

7 Working conceptual hallucinations

The analysis presented in previous chapters has two clear limitations. In the first place, it has been concerned primarily with discourse occurring within the research community. Secondly, we have so far concentrated exclusively on verbal discourse. An omission of non-verbal material would be a serious gap in a form of analysis dealing with scientific discourse, rather than with action and belief, because there can be no doubt that technical communication in science relies heavily on pictorial and mathematical repertoires.

Our objective in this chapter is to begin to overcome these limitations. We will do this by examining a set of pictorial forms produced by bioenergeticists, by studying how these pictorial forms change as they are made available to non-specialists, by investigating a particular non-specialist's reading of one of these pictures, and by looking at what our respondents have to say about this collection of pictorial products and about pictorial representation in general.

Scientists use many kinds of visual display, such as tables, graphs, photographs, electron micrographs, drawings, flow diagrams, and demonstrations, in communicating their knowledge-claims.¹ Here, we will focus on those displays which represent the chemiosmotic processes of ATP synthesis and the associated biological structures. We will refer to such displays simply as 'pictures'. It is clear that these pictures are closely related to verbal formulations of the chemiosmotic theory and that they play an important part in the communication of that theory among bioenergeticists and from bioenergeticists to non-specialists. Chemiosmotic pictures, then, in some sense embody the chemiosmotic theory and reproduce it in visual form.

The analysis of pictorial discourse which follows links up in various ways with what has gone before and with the content of the next chapter. Because we are going to examine numerous pictures which appear in written texts, we will return to the type of analysis which was predominant in chapter three. In that chapter, we showed how verbal discourse differed systematically between formal and informal contexts. In this chapter, we distinguish between the context of the research literature and that of

textbooks and popular presentations of scientific knowledge. We will show that there are systematic changes in the forms of pictorial discourse employed in these contexts.

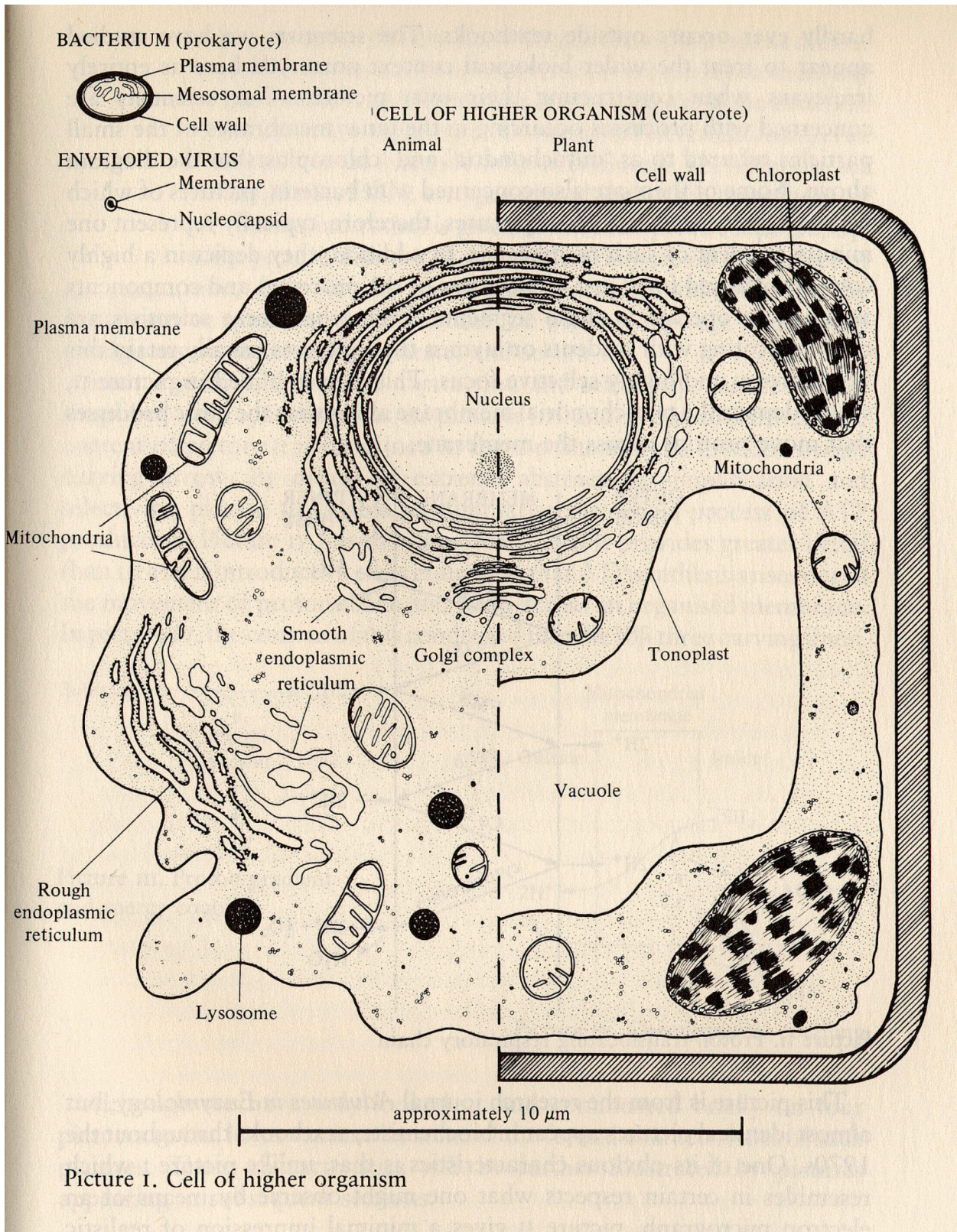
In later sections of this chapter, we will examine numerous quotations from our interviews. In twenty-five of these interviews scientific pictures were explicitly discussed, often at some length. Our procedure was to ask each respondent about his own use of pictures and then to present specific pictures for more detailed comment. The most frequently discussed of these pictures appear below (pictures V to VIII). Unlike many other topics covered in the interviews, reference to pictures occurred as a distinct and separate topic at the direct instigation of the interviewers. It is necessary to mention this, because it may be at least partly responsible for the considerably greater degree of consistency and coherence exhibited in respondents' talk about pictures compared with that found in their talk about most other topics. We must emphasise that, although our respondents only began to reflect on the nature of pictorial discourse in response to our specific requests, many of them *used* pictures of various kinds with no encouragement from

us in order to convey their views on the biochemical processes of oxidative phosphorylation. As most sociologists who have interviewed scientists about their work will probably testify, interviews in which the respondent employs no pictures at all can be regarded as rather unusual.

Some typical pictures from bioenergetics

In order to appreciate some of the distinctive features of pictures appearing in bioenergetic texts, let us begin by considering one which is in some respects unusual. Picture I below is the frontispiece to a textbook on biological membranes and their cellular functions. This book is described in its preface as presenting 'a broad view of the significance of membranes in cellular activities, particularly for use by students and teachers in biochemistry and other biomedical sciences'.² The dual representation in picture I of the typical cell in animals and plants provides an overall context for the contents of the book. In subsequent chapters the authors deal systematically with the components it shows. The picture furnishes its readers with a preliminary idea of what each of the components of a cell 'looks like', how they differ from each other and how they are distributed within the cell. It provides an initial visual *Gestalt* which is filled out in detail as the chapters unfold.

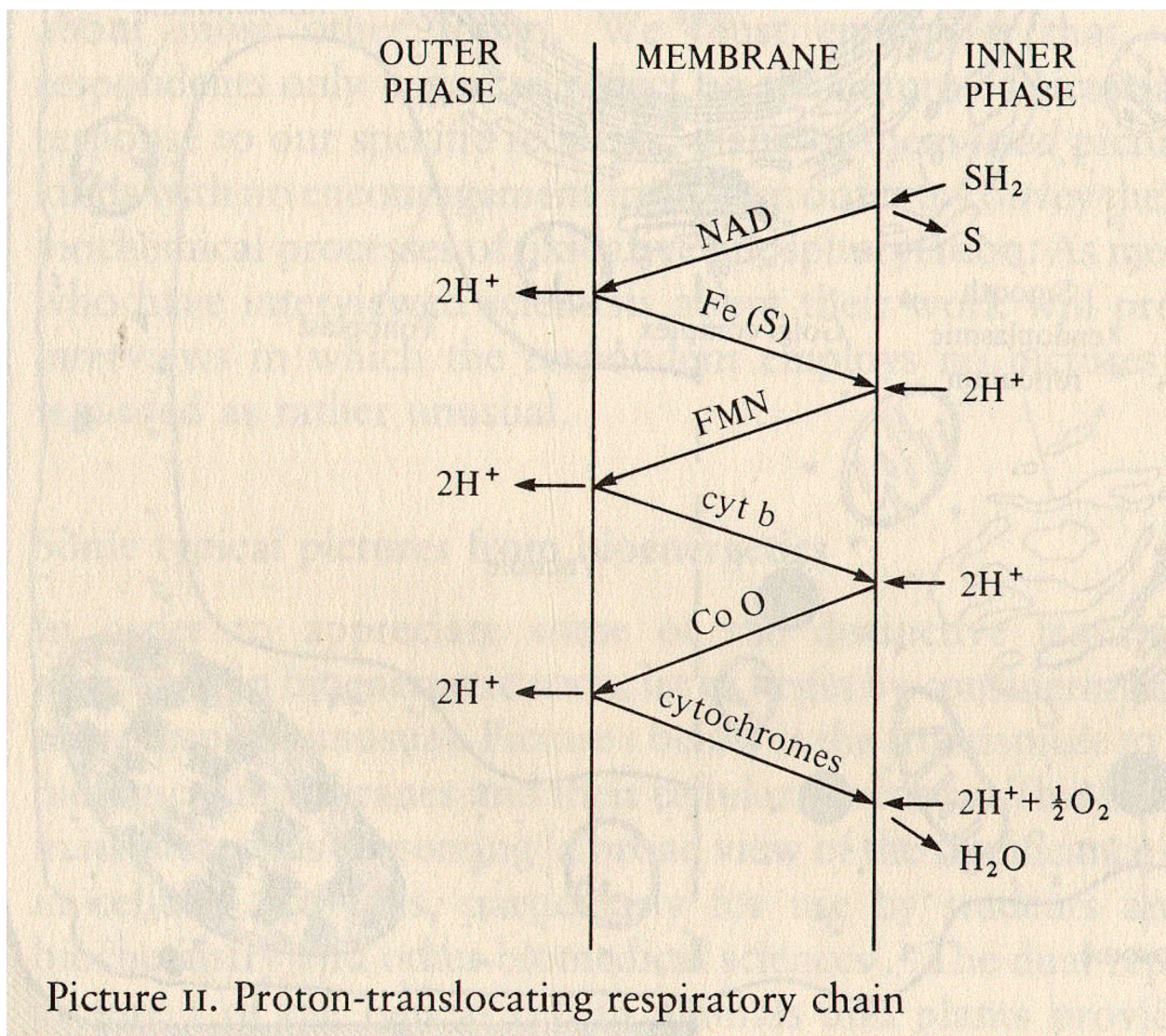
Even though the scope of picture I is restricted to the cells of higher organisms, it is very unusual in representing so many different biological phenomena together. It illustrates a type of comprehensive picture which



Picture 1. Cell of higher organism

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hardly ever occurs outside textbooks. The scientists we have studied appear to treat the wider biological context portrayed here as entirely irrelevant when constructing their own pictures. Our scientists are concerned with processes occurring in the inner membranes of the small particles referred to as 'mitochondria' and 'chloroplasts' in the diagram above. (Some of them are also concerned with bacteria, pictures of which we shall discuss below.) Their pictures, therefore, typically represent one minute segment of such membranes. In addition, they depict in a highly conventionalised form just a select few of the processes and components assumed to operate in these segments. Even when these scientists are communicating with students or laymen their pictures usually retain this very narrow and highly selective focus. This is exemplified in picture It, which depicts the mitochondrial membrane along with the basic processes that move protons across the membrane.



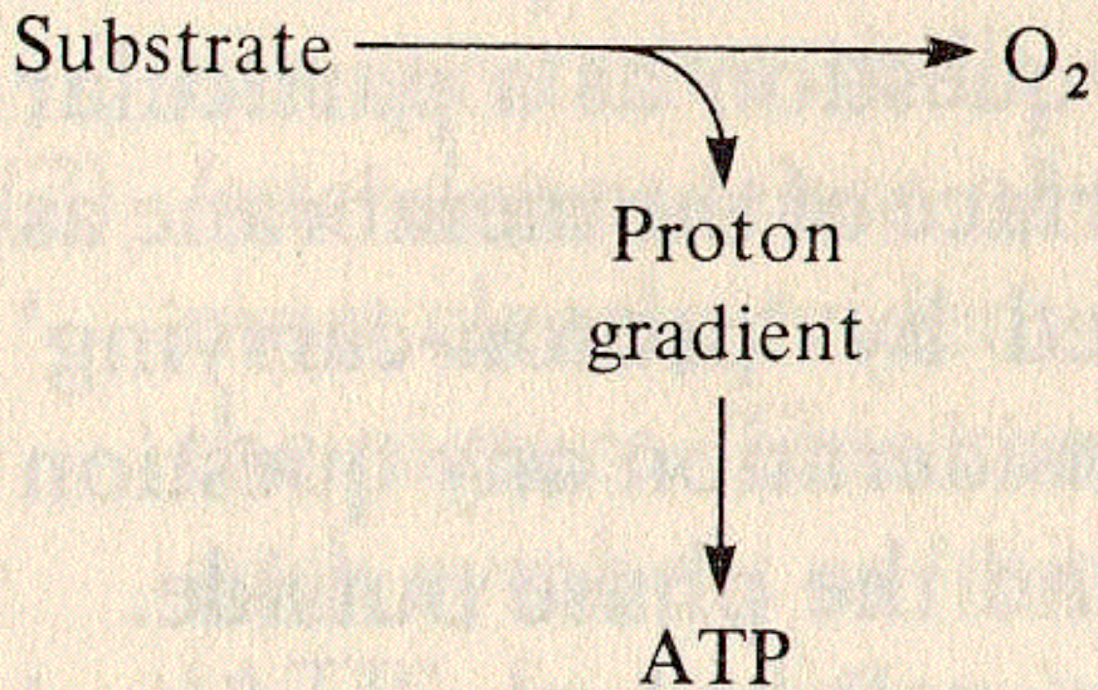
This picture is from the research journal *Advances in Enzymology*, but almost identical pictures appear in biochemistry textbooks throughout the 1970s. One of its obvious

characteristics is that, unlike picture I which resembles in certain respects what one might observe by means of an electron micrograph, picture II gives a minimal impression of realistic representation. For instance, not only is the cellular environment of the mitochondrion totally ignored, but also its outer membrane. For our respondents, such phenomena are consistently treated as irrelevant to the

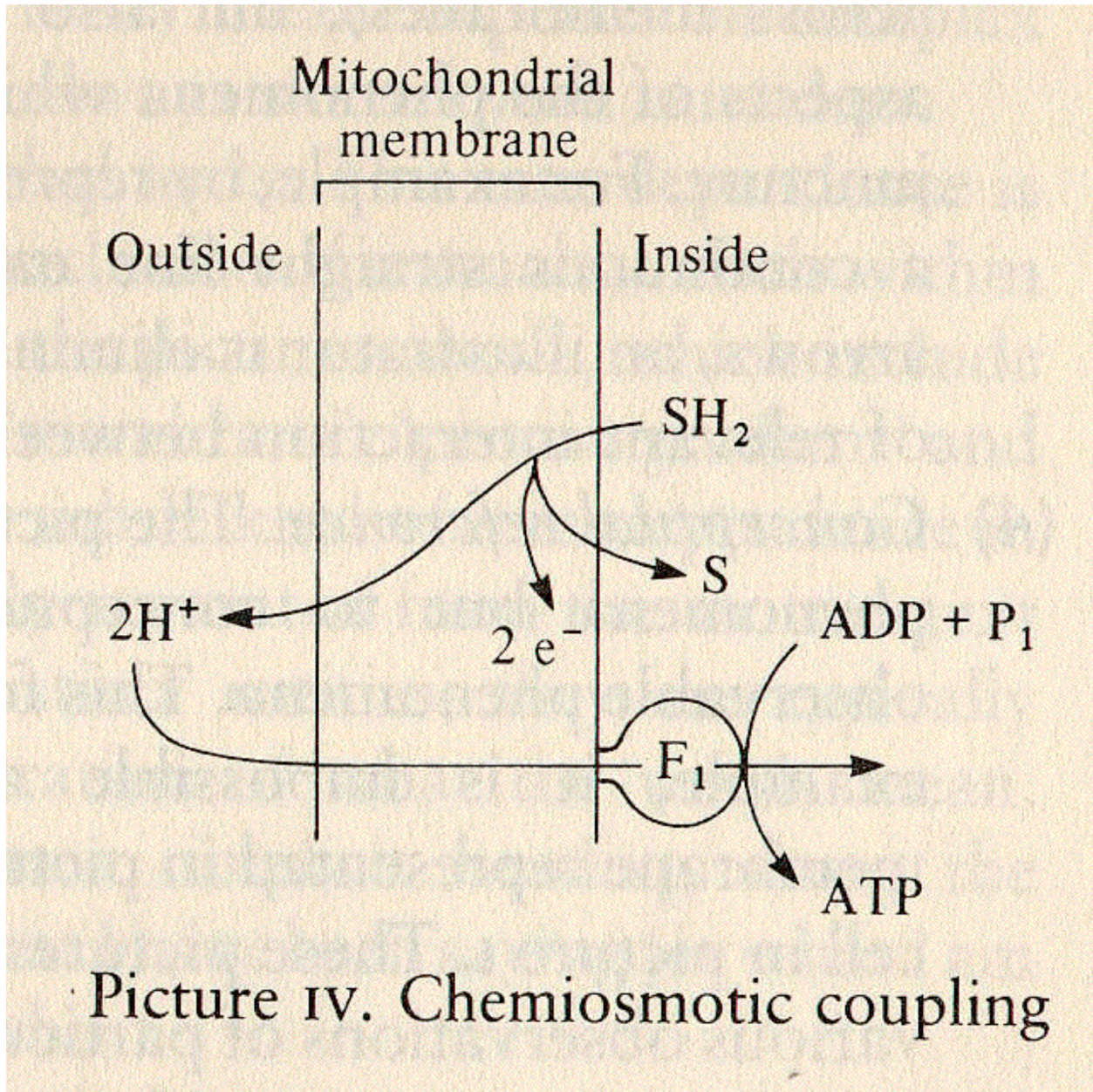
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topic of oxidative phosphorylation. Accordingly, these phenomena almost never appear in their pictures. However, picture II is even more narrowly focused than this. Virtually no information is provided about the structure of the inner membrane. It is represented by two parallel straight lines, even though it is 'known' to be exceptionally convoluted. The symbols for various molecules (Fe(S), FMN, etc.) are placed within the boundaries of the membrane, but no indication is given about their precise topography. For instance, the picture does not show whether they are on the surface of the membrane, fully in the membrane, partially embedded in the membrane or spanning the membrane; or whether they are structurally contiguous or structurally separate, and so on.

Such a picture, despite its abstraction and selectivity, can be further simplified and condensed, as in pictures III and IV. In picture III, the content of picture II is contained in the top line and the first downward curving arrow. By means of extreme abstraction, simplification and selectivity, picture III is able to summarise the whole process of ATP production. Picture IV has the same scope, but it provides greater detail than III and it introduces a clear indication that ATP synthesis arises out of the movement of protons back and forth across an organised membrane. In picture IV, the content of II is condensed into the top three curving lines.



Picture III. Proton gradient and energy coupling



Although we have only looked at and commented briefly on four pictures so far, let us summarise some of the formal characteristics of such pictures. These characteristics will be further illustrated by pictures appearing in subsequent sections.

Some formal characteristics of scientists' pictures

We suggest that the great majority of pictures used by research scientists

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and by textbook authors in relation to bioenergetics and the chemiosmotic theory of oxidative phosphorylation have the following general features:

- (1) *Generality*. Pictures refer to generalised phenomena rather than to specific, observable entities. For example, we find countless pictures of *the* mitochondrial membrane, but no attempt to depict any particular cell's membrane. This may not be equally true of all scientific disciplines. Rudwick has shown that reproductions of particular landscapes have played a part in the 'visual language of geology'.³ Such unique representations seem to be completely absent from the literature on bioenergetics. We suggest that it is likely to be geology rather than biochemistry which is unusual in this respect.
- (2) *Selectivity*. The great majority of pictures deal with very specific research issues. Even when pictures summarise a considerable body of research, they re-present this material in relation to some analytically defined issue. Pictures are very seldom designed to depict phenomena in their full 'naturally occurring complexity'.
- (3) *Conventional simplification*. A limited range of standardised forms is employed; in particular, straight and curved lines, arrows, circles and boxes. These conventional resources are used, not only to depict actual biochemical processes (for example, the movement of protons across membranes), but also to simplify and make unproblematic aspects of the phenomena which are not in question at a particular juncture. For example, by representing the surface of the membrane as a continuous straight line easily transversed by 'proton-carrying' arrows, an illustrator is eliminating from consideration any question of relevant interaction between its surface and the phase outside.
- (4) *Conceptual reference*. The pictures do not refer directly to empirical phenomena but to conceptual entities or idealised versions of observable phenomena. This follows from the three prior points. For example, it is impossible actually to observe the generalised membrane represented in pictures II and IV or the joint animal-plant cell in picture I. These pictures are composite constructions based on various observations of particular cells and membranes together with inferences from a range of experiments involving numerous particular biological objects. This point corresponds to Ravetz's portrayal of the conceptual language of science as dealing with 'intellectually constructed classes of things and events'.⁴
- (5) *Interpretational variability*. Pictures are part of and are embedded in a conceptual argument. Accordingly, the nature of the picture changes as the argument changes. Thus III and IV are adjoining figures in the same text. Picture IV is an elaboration on picture III which takes for granted the central point expressed in III and specifies that point in

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further detail. However, the relatively comprehensive picture IV contains much less specific information about proton translocation than does picture II, which deals solely with the latter topic. The character of the pictorial representation, then, varies in accordance with the interpretational work being carried out in the text as a whole.

- (6) *Contextual variability*. Because scientists' interpretative work tends to vary from one social context to another, pictures are also to some extent context-dependent. For example, pictures in research reports tend to differ from those in reviews. And pictures in textbooks and popular accounts of recent developments, although in some cases copied directly from the

research literature, are often supplemented by pictures devised specifically for the context of teaching. This is true of pictures I and III above and of VII, VIII and IX below. Thus, in so far as pictures can be said to embody scientific knowledge-claims, detailed variations in pictorial form and content serve to reveal the context-dependence of such claims. This is not to suggest that the different pictures produced for different contexts are necessarily inconsistent or incompatible. It is to suggest rather that participants produce different versions of their knowledge for different contexts and that scientists' capacity to extract from these versions an ultimate formulation of 'what the pictures really mean' depends on complex interpretative skills which are not always shared with outsiders.

- (7) *Interdependence of visual and verbal texts.* This interdependence is most clearly evident in the regular inclusion of textual symbols within the picture. This can be seen in all the pictures above, which include such symbols as 'mitochondrion', 'membrane', 'proton gradient' and 'ATP'. In addition, there is a more subtle kind of interdependence in that, although pictures are spatially separated from the written text and usually clearly labelled as distinct entities, they are typically presented as a summary or illustration of what the words mean. Pictures tend to have an unwritten, implicit heading along the following lines: 'In other words, what I have been saying [or what I am about to say] looks *basically* like this.'
- (8) *Non-reflexivity.* Pictorial representation in science is overwhelmingly a form of non-reflexive discourse. For instance, scientists' representations of biological membranes contain various circles, lines, blobs, arrows, etc., which refer to generalised versions of phenomena in living organisms which are supposedly observable in a variety of direct and indirect ways. However, the meaning of these shapes and forms, for example, what connection they are to be taken as having with real membranes, cannot be specified in terms of the shapes themselves. Unlike verbal languages, the resources of which are used routinely to

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consider the meaning of particular verbal statements or even language itself, visual languages of the kind used in science appear to be primarily unidirectional. They seem to point rigidly beyond themselves towards the objects and processes in the natural world which they represent. Thus the nature of the visual language of science can only be portrayed in verbal terms. Yet very few verbal instructions are provided in scientific texts to guide readers' interpretation of pictures. There are occasional references in textbooks to the 'schematic' character of specific representations. But such remarks convey little positive guidance. It is not made clear, for example, whether other pictures which are not so labelled are to be taken as 'non-schematic'; whether the entire picture is equally schematic or whether certain components are more realistic than others, and so on. On the whole, the interpretative practices for 'reading' pictures are left to the readers' discretion and to any clues which he can extract from the verbal or visual text. (Towards the end of this chapter we shall examine in detail an unusual picture which *does* appear to give directions for its reading.)

Pictures and vocabularies of verbal discourse

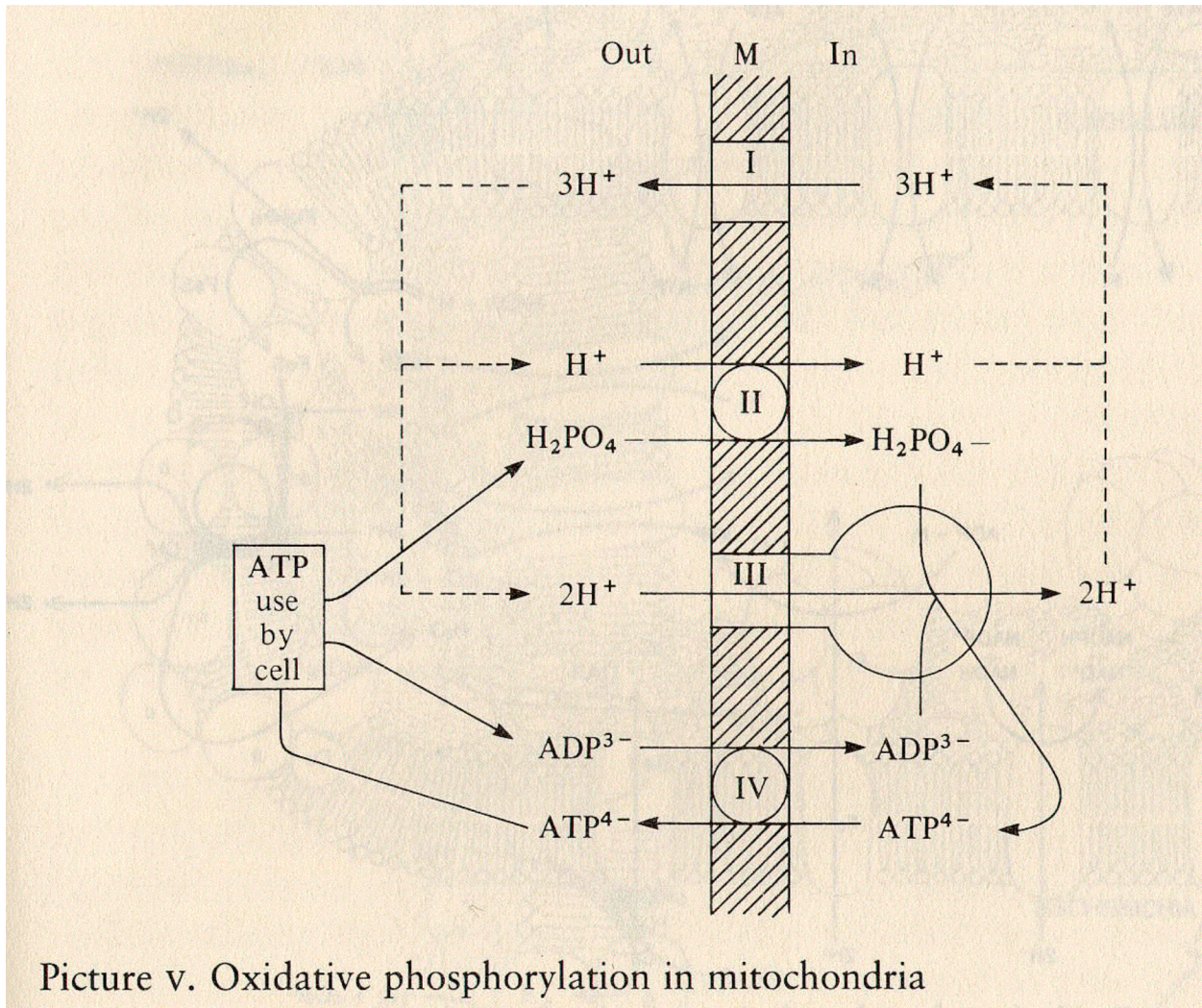
The eight characteristics of scientific pictures given above are neither a comprehensive list, nor

are they necessarily applicable to every pictorial representation produced by scientists. They are rather some of the more obvious features of the great majority of pictures used in bioenergeticists' research papers and reviews and in the appropriate sections of biochemical textbooks. There is no reason to expect, however, that they are unique to this area of research.

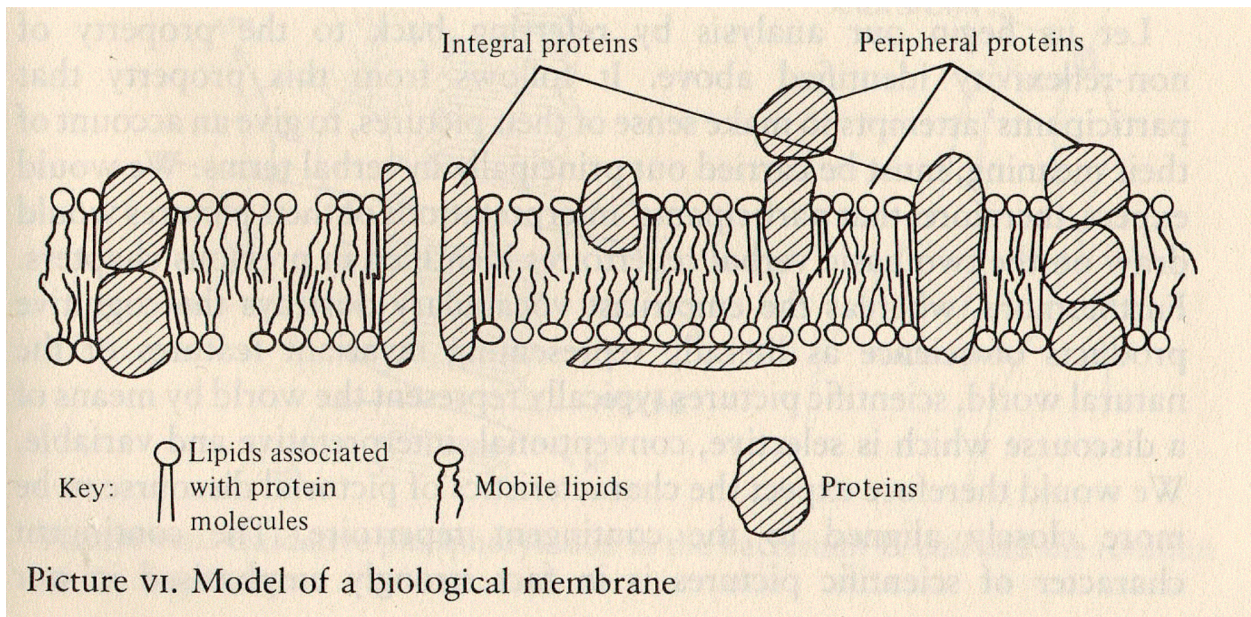
In this section, we will try to draw out some sociological implications of these eight points by examining scientists' talk about four further pictures (V to VIII). Most of the discussion of specific pictures in our interviews dealt with these representations. Picture V is taken from a review paper in *Biochemical Society Transactions* which focuses on the issue of how many protons cross the mitochondrial membrane to create each 'high-energy phosphate bond' (i.e. each unit of ATP). Picture VI is also from a review paper, but one which deals with the broader topic of the structure of biological membranes. Thus this picture is a generalised portrayal of the components and organisation of an unspecified membrane. Picture VII is taken from an article entitled 'How cells make ATP' which appeared in *Scientific American* in 1978 and which furnished a strongly chemiosmotic review of the processes of oxidative and photosynthetic phosphorylation. Like pictures II, III, IV and V, it represents the membrane of the

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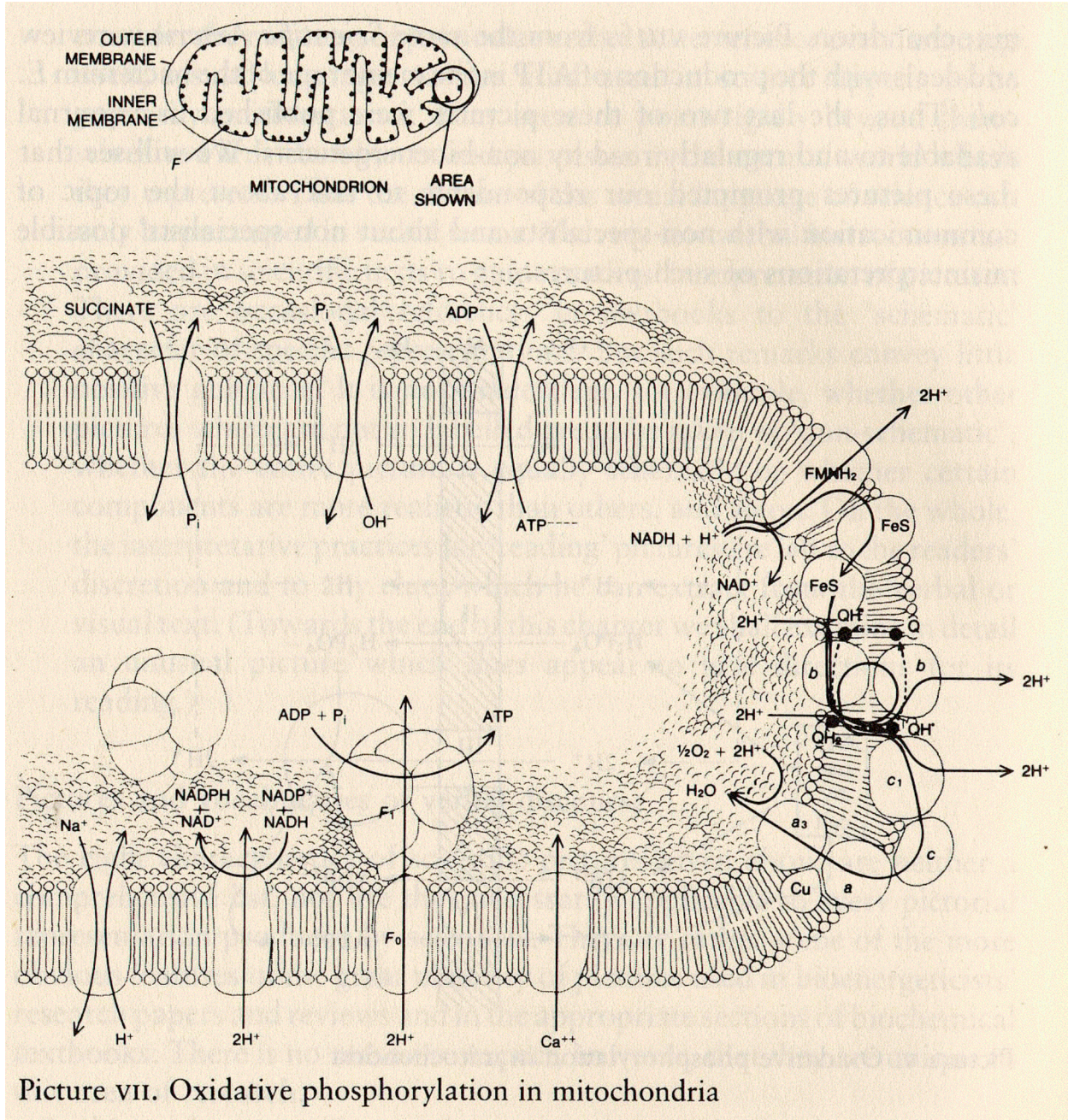
mitochondrion. Picture VIII is from the same *Scientific American* review and deals with the production of ATP in the membrane of the bacterium *E. coli*. Thus, the last two of these pictures were published in a journal available to and regularly read by non-bioenergeticists. We will see that these pictures prompted our respondents to talk about the topic of communication with non-specialists and about non-specialists' possible misinterpretations of such pictures.



Picture v. Oxidative phosphorylation in mitochondria



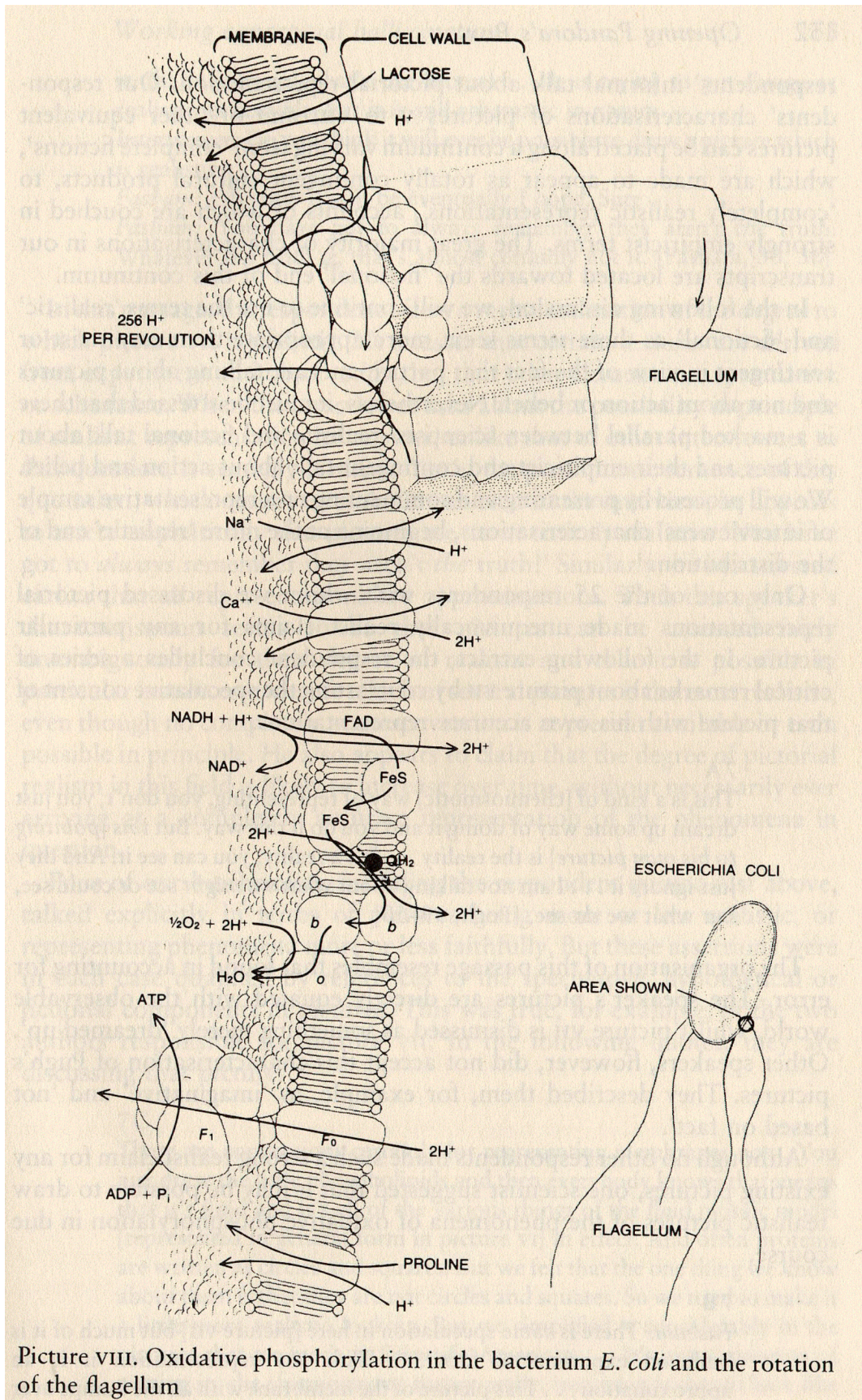
Picture vi. Model of a biological membrane



Let us begin our analysis by referring back to the property of non-reflexivity identified above. It follows from this property that participants' attempts to make sense of their pictures, to give an account of their meaning, must be carried out principally in verbal terms. We would expect, therefore, that participants' interpretations of their pictures would draw on the two basic verbal repertoires identified in previous chapters. Furthermore, whereas the empiricist vocabulary portrays the cognitive products of science as literally representing invariant features of the natural world, scientific pictures typically represent the world by means of a discourse which is selective, conventional, interpretative and variable. We would therefore expect the characteristics of pictorial discourse to be more closely aligned to the contingent repertoire. The contingent

character of scientific pictures is in fact strongly emphasised in our

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Picture VIII. Oxidative phosphorylation in the bacterium *E. coli* and the rotation of the flagellum

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respondents' informal talk about pictorial representation. Our respondents' characterisations of pictures V to VIII and of other equivalent pictures can be placed along a continuum varying from 'complete fictions', which are made to appear as totally contingent cultural products, to 'completely realistic representations', accounts of which are couched in strongly empiricist terms. The great majority of characterisations in our transcripts are located towards the 'fictional' end of this continuum.

In the following discussion, we will continue to use the terms 'realistic' and 'fictional' as these terms seem more appropriate than empiricist or contingent in view of the fact that participants are talking about pictures and not about action or belief. Nevertheless, it must be stressed that there is a marked parallel between scientists' realistic and fictional talk about pictures and their empiricist and contingent talk about action and belief. We will proceed by presenting and commenting on a representative sample of interviewees' characterisations, beginning at the more 'realistic' end of the distribution.

Only one of the 25 respondents with whom we discussed pictorial representations made unequivocally realist claims for any particular picture. In the following extract, the respondent concludes a series of critical remarks about picture VII by contrasting the speculative content of that picture with his own accurate representations.

7A

This is a kind of [chemiosmotic] way of representing, you don't, you just dream up some way of doing it and you do it this way. But *this* [pointing to his own picture] is the reality. . . It's a reality, you can see it. And they just ignore it. . . I am not talking about what we *might* see or could see, but what we do see. [Pugh, 49-50]

The organisation of this passage resembles that found in accounting for error. The speaker's pictures are directly equated with the observable world, whilst picture VII is dismissed as something merely 'dreamed up'. Other speakers, however, did not accept this characterisation of Pugh's pictures. They described them, for example, as 'imaginative' and 'not based on fact'.

Although no other respondents made such a strong realist claim for any existing pictures, one scientist suggested that it may be possible to draw realistic pictures of the phenomena of oxidative phosphorylation in due course.

7B

Fasham: There is some speculation in here [picture VII] but much of it is built on experimental fact . . . With any representation it is an approximation... This picture of the membrane with all the bumps over

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it, that's pictorial, that's not factual . . . It is trying to put things as realistic as possible, but it is still schematic in nature . . .

Interviewer: Do you think it will ever be possible to draw a picture which *is* realistic?

Fasham: Oh sure. It will be eventually I hope. Sure . . .

Fasham: You have got to always remember they aren't *the* truth. Whatever *the* truth is, that's almost certainly not it. [Fasham, 30, 36]

In this passage, the respondent offers a verbal estimation of the *degree* to which picture VII is realistic. He stresses that certain features are derived from experiment and observation, but that other elements are speculative or schematic. When the interviewer asks about the possibility in principle of realistic representation his answer, unlike that of other interviewees to this question, is strongly positive. Yet in the penultimate sentence of this quotation, which occurs several minutes later in the interview, he appears to assert emphatically that pictures are never entirely realistic: 'You have got to *always* remember they aren't *the* truth!' Similarly, he has stressed earlier that all representations are approximations. Thus this speaker's characterisation seems to be that pictures can be assessed fairly unambiguously for their degree of realism and that it is possible in particular instances to decide which of several pictures is the most realistic, even though no completely accurate version is at present available or even possible in principle. He also appears to claim that the degree of pictorial realism in this field is likely to increase over time, without necessarily ever arriving at a completely accurate representation of the phenomena in question.

Four of our biochemists, including the respondent quoted just above, talked explicitly in terms of pictures being more or less realistic, or representing phenomena more or less faithfully. But these assertions were in each case qualified by references to the speculative, hypothetical or fictional components in pictures. This was true, for example, of the two authors responsible for picture VII. In the following quotes, they are discussing that picture.

7C

There are conventions certainly for representing membranes now. You just draw the little phospholipids and then everybody knows that means that it's fluid and it's all of the various things of the fluid mosaic model [represented in general form in picture VI] in effect. And often proteins are written as circles and squares. But we felt that the one thing we know about them is that they are not circles and squares. So we tried to make it a little more realistic looking. But we simplified it considerably in the pictures that we made in *Scientific American* . . . It's just a question of putting in, the chemiosmotic theory really, into what it should look like

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. . . *These things are not really for posterity so much. They're the best guess that we have at the time or they're for purposes of simply making things clearer even if it's wrong. At the time I was writing [a particular feature in one of the pictures] I didn't really think it was right, but it was just a way to talk about it.* [Smith, 54, 59 and 65]

7D

[We tried] to make a model that really had some basis in reality. You know, you can always draw these lines and put boxes on the side, but we even tried to keep the size of the proteins roughly to scale. . . [But a lot of] this kind of information we don't have yet.

So it's 'more realistic', in quotes - a more detailed view of the way it could be. [Trubshaw, 91 and 95]

Both these authors present picture VII as being more realistic than other, more conventional, portrayals of the mitochondrial membrane. They are comparing it here with pictures such as V above. In their picture, for example, proteins are said to be given more realistic shapes and to be drawn approximately to scale. Yet at the same time, Trubshaw emphasises that much of the information necessary for an accurate picture was not available. Hence a great deal of the picture was a speculative view of what the membrane and its constituents *could* look like. The other author similarly refers to the picture as the best guess possible in the circumstances. He describes it as a way of exemplifying how the membrane *should* appear, given the validity of the chemiosmotic theory. And he admits to including one incorrect element in the picture simply in order to maintain a coherent overall presentation.

There is nothing necessarily inconsistent in these authors stressing both the inaccuracies of their picture and its greater degree of realism. They are presenting picture VII and picture VIII as an improvement in this respect on the standard, highly conventionalised, schemes current in the research literature and as realistic as can be expected in view of certain practical limitations. Thus these authors, like Fasham above, provide a realist account of their picture in the sense that its representational inadequacies are treated as a practical problem and as one which is, therefore, potentially resolvable over time. Yet at the same time, they recognise that the pictures they can actually draw at the moment contain a very significant fictional component.

In contrast with Trubshaw and Smith, five of our respondents explicitly stated that picture V was preferable to picture VII precisely because it *was* obviously conventional and made no pretence of realistic representation. These scientists tended also to stress the fictional character of pictures generally in this field. The passages quoted below come closer than those quoted above to treating the unreality of pictures as a feature which has to

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be explicitly recognised and taken into consideration when using them as a means of communication.

7E

Diagrams are dangerous, because drawing a diagram of *this* kind [*pointing to picture vii*], a pictorial representation rather than a reaction scheme, implied a physical reality and a permanence about the concept. I actually prefer [*v-type*] diagrams, because whether they are right or wrong they are formal, entirely formal representations of entirely hypothetical reaction pathways with a topology. . . [Picture v] is a better representation because it doesn't imply that it's telling you how things work. [Harding, 61-2]

7F

If you have been in this field for a while, you have seen a lot of pictures come and go and you take them all with a grain of salt. But I think figures, visual aids, are very important to help you grasp what the author is trying

to get at. . I think this [picture v] might be a little better because this is *obviously* a scheme and that [picture VII] pictures it as really what the membrane might be. Maybe it is a good figure. This one is honest in that it, I think, conveys to me immediately that this is a scheme and no attempt to state the actual. [Hargreaves, 72-3]

7G

[Picture v] is more abstract. This [picture VII] attempts to give a *pictorial* representation . . . It is drawn as if one were a molecular-sized entity taking a look at the field... I think that probably at the molecular level the interaction of light and matter is not sufficiently clear to give you pictures that look like that. I think it's not appropriate. [Miller, 52-2]

These researchers, then, propose that pictures, in this field at least, cannot be regarded as realistic representations; that they should therefore be clearly and explicitly conventional in form; and that the more apparently realistic a picture is the more misleading it is likely to be. In the first two passages (7E, 7F), the speakers do not state whether this is merely a temporary state of affairs, which could be due to the intellectual immaturity of the field and which might change as the corpus of established knowledge grew, or whether it is a permanent characteristic of pictorial representation. The third speaker (7G), however, seems to treat the conventional nature of pictures in this field as unavoidable in principle. Few of our interviewees addressed this issue directly. It is not possible, therefore, to assess how far our respondents in general were treating the fictional nature of pictures as intrinsic to the phenomena of bioenergetics or intrinsic to the realm of pictorial discourse. What is clear, however, is that the great majority of them, that is, twenty out of twenty-five, emphatically characterised pictorial representation in their field up to the

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date of the interview as unavoidably speculative, hypothetical, uncertain, interpretative, highly personal, and so on.

7H

- (a) I think, on the whole, people know them [pictures] for what they are and probably don't take them too seriously. [Holloway, 54]
- (b) We're working with the light harvesting systems which aren't even *in* this model. . . So you can't take a model like this seriously. [Grant, 68]
- (c) [Pictures V to VIII] are *all* so far away from the truth that the difference between them is really rather small, compared with the difference from the truth. [Norton, 59]
- (d) I think they're such personal things. They represent in fact a way that you yourself are thinking about what's going on. And I often think they're highly individual to that person or to a group of people who happen to use the same type of symbol. [Burridge, 31]
- (e) God knows what [these molecules] look like... [Pictures] are bound to be inaccurate and there's no way of telling how inaccurate. It's a mental picture put down on paper,

but put down in a comprehensible
- an attempt to make clear what might be happening. That's the best
you can say. [Richardson, 22-3]

- (f) We have two slides of what we call 'lies and schemes', most of which are redundant. But we keep them to show how we are changing... you haven't a clue what it really looks like. [Jeffery, 63 and 67]
- (g) I think [picture VII] does give you some sense of reality. But I think you've got to be careful of assuming that *is* reality. As long as you know that it's just a view of what we have now, it's good. It could be nothing to do with the reality of the situation. [Scott, 71]
- (h) Generally in these biological fields there is a great deal of pictorial representation which is often very misleading. Look at *Scientific American* for example. There are all these biological papers with nice keys and locks and beautiful shapes drawn. And I often wonder, do the people who read these papers really believe that those things look the way they are drawn there or do they realise this is just supposed to be a pictorial representation of the truth which brings out those features of the problem that the author is trying to explain, and other than that it is totally fiction? . . . [Picture VII is presented at this point]. This picture is along those lines... Nobody knows that these things really move this way. This is science fiction . . . There is no 'reality'. There are so many 'realities' all depending on what you do about it, that there is no unique answer to the question. There are various techniques for getting pictures, freeze etching and the other techniques, and they would all give you different kinds of [pictures]. [Hinton, 15-19]
- (i) I say that pictures are 'working conceptual hallucinations'. Nothing limits you when you make a picture. [Cookson, 80]

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In these representative quotations, pictures are said to be 'far away from the truth', 'not to be taken seriously', 'very individual things', 'inaccurate to an unknown degree', 'lies and schemes', 'perhaps nothing to do with reality', 'science fiction', and even 'hallucinations'. Participants emphasise the fictional character of pictures V to VIII, of other pictures in their field and occasionally of pictures in biology at large. The relationship between the biological phenomena under study and their pictorial representation is treated as highly contingent. As we will see in the next section, however, this relationship is not regarded as entirely arbitrary. For pictures are regularly described as being devised in particular ways in accordance with the requirement of specific social contexts. In particular, our respondents stressed that different *degrees of realism* are appropriate, depending on the audience for which the text is intended.

The context-dependence of pictures and Trubshaw's dilemma

Our respondents' generally fictionalist treatment of pictorial representation is clearly evident in their remarks about the production of pictures for students and for other non-specialist audiences. As we noted in a previous section, one of the formal characteristics of scientific pictures is that

they tend to vary from one context to another; in the sense that, although pictures from research papers do reappear in textbooks and popular presentations, they are accompanied by significantly different kinds of pictures which appear only in the latter texts. A clear verbal rationale for such contextual variation is provided by our sample of researchers. In the first place, it is maintained that pictures often have to be devised specifically for non-specialists because the latter are not properly equipped to understand the esoteric forms of communication employed within the research network. Secondly, it is said that such pictures have a distinctive aim; namely, that of conveying efficiently a *general impression* of the kinds of scientific processes at work. Thirdly, it is asserted that the detailed accuracy of such pictures is not important. Students and other non-specialists will not remember the details. The point of the picture is said to be that of providing them with a coherent overall presentation which will communicate the central scientific principles in operation. Finally, it is regularly proposed that it may be necessary to create an illusion of pictorial realism in order to communicate effectively with this kind of audience; or that an apparently realistic style of representation may somehow be most appropriate for this social context. This type of account of the role of pictures in communication between the specialist community and outsiders was clearly evident in eighteen out of twenty-five interviews. It is illustrated in the quotations which follow, in most of which the speakers are referring initially to picture VII.

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7J

- (a) This model here is acceptable. But if I wanted to be really critical, I'd say [*the speaker identifies a series of errors and shortcomings of picture VII*]... But it's not meant to be like that. All it's meant to do is to show that there is an electron transport chain organised in a certain way and that here is a phosphorylation site which is at another part of the membrane and you're utilising here hydrogen ions. . . It's really just a very superficial thing meant for the layman, really. And there's nothing wrong with that. [Grant, 71-2]
- (b)[Picture VII] is too media-oriented. It's OK for somebody who's naive in the field and who wants to get the feeling that this is part of a real thing. And for the *Scientific American* it would be quite, would perhaps be better to do that [VII] than that [V]. Picture V to the *Scientific American* reader wouldn't mean anything. It's a formal reaction pathway. Picture VII is saying 'well, this really is what it looks like'. [Harding, 62]
- (c)That's quite standard sort of *Scientific American* presentation. They've taken liberties, obviously, but they know that, they've said that... [*various inadequacies are specified*]. But I think that doesn't matter, for this level of article is after all a popularising one. They're not meant to be *that* critical. They give a clear idea of chemiosmosis from which a student or people like yourselves from outside can build. [Thompson, 3 and 5]
- (d)You can explain the *bones* of [the chemiosmotic account of oxidative phosphorylation] to an undergraduate with a piece of paper and pencil now. So, in fact, the principle, the explanation of the principles has come down to a single diagram... This sort of diagram [picture VII] doesn't help *me* at all. And it could even be misleading to those who read the article. But if it enabled them to understand the *principles* of something better, then it would have served the purpose
- you must be very careful. [Barton, 55 and 62]

- (e) [Picture VII] is really an exaggeration of what we know exactly. If it were in a research paper I would not have done it quite like this. [Smith, 65]
- (f) There are uncertainties there. There are things left out. . . . But those are the general principles and for the purposes of that article it's fine. [Miller, 49-50]
- (g) [Various aspects of picture VII] are absolute hog-wash. Those fatty acids are undoubtedly interlaced, so the picture is wrong in respect to that detail. So there are uses; it's alright, this must be from *Scientific American* I take it, and that's alright to introduce concepts like that to semi-lay readers I think. Articles in there are read by people outside the immediate field of interest usually I think it's alright for lay readers. I think it's very bad for, if you were using it as a didactic presentation to students. It could thwart their efforts to find out exactly what is the case. [Waters, 38]

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- (h) I think it [picture VII] is marvellous for an audience of just students. I don't think it does much for third-year students or research workers ... I would not embark on this sort of exposition unless I was talking to this audience. [Roberts, 42]

In these quotations, the variable nature of scientific audiences is emphasised and the need to construct pictures in a way which is appropriate to a particular audience is stressed. There are occasional differences of opinion about the precise audience for which picture VII is suitable (e.g. quotations 7Jg and h). But a generally fictional and socially variable account of pictorial representation in the area is maintained with marked uniformity.

Many of our respondents, having asserted the context-dependence of scientific pictures along these lines, went on to consider whether their non-specialist audiences would be likely to recognise the fictional character of these pictures. In many cases, our interviewees maintained that there was a danger of 'misinterpretation' when pictorial representations were devised for such audiences. In other words, having given an account of pictures in fictionalist terms, speakers often proceed to draw attention to the distinct possibility of others making sense of pictures in terms of the dominant realist or empiricist interpretative repertoire of science and thereby misunderstanding their true character. There are many examples of this, in addition to those already given above (7E, 7Hg and h, 7Jd and e).

7K

The trouble is, of course you, in a way, if you're a non-expert, you say 'Well, that's it.' The fact that it *is* written out in that way [as a picture], you say, 'Well, that's it, that's how it really is.' [Grant, 63]

7L

The important thing, of course, is not to kid the reader. If at the end of the day he winds up genuinely thinking that that's the arrangement of proteins, then that diagram has performed a *mis*-service. . . . [The author must] warn the reader of this subjectivity. [Barton, 62]

7M

One danger that bothered me a little bit [in drawing picture VII], I don't know if I ever really expressed it too well, the fact that people would start taking it too literally. And some of my students did. But it was very few. That was because I gave it to them with the caveat, 'Hey, don't take this too seriously, it's a speculative view.' [Trubshaw, 97]

Many respondents, then, express awareness that pictures easily achieve a degree of facticity which, they are at pains to emphasise, is largely unwarranted. They maintain that pictures have a more powerful impact

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on most readers than do words or equations and they point to the 'danger' of their being 'taken as gospel'; particularly if they are specifically designed to create an illusion of realistic representation. In quotation 7M we see Trubshaw, one of the authors of the picture VII, addressing this issue in relation to his own students. Trubshaw had already stressed that one reason for making this picture more 'realistic' was to give students 'some semblance of reality to hold on to' (Trubshaw, 92). In 7M, however, he states that he was worried about students taking the picture *too* literally. Shortly afterwards in the interview, he mentioned that authors of several elementary biology textbooks had asked permission to reproduce this picture, and expressed a concern that the readers of these textbooks might also misinterpret it.

Trubshaw is faced with a dilemma over picture VII for the following reasons. First, like other scientists in his area, he treats pictures in these passages of reflexive verbal discourse as convenient fictions. He draws attention to their fictional components and stresses that his own picture is only "more realistic", in quotes'. Secondly, he maintains that many lay persons and students will be inclined to approach pictures from an empiricist or realist perspective. Thus, thirdly, he accepts that pictures intended for *this* audience will probably be more effective if they are presented in a style which can be easily read as being fairly realistic. But, at the same time, he stresses that realistic conventions must be used in a way which is not inconsistent with the fictional aspects of the pictures and which does not mislead non-specialists into taking the visual product *too* literally. Given their account of the fictional aspects of pictures and of the realist inclinations of outsiders, Trubshaw and his colleagues are faced with a precarious interpretative tightrope.

We will call this interpretative problem 'Trubshaw's dilemma'. The dilemma grows out of scientists' use of both realist and fictional repertoires to characterise their pictures. It arises out of the attempt to say that pictures are on the whole conventional fictions, yet that in certain contexts they can and should be designed so that they can be interpreted realistically. In this sense, Trubshaw's dilemma resembles the interpretative dilemma which we discussed in our examination of the TWOD. For the TWOD was a solution to parallel interpretative difficulties encountered as participants sought to combine the empiricist and contingent repertoires. However, the kind of dynamic resolution provided by the TWOD cannot easily be employed to solve the interpretative problem of apparently realistic representations which, at the same point in time, should convey their underlying fictional character.

It appears then, that Trubshaw's dilemma is by no means easy to resolve, either visually or verbally. Consequently, most of our respondents

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focus on the danger of encouraging over-realistic interpretation in pictures like VII and VIII, without going on to suggest any way in which it can be or is avoided in practice (see 7E, 7H, 7J, 7K and 7L). Trubshaw himself, who treats picture VII in more personal terms than most other speakers, resolves the problem in his account of his own students' actions, by claiming that he was able to guide them orally towards a correct reading (7M). But this hardly resolves the original dilemma. In the first place, it would seem that at best Trubshaw has reinterpreted his picture to his students in fictional terms and abandoned his claim that fairly realistic pictures are somehow appropriate for such an audience. In addition the broader problem, namely, how to prevent the great majority of students, who did not have the benefit of his authoritative advice, from misinterpreting the picture, is simply ignored.

There does not appear, then, to be any generally available interpretative device by means of which speakers resolve Trubshaw's dilemma at the verbal level. One reason for this may be that the dilemma is not confined to the realm of verbal discourse. Thus if there existed widely established *pictorial* conventions for transferring pictures from one interpretative context to another and for encouraging appropriate contextualised 'readings', some of our respondents would presumably have mentioned them in their discussions of picture VII and in their treatment of Trubshaw's dilemma. In other words, the dilemma may not merely be generated by interpretative problems in verbal discourse, but may be a response to parallel interpretative problems in the domain of pictorial organisation.

If this is so, we would expect that Trubshaw's dilemma would reappear in the pictures themselves. We can, in fact, observe the existence of relevant interpretative tensions in pictures VII and VIII if we compare them with picture II or picture V. As we have noted before, the pictorial style of the two latter pictures from the research literature is coherent, restricted and highly conventionalised. The main pictorial components are arrowed lines crossing a membrane consisting of parallel straight lines plus, in V, a circle for the ATPase. These conventional techniques of representation are also to be found in the two *Scientific American* pictures. However, in the latter two pictures other phenomena are represented in a way which departs significantly from the normal conventions. The membrane, for instance, is given a distinctly spongy texture. The impression is conveyed pictorially, by means of a visual metaphor with everyday objects, that the membrane is a softly resistant, mattress-like strip of material. Similarly, the ATPase projecting inside the membrane is not a conventional circle, but a bulbous and very specifically articulated knob. Perhaps most striking of all these 'recognisable' representations is the cog-like mechanism which

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is shown in picture VIII as being responsible for rotating the flagellum of the bacterium *E. coli*.

Owing to the non-reflexivity of the pictorial language used in these pictures, it is impossible for us or for participants to identify and discuss their organisation except in verbal terms. Nevertheless, it is possible to describe verbally the pictorial means used by Trubshaw and Smith to make their pictures 'more realistic'. They do this, we suggest, by combining the geometrical representations of the research literature with drawings which depict more naturalistically some

of the objects involved in 'ox phos' and by making these objects resemble various kinds of recognisable everyday objects. There can be no doubt, of course, that these latter depictions are also conventional. But they convey a greater impression of 'realism' by the use of a representational style which is closer to that of everyday naturalism and by the visual metaphors with objects from the everyday world.

Trubshaw's verbally formulated dilemma, then, is reflected in the pictorial tension between these two kinds of representation in pictures VII and VIII. The dilemma can now be reformulated in more pictorially relevant terms as: 'Does the use of "realistic" components in addition to "conventional" ones encourage interpretations in realistic terms on the part of non-specialists? And if so, how can this be avoided?'

This restatement of the participants' interpretative problem reveals two interesting questions for us as analysts. First, 'Are the "realistic" components of pictures like VII and VIII ever interpreted as realistically as our respondents suggest? Do they actually provide pictorial resources which can be, in our respondents' terms, "misinterpreted"?' Secondly, 'Is there any evidence of scientists responding in *pictorial* terms to Trubshaw's dilemma?' We will explore these questions in the next two sections. Positive answers to either question would tend to indicate that we have been right to maintain in this section that Trubshaw's verbal dilemma has a genuine pictorial counterpart.

The flagellar motor and the Supreme Being

It is clear that any given picture can be interpreted in various ways by different viewers, in the same way that any verbal text is open to different readings. One reason for this is that the interpretation formulated by a viewer will be related to the kind of interpretative work in which he is engaged. Thus, when we refer to an interpretation of a picture (or to a reading of a text), we are not referring to uncontextualised processes occurring in an observer's 'mind', but to the way in which that observer uses the organisational features of the picture to construct a contextually

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relevant verbal and/or pictorial formulation of his own. In the next few pages we will examine one strongly realistic or empiricist interpretation of picture VIII by a non-bioenergeticist. Our goal will be to discern which components make possible the construction of an empiricist text by this non-specialist interpreter. We will show that, as our respondents 'feared', the non-specialist interpreter is able to extract from picture VIII certain apparently realistic elements and to treat them as directly observable phenomena in the real world.

Picture VIII, as we have noted, represents the membrane of the bacterium *E. coli*. Much of this picture closely resembles picture VII and the biochemical processes said to operate in this bacterium and in mitochondria are very similar. But at the top of the picture a unique feature of bacteria is depicted, the junction of the bacterium's flagellum (a kind of tail which is responsible for the organism's motion) with the membrane. The legend to picture VIII contains the following reference to the operation of the flagellum: 'The rotation of the flagellum is also powered by the influx of protons. At the root of the flagellum is a ring of 16 proteins, opposed to a similar ring in the cell wall. If a proton must pass through each protein to rotate the flagellum a sixteenth of a

turn, 256 protons would be consumed in each revolution.' Unlike picture VII whose legend contains the warning, 'The arrangement of the molecules, however, is not yet certain, and the model presented here is somewhat conjectural', picture VIII is presented with no explicit indication that its realistic structures are not to be taken at face value.

Those of our respondents who were specialists on bacteria commented rather critically on this picture. For example:

7N

I do visualise things, but [this is] almost like an illustrated version of Jane Austen to me. I don't visualise the flagellum *quite* like that. I have my own image of it. [Roberts, 42]

7P

There isn't any evidence that that's a transmembrane protein. The same for these antiporters here. This whole depiction of the flagellum is, that's a real working conceptual hallucination. . . The sub-unit structure of this is highly hallucinatory . . . There *is* evidence for 16 sub-units and he's drawn them all as nice circles. It's just that it's a science fiction model of the flagellar rotor that's all. It does incorporate what's known. You can count them. [*Counts sub-units in picture VIII.*] Well, it's close to 16. So he's got 16 sub-units there. Nobody knows if they're really oriented that way. He's taken a certain poetic licence in doing it. That's OK. [Cookson, 81]

Despite these criticisms of the style and content of picture VIII, both

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respondents deemed the *Scientific American* article to be appropriate for its audience.

The non-specialist's response to picture VIII with which we are concerned appeared in the year following the publication of the *Scientific American* article. It is to be found in *Back to Godhead: The Magazine of the Hare Krishna Movement* and consists of an article entitled 'The machinery of evolution: OUT OF GEAR? A mathematician finds flaws in one of Darwin's basic assumptions'. It was written by Hardy, a mathematician from an American Ivy League college who is described as specialising in probability theory and statistical mechanics.⁵ This article is of interest to us because one of its two pictures is a reproduction of part of picture VIII and because a discussion of the flagellar motor in the light of this picture is the fulcrum of an argument for the existence of 'a primordial, absolute personality' or 'Supreme Person'. It constitutes, therefore, a fascinating reading of picture VIII by a scientifically informed outsider. Despite the transcendental conclusion to Hardy's article, his text is formally organised in strongly empiricist terms and the existence of the Supreme Being is treated as an 'experimentally verifiable' phenomenon. We will give a short sketch of his argument before commenting on it.

Hardy begins with an idea which, he says, is essential to Darwin's theory of biological evolution. He formulates this idea as the hypothesis 'that the physical structures of all living organisms can transform from one to another through a series of small modifications, *without departing from the realm of potentially useful forms*' [emphasis added]. Hardy challenges the assumption that biological diversity could have occurred by means of evolution through a

continuous series of useful forms. '[I]f there exist any significant structures in living organisms that *cannot* have developed in this way, then for these structures, at least, the hypothesis of evolution is ruled out, and some other explanation of their origin must be sought.' The flagellar motor of *E. coli*, as depicted in picture VIII, is taken to be a prime example of such a structure. A crucial step in the argument is that of proposing a close analogy between biological structures and mechanical structures. A picture is provided showing collections of cogwheels, gears, shafts, and so on. Most of these groupings of mechanical parts appear not to be organised in any systematic manner, but here and there, particular collections can be seen to function as organised units. 'If we visualise the space of mechanical forms, we can see that some regions in this space will correspond to wrist-watches and other familiar devices, and some regions will correspond to machines that are unfamiliar, but that might function usefully in some situation. However, the space will consist mostly of combinations of parts that are useful as paperweights at best.'

This representation of the 'space of mechanical forms' is said to be

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directly comparable to that of biological structures. 'These mechanical parts are comparable to the molecules making up the organs of the bodies of living beings. Since mechanical parts and molecules alike fit together in very limited and specific ways, a study of mechanical combinations should throw some light on the nature of organic forms.' By means of this analogy, Hardy displaces his spatial representation of shafts, levers and gears to the realm of biological organisms. Thus he is able to present us with a verbal and visual picture, in which: 'The class of all possible forms made from organic chemicals is like an ocean of tiny mechanical devices, most of them useless. The few useful forms are like islands surrounded by vast expanses of useless ones.'

Given this picture of the distribution of mechanical, and therefore biological, forms, Hardy concludes that it is impossible to maintain the Darwinian conception of evolution by means of gradual movements through a continuous series of useful structures. Movement from one 'island' to another cannot be gradual and continuous, because the intermediate forms are not viable, self-maintaining structures. He concludes that gradual structural evolution is impossible and that we must seek an explanation of the diversity of biological forms which recognises the need for radical leaps between complex biological systems.

Hardy formulates his own alternative to Darwinian evolution by introducing another analogy; this time between the discrete structures of the biological realm and the 'products of human creativity'. The latter, he suggests, often occur as sudden intuitive insights. Hardy then proceeds to argue that: 'If it is the nature of biological form and the forms of human invention to exist as isolated islands in the sea of possible forms, then some causal agency must exist that can select such forms directly. The experience of inventors indicates that this agency lies outside the realm of human consciousness or control. . . .' From this conclusion, it is but a small step to argue that both biological forms and the products of human creativity are the intentional outcomes of a higher or more inclusive personal agent. The *Bhagavad-gita* is then quoted as having clearly identified the 'primordial, absolute personality', the Supreme Being, ultimately responsible for all organised systems. He ends the article with some suggestions for improving the investigatory procedures of science: a personal avenue of approach to the knowledge held by the Supreme Being, he suggests, already exists in the methods of bhakti-yoga which are similar to those of

modern science in that both depend on 'clearly specified procedures leading to reproducible results'.

Clearly, this article is rich in topics worthy of investigation, but we will concentrate on examining how its author has interpreted and used picture VIII. The first point to note is that Hardy interprets this picture and its

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original text in exactly the way that our respondents said was expected of readers of such popularising outlets as *Scientific American*; that is, he extracts the central ideas rather than the precise details.

7Q

The motors are presently thought to be driven by a flux of protons flowing into the cell. Each motor is thought to consist of a ring of sixteen protein molecules attached to an axle . . . Although the exact details of the *Escherichia coli*'s molecular motors have not been worked out, *we can see that* they depend on the precise and simultaneous adjustment of many variables. In the space of possible molecular structures, the functional motors will represent a tiny, isolated island [emphasis added].

In this passage, Hardy acknowledges the uncertainties in current knowledge about the flagellar motor. He stresses that scientists *think* that the motor operates in a certain way, but that the details have *yet to be worked out*. Thus in his verbal discourse the precise molecular mechanism is treated as somewhat speculative. All that is taken as firmly established is the general idea that flagellar activity is somehow powered by the movement of protons across the membrane. But Hardy's overall argument cannot be developed further without a specific organic device which can be seen to resemble a wristwatch in its finely articulated structure.

This need is satisfied by Hardy's reproduction of the top part of picture VIII. His argument is carried forward, as we can see in quotation 7Q, by in effect *pointing* at the picture and by treating it as a literal representation of part of a functioning organism. Despite the *verbal* references to uncertainty, Hardy states that we can actually *see* the precise adjustment of mechanical parts within the structure of *E. coli* in his version of picture VIII. The recognition of uncertainty in the verbal text and the implicit admission that the picture must be to some unknown degree speculative are effectively erased by the apparent facticity of the pictorial representation. Thus this outsider's use of the flagellar motor as a crucial scientific datum for his argument is made possible, not by current experimental findings on proton translocation in bacteria, but by the fact that Trubshaw and Smith chose to present the general idea of the motor in visual form; by the fact that they adopted a 'realistic' or 'mechanistic' visual idiom for this pictorial component and by the fact that Hardy was thereby able to treat what the specialists described to us as at best speculative and at worst an hallucination, as an observable fact about the organic world.

The example of the flagellar motor and the Supreme Being is undoubtedly unusual in certain respects. Few readers of scientific pictures will use them to reach explicitly transcendental conclusions. Yet these unusual features may well be superficial. For Hardy's reading is formally a

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strongly empiricist one and in that important respect it may be typical of much of the interpretative work carried out by non-specialists within the broader scientific community. If this example *is* at all representative, it appears that pictures and the knowledge-claims which they embody may sometimes undergo reinterpretation and transformation of meaning as they cross the boundary between research networks and their members' wider audience. Furthermore, it seems that researchers may on occasion describe this transformation of meaning as one of misinterpretation; even though their own interpretative practices in some cases actively foster the kind of reinterpretation to which they object.

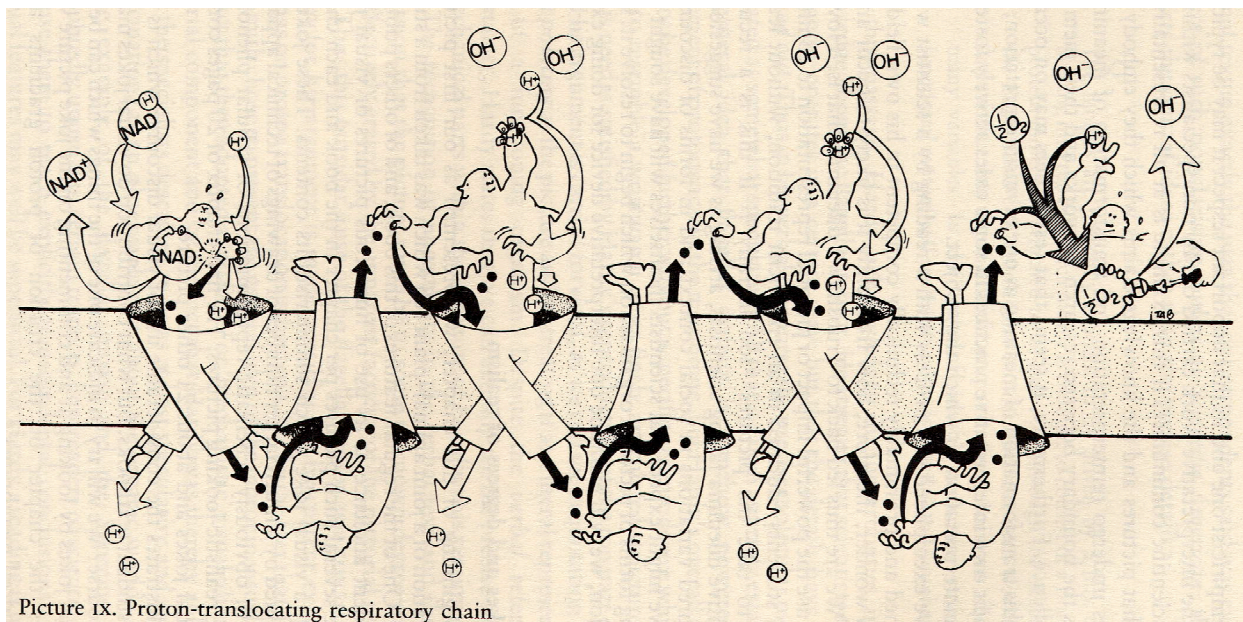
We have exemplified this process with a reading by a scientist who is fully trained and presumably technically competent in his own field. We are led to wonder, therefore, how frequently it is likely to occur among students. We are thus led back to Trubshaw's dilemma; that is, 'How can scientists use the powerful impact of pictorial representation to communicate with students educated in an empiricist tradition, without leading students to take the pictures "*too literally*"?' If this is a recurrent interpretative dilemma facing scientists, arising as we have suggested out of structured variations in social context and in forms of discourse in science, we might expect that scientists themselves will have sought ways of devising forms of pictorial organisation which begin to resolve it. In the next section, we will examine one interpretative device for doing exactly that.

Visual jokes and degrees of realism

At the beginning of this chapter, we presented as our first picture a representation of a joint animal-plant cell which was taken from a student textbook. One of the regular features of this book, and of others published for a student audience, is its use of humorous pictures or visual jokes. There are several such pictures per chapter in the book and each chapter ends with a visual joke which summarises its contents. These jokes are accompanied by a much larger number of drawings of technical apparatus along with obviously schematic representations of cellular phenomena and more realistic-looking pictures. The first chapter of 20 pages contains three visual jokes and about 21 other pictures.

This illustrates the considerable use of visual discourse which is often found in student textbooks. But what contribution do visual jokes make to such discourse? We will try to indicate one of the things which can be done with visual jokes by looking at and commenting on the joke picture which concludes the chapter on the creation of proton gradients across mitochondrial membranes.⁶

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Picture IX. Proton-translocating respiratory chain

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This picture is seen as a joke because it has certain stylistic and formal properties. (We will examine the structure of scientific jokes in more detail in the next chapter.) Formally, like a great many jokes both scientific and otherwise, it combines elements from two normally quite separate areas of discourse. The first class of elements in this case consists of the various standard scientific symbols and the pictorial representation of the mitochondrial membrane. The two parallel horizontal lines are recognisable as a membrane, partly by their position at the end of a chapter on the movement of ions across membranes and partly by their spatial relationship with the symbols representing protons, oxygen and the other constituents specifically required for proton translocation in mitochondria. The symbols NADH, OH⁻, H⁺, etc., are placed visually in relation to the membrane roughly as the preceding text describes the location of the corresponding phenomena in mitochondria. This confirms for the reader that the picture in some sense represents the mitochondrial membrane as well as the processes whereby proton gradients are created across the membrane.

These elements of biochemical discourse, however, are combined in picture IX with representations which are immediately recognisable, despite their distortions, as human figures wearing voluminous trousers. Thus, the incongruity essential to humour is created by the juxtaposition in the picture of elements of discourse, both verbal and visual, which are difficult to reconcile in a literal sense. The humorous intent of the picture is also made evident by the multiple arms and faces, neckless heads, identical physiognomies and extended trousers which are reminiscent of comic-book characters.

Picture IX, like the other end-of-chapter pictures in this textbook, is organised in a way which tells the reader immediately 'not to take it too seriously'. Nevertheless, it is linked directly to the preceding text and constitutes a summary account of what is claimed in that text to be known about the formation of proton gradients in mitochondria. In this respect it closely resembles other pictures we have examined which deal with the mitochondrial membrane (III, IV, V, VII and VIII), and like them, it uses the normal research conventions of two parallel straight lines crossed

by proton-carrying arrows to convey the non-humorous content in a stylised, fictional way. But, unlike pictures VII and VIII, which create the impression that the picture represents the real biochemical world by embedding these conventional elements in a more 'realistic' environment, picture **IX** contrasts them with even more obvious fictions, namely, the baggy-trousered manikins. In this way, we suggest, picture IX, although overwhelmingly fictional in its import, is organised in a manner which attaches different *degrees of realism* to its varied components. As a result,

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the formal structure of picture IX more closely resembles the verbal interpretations furnished by our respondents, whilst at the same time retaining the capacity to convey a basic scientific interpretation of the processes of ATP production.

In the textbook chapter which precedes picture IX, the discussion of the mechanisms of proton translocation begins with the sentence: 'Two major types of hypotheses have been advanced to explain how this proton pumping is achieved.'⁷ The text then proceeds with an exposition of both hypotheses including two corresponding schematic representations in the style of picture II, with no attempt being made to choose between them. The mechanisms of proton pumping, then, are treated in the text as an area of uncertainty. It is clearly difficult, if not impossible, to cope with uncertainty within a single pictorial representation; at least, as long as some attempt is made actually to re-present the phenomena in question. But in the summary picture at the end of the chapter, the device of the visual joke is used in a way which surmounts this difficulty. For it is precisely the speculative mechanisms of proton pumping that are represented by the obviously fictional man-like figures. The effect of this is to ensure that the summary picture confirms those aspects of proton translocation which in the text are taken as established, whilst humorously reminding the reader that certain scientific questions remain unanswered. It indicates that the phenomena being represented have varying claims to be regarded as scientifically accurate, without departing from a strongly fictional overall perspective and, thereby, without falling foul of Trubshaw's dilemma.⁸

It appears, then, that the visual joke in picture IX avoids Trubshaw's dilemma by introducing reflexivity. Its organisation contains a comment on the nature of its own discourse and an indication of the degree to which its constituents are to be taken seriously. The importance of this reflexive structure is that it furnishes a pictorial solution to Trubshaw's dilemma. In this sense, picture IX brings the present analysis full circle. We began this chapter by emphasising the importance of pictorial discourse in science and the crucial part it plays in transferring scientific knowledge from the research community to non-specialists. We then identified a series of formal properties of a particular class of pictures and we suggested that these properties seemed to be more closely aligned with the characteristics of the contingent verbal repertoire than with those of the empiricist repertoire. At this point, we examined scientists' verbal accounts of pictorial discourse and we found that, although they talked about these representational pictures in both realist and fictional terms, their characterisations were overwhelmingly fictional. We suggested that there are strong parallels between fictional and contingent discourse about

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pictures, and between realist and empiricist discourse about action; and that respondents' verbal portrayals of pictorial discourse in our interviews closely resemble our own specification of the formal properties of this discourse.

The issue of communication with non-specialists was approached through participants' talk about the contextual character of their pictures and about the need to provide a greater degree of realism for certain kinds of outside audience. These verbal reflections by participants gave rise to the interpretative problem of Trubshaw's dilemma which, we suggested, has a direct counterpart in the pictorial organisation of some popular pictures. Through a close examination of a particular text, we showed that the 'realistic' components in such pictures could facilitate strongly empiricist interpretations and that non-specialists could treat such components as literal representations of the real world.

Finally, we saw that visual jokes can supply a pictorial device for expressing scientific uncertainty and, thereby, a way of organising pictures to convey 'degrees of realism'. The combination of unlikely visual elements can provide the structural basis for a joke; whilst at the same time resolving Trubshaw's dilemma by conveying the scientific accuracy of the main established ideas without running the risk of too literal an interpretation of speculative conceptions. The fact that scientists sometimes appear to deal with Trubshaw's dilemma by means of a specific pictorial device provides some indication that our prior analysis of the nature of pictorial discourse and of the interpretative problems which arise in the course of communication across interpretative boundaries is 'along the right lines'.