ulation of such defects as are so far reported by molecular geneticists.

It is true that the very nature of such experiments, as those of Benzer, where the K strain is used to reveal recombination, would tend to concentrate attention on defective changes. Still, since these are picked up as changes in appearance of plaques on the B strain, *some* should be of a positive nature and grow on the K strain better than the standard type. Such seem never to have been found or at least remain unreported.

From the creation viewpoint, we could of course expect the DNA system to be a marvelously intricate one. Since designed to accomplish very complex tasks even in the "simplest" organism such at a T_4 phage virus, it obviously could stand little in the way of tinkering. In fact, in light of the picture of just how DNA, RNA, the ribosomes, and the cytoplasm interact to form the needed proteins, we cannot but marvel at the complexity of all these reactions taking place at one time in a single cell.

Surely, the ingenuity of man is taxed to find ways of experimentally solving the exact way in which even a "simple" type of phage operates. Should we not then be filled with a feeling of reverent awe at the glory of God's handiwork as shown by this revelation of the complex way in which His created organisms carry on, their tasks? Truly the calling of a molecular biologist is a great one. Let us hope, that some of our young creation minded students approach this field, realizing that here they are coming close to seeing God at work as He daily maintains and preserves all creatures.

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IS DNA ONLY A MATERIAL CAUSE?

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By means of philosophical considerations and, secondly, through specific examination of experimental facts, the author inestigates the notion that DNA is "the secret of life."

An objection is raised that use of the word "code" in references to DNA involves nothing more than a metaphor. This and other objections are studied regarding DNA as a material, efficient, and formal cause. Objection is raised against the idea that memory is the encoding of experiences in DNA.

Examination of experimental data brings out denial of the normal expectation that complicated organisms would have larger amounts of DNA than less complex forms. Facts indicate that DNA is influenced by environment as well as heredity.

Comparisons are presented between results of ***in vitro*** *and* ***in vivo*** *experiments involving DNA.*

The author concludes from his theoretical arguments and from experimental evidence that DNA is not the whole cause of life and heredity. DNA is a material cause, but the author asserts there still must be a formal cause.

The one thing that most distinguishes living beings is their ability to reproduce themselves. In so doing, they are, of course carrying out God's command to "Be fruitful, and multiply. . .," (Genesis 1:22).

It is true, perhaps, as has sometimes been remarked, that things which are not living, for instance crystals under suitable circumstances, may "grow." Be that as it may, certainly the things which are not living do not show the same striving to reproduce themselves; if the crystals ever received a commandment to multiply they have not yet done much about it.

A second difference is that the living things are alike "after their kind" (Genesis 1:24); much more so than those that are not living. A snowflake, for instance, is a common crystal, or collection of crystals. Whether or not it be true, as is so often said, that no two snowflakes are alike, certainly there is much variety among them, much more than there would be among bees in a swarm.

A third feature of living beings is nutrition. Metaphorically, it is true, we say that a fire is "fed;" we might say the same about a crystal growing from a solution. But any unprejudiced person would say that there is a difference; a living being uses its food in a discriminating way: some goes to its growth, some to maintenance, and some to act as fuel to keep life going. This is quite different from the "feeding" of a crystal in which material merely happens upon certain sites and sticks there. The crystal, in a sense is an effect of the solution and of the circumstances; the living being, on the other hand, is in some way a cause.

This brings up a fourth point. The word "cause" suggests action with a purpose: the kind of action which we do as a result of thought. Thought, so far as we know, does not exist apart from life (not necessarily corporeal life); it might not be going too far to say that life does not exist apart from the action with a purpose which, in us, would be considered as or related to thought.

Kinds of Causes

Since we have had to consider causes, let us look into that notion a little more. We may distinguish four kinds of cause, as Aristotle did: material, formal, efficient, and final.[1] Of a statue (to use Aristotle's own example), the material cause is the marble; the formal, the pattern of the finished statue, which was in the sculptor's mind before it was in the statue; the efficient, the sculptor and his tools; and the final, the sculptor's fee and his fame as an artist. We shall shortly use these distinctions profitably.

What we want to investigate is the notion that DNA is the "secret of life." First of all, what does such a statement mean? Presumably it means that it is the presence and activity of DNA that gives living beings their abilities. Is such a statement true? That is what we have to investigate.

Since the common theory has been discussed for several years, and is considered elsewhere in this Annual, there is no need to describe it at length here. It is enough to notice that molecules of DNA are supposed to be duplicated, an existing molecule acting as a template for a new one, as if, in the building of a house, a brick acted as a mould for making another brick. Thus the appropriate proteins are built up. Also, enzymes are formed, which somehow influence the larger features of the growing creature. The whole proposed "mechanism" is often spoken of as the "genetic code."

Objection to DNA As Code

Here an objection must be raised. So far, the word "code" is nothing more than a metaphor, and there are codes and codes. Until more has been said, nothing will really have been explained.

Is the "code" something like the Morse code? But this would require an intelligent being to read the code, and to do something about it with suitable organs. Is it like the punched cards of a Jacquard loom? This would require a mechanism to be operated by the code, a mechanism, moreover, much more complicated than the code, if our experience with automatic machines is at all applicable. (And if it is not, we are using words without meanings.)

The DNA would, it would seem, be considered in some sense a cause of the growing organism. But in what sense? Which of the four causes would it be? To elaborate on the distinctions between them, as Aristotle said[2], "cause" means: (1) that from which, as an immanent material, a thing comes into being . . . (2) the form . . ., (3) that from which the change, (here the production) first begins . . ., and (4) the end.

Of these we may remark that: (2) the form is immaterial, for "the soul is the place of forms"[3] (3) the efficient cause does not remain in the effect; and, (4) the end is surely not DNA. It is true that someone once said that "a hen is an egg's way of producing another egg," but actually to believe such a thing is not only to put the cart before the horse, but also to mistake the cart for the horse.

So, the remaining possibility is that DNA is a material cause. Of course, a material, to be a material cause, need not be the only material, or even the one used in the greatest amount. A tiny amount of a crucial material may have a very large effect.

A striking example of this is the effect of iridium or antimony, added to the extent of maybe only a few parts per million, on germanium for making transistors. Again, the design of a masonry structure might depend on the kind of mortar to be used; and an examination of old wooden buildings will show how their design was influenced by the use of pegs rather than nails.

Further Objections to DNA

Let us now consider some more objections to the notion that DNA could be an efficient or formal cause. (For this is what the common theory really means, although it is not put into these words. Supporters of this theory usually do not even consider finality.)

It has been common to imagine huge automatic machines, capable of many intricate tasks, and to say that living things are somehow like them.

Elsasser[4] has investigated this question, and points out that if a molecule of DNA, or a whole germ cell for that matter, somehow causes the whole organism, in the way alleged by the common theory, it must contain a tremendous amount of information. In fact, the information required could be stored only by assigning meanings to various dispositions of atoms. Even so, there would not be room for much redundancy (over-abundant, excessive amount) of information.

On the other hand, the disposition of individual atoms is (to say the least!), a very ephemeral thing. Any stability of information require enormous redundancy, which, as we just saw, could not be fitted in. Thus, Elsasser concludes, any mechanistic theory which makes heredity depend on mechanically stored information simply will not work.

Another quite apt illustration may be drawn from the "degeneration of workmanship." Suppose that a man had a machine shop, equipped with new machines. Using those machines, he could build a second lot of machines, a second "generation" so to speak, nominally duplicating the first generation. But only nominally, for inevitably errors, tolerances, etc., will combine to make the second generation a little worse than the first.

And if the second generation of machines is used to build a third generation, it in turn will be yet worse, and so on. After a certain number of generations the machines would be so "bad" as to be almost useless.

It is hard to see how living things, if they depend on a material "code," would not undergo a similar degeneration. Now though some degeneration, as expressed by mutation does occur, the most harmful mutations are soon eliminated by natural selection.

Of course, machines do not degenerate from generation to generation, because the toolmaker intervenes. For instance, he can make a surface plate–a plane surface–independently of the accuracy of any machine. He does this by making three plates, and scraping them until any two will fit together over their whole surface. Then they are all truly plane. Notice, though, that he did this by referring to the form of the plane surface which was in his soul.

Another point which Elsasser has made is that if information be stored corporeally at all in living beings, it is stored in the softest and apparently most unstable parts. If a lobster, for instance, stores information, it is in the soft parts of his body, not in his shell.

Nor is the chemical storage of information, which has sometimes been suggested, in any better position. For most of the reactions in the body are close to equilibrium, and thus very subject to fluctuations.

Incidentally, the soft and delicate parts of the organism, in which information is supposed to be stored, are just those in which metabolism goes on most strongly. This means that the components are changed very frequently, which, again, does not fit in well with any corporeal storage of information. No one would print information needed permanently on the scratch pad beside the telephone.

Is Memory Encoded in DNA?

Heredity and the maintenance of the body during a being's life (so that, for instance, a man's fingerprints remain the same although his skin changes many times) would seem to be closely related. Memory, in the ordinary sense of the word, has at least some similarity to these things. So it has been suggested that memory is the encoding of experiences in DNA.

However, recently, this has been challenged. It had been reported that planaria, which had learned to do certain tasks, were fed to other planaria, which then showed the same abilities. But it now seems that nine laboratories, which have been trying to duplicate these alleged results, have been unable to do so.[5]

Moreover, mice, into whose brains had been injected drugs which inhibit the synthesis of RNA and protein, were still able to learn and to remember. In fact, there seem to be difficulties in the way of any theory of memory which makes it a purely corporeal thing.

No doubt the brain has something to do with memory. Yet, it seems that memory itself (as distinguished from the ability to act on memory), is not harmed by the removal of some of the brain. Moreover, memory itself does not seem to be localized in particular parts of the brain.[6]

It is, perhaps, not certain that memory, heredity, and the development of the individual are all connected. There is though, one consideration which seems to point in that direction.

We ourselves, when we set out to make something, rely on memory; even if there is a pattern before us we have to remember how to read it, how to use the tools, and, indeed, even that we set out to make such and such a thing.

Now memory in this sense is certainly conditioned by the mind; we are not always thinking about how to read a blueprint, but can turn our attention to it when we wish. So an activity of the mind is involved here. And mind, in the strictest sense, seems to be incorporeal.

In support of this view, we can perhaps do no better than recall Aristotle's argument that as for corporeal functions, including the senses in so far as they are corporeal, (and the same could be said of muscular activities), a strong exercise of the function leaves it impaired for a while. For instance, one is temporarily blinded by a strong light. But the exercise of the mind on something which is highly intelligible leaves it more, rather than less, able to deal with other matters.[7]

Examination of Experimental Data

So far, this discussion has been rather philosophical. Indeed, that is nothing to be ashamed of; for to discuss a thing philosophically is to try to know what we are talking about, and to talk sense about it. On the other hand, we can reason about anything only by starting from some premises, and if the question has to do with experimental facts some of the premises should come from experiment.

So let us consider some experimental facts. Many of these are collected in the writings of Commoner, who is one of the strong contenders against the view that the whole "secret of life" is contained in DNA.[8-11]

First of all, while we certainly should not underrate the humbler creatures, yet anyone would agree that a man is much more complicated than an amoeba. Now, as Commoner has pointed out, if the development of the creature is governed by DNA, it would be natural to expect the more complicated creature to have the larger amount of DNA.

Is this, in fact, what is found? It is not. Man's cells, for instance, contain about 7 picograms of DNA each; but those of the African lungfish contain about 100 picograms, and the cells of Amphiuma, a primitive amphibian, about 168 picograms.[12-14]

On the other hand, there is a case in which two very similar species of insect, although morphologically indistinguishable, differ by 50% in the amount of DNA *in* their cells.[15] This would suggest that, at least in part, the function of DNA is something other than to serve as a "carrier of structural information,"

Another fact pointing to this same conclusion is the evidence that the formation of DNA is itself a more involved thing than the copying of templates. The static specificity of DNA, (i.e., its nucleotide sequence), is, it seems, regulated not only by the nucleotide sequence of the template, but also in part by the specificity of the polymerase enzymes which catalyse DNA synthesis.[16,17]

In other words, DNA, the supposed "vehicle of heredity," is itself influenced by environment as well as by heredity. Indeed, the sharply enhanced rate of mutation, which has been observed in bacteria under conditions of extreme thymine deprivation, suggests: (1) that an alteration in the nucleotide sequence of the DNA occurs under these conditions, and, thus, (2) that the specificity of the DNA synthesis may be partly controlled by the concentration of available free nucleotides.[18-22]

Experiments on Synthesis of DNA

Some experiments in which DNA is synthesized *in vitro* have a bearing on our question. Three things are involved: some DNA put in as a "primer," the necessary enzyme, the DNA polymerase; and the necessary deoxynucleatides. Some experiments in which DNA primers from various sources were used along with polymerase from *Escherchia coli* showed that the nature of the resulting DNA was affected by the polymerase as well as by the primer.[23]

If the DNA primer and the enzyme are from the same organism the new DNA will be the same as the primer DNA within 5%. But, if the primer and the enzyme are from separate differing species of organisms, the disparity of sequence of the new DNA and the primer DNA is as much as 17.25 percent! The precision of protein synthesis also depends on *both* the DNA code and the specificity of the synthetic enzyme. Also the pH, magnesium content or concentration, and temperature affect the reaction system. As Commoner sums it all up, "Self duplication and biochemical specificity is a property of an intact whole cell, which is an inheritably complex system, and not the property of one or another molecule. We can ignore this fact only at the price of self-delusion."

On the other hand, *in vivo* experiments have shown that the precision with which an intact *E. coli* cell is capable of regulating the specificity of the proteins, which it synthesizes, depends not only on the specificity provided by the DNA genetic agent, but also on the amino-acyl RNA synthetase which is involved.[24]

DNA as Other Than Code

There are other observations which it is difficult to fit in with the notion of a "code," but which favour another interpretation. For a wide range of creatures, the amount of DNA in a cell is about proportional to the volume of the cell. (That is to say, the ratio of amount of DNA per cell to the volume of a typical cell is about the same for a wide variety of creatures.)

Moreover, the rates of consumption of oxygen, and of metabolism, are about inversely proportional to the amount of DNA per cell.[8] Commoner suggests that this is because

DNA synthesis and the resultant sequestration of the catalytic nucleotides which are active in the oxidation electron transport system will tend to reduce the rate of catabolic degradation of the metabolites. In turn, this may be expected to increase the relative proportion of the available metabolites which enter into the anabolic process and thereby contribute to the synthesis of cell substance . . . one may anticipate a positive correlation between the DNA content and the overall size characteristic of the mature cell and a negative correlation between DNA content and the cell's characteristic rate of oxidative metabolism.[8]

Which, in other words, means that DNA is here acting as some sort of material cause. On the other hand, as Commoner concludes, in another place, "The unique precision of the chemistry of intact biological appears to be conditioned, in some as yet unknown way, by the inherent structural organization of the cell."[10] To which one might add: "that is to say, by the form–the formal cause."

There are other points which might be mentioned. There seems to be evidence to show that in special cases certain features can be inherited independently of DNA. And more important, even though it were established that DNA somehow arranges the growth of cells, no one seems even to have suggested a way in which it could control the pattern of a flower, say, or the structure of a bird's feathers. To say that it is "by enzymes" is just to imitate the dear old lady who said that machinery works "with screws, somehow." Moreover, it is undoubtedly true that living beings, as they grow, adapt themselves to the circumstances to some extent. It is hard to see how this could be if their development were completely controlled by a "code," like the working of an automatic screw machine.

Conclusion

Now to conclude this discussion. Theoretical arguments and experimental evidence have been given to show that DNA is not the whole cause of life and of heredity. Indeed, anyone who holds the doctrine of the four causes would not have expected otherwise. And if anyone doubts that doctrine, it is suggested that he try to think of a case in which he knows that there are not the four causes (as distinguished from not knowing what they are).

On the other hand, DNA seems to be a cause in some sense, and an immanent one. So it must be a material cause. But a very special and crucial material; hence it is not surprising that it has a great effect on the development of the creature.

But there must still be a formal cause, and that can be only in a soul, or that which stands in the same relation to a single cell as the soul does to the whole creature. (It is sufficient here to take the word "soul" in Aristotle's sense; the Christian sense includes and goes beyond that).

The two other causes exist, but this argument is not especially concerned with them.

An account such as this, then, which satisfies the biology without doing violence to the metaphysics, seems to be what we set out to find.

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