far as ontological or metaphysical arguments are concerned, there are great differences between holists and reductionists, but also important points of agreement. As to points of agreement, most biologists, reductionists and holists alike, are in the first place *materialists*. That is, they assume that nature is entirely and exclusively made up of 'material' substances and forces, where 'material' is meant in the sense of modern physics. Thus, the hierarchical structure of nature (figure 1) forms in itself, probably even given its complications (figure 2), no source of disagreement between holists and reductionists. Both are of the opinion that entities of higher levels of organization are complex composites of entities of lower levels.

In the second place, both holists and reductionists are *causal determinists* in the sense of the (metaphysical) principle of causal determinism. According to this principle, everything in nature has a cause (either single or multiple factored) and there are only so-called efficient causes, that is, causes preceding their effects (as opposed to final causes that follow, in time, after their supposed effects). This principle is being subscribed to by all modern biologists, including holists or autonomists (see Simpson 1964; Ayala 1970; Mayr 1961, 1982, 1988).

Still, there appear to be two major points of disagreement between holists and reductionists, which are associated with the principle of causal determinism. Firstly, the principle lies at the heart of the dispute about the role of functional explanations (holism) *versus* causal

¹²There seems to be some misunderstanding about the meaning of the words 'exoteric' and 'esoteric'. I use them in the sense of Fleck (1979), that is, for, respectively, not working within or belonging to a particular discipline, and working within or belonging to a particular discipline. 'Exoteric' has nothing to do with 'exotic', therefore, and 'esoteric' has nothing to do with 'secret' or 'spiritual'.

explanations (reductionism) in biology, because the former are being (unjustly) associated with the occurrence of final causes. Secondly, holists and reductionists appear to disagree about the way in which the principle works: whereas reductionists emphasize the causal influences exerted by the parts on the whole, holists maintain that in biology there are also important causal influences exerted by the whole on its component parts. I will return to both points later.

2.4.2 Vitalism versus constitutive reductionism

The agreement on materialism means that, in the first place, holism should not be confused with a former doctrine in biology, to wit vitalism. Vitalists claimed that animate nature is different from inanimate nature in that there is a non-material force operative in living beings which they called vital force, *élan vital* (Bergson 1911) or *Entelechie* (Driesch 1909). One particularly well-known vitalist was Hans Driesch (1909, 1914, 1927) who became famous for his experiments on sea-urchin eggs and who claimed he was able to explain the embryonic development of these eggs by the directive operation of a vital force. I will not extend on this, because vitalism is practically a dead issue in biology today. Once in a while certain ideas or theories emerge that bear a certain resemblance to vitalism, such as Sheldrake's (1981) theory of morphogenetic fields, but these happen not to be taken seriously by the majority of other biologists. The major reason for its bankruptcy seems to be that vitalism has not been able to provide heuristics for empirical research. It has not been possible to empirically test the operation of a vital force. Also, biologists have been able to provide materialistic explanations for many of the phenomena which vitalists claimed needed a vitalistic explanation (see also Mayr 1982, p. 52). For these and other reasons, biologists have come to develop a great resistance against, if not aversion to, any idea of a non-material force, entelechie or 'soul' which would distinguish animate nature from inanimate nature.¹³

The agreement on materialism means in the second place that both reductionists and holists are, in the terminology of Mayr (1982), *constitutive reductionists*: both assume that entities of higher levels of organization are composed of entities of lower levels. The term '*ontological reductionism*' has also been used for this (Ayala & Dobzhansky 1974), but that seems to me a most unfortunate term, firstly because constitutive reductionism is very well compatible with ontological pluralism ('holism') and the associated doctrine of emergence (see below), and secondly because the term '*ontological reductionism*' carries the strong connotation that somehow in scientific reductions not only concepts, laws or theories are being reduced, but also the ontologies to which they refer, that is, the phenomena, entities or attributes which are the objects of these concepts, laws or theories. In the next two chapters I will argue that this is a grave misunderstanding and that reduction is an epistemological

¹³This even goes so far that most biologists, in particular behavioral biologists, refuse to attribute any form of feeling, awareness or consciousness to any other animals than humans. This is probably largely due to the influence of Cartesian thinking in biology and its metaphor of the (non-human) animal as a machine. I strongly disagree with this view, but it goes too far to extend on the issue here (see Wemelsfelder 1994 on this issue). Also, I think the solution to the problem of 'mind' in other animals will depend on the solution to this problem in humans and this solution still seems a long way ahead.

issue, involving logical relations between statements or systems of statements (theories), and as such has nothing whatsoever to do with ontological reduction.

Thus, if one wishes to use the term ontological reductionism at all, I think it is best reserved for ontological monism which, in the present context, boils down to atomism.¹⁴ The difference between holism and reductionism with regard to ontological issues may then be formulated in terms of *ontological monism* (atomism) versus *ontological pluralism* (emergentism, organicism).

2.4.3 'Ontological' reductionism: atomism

Atomism may be considered an extreme or radical ontological counterpart of reductionism holding that the entities of the 'lowest' level of organization (atoms, sub-atomic particles, quantum particles, but where does it end? See note 8), are somehow 'fundamental', that they have an ontological 'surplus value' over entities of higher levels. They are the 'building blocks' of nature, the 'cement of the universe' (Mackie 1974), of which the entities of higher levels are mere 'derivatives'. In this view, which was held by, among others, members of the Vienna Circle, higher level entities and their attributes are nothing but epiphenomena, mere derivatives of fundamental physical particles.

In a less radical form, 'ontological' reductionism may be held to be the view that higher level entities are not only composed of lower level entities (constitutive reductionism), but also that the properties and other attributes of the former are causally determined exclusively by the properties of the latter, and interactions between them. One of the arguments supporting (assumedly, but see below) this view is formed by the theories of chemical and biological evolution, the idea, roughly, that after the so-called Big Bang there has been a development on earth starting with the fusion of hydrogen atoms into helium nuclei and followed by the emergence of more complex atomic, molecular and macro-molecular structures and then the forming of first unicellular and next multicellular biological structures (Oppenheim & Putnam 1958; Schaffner 1969). Needless to say that the details of these processes are still to a large extent mysterious, but (excepting creationism) there seems to be an ever growing consensus about their global nature. However this may be, 'ontological' reductionists assume that biological structures are composed of and have developed from physico-chemical structures, and that therefore the former must be causally determined by the latter. Hence, it should be possible to reduce theories about the former to theories about the latter.

However, most holists or autonomists in biology, particularly of course evolutionary biologists like Mayr, Simpson, Ayala and Dobzhansky, are pre-eminent proponents of evolutionary theory. Thus, there is no disagreement between holists and reductionists about the theory itself. The disagreement occurs over the theory's interpretation. Whereas reductionists stress its causal developmental history, the development of organic life out of

¹⁴There are basically two opposite forms of monism, to wit materialism ('body') and idealism ('mind'). The corresponding epistemological positions are physicalism ('everything is reducible to physics') and psychologism ('everything is reducible to psychology'), respectively. The latter was preached by, amongst others, Ernst Mach. See also note 19. Atomism is the radical ontological counterpart of physicalism.

inorganic, physico-chemical structures, holists point to the *emergent* aspects of the evolutionary process (called 'emergent evolution'): the coming into being of ever new forms or structures each having new, 'emergent' properties (see below and chapter 5; see also Prigogine's ideas of 'self-organization' in nature: Prigogine & Stengers 1984). But there are also other differences.

2.4.4 **Ontological holism: emergentism and organicism**

The opposite of radical 'ontological' reductionism (monism in the form of atomism), ontological holism, involves some form of *pluralism*, the idea, roughly, that all levels of organization are ontologically of equal value (see Bunge 1977). In biology, the relevant versions of this are emergentism and organicism.

Emergentism is the view that at each higher level of organization new and irreducible properties appear (emerge) which are not present at lower levels. These are called 'emergent' properties, defined as properties of wholes which are not possessed by their component parts, neither when taken separately nor when put together in other partial combinations. As formulated by Broad (1925, p. 59), "Emergence is the theory that the characteristic behaviour of the whole could not, even in theory, be deduced from the most complete knowledge of the behaviour of its components, taken separately or in other combinations, and of their proportions and arrangements in this whole". Because of the last component ("and of their proportions and arrangements in this whole"), this is a rather strong and far-reaching claim which probably has few if any adherents today, but there are other, less radical versions of the doctrine (for example Mayr 1982) retaining the core of Broad's formulation: a (biological) whole has new, emergent properties which its component parts do not possess, neither separately nor in other partial combinations. Hence the familiar holistic phrase 'the whole is more than the sum of its parts'. Emergent properties are generally considered, by (radical) holists, to be 'irreducible' (but see chapter 5).

As an example of emergent properties, one might take the properties of an individual cell or of a unicellular organism. A cell is composed of a cell wall and cell plasma containing several organelles such as the nucleus, in which (most of) the cell's genetic material is laid down, and mitochondria, which are the cell's energy factories, so to speak. Each of these structures is ultimately comprised of more or less complex chains of macro-molecules. However, none of these parts possesses the properties of cell as a whole. A cell is 'born' (through either fusion of two parent cells or division of one), grows and dies or splits into two new cells; it can literally take up and assimilate food; it is up to a certain extent able to recover from damage or disease; and, as far as unicellular organisms are concerned, it often has the capacity to move about in its environment in uni-directional, non-random ways. On the holistic definition, these are all emergent properties, because the component parts do not possess them, neither separately nor in other partial combinations. Of course, a list of such properties would increase enormously at the level of multi-cellular organisms. In chapter 5 I will discuss many such properties.

Organicism is the view that living organisms are complex, hierarchically structured wholes, whose parts are all *functionally integrated* in and *co-ordinated* by the whole. Because of this, the parts behave in a different way than they would when in isolation: they are co-ordinated by the whole. This means that not only is the whole determined by its parts, but so are the parts determined by the whole (for example Smuts 1927; Campbell 1974; Mayr 1982, 1988).

Chapter 2

The latter is referred to by Campbell (1974) as '*downward causation*'. Thus, in this respect too, the phrase 'the whole is more than the sum of its parts' applies, but for different reasons than in emergentism.

Organicism stresses on the one hand the functional relationships between parts in the whole and on the other hand the causal (integrating, co-ordinating) influences from the whole on the parts. These are two sides of the same coin. For it means that the properties or the behaviour of the parts can be explained only in terms of their functions in the whole: they contribute to the adequate functioning, the survival and reproduction of the whole. According to organicists (holists), such *functional explanations* are indispensable in biology. And because they do not occur in physics and chemistry, they form an important argument in favour of biology's autonomy with respect to these other sciences. I will discuss the nature and status of these explanations in chapter 7.

Organicism stresses not only the causal influences of the whole on its component parts, but also the causal influences exerted on the whole itself by its surroundings, by the environment or by the larger whole of which it is itself a part. These too are two sides of the same coin, because all intermediate entities in the hierarchical organization of nature may be considered as both parts and wholes. This is an important aspect of holism: a certain entity may be regarded as a whole with respect to lower levels, but at the same time as a part with respect to higher levels of organization. In this connection Koestler (1967) introduced the term 'holons', that is, part-wholes having a two-faced Janus¹⁵ head: one directed downwards and the other upwards.

As an example of this role of the environment, or of the larger whole of which a certain whole may itself be a part, one might take the embryonic development (ontogenesis) of organisms. In sexually reproducing species, this development starts with the fertilized egg, which develops into a multi-cellular organism through a great many cell cleavings or divisions. In the course of this development, a differentiation occurs between nervous cells, muscle cells, bone cells, blood cells, etcetera. This differentiation cannot be explained, however, by differences between the component parts (individual cells or parts of these cells), because these are all initially identical, also in genetic respect: they all stem from the same (one) fertilized egg. According to organicism, the differentiation can be explained only in terms of the different positions which different cells come to obtain in the course of the embryonic development, and by the different causal influences exerted upon them by their environments as a result of these differences in position. That is, in each of the developmental phases of the embryo, different parts of the genome become operative in different cells, each of these parts coding for the production of different cell constituents (proteins and other macro-molecules). Thus, whether a cell develops into a nervous cell or a bone cell depends on the phase of development of the embryo in which it comes into existence and on the environment in which it occurs, on the position it takes within the embryo as a whole.

Other and evident examples of this role of the environment may be found in the evolution of species and in the ecology of organisms. On the present view, the evolution of species is governed by on the one hand genetic mutations and recombinations and on the other hand natural selection by the environment. Without the role of the environment evolution is

¹⁵Janus was a Roman god who was pictured as having two faces, one in front, which is directed at the future, and another at the back, which is directed at the past.

unthinkable. Similarly, one cannot even conceive of the ecology of organisms without considering the environments (or biotopes, see chapter 10) in which they live. For this reason, ecology is sometimes claimed to be the only truly holistic science (but see part 2).

It may seem as if these examples amount to something like kicking in open doors, and the role of the environment in ecology and evolution is indeed uncontroversial, but this does not apply to other cases. (One may think of, for example, nature-nurture debates: whether and to what extent behaviour is determined by genetic factors or by environmental factors.) Neither does it apply to the other aspects of organicism: the functional relationships between parts in the whole and the co-ordinating role of the whole.

It will be clear that emergentism and organicism are perfectly compatible with one another, but they are actually independent. That is to say, emergentism doesn't need organicism and organicism doesn't need emergentism. Thus, one may be both an emergentist and an organicist, but also an emergentist without being an organicist and vice versa. Moreover, a major difference between the two doctrines is that organicism is particular of organismal biology (though it is being used as a metaphor in other sciences), whereas emergentism applies to all levels of organization (except that of the 'fundamental' physical building blocks).

2.5 Methodological aspects

In methodological respect every scientist may be regarded a reductionist in the sense of restricting himself or herself (at any particular moment) to only certain aspects of reality and of generally attempting to find unity in diversity. However, we may have to make a distinction in this context between methodology as method of research ('scientific method': every scientist is a reductionist) and methodology as strategy of research. The differences between holists and reductionists lie in the latter field. These differences are related to, or follow from, the ontological positions taken.

As mentioned above, reductionists claim that the entities of higher, biological levels of organization are comprised of entities of lower, physico-chemical levels, and also that the former are causally determined by the latter. In their eyes, therefore, the best strategy for obtaining knowledge of higher levels of organization is to study lower level entities and interactions between them. The best way to understand phenomena at the level of the whole is to study causal mechanisms at the level of its constituent parts. For this reason, reductionists are also called *mechanicists*. Beside that, reductionists appeal to some (supposedly) universal principles, such as our striving for simplicity (for the simplest explanations and the most parsimonious hypotheses and theories), for universality (for the most universal theories having large empirical content), and in particular for integration of knowledge, for coherence and not just consistence of knowledge of different domains of reality. For these purposes reductions are considered an ideal means and this is of course of great interest to the unity of science.

Holists (emergentists and/or organicists), at the other side, emphasize the emergent, and supposedly irreducible, properties of biological wholes and/or the functional relationships between parts and wholes, as well as the causal influences of wholes on their component parts. Logically, they claim that in order to obtain knowledge of a certain level of organization in biology, one must study not (or at least not only) lower levels of organization, but (also) the higher level itself as well as its relationships to still higher levels. Put

Chapter 2

differently, in order to understand the whole, one must not (only) study its component parts, but (also) the whole itself as well as the larger whole of which it is itself a part.

Because of the emphasis put on the study of wholes at their own level of organization, holism is often associated with a descriptive or phenomenological method, and holistic theories are indeed often phenomenological theories.¹⁶ This doesn't mean, however, that they cannot be explanatory theories. In later chapters I will provide several examples of holistic, phenomenological theories (or models) which are at the same time explanatory.¹⁷ Apart from this, functional explanations are of course important aspects of holism, but their status as genuine explanations is disputed (see chapter 7).

It appears, then, that the major difference between holism and reductionism in methodological respect is that (radical) reductionists direct themselves exclusively at the lower level of the parts of some whole, whereas holists direct themselves exclusively at the higher level of the whole itself and at its relationships with still higher levels. Reductionism is directed downwards, holism upwards. Reductionism is associated with analysis, holism with synthesis. The terms 'bottom-up' and 'top-down' are often used to denote these strategies, but both of these terms seem to indicate more of a mixed approach, directed at relations between levels, than mutually exclusive approaches.¹⁸

2.6 Ethical aspects

More or less as a side-note, it should be mentioned that there is also a radical version of holism which holds not only that it is factually impossible to reduce theories about biological wholes to theories about their component parts, but also that it is ethically inadmissible to carry out the analyses of biological wholes into their components parts preceding such reductions. Put differently, in this view biological wholes are to be respected and not analyzed, dissected or otherwise manipulated. For evident reasons, one may come across this

¹⁶When using the term 'phenomenological', I don't intend to refer to the so-called method of 'Verstehen' in sociology. By 'phenomenological' I mean 'descriptive' or 'staying at the same level'. A phenomenological theory is a descriptive theory with respect to a given level of organization. See also the next note.

¹⁷Generally speaking, however, they are not mechanistic theories, nor, for the same reason, (micro-)reductive theories. But even the distinction between explanatory, phenomenological theories and reductive, mechanistic theories appears to be vague. Whether a theory should be called 'holistic' (phenomenological) or 'reductionistic' (mechanistic) depends on the level of organization relative to which it is applied or considered (see in particular chapter 6). On the other hand, a phenomenological *explanation* is an explanation that stays at the same level, whereas a (micro-)reductive explanation relates levels. A phenomenological explanation may be called a 'horizontal' explanation, therefore, as against 'vertical' or micro-reductive explanation.

¹⁸In fact, when thinking about bottom-up and top-down strategies, I wouldn't really know which one is holistic and which one reductionistic.

view, which may be called 'ethical holism', especially in exoteric circles of biology, such as in animal protection movements and, in ecological contexts, in nature conservation groups (as far as animal welfare is concerned, see Wemelsfelder 1993, and references therein).

I am most certainly sympathetic towards this view, but on the other hand I think it goes too far to equate reduction or reductionism with dissection or manipulation. Firstly, not every analytical method in biology consists of literally cutting up living organisms. Secondly, as I will argue at length in the following two chapters, reduction pertains to the logical relations between statements (concepts, laws, theories), not to the objects of those statements. As such, reduction has nothing whatsoever to do with manipulating or cutting up organisms or other wholes, even though many reductions would not have been accomplished had there not been previous analytical (for instance anatomical or physiological) research. In so far as the welfare of animals or other living beings is thereby unjustifiably being harmed, one has every right to object to it. Generally speaking, however, one is often forced in such situations to weigh several factors for and against such manipulations (as in the case of testing new medicines on animals).

I will not discuss this issue any further, as a proper discussion of it would require quite a different book, and quite a different research from the one I have made. I will return, however, to the one point, that reduction has nothing to do with ontologically reducing or harming organisms or other wholes, in chapters 3 and 4.

2.7 Concluding remarks: radical, moderate and anti-reductionist research strategies

Summarizing, we may conclude that in biology the following contradistinctions between reductionists and holists occur.

Reductionists assert that biological wholes are comprised of and have developed from physico-chemical parts and that they are causally determined, therefore, by the properties of these parts and interactions between them. Thus, it should be possible, in principle, to reduce all biological concepts, laws and theories to physico-chemical ones, and the best way to arrive at such reductions is to study the causal mechanisms at the level of the parts. Holists, at the other side, maintain that biological wholes are complex, integrated structures whose parts are functionally related into and co-ordinated by the whole, and/or that biological wholes have emergent properties which cannot be reduced to properties of their component parts. Therefore, biological concepts, laws and theories cannot be reduced to physico-chemical ones, and biological research should be directed at the level of the whole itself, on the functional relationships between parts and wholes, and at the whole in relation to its environment.

It should be noticed, however, that these are not the only possible or even actual positions. In fact, these positions may be regarded as the two radical extremes of a continuum of positions, where the intermediaries are more or less moderate. When we decompose the radical positions into their ontological, epistemological and methodological elements, we see the following contradistinctions:

Ontological reductionism (monism): atomism
Ontological holism (pluralism): emergentism, organicism¹⁹
Epistemological reductionism: provincialism
Epistemological holism: autonomism
Methodological reductionism: mechanicism
Methodological holism: phenomenology, 'functionalism'²⁰

On these grounds, we can define *radical reductionism* as ontological *cum* epistemological *cum* methodological reductionism, that is, atomism *cum* provincialism *cum* mechanicism. *Radical holism* can be defined as ontological *cum* epistemological *cum* methodological holism, that is, emergentism and/or organicism *cum* autonomism *cum* phenomenology and/or functionalism.

However, a common moderate position is ontological holism or pluralism *cum* methodological pluralism (in the strategic sense) *cum* epistemological reductionism, the view, roughly, that all levels are interesting and should be studied, but with the aim of reducing higher-level theories to lower-level ones (for example Bunge 1977; Kuipers 1990). Another moderate position is constitutive reductionism (without further characterization) *cum* methodological (strategic) pluralism *cum* epistemological holism or autonomism (roughly: all levels are interesting and should be studied, but biology is too complex to be reduced; see Ayala & Dobzhansky 1974). In my experience there are also many biologists who are constitutive reductionists (without further characterization), methodological pluralists, but epistemological reductionists, a position roughly equivalent to the first mentioned moderate one, without bothering, however, about emergentism or organicism. Another common position in my experience is ontological reductionism (atomism) *cum* methodological pluralism *cum* epistemological reductionism (roughly: all levels are physical through and through, but in order to reduce theories about higher levels they must be studied first). A striking position, finally, is the one taken by Maull (1977) and Darden and Maull (1977) (see also Bechtel 1986, 1988, 1993) who defend the *unity of science without reductions*. This is supposed to be accomplished through complex 'interlevel' or 'interfield' theories relating levels without, however, reductions taking place (but see chapter 6 and also Schaffner 1993a, 1995). This position should probably be classified as ontological pluralism *cum* methodological (strategic) pluralism *cum* epistemological holism and is therefore almost identical to radical holism, an essential difference being, however, that Darden and Maull's model doesn't imply autonomism.

In this book I myself will defend the first mentioned moderate position, that is, ontological holism *cum* epistemological reductionism *cum* methodological pluralism. I will do so in

¹⁹Another, and the simplest, form of pluralism is dualism, that is, the combination of materialism (body) and idealism (mind).

²⁰There are many sorts of functionalism in science and philosophy. Here, of course, the term refers to the need for functional explanation in biology.

particular by arguing against the alleged contradistinctions between the two radical positions. These are (1) the doctrine of emergence versus the reduction thesis; (2) functional explanations versus causal explanations; and (3) phenomenology versus mechanicism. The first contradistinction will be dealt with, and resolved, in chapter 5, and the second in chapter 7. In almost all chapters, but especially chapters 6, 11 and 12, I will discuss, and take steps to resolve, the third contradistinction. It is particularly to this third contradistinction that my thesis about the co-operation and mutual dependence of holistic ('phenomenological') and reductionistic ('mechanistic') research programmes applies.