Chapter 4: The classical attempts

4.1 Introduction

In chapter 2 I described the practice of reasoning about functions in functional biology. I aim to explain what these kinds of reasoning add to our knowledge. I focus on the kind of reasoning which I have called ‘design explanation’. In this chapter I examine the now classical attempts of Carl Hempel (1959)[1] and Ernest Nagel (1961, 1977) to analyse the meaning of ‘function’ and to account for the explanatory force of reasoning that appeals to function. These attempts constitute the point of departure of many later discussions.

Both Hempel and Nagel employ an inferential theory of explanation. On this theory explanations work by showing that the phenomenon to be explained is to be expected in virtue of the explanatory facts. Applied to reasoning about functions, this means that a function attribution should allow one to infer the presence of the item to which the function is attributed if such an attribution is to be explanatory. According to Hempel, so-called ‘functional analyses’ aim to show that an organism is in such conditions that the trait under study has an effect that satisfies a need. Hempel argues that because, in general, the trait under study is not the only trait that may satisfy the need, functional analyses do not suffice to derive the conclusion that the trait under study is to be expected. Functional analyses are therefore explanatory only in the limited sense that they allow one to infer that one of the elements must be present of an ill-defined class of traits that may satisfy the need. Nagel gives another analysis. He argues that given the form of organization of a certain organism the presence of a certain item is a necessary condition for a certain function to be performed. Hence, given the fact that a certain function is performed, we may derive the conclusion that the corresponding item is present. Such derivations constitute, therefore, valid functional explanations.

I shall argue that both attempts are unsatisfactory. Hempel appears to be concerned with design explanations that explain the need to perform a certain causal role. He is right that the possibility of functional equivalents precludes the conclusion that a particular kind of item must be present. However, he draws the wrong conclusion from this observation. His conclusion is that appeals to need are explanatory to a limited extend only. I argue that the proper conclusion is that the inferential theory fails to account for what is learned from a design explanation.

Nagel argues that the problem of functional equivalents does not occur if the relevant conditions and the function in question are sufficiently detailed. I argue that this move is unsatisfac-

---

[1] I will quote this paper from its reprint in Hempel (1965), p. 297-330.

tory for several reasons. First, because none of the premises of the resulting argument is law-like this move does not safeguard the explanatory character of appeals to function on the inferential account. Second, this moves deprives functional explanations from providing an important insight: namely that different structure is different animals might be seen as different solutions to the same problem. Last (but not least!), it misrepresents the structure of explanations as these are put forward by functional biologist.

4.2 Hempel (1959)

This section consists of roughly two parts: one part (4.2.1, 4.2.2) deals with Hempel's analysis of 'function' and 'functional analysis'. In section 4.2.1 I explain Hempel's analysis of the meaning of these notions. According to Hempel functional analyses aim to show that a certain activity or behavioural pattern satisfies a need. Functions are defined as traits satisfying needs. In section 4.2.2 I argue that Hempel is wrong in this identification of having a function and satisfying a need. The second part (section 4.2.3, 4.2.4 and 4.2.5) deals with Hempel's appraisal of the explanatory force of functional analyses. In section 4.2.3 I give some examples of studies that Hempel would label 'functional analysis'. In section 4.2.4 I explain Hempel's attempt to account for the insights such studies provide. On Hempel's account they have a very weak explanatory force but an important heuristic value. In section 4.2.5 I argue that analyses that show that a trait satisfies a need do have an explanatory character and that Hempel's fails to account for this character.

4.2.1 Hempel's account of 'function' and 'functional analysis'.

Hempel starts his discussion of functional explanation with the observation that it is often claimed that, in contrast to the physical sciences, biological, social and historical sciences cannot confine themselves to establishing causal or correlational connections. Proper understanding of the phenomena studied by these disciplines is supposed to require other types or methods (Hempel uses these words interchangeably) of explanations. One of the explanatory methods that has been developed for this purpose is the method of 'functional analysis'. Functional analysis is typically invoked to explain some recurrent activity or behavioural pattern in an individual or a group by appeal to its contribution to the preservation or development of the individual or the group in which this activity occurs. Hempel aims

> to examine the logical structure of functional analysis and its explanatory and predictive significance by means of a confrontation with the principal characteristics of the explanatory procedures used in the physical sciences (Hempel 1965: 297).

Hempel’s main interest appears to be the use of functional analysis in the social sciences and his account of functional analysis owes much to a paper of the sociologist Robert Merton (1957). However, Hempel begins his discussion of functional analysis by considering a variant of the philosopher’s standard example of a function attribution in biology:

> The heartbeat in vertebrates has the function of circulating blood through the organism (Hempel 1965: 305).

As he sees it, the meaning of this statement can not be expressed by replacing ‘function’ with ‘effect’, for this would make the production of heart sounds one of the functions of the heart, which it is obviously not. Hence, a first requirement for a philosophical theory of function is that it distinguishes between effects that are functions (such as circulating the blood) and effects that are side-effects (such as heart sounds). Hempel seeks this distinction in the fact that circulation, but not heart sounds, contributes to the satisfaction of certain requirements, the satisfaction of which is indispensable for the organism to remain in proper working order. Hempel proposes the following analysis of the foregoing function attribution:

> The heartbeat has the effect of circulating the blood, and this ensures the satisfaction of certain conditions (supply of nutriment and removal of waste) which are necessary for the proper working of the organism (Hempel 1965: 305).

More generally, functions are effects that satisfy needs. This suggests the following “basic pattern of functional analysis”:

> The object of functional analysis is some “item” *i*, which is a relatively persistent trait or disposition (e.g., the beating of the heart) occurring in a system *s* (e.g., the body of a living vertebrate), and the analysis aims to show that *s* is in a state, or internal condition, c_i and in an environment representing certain external conditions, c_e such that under conditions c_i and c_e (jointly to be referred to as *c*) the trait *i* has effects which satisfy some “need” or “functional requirement” of *s*, i.e., a condition *n* which is necessary for the system’s remaining in adequate, or effective, or proper, working order (Hempel 1965: 306)

In other words, a functional analysis is an attempt to show that in the conditions in which the organism lives the item in study has an effect that satisfies a need. Hempel says nothing about the relation between a functional analysis and a function attribution, but I take it that he takes it that a function attribution expresses the result of a functional analysis.

4.2.2 Why ‘having a function’ is not the same as ‘satisfying a need’.

Hempel defines functions in terms of needs. He does not distinguish different kinds of functions. Moreover, he does not discuss any detailed example of a functional analysis in biological research. Nor does he give bibliographic references to such an example. This makes it difficult to determine what kind of study he has in mind when he talks of functional analysis and what kind(s) of function he wants to define in terms of needs. At first sight it seems that the kind of study he has in mind is a search for causal roles (the search for an answer to a type (2) question). Consider, for example, once more, Hempel's example of a function attribution:

> The heartbeat in vertebrates has the function of circulating blood through the organism (Hempel 1965: 305).

This example differs from function attributions in morphology in that the function of circulating the blood is attributed to an activity (the heartbeat), rather than to an item (the heart).[2] Apart from that it is clearly concerned with the causal role ($function_2$) of the heart in circulating the blood. Functional analysis might thus be seen as a search for causal roles. On Hempel's account, however, functional analysis does not merely aim to find out how a certain activity contributes to a complex activity or capacity. In addition, the functional analysis must show that the performance of the activity to which the activity under study contributes is (in its turn) a necessary condition for the organism to function adequately. To attribute the function of circulation to the heartbeat one must not only show that the heart contributes to circulating the blood by beating but also that the organism needs the circulation of the blood. This way of looking at attributions of causal roles does not conform to biological practice. One aim of functional biology is to explain how a certain organism is able to meet the requirements imposed on that organism by the way it is built / works / behaves and the environment in which it lives. Hence, functional biologists will often look for causal roles that help to explain an activity that needs to be done or a capacity that is needed by the organism. Yet, it is the fact that it helps to explain a certain activity or capacity that makes the causal role a causal role, and not the fact that that activity or capacity is needed. I have three arguments to support this claim that one should distinguish between satisfying a need and having a causal role ($function_2$).[3]

First, biologists are ready to talk of $functions_2$ (causal roles) even in cases in which the performance of this function is not needed to remain in proper working order. For example, the glandular hairs on the leafs of sundew are said to have the function to catch flies, even in circumstances in which sundews can survive without capturing prey.[4]

---

[2] Perhaps this is Hempel's way to mould the complex function attribution 'the heart contributes to circulating blood by beating' into the philosopher's standard form ('the function of ... is ...').

[3] George Williams's (1966) argument that one should distinguish between the needs a trait satisfies and its function as selected effect ($function_4$) was discussed in section 2.2.4.

[4] The fact that biologists are ready to say that the hairs of the sundew have the function to catch flies even in cases in which that function is not needed shows that Hempel's reading of this function attribution would be wrong but not that my reading is the right one. On my account the attribution of the function to catch flies to the hairs at the sundew's leaf is an attribution of a causal role. This interpretation explains the linguistic

Second, when searching for functions biologists often do not pay attention to the question whether or not the activities of an item satisfy a need. There is, for example, no mention of needs or demands in Harvey's (1628) account of the function of the heart (example 2.1 of chapter 2), neither in Miller's (1961) account of the function of the thymus (example 2.2).

Third, many design explanations explain the character of the item to which the causal role is attributed by appeal to that causal role without appeal to the needs satisfied by that causal role. For example, Schwenk's (1994) explanation of the form of the snake's tongue (example 2.3) appeals to the fact that the tongue has a causal role in trail-following, but not to the need to perform that causal role. He appeals to the fact that having a trail following role imposes demands on the tongue. The issue whether or not this function itself needs to be performed is irrelevant to this explanation. Hence, an account of the explanatory force of such explanations should not define functions in terms of needs.

These three arguments show that in order to attribute a function as a causal role ($function_2$) to an item it is sufficient to discover how that item contributes to an activity or capacity of a containing system and that one should distinguish between having a causal role ($function_2$) and satisfying a need.

4.2.3 Examples of functional analyses: the need to circulate oxygen

Although 'having a causal role' and 'satisfying a need' should not be identified (as I have shown in the preceding section) it is certainly the case that many studies in functional biology aim to show that the performance of a certain causal role ($function_2$) satisfies a need. Such studies aim for a design explanation that explains why it is useful to perform a certain task (that is a design explanation that answers a type (4a) question). Perhaps, it is this kind of study rather than the search for causal roles that Hempel had in mind when he talks of "functional analysis". In this section I give some examples of this kind of analysis, in the next two sections I will use these examples to show that Hempel fails to account for their explanatory force.

Outstanding examples of design explanations that explain the need to perform a certain task are explanations that are concerned with the need to circulate oxygen. The basics for such explanations were established by Krogh (1941). Krogh's work provoked a break through in respiratory biology. Krogh established that all oxygen transport ultimately relies on two kinds

---

behaviour of the biologists: functions as causal roles are determined by what an item does or is capable of doing rather than by the needs it satisfies. Proponents of an etiological reading of this function attribution would explain the biologists' behaviour by pointing out that the function is determined by what items of this kind *did* in the past (that accounts for the current presence of items of this kinds) rather than by their current needs. My arguments for reading this type of function attributions as attributions of causal roles, rather than as attributions of selected effects are given in chapter 7.

of physical process: diffusion and convection. The principles of diffusion are given by Fick's law of diffusion. This law states that the rate of diffusion of a gas is proportional to the gradient of partial pressure:

$$J = -D\,A\,\mathrm{d}P/\mathrm{d}x$$

In which:

J	the rate of diffusion (mm^3/s)
D	the diffusion coefficient ($mm^2/atm{*}s$)
A	the surface area available for diffusion (mm^2)
P	the partial pressure of the diffusing gas (atm)
x	the distance of diffusion (mm)
$\mathrm{d}P/\mathrm{d}x$	the gradient of partial pressure (atm/mm)

For an organism to be able to survive and reproduce the oxygen supply must meet the demand. The oxygen supply at a certain point in the body of an organism is determined by the rate of diffusion. For an organism that has to rely on diffusion alone the relevant distance is that between the organs and the periphery. It follows from Fick's law that the rate of diffusion decreases with the distance if the concentration gradient remains the same. Hence, an organism that has to rely on diffusion alone will run into trouble if the distance between its organs and the periphery is too long. Krogh estimated that the radius of a hypothetical spherical organism living in water saturated with air cannot exceed 0.5 mm if it is to fill its need for oxygen by mere diffusion. Such an organism needs a system of convection in addition to diffusion. The system of blood circulation in Vertebrates provides such a system of convection. Other organisms employ other kinds of convection systems. Insects, for instance, transport oxygen by means of trachea (small tubes that circulate air) and sponges and coelenterates transport oxygen by means of water currents. All these systems satisfy the need for a system of convection in addition to diffusion.

Whereas in the above explanation the size of a "larger" organism explains the need for a circulatory system in such organisms, the absence of a circulatory system in its turn explains the small size of organisms that lack such a system. For example, McNeill Alexander (1979) argues that "flatworms are less than a millimetre thick because oxygen could not diffuse into them fast enough if they were thicker" (p. ii, see also p. 183). This conclusion is based again on a derivation using Fick's law of diffusion.

Another example concerns the respiratory pigments like haemoglobin and haemocyanin which are present in the blood of many animals. These pigments serve as oxygen-carriers: they bind the oxygen in the capillaries of the respiratory sites and release it in the capillaries of the organs. This function attribution answers a type (2) question (what is the causal role of the respiratory pigments?): it describes the causal role of the respiratory pigments in the circulatory system (this attribution helps to explain how the organism is able to circulate oxygen). It is appropriate not only to ask how respiratory pigments are able to perform this task (how is oxygen bonded, how is it released and how is this regulated?—type (3) questions), but also why the performance of this task is needed (why are oxygen-carriers needed?–type (4a) questions). The short answer to the latter question is that the solubility of oxygen in a simple saline solution is too low to carry enough oxygen to supply the tissues with oxygen at the required rate. McNeill Alexander (1979: 275-280) explains in more detail why the gastropod *Helix* needs a respiratory pigment. In order to do so, he calculates the rate at which the heart of *Helix* should pump the blood if the blood would not contain respiratory pigments. This calculation supports the conclusion that "the tissues could not be supplied with oxygen at the required rate unless the heart were larger or beat faster" (p. 276). The blood of *Helix*, however, is not a simple saline solution, but contains haemocyanin. Animals that carry oxygen by means of haemocyanin are able to carry $2^1/_2$–3 times as much oxygen as will dissolve in a physical solution. This suffices to meet the demand.

A fourth example is McNeill Alexander's (1979: 357-259) design explanation of why intertidal polychaetes (for instance *Arenicola*) need gills, whereas earthworms can do without. Once again this explanation employs Fick's law of diffusion. Earthworms and polychaetes both have a circulatory system. The distance between the superficial blood vessels and the air is about the same in earthworms and in polychaetes. McNeill Alexander calculates that "an earthworm more than about 30 mm in diameter would not be feasible unless it had a lower metabolic rate [..] or the blood came nearer the surface of the body" (p. 356). The thickest earthworms have diameters around 25 mm. Earthworms generally take their oxygen from the air. Polychaetes, however, take their oxygen from water. Oxygen diffuses much less fast through water than through air. According to Fick's law and keeping all other things equal this would result in a rate of diffusion too low to meet the demands. Polychaetes solve this problem by irrigating their burrows. This keeps the partial pressure of oxygen high enough to maintain the required rate of diffusion. However, irrigation is impossible for intertidal species at low tide. As a result, keeping other things equal, the rate of diffusion would decrease. The gills solve this problem by increasing the surface area available for diffusion.

As I explained in section 4.2.1, Hempel describes a functional analysis as an attempt to show that in the conditions that apply to the organism in study the item in question has an effect that satisfies a need. This description applies to the examples above. So, let us see whether or not Hempel is able to account for the explanatory force of these examples.

4.2.4 Hempel's account of the scientific value of functional analyses

After having discussed the meaning of function attributions and the basic pattern of functional analysis, Hempel turns to an appraisal of the scientific value of such analyses. He observes that "functional analysis is widely considered as an *explanation* of the 'items' whose functions it studies" (p. 308). In his view proponents of functional analysis purport to explain the presence of a certain item by showing that it has some effects that satisfy a need. Hempel argues that the explanatory force of functional analyses is much more limited. This is due to the possibility of so-called 'functional equivalents', that is of different ways to satisfy a need or requirement. Hempel thinks of man made devices such as artificial hearts that might circulate the blood. Other examples of functional equivalents can be found in the examples above. I have mentioned three different ways to satisfy the need for a system of oxygen convection in addition to diffusion: blood circulation, trachea, and water currents. Further, both haemocyanin and haemoglobin may solve the need to carry oxygen.

According to Hempel, the possible existence of functional equivalents precludes the conclusion that a certain trait is present from the observation that a certain requirement is met. Consider the following pattern of explanation of an item (trait *i*) by functional analysis:

(a) At *t*, *s* functions adequately in a setting of kind *c* (characterized by specific internal and external conditions)

(b) *s* functions adequately in a setting of kind *c* only if a certain necessary condition, *n*, is satisfied

(c) If trait *i* were present in *s* then, as an effect, condition *n* would be satisfied

(d) (Hence), at *t*, trait *i* is present in *s* (Hempel 1965: 310)

In this pattern a description of the phenomenon to be explained (d) is derived from a combination of statements describing general laws (b and c) and a statement describing initial conditions (a), just as in a deductive-nomological explanation. However, in contrast with a deductive-nomological explanation, the conclusion (d) does not follow deductively from the premises (a-c), because it might well be that some trait *i*' different from *i* would suffice to satisfy need *n*. Conclusion (d) could be validly inferred only if (c) is replaced by (c"): 'requirement *n* can be met *only* if trait *i* were present in *s*'. In other words, in order to derive the conclusion that trait *i* is to be expected, trait *i* must not merely satisfy a need, it must be *indispensable* to satisfy that need. Hempel argues that his modified premise (c") is usually false. For example, an artificial pump can, perhaps, be used to pump the blood around. A functional analysis allows one only to derive the "very weak" (p. 313) conclusion that one of the several possible sufficient conditions is present. Therefore, the explanatory import of functional analysis is "limited to the precarious role" (p. 314) schematized in this pattern:

> (a) At *t*, *s* functions adequately in a setting of kind *c* (characterized by specific internal and external conditions)
>
> (b) *s* functions adequately in a setting of kind *c* only if a certain necessary condition, *n*, is satisfied
>
> (c') *I* is the class of empirically sufficient conditions for *n* in the context determined by *s* and *c*; and *I* is not empty
>
> (d') Some one of the items included in *I* is present in *s* at *t* (Hempel 1965: 313)

With respect to the predictive value of functional analysis Hempel observes that the possibility of functional equivalents limits the predictive power of functional analysis just as that possibility limits the explanatory power of functional analysis. Moreover, even the weak pattern given above can not readily be applied in prediction, for we do not know whether or not premise (a) (the organisms functions adequately) applies at some future time. To use this schema in prediction one should add a hypothesis to the effect that within certain limits the system under analysis will develop the means to satisfy its future needs (Hempel calls this "a hypothesis of self-regulation"). Hempel emphasizes that this hypothesis must be stated in an objectively testable form. In sum:

> [The] explanatory force [of functional analysis] is rather limited; in particular it does not provide an explanation of why a particular item *i* rather than some functional equivalent of it occurs in system *s*. And the predictive significance of functional analysis is practically nil—except in those cases where suitable hypothesis of self-regulation can be established (Hempel 1965: 324).

This does not mean that such analyses do not add to our knowledge. In Hempel's view their scientific value is to be sought in their contribution to the process of discovery rather than in their contribution to explanation or prediction:

> Functional studies in biology have been aimed at showing, for example, how in different species, specific homeostatic and regenerative processes contribute to the maintenance and development of the living organism; and they have gone on (i) to examine more and more precisely the nature and limits of those processes (this amounts basically to establishing various specific empirical hypotheses or laws of self-regulation), and (ii) to explore the underlying physiological or physiochemical mechanisms, and the laws governing them, in an effort to achieve a more thorough theoretical understanding of the phenomena at hand (Hempel 1965: 329/30)

Hence, on Hempel's account, analyses which show that a certain organism needs to perform a certain task (that is design explanations of the utility to perform a certain task) have a very weak explanatory value. Their main upshot is that they prompt biologists to study mechanisms of self-regulation. This analysis fails to do justice to the insights provided by such analyses in biology, as I shall show now.

4.2.5 Why Hempel's account fails

In the previous section I described Hempel's attempt to account for the explanatory force of analyses that show that a certain organism needs to perform a certain task (that is of a certain type of design explanation) by means of the inferential theory of explanation. On this theory analyses that show that a certain trait satisfies a need are explanatory if and only if such analyses allow us to infer the presence of the item that satisfies the need from the observation that the need is met. Hempel rightly observes that on this theory the explanatory force of such an analysis is rather weak because of the existence of functional equivalents. In this sections I shall use the examples of section 4.2.2. to show that Hempel draws the wrong conclusion from this observation. He draws the conclusion that functional analyses really have a very weak explanatory power. The proper conclusion is that the inferential theory fails to make sense of the explanatory power of functional analyses (that is of design explanation).

Consider Krogh's analysis of the need for a circulatory system. It does not report newly discovered phenomena or laws. Nor does it yield any insights into mechanisms. What does this analysis add to our knowledge? The main insights provided by this study are insights in (1) how the need for a circulatory system is connected to the size of an organism, its activity and its environment, (2) how blood circulation, trachea and water currents are all solutions to the same problem and (3) how the need for a circulatory system relates to Fick's law of diffusion. McNeill Alexander's studies provide insights in (1) how flatness is connected to the absence of a circulatory system, the activity of the flat organism and the state of its environment, (2) how flatness is related to Fick's law of diffusion, (3) how the presence of respiratory pigments is connected to the physical properties of the blood, the nature of the heart, the activity of the organism, and the environment, (4) how one difference between earthworms and polychaetes is related to their different environments.

Because of these insights biologists think of these analyses as explanatory. Hempel, however, finds himself enforced to deny the explanatory character of these analyses on the ground that they do not allow us to infer the presence of a particular item and dismisses the feeling that they are explanatory as an illusion of hindsight:

> The information typically provided by a functional analysis of an item *i* affords neither deductively nor inductively adequate grounds for expecting *i* rather than one of its alternatives. The impression that a functional analysis does provide such grounds, and thus explains the occurrence of *i*, is no doubt at least partly due to the benefit of the hindsight: when we seek to explain an item *i* we presumably know already that *i* has occurred (Hempel 1965: 313).

This puts the cart before the horse. Biologists are well aware of the existence of functional equivalents and they know that design explanations do not provide grounds for expecting one functional equivalent rather than another. Hence, it is not the illusion that a design explanation provides grounds for expecting a certain item that makes them think of design explanations as explanatory. However, the intuition that functional analyses are explanatory in combination with the awareness that functional analyses do not provide grounds for expecting a certain item should make philosophers think that providing grounds for expecting a certain item is not an adequate account of what makes an account explanatory. Let me emphasize that this is not a linguistic point. My point is not that Hempel's account fails as a conceptual analysis of what biologists call explanation, but rather that his account fails to account for the fact that design explanations add to our knowledge. Let us now see whether Nagel's account fairs better.

4.3 Nagel

4.3.1 Nagel's account of the meaning of function attributions

Nagel's focus is the question whether or not the use of teleological language in biology and the rejection of teleological explanation in the physical sciences entails the autonomy of biology from the physical sciences. Teleological statements are characterized by the occurrence of

> such typical locutions as 'the function of', 'the purpose of', 'for the sake of' and the like—more generally, the occurrence of expressions signifying a means-end nexus (Nagel 1961: 403).

An example of such a teleological statement is the following function attribution:

> the function of chlorophyll in plants is to enable plants to perform photosynthesis (i.e., to form starch from carbon dioxide and water in the presence of sunlight)[5] (Nagel 1961: 403).

A second example:

> The function of leucocytes in human blood is to defend the body against foreign microorganisms (Nagel 1961: 405).

Nagel argues that teleological statements can be translated without any loss of asserted content into non-teleological ones. However, he is not very clear about the form this translation is supposed to take. In fact, he suggests at least four different schemes.

At p. 403 Nagel (1961) states that teleological statements are "telescoped arguments" which when unpacked explain the presence of a certain item (chlorophyll, leukocytes) by showing that the presence of this item is a necessary condition for the occurrence of an activity (photosynthe-

[5] To put the record straight: biologists distinguish between photosynthesis, which is the production of organic carbon (sugar) from inorganic molecules in the presence of light, and the synthesis of starch from the sugars produced by photosynthesis. The first process takes place in the presence of light in the green parts of the plant. The second process does not depend on light and occurs also in storage organs such as the potato tuber.

sis, defence against micro-organisms) performed by the organisms that have the item (plants, humans). Such unpacked explanations are valid explanations in accordance with the deductive-nomological model. The attribution of the function of photosynthesis to chlorophyll, for instance, could be unpacked as follows:

> When supplied with water, carbon dioxide, and sunlight, plants produce starch;
>
> If plants have no chlorophyll, even though they have water, carbon dioxide, and sunlight, they do not manufacture starch;
>
> hence, plants contain chlorophyll (Nagel 1961: 403).

More generally, function attributions of the form

> The function of A in system S with organization C is to enable S in environment E to engage in process P

can be reformulated as:

> Every system S with organization C and in environment E engages in process P;
>
> if S with organization C and in environment E does not have A, then S does not engage in P;
>
> hence, S with organization C must have A (Nagel 1961: 403).

Nagel does not always stick to the idea that function attributions are telescoped arguments. Sometimes, he merely holds that teleological statements of the form “the function of *i* in organisms of type *s* is to enable *f*” can be translated into non-teleological statements of the form “*i* is a necessary condition of *f*” without loss of “asserted content”. For example at p. 405 of *The Structure of Science* Nagel states that

> the initial, unexpanded statement about chlorophyll appears to assert nothing that is not asserted by ‘Plants perform photosynthesis only if they contain chlorophyll,’ or alternatively by ‘A necessary condition for the occurrence of photosynthesis is the presence of chlorophyll’ (Nagel 1961: 405).

On this view the functions of an item are processes or activities in which that item takes part and for which the existence of that item is a necessary condition. A teleological statement expresses consequences (effects) and is equivalent to a causal (“non-teleological”) statement asserting conditions necessary for the performance of a certain activity. Function attributions, on this view, are explanatory not because they are telescoped functional explanations but because, they may be used (in their non-teleological reformulation) in functional explanations as the lawlike premise.

At page 406 Nagel raises the problem why functions are attributed to the parts of living organisms but not to the parts of physical systems such as gases and solar systems. He is interested in this problem because he suspects that some biologists will use this difference in the application of function attributions to argue that there is a difference between function attributions and non-teleological statements that is not captured by Nagel's foregoing analysis. Those biologists might bring up the following counter-example against Nagel's account: "the function of the pressure varying inversely with the volume is to keep the temperature constant". On Nagel's account this statement would be a valid function attribution, since, according to Boyle's law, the temperature of a changing volume of gas remains constant only if the pressure varies inversely with the volume. However, few physicists, if any, would be prepared to accept this statement. Those biologists might subsequently claim that it is the "goal-directed" character of organisms which makes teleological statements appropriate to biology and that the fact that teleological explanations are usually advanced only in connection with "goal-directed" systems affects the claim that teleological explanations are equivalent to non-teleological ones.

Nagel's answer to this problem is basically this: indeed, function attributions presuppose that the system under consideration is goal-directed and that the function ascribed to an item contributes to the realization of some goal for which the system is directively organized.[6] However, according to Nagel, the notions of 'goal' and 'goal-directed system' can be analyzed into non-teleological terms. The presupposition, therefore, does not affect the thesis that every teleological explanation is translatable into a non-teleological one.

Nagel's example of a goal directed system is the system that maintains the temperature of the human body within a narrow range around 37°C. This goal is achieved by means of a number of mechanisms. The most important source of heat is the energy lost in oxidative metabolism. The basal metabolic rate is influenced, among others, by a hormone produced in the thyroid gland. Under many circumstances the wasted heat is sufficient to keep us warm enough. If one gets too cold shivering may provide an additional source of heat. The main way to loose heat is via the skin. The heat radiated through the skin depends on the quantity of blood flowing through the peripheral blood-vessels, a quantity which is regulated by dilation or contraction of this vessels. Sweating is another important mechanism to get rid of excess heat. The adrenal gland produces a hormone that affects internal metabolism and shivering.

According to Nagel, goal-directed systems are characterized by the fact that they are "directively organized". Roughly speaking, a system *S* (for instance the system that maintains the inner temperature) is directively organized ("goal-directed") with respect to a certain goal-state *G* (e.g. the temperature falls within a specified range) during a certain time if during that time:

---

[6] This is most clearly stated in his "Teleology Revisited" (1977):

> A functional statement of the form: a function of item *i* in system *S* and environment *E* is *F*, presupposes (though it may not imply) that *S* is goal-directed to *some* goal *G*, to the realization or maintenance of which *F* contributes (Nagel 1977: 297)

> (1) *S* consist of a set of related parts or processes (the state variables) the states of which jointly determine the occurrence of *G* in S (some relevant state variables in the temperature example are: the states of the peripheral blood vessels, the thyroid gland, and the adrenal glands);
>
> (2) a change in one of the state variables (a primary variation) will take the system out of the goal-state if unaccompanied by changes in the other state variables;
>
> (3) the parts are so related that as a matter of fact a primary variation results in changes in the other state variables in such a manner that the goal-state is maintained (adaptive variation).

If this analysis of goal directed systems as directively organized systems succeeds, Nagel has shown that the observation that function attributions are usually advanced only in connection with goal-directed systems does not support the thesis of the impossibility of the translation of teleological language into non-teleological language. However, Nagel's discussion of goal-directed system does not answer the original objection that the translation of function attributions into statements of the form "*i* is a necessary condition of *f*" is incomplete. In fact, Nagel's discussion supports this objection and suggests a revision along the following lines:

> A statement of the form "a function of item *i* in systems of type *s* is to enable *f*" can be reformulated as:
>
> (1) systems of type s are directively organized with respect to at least one goal
>
> (2) in systems of type *s*, item *i* is necessary to perform f
>
> (3) the occurrence of *f* contributes (at least under appropriate circumstances) to the realization or maintenance of at least one of the goals with respect to which systems of type s are directively organized.

On this view function attributions are not equivalent to teleological explanations, because on this revised account function attributions assert more than the corresponding teleological explanations do (namely that the function contributes to a goal state). However, neither in chapter 12 of *The Structure of Science*, where Nagel discusses "the structure of teleological explanations" in biology, nor in "Teleology Revisited" is this possible revision and its relation to functional explanation explicitly discussed. Nagel largely restricts himself to the observations that when biologists attribute functions they are usually interested in how a certain item contributes to the maintenance of the organism (p. 408, 422) and that they usually presuppose that the system they are interested in is goal-directed (p. 421). He fails to draw the consequences from this observation for his analysis of function attributions and functional explanation. The item's contribution to the maintenance of a goal-state plays no role whatsoever in Nagel's account of functional explanation.

However, in chapter 14 of *The Structure of Science*, where Nagel discusses "functionalism in social science" he talks in yet a different mode. For example, at page 525 he distinguishes as one meaning of the term 'function' in social science "the sense that has occupied us in chapter 12". In this sense

> the function of some item signifies the contribution it makes (or is capable of making under appropriate circumstances) toward the *maintenance* of some stated characteristic or condition in a given system to which that item is assumed to belong (Nagel 1961: 525)

This quote suggests not merely that function attributions presuppose that the function contributes to the maintenance of some goal-state or other (as in the third translation scheme), but rather that the goal-state is explicitly mentioned in function attributions. Moreover, as Lehman (1965a: 9) points out, in this part of his book Nagel seems to have forgotten his earlier contention that items are necessary for their function . Indeed, Nagel warns his readers that they should not think, that functional items are indispensable:

> One of the functions of the thyroid glands in the human body is to help preserve the internal temperature of the organism. However, this is also one of the functions of the adrenal glands, so that in this respect there are at least two organs in the body that perform (or are capable of performing) a similar function. Accordingly although the maintenance of a steady internal temperature may be indispensable for the survival of human organisms, it would be an obvious blunder to conclude that since the thyroid glands contribute to this maintenance they are for this reason indispensable for the continuance of human life. Indeed, there are human beings who, as a consequence of surgical intervention, do not have thyroid glands, but nevertheless remain alive (Nagel 1961: 533).

Subsequently, he scorns Malinowski for committing this fallacy:

> This point has not been consistently recognized by functionalists. For example, Malinowski argued that because the function of myth is to strengthen tradition by attributing to it a supernatural origin, “myth is, therefore, an indispensable ingredient of all culture” (Malinowski 1948: 146). However, although one may grant, if only for the sake of the argument, the role Malinowski ascribes to myth in strengthening traditions, as well as his tacit claim as to the indispensability of tradition in all societies for the persistence of their cultures, his conclusion is nevertheless a *non sequitur*. For he transfers without warrant the admitted indispensability of *tradition*, to a *particular means or instrument* that happens to be employed in certain societies for sustaining tradition (Nagel 1961: 533).

Note that Nagel’s example of a function attribution in biology (“the function of the thyroid is to help preserve the internal temperature”) only states that a certain item contributes to a certain goal. Malinowski’s function attribution (“the function of myth is to strengthen tradition by attributing to it a supernatural origin”) on the other hand states both the goal (maintaining the tradition) to which the item (myth) contributes and the manner in which that item contributes to the maintenance of the goal state (by giving it a supernatural origin). These remarks suggests that function attributions might by more or less complete. They are complete if they specify both the goal-state and the means by which the item contributes to the realization or maintenance of that state. They are incomplete if they specify only one of these two. Nagel’s main example in chapter 12 (the function of chlorophyll in plants is to enable plants to perform photosynthesis) now emerges as an incomplete function attribution that specifies the means but not the goals. Nagel's discussion of function attributions in chapter 14 suggests the following translation scheme for complete function attributions:

> A statement of the form "A/the function of item *i* in systems of type *s* is to contribute to the maintenance of goal *g* by means of *m*" (e.g. "the function of myth is to strengthen tradition by attributing to it a supernatural origin") can be reformulated as
>
> (1) systems of type *s* are directively organized with respect to *g*
>
> (2) in systems of type *s*, item *i* effects *m* (at least under appropriate circumstances)
>
> (3) in systems of type *s*, the occurrence of *m* contributes (at least under appropriate circumstances) to the realization of *g*.

Incomplete function attributions mention only the goal

> A statement of the form "A/the function of item *i* in system *s* is to contribute to the maintenance of goal *g*" (e.g. "the function of the thyroid in human bodies is to help humans to preserve the internal temperature") can be reformulated as
>
> (1) systems of type *s* are directively organized with respect to *g*
>
> (2) in systems of type *s*, item *i* contributes to the realization or maintenance of *g*

or the means

> A statement of the form "A/the function of item *i* in system *s* is to perform or enable *m*" (e.g. "the function of chlorophyll in plants is to enable photosynthesis") can be reformulated as
>
> (1) systems of type *s* are directively organized with respect to at least one goal state
>
> (2) in systems of type *s*, item *i* effects *m* (at least under appropriate circumstances)
>
> (3) in systems of type *s*, the occurrence of *m* contributes (at least under appropriate circumstances) to the realization of at least one of the goals with respect to which systems of type *s* are directively organized.

Nagel's account of functional explanations leaves the explanatory force of this kind of function attributions entirely unexplained.

In this section I have argued that Nagel provides at least four different analyses of function attributions, namely (1) function attributions as telescoped arguments, (2) function attributions as stating that the presence of a certain item is necessary condition to perform a certain activity, (3) function attributions as stating that a certain item is necessary for a certain effect which in its turn helps to maintain a certain goal-state, (4) function attributions as stating how a certain item contributes to the maintenance of a certain goal state. On the first three schemes function attributions imply that the item to which the function is attributed is necessary for its function. On Nagel's account of functional explanation, it is this implication (and only this implication) that is important in a functional explanation. In the next section I discuss the question whether or not such an analysis sufficiently accounts for what is achieved by appeals to function in explanations in functional biology.

4.3.2 Nagel's account of functional explanation

As I have emphasized in section 4.2.3 attributions of needs as they are used in functional biology typically allow for functional equivalents, that is they allow for different ways to meet a certain requirement. For example, many organisms satisfy the need for a system of convection by means of a system of blood circulation, insects circulate air and sponges and coelenterates circulate water. Haemoglobin and haemocyanin can both satisfy the need for a oxygen carrier and so on. I have also emphasized that such attributions have an important explanatory role. Nagel (1961, 1977) tries to account for the explanatory force of attributions of needs in terms of the inferential theory of explanation, just as Hempel (1959) does. On this account, explanations work by showing that the phenomenon to be explained is to be expected in virtue of the explanatory facts. As I have discussed in section 4.2.4 Hempel argues that the existence of functional equivalents prevents the derivation of the conclusion that a certain item is present from a functional analysis. In order to show that the phenomenon to be explained was to be expected the item under study must be shown to indispensable. Hempel rightly observes that, usually, this is not the case and draws the conclusion that analyses that appeal to needs are explanatory only in a very limited sense. Nagel on the other hand argues that, given a certain form of organization, the items of which the presence is explained by means of a functional explanation are, indeed, indispensable for their function and, more general, for that organism to survive. Analyses that appeal to functions are, therefore, really explanatory.

As I have discussed in section 4.3.1 according to Nagel (1961) functional explanations conform to the deductive-nomological model. They have the following form:

> Every system S with organization C and in environment E engages in process P;
>
> if S with organization C and in environment E does not have A, then S does not engage in P;
>
> hence, S with organization C must have A (Nagel 1961: 403).

For example:

> When supplied with water, carbon dioxide, and sunlight, plants produce starch;
>
> If plants have no chlorophyll, even though they have water, carbon dioxide, and sunlight, they do not manufacture starch;
>
> hence, plants contain chlorophyll (Nagel 1961: 403).

Nagel's reconstruction of functional explanations in "Teleology Revisited" (1977) is slightly different from that in *The Structure of Science* (1961). The conclusion of the explanation is now rendered as a statement about an individual system (e.g. a certain plant) during a certain period, rather than about a certain type of systems (e.g. plants) in general. The argument consists of three premises, rather than two:

> The explanatory premises for the assertion having the form "the item *i* occurs in *S* during a given period *t* and circumstances *E*"—for example, "during a stated period and given circumstances, chlorophyll is present in the specified green plant"—are as follows:
>
> (1) "During a stated period, the system *S* is in environment *E*" (for example, "during a stated period, a green plant is provided with water, carbon dioxide, and sunlight");
>
> (2) "During that period and in the stated circumstances, the system *S* does *F*" (e.g., "during the stated period, and when provided with water, carbon dioxide, and sunlight, the green plant performs photosynthesis")
>
> (3) "If during a given period *t* the system *S* is in environment *E*, then if *S* performs *F* the item *i* is present in *S*" (e.g., "if during a given period a green plant is provided with water, carbon dioxide, and sunlight, then if the plant performs photosynthesis the plant contains chlorophyll") (Nagel 1977: 300)

In this scheme:

> the first two premises are instantial statements, and the third is lawlike (Nagel 1977: 300)

The differences between these two schemes of functional explanation are not important for the criticisms I will bring up in section 4.3.3.

In regard to functional equivalents, Nagel observes in *The Structure of Science* that it has been objected against his analysis that the second premise of his explanatory scheme would be untenable if chlorophyll is not necessary to produce starch or if plants can maintain themselves without photosynthesis. He argues that this objection rests on a misunderstanding. Nagel concedes that it is logically possible that there are plants which do not produce starch or which produce starch in absence of chlorophyll. He even points out that there are in fact plants that survive without chlorophyll. However, the functional explanation of the occurrence of chlorophyll is not concerned with logical and physical possibilities but with a definite form of organization, the so-called "green plants". Given this form of organization there is no reason to question the need for chlorophyll:

> It is certainly *logically* possible that plants might maintain themselves without manufacturing starch, or that processes in living organisms might produce starch without requiring chlorophyll. Indeed, there are plants (the funguses) that can flourish without chlorophyll; and in general, there is more than one way of skinning a cat. On the other hand, the above teleological explanation of the occurrence of chlorophyll in plants is presumably concerned with living organisms having certain determinate forms of organization and definite modes of behavior—in short, with the so-called "green plants." Accordingly, although living organisms (plants as well as animals) capable of maintaining themselves without processes involving the

> operation of chlorophyll are both abstractely and physically possible, there appears to be no evidence whatever that in view of the limited capacities green plants possess as a consequence of their actual mode of organization, these organisms can live without chlorophyll (Nagel 1961: 404, emphasis in original).

To avoid such misunderstandings function attributions should detail the form of organization to which they apply:

> a teleological explanation must articulate with exactitude both the character of the end-product and the defining traits of the systems manifesting them, relative to which the indicated processes are supposedly indispensable (Nagel 1961: 404).

A similar argument is given in “Teleology Revisited” where Nagel discusses Hempel’s argument that the possibility of functional equivalents (such as artificial hearts that pump the blood around) deprives functional analyses of much of their purported explanatory power. Nagel argues that since physiologists are concerned with normal human beings, observations about humans with artificial hearts are not relevant:

> A convincing case can be made for the claim that in normal human beings—that is, in human bodies having the organs for which they are at presently genetically programmed—the heart *is* necessary for circulating blood; for in normal human beings there are in fact no alternative mechanisms for effecting the blood’s circulation. For physiologists seeking to explain how the blood is circulated in normal human bodies have discovered that human bodies have no organs other than the heart for performing that function. The observation that it *may* be (or actually *is*) physically possible to circulate blood by means of other mechanisms is doubtfully relevant to those investigations of how the blood is circulated in the human beings, upon which physiologists are embarked (Nagel 1977: 292).

He repeats his idea that the impression that there are functional equivalents is due to the imprecise way in which the system to which the function is attributed is specified:

> The denial of the claim that the heart is necessary for circulating the blood appears to derive part of its plausibility from the imprecise way in which the expression ‘human body’—and more generally the expression ‘the system S’ is usually specified (Nagel 1977: 292).

He adds to this that the problem of functional equivalents is well-known in the context of causal explanation. At first sight death may result from a plurality of causes (e.g. drowning, poison, gun shots and so on), none of which is in itself indispensable for its effect. However, if the condition of the corpse is specified in a more precise way only one type of cause remains for each type of death and the occurrence of this cause is a necessary condition for all effects of this type. Similarly, in the case of functional explanation the problem of functional equivalents should be solved by a more precise description of the system in which the item functions. In the example of the function of the heart the system in which the heart has a function should be described as a “normal human being” rather than as a “human being”. Given this form of organization the presence of a heart is a necessary condition to pump the blood around.

In sum, Nagel’s way of dealing with the problem of functional equivalents in the context of explanations that appeal to functions appears to be: (1) to emphasize that the scope of the premise stating that the presence of a certain item is indispensable to perform a certain function is restricted to those organisms (“systems”) that indeed have that item, and (2) to deny on that ground the relevance of observations about possible or actual organisms that lack that item. In the next section I argue that this way of dealing with the problem of functional equivalents not only confuses attributions of needs with attributions of functions, but also prevents the relevant premise of its lawlikeness. As a result, Nagel’s analysis fails to account for the explanatory force of attributions of needs.

4.3.3 Physical possibilities

As I have shown in the previous section, Nagel repeatedly suggests that functional biologists are concerned with what is the case in actual existing organisms rather than with logical or physical possibilities. This is a severe misunderstanding. It is certainly true that functional biologists are not concerned with *logical* possibilities, but *physical* possibilities play an important role in functional biology, just as in any other natural science. More specifically, the point of many design explanations is to show that the existing form is physically possible whereas certain alternative forms are not. Consider, for example, Krogh’s study of the need for a circulatory system. As I have discussed in section 4.2.3, Krogh showed with the help of Fick’s law of diffusion that organisms larger than a certain size that rely on diffusion alone are physically impossible. Another example is McNeill Alexander’s explanation of why *Helix* needs respiratory pigments (example 3 in section 4.2.3). He uses the laws of physical chemistry to establish (1) that organisms that are built in the way in which *Helix* is built but which do not have respiratory pigments are physically impossible because they cannot satisfy their need for oxygen, and (2) that the presence of haemocyanin solves this problem.

This concern with physical possibilities is a crucial difference between attributions of needs and attributions of causal roles (function$_2$ attributions). Attributions of causal roles are generalizations about how a certain item is actually used in a certain group of organisms. Attributions of needs on the other hand are lawlike. They do not merely tell us what is the case (in a certain group of organisms), but what is physically possible and what not (given the conditions stated in the attribution). For example (example 2.3 of chapter 2), Schwenk’s attribution of a trail-following role to the tongues of all snakes and certain lineages of lizards (an attribution of a causal role) is a generalization about how the tongue is used in those organisms. It does not allow any conclusion about yet unknown species. Perhaps there are yet undiscovered species of snakes that have stopped using their tongue in this way; perhaps there are lineages of snakes that have never developed this habit. If such a species were discovered, the statement that the tongue has a trail-following role would still apply to the species to which it applies now. Schwenk's observation that in order to use chemosensory tropotaxis those organisms must be able to sense simultaneously the chemical stimuli at two points (an attribution of a need), however, is not concerned with what is actually the case in those organisms, but with the conditions under which chemosensory tropotaxis is physically possible (or not). From this attribution one may derive valid conclusions about unknown species. For instance, one may derive the conclusion that unknown species that use their tongue in chemosensory tropotaxis must have either a forked tongue or a functional equivalent device (that is another device that enables them to sense simultaneously the chemical stimuli at two sides of the body). If a species were found that does not meet this requirement but still uses its tongue in chemosensory tropotaxis this would give reason to doubt Schwenk's attribution of a need. Hence, although observations about possible or actual organisms that lack the item to which the $function_2$ is attributed are irrelevant to attributions of causal roles such observations are, *pace* Nagel, highly relevant to attributions of needs.

Because attributions of causal roles are nothing but generalizations about how a certain item is used or about how a certain causal role is performed, an attribution of a causal role in itself does not explain the item to which the causal role is attributed. To explain an item by appeal to its causal role one needs a lawlike statement in addition to the attribution of a causal role. Often this lawlike statement takes the form of an attribution of a need. For example, to explain the forkedness of the snake's tongue, Schwenk uses the attribution of the need to sense simultaneously the chemical stimuli at two points in addition to the attribution of a trail-following role. This explanation can be expressed by means of the following train of thought:

(1) The tongues of snakes have a role in chemosensory tropotaxis

(2) Chemosensory tropotaxis is physically possible only if an organism is able to sense simultaneously the chemical stimuli at two points

(3) In snakes this requirement is met by the forking

----

(4) That's why_2[7] the tongues of snakes are forked

Note that what is explained by appeal to the trail following role is not the presence of the item to which the function is attributed (the tongue) but its forked character. Both Hempel and Nagel erroneously assume that function attributions are used to explain the presence of the item to which the function is attributed.

[7] Recall that 'why_2' is short for 'why it is useful that' (see section 2.3.2).

More generally, the train of thought of many design explanations that appeal to the demands imposed on an item by the causal roles (function$_2$) that item has (that is design explanation that address a type 4b question), can be expressed by means of the following scheme of explanation:

(1) In *s*-organisms: item *i* performs causal role *f*

(2) The performance of causal role *f* is physically possible only if requirement *n* is satisfied

(3) In *s*-organisms: if item *i* has character *c* then requirement *n* is satisfied

----

(4) That's why$_2$ in *s*-organisms item *i* has character *c*.

The train of thought represented by this scheme is not an argument in the sense in which the term 'argument' is used in logic: the explanatory statements are not intended to support a conclusion, but to explain the phenomenon described in the last statement. The first statement in this scheme is an attribution of a causal role (function$_2$), the second one an attribution of a need and the third one states how the need is satisfied in a certain group of organisms. The first statement is a generalization about the causal role of a certain item in a certain group of organisms. The third statement is a generalization about the way in which a need imposed by that causal role is satisfied in that group of organisms. The group of organisms mentioned in the first and the third statement is not necessarily a systematic or phylogenetic category. An enumeration of the individuals to which these statements apply would work too. The second statement is lawlike. Instead of an attribution of a need biologists often use a weaker kind of lawlike statement to explain the character of an item, namely the statement 'in order to perform function *f* it is useful if condition *n* is satisfied'.

Design explanations that appeal to the need to perform a certain causal role (design explanations that address a type 4a question), too, consists of a lawlike statement in addition to the function attribution. Many of them follow the following scheme:

(1) s-organisms are in condition c_n

(2) in condition c_n: organisms are able to survive and reproduce only if causal role *f* is performed

(3) in s-organisms: item *i* performs causal role *f*

----

(4) That's why$_2$ s-organisms have item *i*

An example is Krogh's (1941) explanation of why$_2$ vertebrates have a circulatory system:

(1) The distance between the inner organs of Vertebrates and their periphery is more than 1 mm

(2) If the distance between the inner organs and the periphery is more than 1 mm an organism is viable only if it has a system of convection in addition to diffusion

(3) The circulatory system of Vertebrates provides a system of convection

---

(4) That's why$_2$ vertebrates have a circulatory system.

In this explanation again the attribution of a causal role (function$_2$) (3) is combined with a law-like statement (2) in order to generate the explanation. The latter statement, an attribution of a need, expresses what is physical possible.

A philosophical theory of explanation in functional biology should (among other things) account for the explanatory character of trains of thought of this kind. On the inferential account this train of thought would be explanatory if and only if the explanatory statements give us reason to expect the phenomenon to be explained. In order to do so the scheme must represent a valid argument, the premises of which must be true and at least one of the premises must be lawlike. Because of the possibility of functional equivalents (ad. (3)) the schemes of the previous paragraph are invalid. For that reason the inferential account fails to make sense of the explanatory character of this kind of design explanations.

As I discussed in the previous section, Nagel attempts to save the inferential account from the above objection by observing that given a certain form of organization there is in fact only one kind of item that performs the function. In his view a function attribution in itself explains the presence of the item to which the function is attributed. Given an appropriate specification of both the function and the system to which the function attribution applies there is only one type of item in the world that performs this function. For that reason one may infer the presence of the item to which the function is attributed from the observation that the function is performed. This move saves the validity of the argument at the cost of the lawlikeness of the general statement (which is the second premise in the scheme of *The Structure of Science* and the third in "Teleology Revisited"). This is most clearly illustrated by means of his own example: the explanation of the presence of chlorophyll.

Nagel does not discuss this example in any detail. Nor does he give bibliographic references. This makes it difficult to determine exactly what explanation he has in mind. Let us take a look at the history of the study of chlorophyll to see if we can make sense of his example. In section 2.2.2 I discussed several examples of attributions of causal roles. In all those cases one was looking for an unknown causal role of a known item. The case of chlorophyll is quite different. The causal role was known before the item. The history of the study of photosynthesis starts in 1772. In that year the famous English chemist Joseph Priestley reported to the

Royal Society that air rendered impure by a breathing mouse or a burning candle could be purified by a living plant. A few years later Jan Ingenhousz, a Dutch physician, discovered that this process of purification took place only in sunlight and only in the green parts of plants. In 1782 the Swiss Jean Senebier showed that the process depends on the presence of a gas he called 'fixed air' (carbon dioxide). Another Swiss researcher, Nicolas Théodore de Saussure, discovered the role of water in 1804 and established the following overall equation of the photosynthetic process:

carbondioxide + water + light --> organic matter + oxygen

This is essentially the overall equation as it is known now. In 1817 two French chemists, Pelletier and Caventou, managed to extract the green substance from the leaves. They called this substance 'chlorophyll'. From this point in the history of biology it was known which substance performed photosynthesis. The structure of this substance became known only in the mid of the twentieth century.

Biologists do not think of the attribution of the role to perform photosynthesis to chlorophyll as an explanation of the presence of chlorophyll. When biologists ask the question 'why do plants have chlorophyll?' (e.g. Mauzerall 1977, Seely 1977) they have in mind very specific type (4b) questions about the structure of chlorophyll. This structure was established from degradation studies by H. Fischer in Germany in 1940. R.B. Woodward confirmed this analysis in 1960 by a complete synthesis of the molecule. The chlorophyll molecule contains a porphyrin 'head' and a phyttol 'tail'. The porphyrin head is made of a tetrapyrole ring containing a magnesium atom. There are several forms of chlorophyll and there are many other pigments (such as carotenoids and phycobillins) involved in photosynthesis. However, only two forms of chlorophyll are involved in the photochemical process itself: chlorophyll a is used in all forms that employ oxygen and bacteriochlorophyll is used in photosynthetic bacteria. All other pigments serve as light harvesting pigments: they absorb light in a variety of wavelengths and transfer the excitation energy to chlorophyll a or bacteriochlorophyll. One way of explaining why plants have chlorophyll is answering the question 'why do plants use chlorophyll a rather than one of the available alternatives (carotenoids and phycobillins) as the first step in the photochemical process?'. Part of the answer is that chlorophyll absorbs in the low energy end of the visible spectrum. Radiation with less energy does not produce chemical reactions. Radiation with more energy is harvested by the other pigments. For physical reasons, a harvesting pigment needs to dump its energy at an energy level lower than the energy of the light it absorbs. For that reason it is useful if the receiver pigment absorbs energy at a level that is as low as possible. Other issues in this area of research concern questions about the presence of specific organic groups and the question why magnesium rather than some other metal is trapped in the tetrapyrole ring.

Hence, when biologists study the type (4b) question ‘why do plants have chlorophyll’ they try to explain why$_2$ the photochemical reaction is performed by a molecule which has the structure chlorophyll has by appealing to the usefulness of having a certain structure in performing the causal role in photosynthesis. Nagel’s scheme does not represent this practice. When he talks about an explanation of chlorophyll he has something much less interesting in mind, namely a derivation of the conclusion that chlorophyll is present from the observation that photosynthesis is performed together with the general statement that all green plants that perform photosynthesis have chlorophyll (this is the second premise in the scheme of *The Structure of Science* and the third in “Teleology Revisited”). This view of functional explanation not only fails to do justice to the practice of functional biology, it also fails to reveal the explanatory force of the function attribution on the inferential account. To count as an explanation on the inferential account the general statement must be a lawlike. On Nagel’s account, however, this statement is only a generalization about what is the case in a certain group of plants.

The trouble is the definition of ‘green plants’. Nagel is not quite clear how this form of organization is defined. ‘Green plants’ might simply mean those plants that are green. Because the green colour of green plants is due to the presence of chlorophyll, the statement “all green plants perform photosynthesis only if they have chlorophyll” is a truism on this reading, rather than a law. Moreover, many photosynthetic algae are not green but red, brown or purple. On this reading the attribution of the causal role to perform photosynthesis would not apply to this group of organisms. Yet, according to biologists the causal role of chlorophyll in these algae is to enable photosynthesis.

On the other hand, Nagel could try to identify ‘green plants’ with a certain taxonomic group, such as the kingdom of plants. Folk biology tends to divide living organisms into two kinds: plants (including algae, fungi and perhaps bacteria) and animals. Biologists are more sophisticated and distinguish *at least* six kingdoms: (1) eubacteria, (2) archaebacteria, (3) protista, (4) plants, (5) fungi, (6) animals. There is a lively discussion on this subject (the protista group is highly problematic) but it is undisputed that the fungi are not to be included in the kingdom of plants and, for that reason, it would seem to help Nagel to relativize the attribution to this group in order to avoid functional equivalents. However, some of the organisms included in the kingdom of plants (no matter its exact definition) do not need chlorophyll: parasitic forms such as the Birdsnest orchid and all species of the Broomworth family do not perform photosynthesis but get their energy from sugars taken from their hosts. Saprophytic forms such as *Monotropa* also do not have chlorophyll but extract sugars from leaf litter, with the help of funguses. Furthermore there are certain groups of eubacteria (which on no account belong to the kingdom of plants) that use chlorophyll to perform photosynthesis. The same problem occurs if one would try to define green plants as a phylogenetic group

4.4 Conclusions

Hempel and Nagel are concerned to account for both function attributions and design explanations. I have argued against Hempel's meaning analysis that 'having a function' is not the same as 'satisfying a need' and against Nagel's meaning analysis that 'having a function' is not the same as 'being needed'. Although causal roles are not *defined* in terms of needs, Hempel and Nagel were right in thinking that the kind of reasoning which functional biologists call 'functional explanation' (and which I have called 'design explanaton') appeals to needs and requirements. However, the attempts of Hempel and Nagel to account for such explanations on the inferential theory of explanation fail.

My diagnosis of Hempel's and Nagel's failure is as follows. Both Hempel and Nagel are of opinion that the existence of functional equivalents would prevent an account from being explanatory. This poses the following dilemma: either there exist real functional equivalents in which case one should deny that appeals to needs are explanatory or appeals to function are really explanatory in which case one should deny the existence of real functional equivalents. Hempel takes the first horn of this dilemma, Nagel the second one. Hempel's move is not acceptable because it fails to account for what is achieved by a design explanation. Nagel's move does not work because it saves the validity of an appeal to needs at the cost of the law-likeness of that appeal. But even if Nagel's attempt to downplay the existence of functional equivalents had been succesful his account would have had severe problems. One of the things one may learn from a design explanation is precisely that two or more different structures or behaviours are functional equivalent. Krogh's explanation, for example, yields the insight that blood circulation, trachea and water currents might all provide different solutions to different problems. An account of explanation that denies the existence of functional equivalents must deny these insights and is for that reason not acceptable. That is, any account of explanation in functional biology should allow for functional equivalents. Apparently there is something wrong with the inferential conception of explanation.