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DNA, RNA AND PROTEIN BIOSYNTHESIS AND IMPLICATIONS FOR EVOLUTIONARY THEORY

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The current theories, particularly the Watson-Crick hypothesis, for the replication of DNA and biosynthesis of RNA and protein are discussed. Possible mechanisms for mutations due to alternation in base sequence of the DNA of the gene are reviewed. In view of the extreme complexity and high degree of specificity of the DNA-RNA-protein system and complete inter-dependence of nucleic acid and protein synthesis, difficulties involved in attempting to construct mechanisms for an evolutionary development for the origin of life are pointed out. The complete dependence of DNA on the living cell for its replication and function emphasizes that DNA is the servant, rather than the master, of the cell.

CURRENT THEORIES CONCERNING DNA, RNA AND PROTEIN BIOSYNTHESIS AND INFORMATION TRANSFER

According to current theories, most if not all genetic information is carried by the DNA of the cell. In higher cells, this DNA is organized into chromosomes contained in the nucleus. The genetic material of a bacterial cell is believed to consist of one long strand of DNA not enclosed within a membrane.

The generally accepted structure for DNA and its mode of replication is that proposed by Watson and Crick (1, 2). Their model consists of a double-stranded helix, the purine and pyrimidine bases of each strand being paired with a complementary base in the other strand. Thus, adenine in one strand pairs with thymine in the other strand, and guanine pairs with cytosine. Watson and Crick's model employs hydrogen bonding as a sufficient force for template specificity, the 6-amino group of adenine being hydrogen bonded to the 6-keto group of thymine, and the 6-amino group of cytosine being hydrogen bonded to the 6-keto group of guanine. They have proposed that during replication of DNA there is a separation of strands and a synthesis of two new strands, complementary to each of the parent strands. In addition to the presence of the DNA being replicated, other requirements for this synthesis include the four deoxyribonucleoside triphosphates, Mg^{++} and the enzyme DNA polymerase. Although the Watson-Crick model has gained wide acceptance, there are certain difficulties with the model which have yet to be answered (3).

The site of protein synthesis is on the ribosomes, located in the cytoplasm remote from the nucleus and, in fact, protein synthesis will proceed in the absence of DNA. It was recognized, therefore, that transcription of the information contained in the genetic material into a specific protein structure must require some sort of a messenger. Jacob and Monod (4) have proposed that the information contained in the DNA of the gene is carried to the ribosomes by a short-lived messenger, a ribonucleic acid, which they have called messenger RNA (m-RNA). The information for determining the amino acid sequence of a protein is believed to be encoded in the base sequence of its corresponding messenger RNA. Thus, the base sequence of the DNA of the structural gene determines the base sequence of the messenger RNA, the base sequence of which in turn dictates the amino acid sequence of the protein.

It has since been proposed (5) that DNA serves as a template for the synthesis of m-RNA, there being a complementary base pairing between the bases of the DNA strand and of the m-RNA as it is synthesized. Only one strand of DNA is read. In this synthesis, adenine pairs with uracil, thymine with adenine and guanine with cytosine.

The nature of the amino acid code has been under investigation for some time. Crick and coworkers (6) have proposed a triplet code, that is, three bases in the m-RNA code for one amino acid. Thus UUU codes for phenylalanine, AGA for arginine, GUU for valine, etc. Most evidence so far seems to support a triplet code. Some important progress has been made in solving this code, and recently at the Sixth International Congress of Biochemistry in New York City, M. W. Nirenberg announced the base sequence code for valine, and predictions for base sequence codes for several other amino acids based upon the sequence for valine and amino acid exchanges previously known. Prior to this, only the base composition, and not the sequence, of the triplets were predictable.

1 Abbreviations: DNA = deoxyribonucleic acid, RNA = ribonucleic acid, ATP = adenosine triphosphate, AMP = adenosine monophosphate, GTP = guanosine triphosphate, A = adenylic acid, T = thymidylic acid, G = guanylic acid, C = cytidylic acid and U = uridylic acid.

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As previously mentioned, the site of protein synthesis is on the ribosomes. The ribosomes consist of about 60% RNA and 40% protein. Very little, if anything, is known about their structure or method of synthesis. No doubt the structure of both ribosomal RNA and protein is highly specific. A number of ribosomes are organized into larger units called polyribosomes or polysomes. This is believed to take place under the influence of m-RNA.

Protein biosynthesis is indeed very complex (7). The first step in protein biosynthesis is the activation of the amino acids *via* an amino acyl-AMP-enzyme complex. Under the influence of an activating enzyme, a reaction between the amino acid and ATP, leading to the formation of an anhydride bond between the carboxyl group of the amino acid and the 5' phosphate group of AMP, takes place. This product is held in a complex with the enzyme. Here specificity in protein synthesis is first exerted, since

1) $AA + ATP + E \rightleftharpoons (AA - AMP) - E + PP$
2) $(AA - AMP) - E + RNA \rightleftharpoons AA - RNA + E$

there is a specific enzyme for each individual amino acid. This complex reacts with a cytoplasmic RNA, called soluble RNA (s-RNA), or transfer RNA, to form an activated amino acyl-s-RNA complex. Here again, specificity is exerted, for there is a specific s-RNA for each individual amino acid. I believe we should attach special significance to these activating enzymes, for they represent a true juncture of protein and nucleic acid chemistry in the living cell. Each is designed to recognize a specific amino acid, the building blocks of proteins, and a specific nucleic acid, s-RNA. Each enzyme must select a specific amino acid from a mixture of 20 or more, cause it to react in a specific manner with ATP, and then each enzyme while in the form of this amino acyl-AMP-enzyme complex must select a specific s-RNA from a mixture of 20 or more, and bring about a reaction between the amino acyl-AMP and the s-RNA in a specific manner.

Not much is known about the tertiary structure of s-RNA. It is known that the amino acid is combined with the ribose portion of a terminal adenosine, and two cytosines follow in sequence. This A-C-C sequence is common to all s-RNA's, plus a guanine at the other end. Except for these similarities, the sequence for each s-RNA is specific and different from that of each other s-RNA. The A-C-C is enzymatically removed and replaced in a very specific way. The significance of these reactions is, as yet, unknown. The mode or site of synthesis of s-RNA is still unknown. s-RNA is unique among the RNA's by virtue of its content of odd bases, such as thymine (usually found only in DNA), pseudouridine (the sugar is attached to the No. 5 carbon, rather than to the No. 3 nitrogen), 1-methylinosinic acid (a derivative of hypoxanthine) and various methylated bases. The activating enzymes exhibit considerable, although not absolute, species specificity (the rate at which an activating enzyme will activate its amino acid is much faster with its homologous s-RNA than the rate with s-RNA from another species).

The amino acyl-s-RNA complexes are transferred to the polyribosomes, the site of protein synthesis, and the amino acids are incorporated into protein. For this, m-RNA is required, of course, to dictate the sequence of the amino acids in the protein. GTP and Mg^{++} are required. One or more enzymes, called transfer enzymes, not specific for each amino acid, are required. Very little is known about the actual assembling of the amino acids into the polypeptide chain, or the requirements for each step in this synthesis which may involve several steps. The transfer enzymes are species specific. For instance, the transfer enzymes from rat liver are not active in the protein synthesizing system from *E. coli.* The synthesis of the peptide chain is believed to be sequential, beginning at the N-terminus. The steps involved in releasing completed protein from the ribosomes are not known. A releasing enzyme or enzymes may be required.

We should emphasize that, in spite of the great progress that has been made during the past decade or so, the extent of our knowledge concerning the biosynthesis of DNA, RNA and protein is still actually scanty. Most of the material which we have presented must be held as tentative until further evidence is forthcoming. What we have given here has been presented in outline form only. We have said nothing about the systems which synthesize the precursors needed for the synthesis of DNA and RNA. We have said nothing about the complex system in the cell required to generate the energy for this synthesis. Nor have we mentioned the structural integrity of the cell that is required for protein synthesis to proceed at normal rates. We have seen, however, the extremely complex system required to synthesize a protein molecule in the living cell. Furthermore, one of the most striking features of this system is the high degree of specificity exhibited in every detail of the system. Apparently the position of every nucleotide and amino acid is uniquely and purposefully determined. Each of us should stand in awesome wonder as we witness the unfolding of this ingenious plan of the Master Planner.

NATURE AND MECHANISM OF MUTATIONS

As we have accumulated some knowledge concerning the replication of DNA and of information transfer, we are now able to postulate mechanisms for certain types of mutations. Nuclear or chromosomal heritable variations may be divided into those variations which involve a change in chromosome number (polyploids, aneuploids) and those variations which involve a change in information content. We will concern ourselves here only with those variations due to changes in information content. Heritable variations due to changes in information content may be subdivided into those occurring by recombination (a reshuffling of the genes by crossing over, transduction, etc.) and those due to mutations. Finally, mutations may be classified as "point" mutations, mutations which may be due to as small a change as a single base pair of the DNA, and larger alterations, such as loss of a piece of a gene.

These base changes may be induced by various means. Inhibitors of the synthesis of nucleic acid precursors, such as 5-amino uracil, which inhibits the synthesis of thymine, may cause chromosomal breaks or mistakes in base pairing. Certain base analogs, such as 5-bromouracil and 2,6=diaminopurine, are incorporated directly into DNA and may cause mistakes in base pairing during replication. Some dyes, such as acridine orange, are believed to be mutagenic by causing deletions and insertions of base pairs. Some chemicals, such as nitrous acid and alkylating agents, bring about these base changes by directly altering the structure of the bases. Nitrous acid, for instance, deaminates cytosine to yield uracil, a normal constituent of RNA. It is highly mutagenic, therefore, towards RNA viruses such as tobacco mosaic virus. Temperature, pH, radiations and ultraviolet light are other causes of mutations. Spontaneous mutations may come about by mistakes in base pairing in the normal replication of DNA or RNA. Under certain conditions, A can pair with C (instead of T) and G with T (instead of C). Certain metabolites of the cell, such as peroxides, may react with the bases of DNA to produce mutations.

Studies that have been carried out during the past few years have strongly indicated that alteration in a single base pair is sufficient to cause a mutation. For instance, tobacco mosaic virus (TMV) has been treated with nitrous acid, resulting mutants have been isolated, and the amino acid composition of the protein compared to that of the wild type. In many cases, it was shown that there had been a single amino acid exchanged in the protein, indicating that a single base pair in the nucleic acid of the virus had been altered. In the studies on abnormal human hemoglobins, it has been shown that a single amino acid has been exchanged in the β -chain of the hemoglobin. These result in some cases, such as sickle cell anemia, in severe anemias. Sickle cell anemia is invariably fatal for those homozygous for this trait. We cannot positively say, however, in these cases cited that only a single base pair has been effected. There may have been another base pair exchanged which did not effect the structure of the protein under study and yet could have exerted a mutant effect. In the case of the hemoglobins, a mutation may have occurred, in addition to the one which induced the change in amino acid sequence, which affected the mechanism controlling the rate of hemoglobin synthesis. In the case of TMV, many mutants were isolated in which there had been no change in amino acid sequence of the protein. Apparently, only a portion of the RNA chain of this virus (6600 nucleotides, M.W. 2,000,000) codes for the protein structure. These mutants were detected by a change in such properties as host specificity or the nature and severity of the disease invoked.

This discussion serves to remind us of the limitations of our present knowledge. We are able to elucidate the amino acid sequence of proteins and thus, as with TMV and the hemoglobins, to indirectly relate certain mutations, which have caused a change in amino acid sequence, to a change in the nucleotide sequence of the genetic material. However, we have no direct knowledge about the sequence of the nucleotides in the genetic material, and we do not have the methods available today that would permit us to undertake a study of, say, the sequence of TMV RNA. It is possible that within the next few years, the amino acid code will be solved. That is, we will know the nucleotide triplet in messenger RNA that codes for each amino acid, and thus indirectly the portion of the nucleotide sequence in the DNA of the genetic material that codes for a certain protein, the amino acid sequence of which is known. As important an achievement as this will be, we must be cautioned concerning the exaggerated claims that will be made in the popular press and even in some of our scientific journals. Claims will be made that now man in the near future will be able to control inheritance, including his own. This claim has already appeared, even in scientific articles. We might outline some of the stumbling blocks still in our way in this respect, however. Even though we knew the amino acid code, we still would have no idea where the corresponding base change took place in the DNA of the genetic material, because we cannot determine the sequence of the nucleotides in the DNA. If we did know the sequence, even of a single gene, we still would not have the slightest notion of how a change in a particular base pair would be expressed phenotypically, that is, we could not predict how the corresponding amino acid exchange would effect the activity of an enzyme or the integrity of a structural protein, whatever the case may be. Even if we knew this, we would have no way of bringing about a selective change in one or two base pairs among several thousand or several million, nor can we imagine how this would ever be possible. Supposing this were possible, we would still have no way of selecting and segregating a particular gene from among the tens of thousands present in the genetic material. In a bacterium, the genome, which of course consists of many genes, is a single DNA strand of about three million base pairs. The corresponding complexity in a mammalian cell may well be imagined. Finally, no one has yet devised methods by which the genetic material may be removed from the sperm or ovum, manipulated and replaced, with retention of viability. For man to control heredity by a controlled change in the genetic material would thus require his overcoming a whole series of fantastic improbabilities.

PROBLEMS RELATED TO EVOLUTIONARY THEORY

What we have discussed so far, as limited as it has been, should lead us into a consideration of the significance to the origin of life. If, as we believe, the origin of life and therefore the origin of these complex macromolecular systems was by the design and exercise of the creative power of God, then the nature of that origin and the processes leading up to it may well be beyond the power of scientific investigation. I certainly believe this to be the case. These convictions need not affect our scientific ability, our scientific curiosity, nor our willingness or boldness in attacking any problem open to scientific investigation. All of the secrets of the living cell, such as its mode of replication, its ability to vary and adapt, its biosynthetic pathways and its energy systems, are open to study. The scientist who is a creationist leaves the side of his evolutionist colleague only when the boundary between scientific fact and speculation in this area is crossed. And, I may add, that boundary is becoming very diffuse today, especially in evolutionary theory.

Concerning the possibility of the origin of life in a purely mechanistic, materialistic manner, I believe no one has succeeded in stating the problem in a more cogent manner than has A. I. Oparin in his book, "The Origin of Life on the Earth" (8). Many contemporary authors believe that the key to the origin of life may be found in the primary development of those compounds specific to living things, such as proteins with enzymic activities and nucleic acids endowed with genetic properties. Oparin recognizes the futility of such views, stating that the relatively simple laws of thermodynamics and chemical kinetics could not have determined the origin of these complex molecules endowed with highly specific structures and functions.

He states the necessity of there first having arisen a new specific organization, and afterwards, on the basis of it, the substances appeared, not vice versa. Oparin's proposal concerning the nature and origin of this system, I believe, has certain fatal flaws. His proposal will be discussed later. I, personally, cannot imagine either a specific organization or macromolecules endowed with specific structures and functions, arising independently of one another.

Earlier speculations on the origin of life took place during the "golden age of proteins" and proposed that the origin of life was based upon the formation of some catalytically active protein that could be formed autocatalytically. Calvin's proposals followed this line (9, 10). Models have not supported such views (8).

Today we are in the "golden age of nucleic acids", and speculations are centering around the origin of nucleic acids. It is proposed that all genetic information resides in nucleic acid, that this genetic material is self-replicating, and thus the gap between the inanimate and the living cell may have been bridged by something akin to a virus, which they state is self-replicating. Such proposals must fail, because among other reasons there is no self-replicating molecule known, virus, gene, chromosome or otherwise. The only self-replicating entity known today is the living cell. It is somewhat dismaying to note how often we find expressed in scientific articles and texts the statement that a virus can replicate itself and that such a self-replicating molecule may have been the precursor to the living cell. In fact, Lindegren has stated (11) that the possibility that something similar to the viruses we now study was a stage in the evolution of more elaborate organisms is *"the basic hypothesis which directs the scientific activities of most of the foremost geneticists and biochemists of the present time"*. If Lindegren is right, then this indicates an appalling ignorance in our scientific community concerning the nature of viruses. A virus, or any other nucleoprotein, possesses no catalytic ability. Outside of its environment in the living cell, it is biologically inert. The synthesis of a virus, a nucleoprotein, calls into play the entire synthetic apparatus of the cell previously discussed in this paper. DNA and RNA precursors are required, the high energy bonds of which are supplied by the energy-producing apparatus of the cell, in itself complex. DNA and RNA polymerases, the entire system of activating enzymes and s-RNA's, transfer enzymes and ribosomes are some of the other requirements. *The cell replicates the virus,* using information supplied by the virus to produce an exact copy.

Any speculation concerning the primary origin of proteins or nucleic acids must take into account the fact that the specific structure of proteins is dictated by nucleic acid, which itself is synthesized by protein enzymes. Either is helpless without the other, thus neither could have existed independently of one another in a functional system. Since the genetic information of the cell rests largely in its DNA, evolutionists seem to believe today that its primary origin should be assigned first place in an evolutionary scheme. Before synthesis of DNA can take place in the cell, however, DNA precursors must be synthesized from RNA precursors. Thus, adenylate, guanylate and cytidylate must be converted into deoxyadenylate, deoxyguanylate and deoxycytidylate, respectively, and uridylate serves as the precursor for deoxythymidylate. All of these syntheses require specific enzymes, of course. On the basis of this fact then, it would seem more logical to assign priority to RNA, since it can be synthesized directly from precursors which must be converted into other precursors for DNA synthesis. How DNA got into the picture would be, then, yet another story.

Alexander Rich, in recent speculations concerning the problems of evolution and information transfer (12), used the same approach that authors were proposing twenty and thirty years ago, namely the primary formation in some primordial sea of an autocatalytic molecule endowed with certain specific functions. His molecule is, of course, a nucleic acid. The same arguments which can be raised against the primary formation of a protein molecule from a so-called primordial soup, can be raised with even greater force against the primary formation of a nucleic acid molecule. No nucleic acid molecule has been shown to possess any catalytic ability, let alone any ability to autocatalytically replicate itself. Rich is forced to a liberal use of such terms as "we postulate", "we imagine", "we theorize", "we could imagine", "let us imagine", "we might imagine." Such an exercise, I submit, is not science. As W. R. Thompson would put it, Rich has built those fragile towers of hypothesis based on hypothesis. Surely we must take into account the basic properties of macromolecules that we are discovering today, and these basic properties most certainly would have remained essentially unchanged. Yet Rich and others in their evolutionary schemes, are forced to assign properties to macromolecules observed nowhere in nature today.

Oparin has recognized the futility of such speculations as those of Calvin and Rich. As stated earlier, he postulates that certain, new biological laws had to be operating before a system of specific, functional molecules could have arisen. He proposes that a new specific organization arose and, based on this, specific molecular systems were formed. Oparin imagines the separation from an organic-rich primordial sea of coacervates, or droplets of colloid-rich material. Such coacervates can form by interaction of certain macromolecules, such as proteins, nucleotides, polysaccharides, etc. We will not detail here the manner in which he proposes such coacervates might have evolved into more complex systems, but will point out certain basic objections to his proposal. First of all, the tendency of any molecule to separate out of solution or to complex with other molecules, compared to its tendency to remain freely dispersed in solution, is proportional to its concentration. This tendency generally is not a function of the concentration of similar molecules.

Thus, the tendency of a protein molecule to form a monomolecular coacervate or a complex coacervate with other molecules would be a function of the concentration of the molecular species involved. The number of protein molecular species that would have arisen by purely chemical means, if this were possible, would have been truly astronomical. The same would be true of the nucleic acids. For instance, a polynucleotide consisting of 10,000 nucleotides (M.W. $3x10^6$) could exist in more than 10^{8000} isomers (13). Taking into account every conceivable sequence and chain length, even ignoring optical isomers, the number would be beyond our imagination. Assuming a total concentration of protein and nucleic acid of even as high as 1 or 2% each, the concentration of any single molecular species would be insignificant. The forces tending to keep these molecules freely dispersed would vastly exceed any forces that might cause them to aggregate and separate. Under these circumstances, I cannot imagine even a fleeting existence of such coacervates.

Another basic objection to Oparin's suggestion is the fact that his coacervates once formed, in order to have ever contributed to higher forms, must have existed indefinitely until they became self-replicating. This would have meant that those coacervate drops which eventually evolved into self-replicating forms would have had to exist for perhaps millions of years without disruption. Such a possibility simply never could have existed. Forces seeking to disrupt such coacervates would have been at work continually. The only way a species survives is for its birth rate to equal or exceed its death rate. It obviously must be self-replicating. Oparin really never comes to grips with self-replication in his complex coacervate system.

In our discussion on the role of DNA and RNA in protein synthesis we have said nothing about control mechanisms. The existence of control mechanisms is, however, indispensible for the success of any biological system, no matter how primitive. Every metabolic pathway in the living cell is under close control and is coordinated with all other pathways. Cairns has aptly stated (14) that the presence of such control mechanisms converts what might be purposeless or even destructive activity into the ordered systems we find in the living cell today. One type of control mechanism is that proposed by Jacob and Monod (4). They have proposed that the structural genes which code for a series of functionally-linked enzymes are under control of an operator gene. The operator gene and the structural genes it controls lie adjacent in the chromosome and constitute what they call an operon. The operator gene must function in order for the structural genes to be expressed. The operator gene, in turn, is under the control of a regulator gene which is located on some other chromosome or at some other point in the genetic material remote from the operon. Let us consider, for instance, the induction of the synthesis of the enzyme β-galactosidase in *E. coli,* in which this enzyme is inducible and not constitutive. They propose that when these cells are growing in the presence of glucose, the regulator gene for galactosidase is elaborating an inhibiter which prevents the function of the operator gene, and thus the synthesis of messenger RNA by the structural gene for galactosidase cannot take place. When glucose is replaced with lactose, the substrate, lactose combines with the repressor, and the operator gene is then able to activate the structural genes in the operon, which include not only that for galactosidase but also that for permease, an enzyme necessary for penetration of lactose into the cell. Messenger RNA's for galactosidase and permease are formed and the enzymes are synthesized. Removal of the substrate reverses this process. Jacob and Monod have emphasized the importance of such control mechanisms by pointing out that in mutants that have become constitutive for the lactose system, 6-7% of their protein material consists of β-galactosidase. In constitutive mutants of the phosphatase system, 5-6% of the total protein consists of phosphatase. It becomes clear then, that the cells could not survive the breakdown of more than two or three of the control mechanisms which regulate the rate of synthesis of enzyme proteins.

One may ask, then, which came first in the alleged evolution of the DNA-RNA-protein synthesis system, the regulator gene, the operator gene or the structural genes? If unregulated expression of the structural gene results in self-destructive activity, it must have been under control from the very start. If the regulator gene was formed before the operon it regulates, what selective advantage would it have conferred upon the system? The same could be said for the operator gene. We see the same situation here on the macromolecular level as on the structural level of, say, the humming bird. In such correlated systems, no individual feature would confer selective advantage until all components were functioning. Thus, in the humming bird, none of its individual unique features, such as its bill, tongue or wing structure, would have conferred selective value until all were present and correlated in a functional system. Neither would regulator, operator or structural gene confer selective advantage until all were present and functioning.

Earlier I have called the present day the "golden age of nucleic acid". At the recent Sixth International Congress of Biochemistry in New York City, the room in which the papers on nucleic acids were being given was crowded to overflowing. Rooms devoted to other sections had as low as 20% occupancy. DNA is being called the "master chemical", the "secret of life". Nucleic acid has replaced protein as the primary molecule in evolutionary schemes. It is claimed that all genetic information resides in DNA of the cell and that DNA is a self-replicating molecule. Furthermore, it is being claimed that the boundary between life and non-life has all but been wiped out. However, there are still some who are willing to come to the defense of biology. Those that are in hot pursuit of the DNA molecule seem to forget that they are chasing only a sub-unit of the living cell. Let us consider for the moment the possibility of synthesizing a biologically-active DNA molecule in a test tube, a feat yet to be accomplished (3). Let us forget for the moment that to accomplish this purpose we have extracted DNA and appropriate enzymes from the living cell. We still would have only a miniature factory for producing a particular DNA molecule. In fact, even if we were able to produce all of the DNA in the nucleus of a mammalian cell, we would still be left with nothing but a DNA factory.

Earlier in this discussion we reviewed the complex apparatus that must work with DNA to synthesize a protein molecule. We have noted the many enzymes that must participate, the cooperation of ribosomes and of the energy-producing system which is found in the mitochondria. We might mention the structural integrity of the cell that is so vital to these processes. Roberts has pointed out (15) that almost every part of the cell is suspected of playing some role in protein synthesis, and that disruption of the cell usually decreases the rate of protein synthesis by a factor of a thousand or more.

I believe it is extremely significant that the function built into the DNA molecule has been designed to exert itself solely in the living cell. It is evident then that these DNA molecules did not precede the cell, but both must have existed together from the very beginning. Neither has existence, function or meaning without the other. Hinshelwood has stated (16) that "the building blocks of the cells, wonderful as they may be as structures, are useless by themselves. Cell function depends upon the rhythm and harmony of their reciprocal actions: the mutual dependence of protein and nucleic acid; the spatial and temporal relations of a host of elementary processes which with their sequences and bifurcations make up the reaction pattern of the cell. A system of mutually dependent parts, each of which performs something like enzymatic functions in relation to another will, as can easily be shown, in the steady state appear as a whole to be autosynthetic. No individual part need be credited with a new and mysterious virtue by which to duplicate itself". It is Hinshelwood's view then that nothing less complex than an entire cell is capable of self-duplication.

One of those arising to the defense of biology today is Barry Commoner (17, 18, 19). This heretic has even been bold enough to defy the "central dogma" that information may pass from nucleic acid to protein but never from protein to nucleic acid. He believes that the information content of a DNA molecule is insufficient to dictate the synthesis of an exact copy of itself and that information is derived from some of the protein enzymes that participate as well as from the DNA itself. We can only mention that here in passing, but I would like to quote from one of his papers. He states "the remarkable roles which DNA plays in inheritance are a reflection of certain chemical attributes, particularly its nucleotide sequence and its considerable stability. But these properties lead to replication and determination of inheritance only when DNA is a participating constituent of the living cell. The effects of DNA on inheritance are, rather than simply an aspect of the chemistry of DNA, a manifestation of the living state". He goes on to suggest that, rather than DNA being the secret of life, *"life is the secret of DNA"* (19).

REFERENCES:

1. Watson, J. D., and Crick, F. H. C., Nature *171*:737 (1953).
2. Watson, J. D., and Crick, F. H. C., Nature *171*:964 (1953).
3. Cavalieri, L. F., and Rosenberg, B. H., Ann. Rev. Biochem. *31*:267 (1962).
4. Jacob, F., and Monod, J., J. Mol. Biol. 3:318 (1961).
5. Hurwitz, J., and Furth, J., Sci. Amer. *206*(2):41 (1962).
6. Crick, F. H. C., Barnett, L., Brenner, S., and Watts-Tobin, R. J., Nature *192*:1227 (1961).
7. For a recent review see Korner, A., in "Mammalian Protein Metabolism", ed. H. N. Munro and J. B. Allison, Academic Press, New York, 1964, p. 177.
8. Oparin, A. I., "The Origin of Life on the Earth", Academic Press, New York, 1957.
9. Calvin M., Am. Scientist *44*:248 (1956).
10. Calvin, M., Science *130*:1170 (1959).
11. Lindegren, C. C., Nature *197*:566 (1963).
12. Rich, A., "Horizons in Biochemistry", ed. M. Kasha and B. Pullman, Academic Press, New York, 1962, p. 103.
13. Chargaff, E., "Essays on Nucleic Acids", Elsevier Publishing Co., New York, 1963, p. 124.
14. Cairns, J., Endeavour *22*:141 (1963).
15. Roberts, R. B., Ann. N.Y. Acad. Sci. *88*:752 (1960).
16. Hinshelwood, C., Proc. Roy. Soc. London *B146*:155 (1956).
17. Commoner, B., Science *133*:1745 (1961).
18. Commoner, B., J. Nat. Ed. Assoc., March, 1964, p. 17.
19. Commoner, B., Nature *202*:960 (1964).

SOME PRESUPPOSITIONS IN THE PHILOSOPHY OF SCIENCE

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The history of science reveals at least three major attitudes as to the nature of scientific theories. Popper calls these essentialism, instrumentalism, and genuine conjecture. This paper begins by outlining the disadvantage of the first two and sides with the third. Illustrations of each attitude in the history of astronomy are also sketched. The latter portion of the paper explores contemporary cosmological theorizing, in the light of the above survey, so as both to show the presence of these attitudes today and to point up why cosmologists give their theories the bent which they do. Certain lessons of an apologetic sort are mentioned in conclusion.

It is not the purpose of this paper either to explore the competing methods of the philosophy of science in a systematic manner or to examine in detail their theoretical meta-philosophical orientation. Rather, we shall set our sights toward several more readily achievable goals within the broad landscape above. Precisely, an attempt will be made to delineate certain positions widely held as to the nature of scientific theories, to illustrate these from past and present speculations in physics and cosmology, and to search out some of the controls operating in such choices together with a few consequences arising from these influences.

In his *Logik der Forschung* published in Vienna in 1934 (with the imprint '1935') and which has, since 1959, been available in English as *The Logic of Scientific Discovery,* Karl Popper first enunciated several useful distinctions among the attitudes of scientists as to the character of their theoretical work.[1] The divisions which he suggests center upon the ideas that theories aim at ultimate explanation by essences, that theories serve merely as instruments, and that theories are conjectures aiming at severe testing. Since this schema, is to my way of thinking, valuable we shall utilize it in our exploration after pointing out what Popper says about each of the divisions he names.

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Essentialism he finds to consist of three doctrines. It claims that the scientist's goal is to find a true description of nature and of its laws which also explains the facts of observation. It proclaims that scientists can succeed in establishing the truth of these theories beyond reasonable doubt, and it states that the best theories describe the reality lying behind appearances. Popper accepts the first belief but concludes that the second fails to see that tests (or even a new theoretical discussion) can lead to discarding a theory. Theories all remain conjectural. The third idea, that science aims at ultimate explanation, he also rejects, saying "[Whether] essences exist or not, the belief in them does not help us in any way, and indeed is likely to hamper us; so that there is no reason why the scientist should assume their existence."[2] The belief in essences, whether true or false, may create obstacles to our posing new and fruitful questions; it isn't part of science since we could never be certain of even a theory which might fortuitously succeed in describing the essence of something, and it isn't "one of those extra-scientific beliefs (such as faith in the power of critical discussion) which a scientist need accept."[3]

Instrumentalism holds that theories are merely instruments helping us to explain why one symbolic representation of reality leads to another symbolic representation.[4] Theories are sets of instruction for deriving one logically singular statement from another.[5] Popper claims, however, that theories are *not* computation rules. In summary, his view is that the

> logical relations which may hold between theories and computation rules are not symmetrical; and they are different from those which may hold between various theories, and also from those which may hold between various computation rules. The way in which computation rules are *tried out* is different from the way in which theories are *tested;* and the skill which the application of computation rules demands is quite different from that needed for their (theoretical) discussion, and for the (theoretical) determination of the limits of their applicability. 6

Thus instrumentalism leaves us unable to account for the actual progress of science which involves attempted refutation and not just the establishing of theories as having differing ranges of applicability.

> [By] *neglecting falsification, and stressing application, instrumentalism proves to be as obscurantist a philosophy as essentialism* . . . . It is only in considering how [in science] various theories stand up to tests that it can distinguish between better and worse theories and so find a criterion of progress. 7

If theories are merely predictive instruments they cannot be falsified; indeed they may, as *ad hoc* hypotheses, rescue a scientific theory threatened by falsification.

> In contrast to the highly critical attitude requisite in the pure scientist, the attitude of instrumentalism (like that of applied science) is one of complacency at the success of applications. Thus it may well be responsible for the recent stagnation in theoretical physics. 8

Popper, as a consequence, rejects it as an alternative to essentialism.

Finally, Popper describes his own attitude regarding scientific theories. They are

> *genuine conjectures*—highly informative guesses about the

world which, although not verifiable . . . can be submitted to severe critical tests. They are serious attempts to discover the truth . . . even though *we do not know, and may, perhaps, never know, whether [they are] true or not.*[9]

As a result, this view is unlike essentialism in that it does not claim to describe, even partially, some real world behind appearances but rather postulates a world for each theory, described in their turn by further theories more universal and testable. "The doctrine of an *essential or ultimate reality* collapses together with that of ultimate explanation."[10] New theories, like older ones, "are genuine attempts to describe these further worlds . . . as equally real aspects, or sides, or layers, of the real world."[11] A piano is no more real than its molecules or atoms. The theories delineating all three are equal in "their claims to describe reality, although some of them are more conjectural than others."[12]

The view is also unlike instrumentalism in that while Popper calls a state of affairs "real" if, and only if, the statements describing it are true, this doesn't diminish the claim of such a conjectured state of affairs to describe something real. Conjectures *may* be true and thus describe a real state of affairs or they may be falsified and thus contradict what is really the case.[13] Testable theories assert that something cannot happen and thus they assert something about the real world. Hence the more conjectural a theory is, the higher should be its degree of testability. There is undoubtedly much which we don't know at all that is real! Therefore, "[with the belief] that science can make real discoveries I take my stand . . . against instrumentalism."[14] In sum, true science can predict events of a type already experienced (e.g. eclipses) and also new kinds of events (e.g. the birth of a galaxy). Instrumentalism cannot handle the second of these. Discoveries are guided by theories which do not offer only predictions from the known but which aim at creating novel situations for new tests.

It might be helpful to look at a historical example of each of the above three attitudes. Anyone familiar with the monographs in the history of science will be able to add many others for himself. Since Popper discusses Galileo, whose view of scientific theory is largely essentialistic, we may take Kepler as our example of that position for the sake of variety.

Some of Kepler's early thought, in the *Mysterium Cosmographicum* which he published when only twenty-five years of age, is familiar to most scientists. It will be recalled that in that work Kepler provided his first suggestion as to the mathematical reason for the number and distances from the sun of the planets; a solution he found in solid geometry. The shell of Mercury's orbit fits inside an octahedron whose points touch the shell of Venus' orbit. This in turn fits an icosahedron touching the shell of the orbit of the earth. Then between our shell and that of Mars is a dodecahedron; between Mars and Jupiter he fits a tetrahedron; and between Jupiter and Saturn a cube.

In the subsequent examination of Tycho Brahe's records of planetary motion, Kepler both revised the above schema, on the assumption that God might use other principles in laying out the paths than the above geometry suggests, and developed his three famous laws. Behind this work, as in his early ideas, lies the belief that the preferred theory is that one which best ties together previously distinct facts, and experience has shown this to be of some mathematical nature. He concluded from this that the world of the planets must therefore itself be a mathematical order; he argues that we do not accept a theory of planetary motion because of its utility or even its mathematical elegance but rather because the planetary world is a beautiful order in its essence.[15] He is quite explicit in arguing that theories are not merely instruments of calculation, and hence mere formal aids in science, but that to be true, they must fit the facts of experience which mirror the structure beneath them. Thus, while we know *a priori* that the universe is mathematical and that true knowledge of it must therefore be mathematical too, Kepler argues that only experience shows us the exact nature of this harmony.

The major problem here is that Kepler did not prove his case as to the mathematical essence of reality. To be sure we do find him offering mystical analogies for the purpose in his *Harmonice Mundi* of 1619, such as the attribution of different vocal ranges to the various planets[16] or the treatment of the sun as God the Father, the fixed stars as God the Son, and the intervening ethereal medium, through which the power of the sun is communicated to impel the planets around their orbits, as the Holy Spirit.[17] But the fact that a mystical metaphysic agrees with an elegant mathematical arrangement empirically found for the planets, is not sufficient to provide credibility to what is only an analogy. Also, because a religious view predicts a rational and mathematical planetary system, even if such a prediction were exact (which it was not, for Kepler), this is not sufficient to obviate other theoretical foundations for the same data. Kepler commits the fallacy of arguing that, by affirming certain empirical consequences, one can thereby affirm a precise mystical or religious antecedent. His essentialism fails, as it must always fail on such argument, to prove its case.

Instrumentalism is well illustrated in Bishop Berkeley. A most severe and intense critic of the fundamental concepts of Newtonian mechanics, Berkeley argued that Newton's absolute space, time, and motion were without physical meaning. Rather, such concepts as space and time are neither perceived by the senses nor proven by reason, and motion as people know it is always relative. Similarly, to talk of "force" taken as the cause of motion is to introduce into physics an occult quality. While a physics based upon forces does have a utilitarian value, since it leads to correct results, we must never confuse it with metaphysical explanation. As a consequence, Berkeley firmly espouses a formalistic or instrumentalistic attitude toward science. Its theories are instruments for calculation and prediction of the regularities of nature.[18]

Popper calls Berkeley's principle of analysis "Berkeley's razor" since

> it allows us *a priori* to eliminate from physical science all essentialist explanation. If they have a mathematical and predictive content, they may be admitted *qua* mathematical hypotheses (while their essentialist interpretation is eliminated). If not, they may be ruled out altogether. This razor is sharper than Ockham's: all entities are ruled out except those which are perceived.19

Jammer summarizes this in one sentence. "All that natural science can supply is an account of the relations among symbols and signs; but the sign should not be confused with the *vera causa*, the real cause of the phenomenon."[20]

This sort of thinking shows up repeatedly in later philosophy of science. In Ernst Mach, Berkeley's rejection of absolute space, time, and motion and of hypothetical forces is carried over to include the idea of cause and effect. Science was to discard such concepts entirely. He also rejects all metaphysical and theological tradition where Berkeley, ever the good churchman, used these ultimately to explain phenomena. "While Berkeley says that there can be nothing physical behind the physical phenomena, Mach suggests that there is nothing at all behind them."[21] Or, as Einstein in his obituary to Mach put it, "Concepts have meaning only if we can point to objects to which they refer and to the rules by which they are assigned to these objects."[22]

Instrumentalism re-appears clearly in William Clifford, and in his editor Karl Pearson.[23] "The terms matter and force, together with the ideas associated with them, [should be] entirely removed from scientific terminology— [reducing], in fact, all dynamic to kinematic."[24] Finally, we may note its appearance on Henri Poincaré for whom the laws of physics became arbitrary stipulations, expedient conventions, about how words like "force" and "straight lines" are to be used.[25] This view is really an extreme logical wing of positivism as opposed to the extreme empirical wing represented by Mach's view that laws are summaries of experimental facts.

It seems apparent that in reacting to essentialism this positivistic instrumentalism, still very common today, has gone too far. Its results are debilitating to scientific advance. If we consider hypotheses in science to be nothing but instruments for predicting phenomena we must ignore the fact that there are no phenomena which are not themselves hypothetical. All "observed facts" are actually theories about reality—statements about instruments and clock readings, for example, are convenient bases for testing theories but they are really only corroborated theories themselves and hence ever open to further testing. Are we never to be permitted to revise the meaning of our prior interpretations of phenomena in the light of new theories? Are we not to be permitted to devise competing theories, each explaining all current data, but differing on their predictions as to future data so we may test among them? Are we to assume that the idea of a hierarchy of explanatory theories isn't useful in science and that the historical development of these hierarchies has not arisen because people sought a deeper and deeper insight into the character of the real world? Are we not to be permitted to suggest explanations for the phenomena we observe in science, however much the mistakes of essentialism have shown us we should be cautious in *believing* what we speculate? Surely not.

Finally, as an example of the conjectural method let us look at Newton. It must be admitted that Newton was in many ways an instrumentalist in his conception of scientific theory.[26] A mathematical framework which adequately describes the data of contemporary physics usually appears to satisfy him, without feigning additional hypotheses to explain such things as the observed fact of gravity. But inconsistencies in applying this reveal that there were also essentialistic elements in his thought. The inability to leave apparent action at a distance unexplained, for example, led him to demand an ultimate explanation of gravity in terms of the action of a Divine Spirit.[27] While empiricism could not accurately determine such action, Newton believed this to be an ultimate explanation, that is, an explanatory theory not needing further explanation; not indeed capable of being further explained.

But Newton was quite aware that the mathematical and mechanical elements of his model would be subject to the test of future applicability in his new situation and in the light of new information. In this sense Newton operated within what Popper would call the conjectural framework—the method of tentative hypothesis (in the current, not Newton's, use of this term) and test. Any hypothesis must be scientifically acceptable, capable of experimental verification, and be subject to sacrifice if it conflicts with the data of physical experience.[28]

Indeed, taking some liberties with Strong's analysis, we might outline Newton's method fairly readily as follows:

1) A query asks if some deduction from a proposed theory is or is not a fact. It seeks to settle some doubt about the theory.

2) The proposed theory arises originally by abstraction rooted in the analysis of past data of observation and experiment.

3) A query, when no contrary evidence is submitted and to which no exceptions are taken, corroborates the theory (or part of it) subject to further queries suggested by new empirical data or by the logic of the theory.

It seems that a strong case can be made for such an attitude, refined of course to handle the minutiae of logic and method necessary to satisfy the sophisticated contemporary philosopher of science and suitable to everyday theoretical science. Of course it is impossible to develop the theme here, but we might summarize a few of the major attitudes of this type of approach.

1) Scientific theories (which are not just laws summarizing observation) are justified, not by their in-

duction from experience, but by their ability to withstand severe testing when consequences deduced from them are tried out.

2) If a theory is not potentially refutable by some conceivable event it is not scientific at all. To the degree that it is testable in new and risky situations it is to be preferred over a less testable alternative. If a theory is in error we should want to discover that it is, regardless of how well it has survived past testing.

3) Our prior convictions tend to influence our attitudes regarding the worth of specific tests and even to prejudice what theories we bother thinking about. This biasing can best be reduced by requiring that tests be reproducible so others may check, by not attempting *ad hoc* escapes from a test which has seemed to falsify our pet theory, and by consciously trying endlessly to refute rather than verify known theories and to think up more falsifiable alternatives.

4) This sort of methodology will prevent the usual dogmatism of the essentialist and the artificialities of the instrumentalist. To the degree that any theory is falsified it will tell us some character which the world does *not* have. To the degree a theory is corroborated by severe tests it tells us what the world *might* be like; hence, as we move to more testable theories for future work we must try to retain whatever we can of this prior insight.[29]

We may now turn to some interesting aspects of the above three views on the character of scientific theories as revealed by recent cosmological theorizing. Our findings will be utilized, in the final section of the paper, to define the basis for the conclusions noted there.

Looking first at essentialism, it appears that in current cosmological constructs this position appears in a weakened form from that of Kepler, who we chose as our early representative. At present essentialism is usually held only with regard to certain fundamental factors in the cosmological theory and not for the theory as a whole. For example, in the steady state model of Bondi and Gold,[30] the perfect cosmological principle is conceived essentialistically although the detail of the model is open to a sizeable variation and change. It will be recalled that this principle, a modern combination of the traditional uniformity and economy principles, assumes that any permissible theory of the nature of the universe must be controlled by the realization that the large-scale description of the universe remains constant indefinitely through space and time.

To show why we interpret Bondi's and Gold's position here to be essentialism, it is necessary to show that they conceive of the perfect cosmological principle as a presently achieved true description of nature. Of course there is a variety of ways a believer in the principle might defend his thesis. He might have taken the principle to be self-evident, but this can hardly be the case logically, since its contradictory is not internally inconsistent, or in fact, since it is argued that the empirical consequences of applying it are what weigh so heavily in its favor. Or, it might be claimed that the principle is simply an extrapolation of what has been so far observed to be the case in large-scale astronomy into regions of future observation. However, changes that have been necessitated by researches since 1948 (when the principle was first enunciated) into just what the observations in fact are that we must extrapolate in future, show that the content of the principle may require yet further revision and that what we have presently is therefore hardly the last word.[31]

Another tack might be to treat the principle as an axiom in some theory, but if this is done it must have deducible consequences. Now it is obvious that the *models* which the steady-state school present do have testable, or at least potentially testable, consequences. But the perfect cosmological principle is not one of the statements involved in the complex making up these models, for they can be constructed without it. It serves rather as a regulative principle in deciding what physical laws and theories the steady-state people will permit in their models, either from the start (as in Bondi and Gold) or after some later point (as in Hoyle).[32] Indeed its advocates use it to define what laws and theories may be given the appellation "scientific". These choices are logically arbitrary (however preferable they may seem, *a priori*, from past results or in comparison to present alternatives) and their value will have to be proven out against competing ideas, equally arbitrary on logical ground. Thus we may test their steady-state models, but some other construct, "unscientific" by their definition, may prove to be preferable. At that point we may look back and decide which regulative principles were not justified in suggesting the restriction of science to certain specified classes of descriptive relation (laws and theories).

Hence, we see that the perfect cosmological principle is really a regulative meta-theoretic concept defining the scope of what is science and what cosmological models are permissible. But the steady-state people illicitly tend to treat what should be merely a proposal as a true and necessary prescription, hence as essentialistic. While dogmatism here is surely undesirable, fairness requires that we point out that treating the perfect cosmological principle as if it *had to be true* has served as an incentive to exploring models based on it and to developing some very suggestive astrophysical ideas. But we must also point out that this essentialistic attitude has had several deleterious consequences. One is that, in arguing that on any other ground than the perfect cosmological principle, astrophysicists must remain agnostic about the universe in its distant reaches and its far past, it has ignored possibilities that avoid such a distasteful consequence offered by competing cosmological principles.[33] Another has been that apologetes for particular antireligious arguments and synthesizers who saw in the steady-state ideas a correspondence with their metaphysical predilections have suffered a sort of mental petrifaction as a result of tying their theses in part or entirely to such a particular cosmological assumption as if it were final.

Instrumentalism, while very common in many areas of contemporary science and particularly physics, is not too common in cosmological theory. But it does appear in the early Einstein, in later discussion on the famous cosmological constant in the field equations, in kinematic relativity (particularly its artificial time scale, in the odd relativities of Eddington and Jordan, in Hoyle's revised field equations, and above all in the purely descriptive side of Dirac and Jordan's work and the untestable aspects of Gödel's, Omer's, and Heckmann's models.

For the sake of those unfamiliar with the Gödel-Heckmann-Omer models in cosmology let us quickly describe them. [34] Gödel's models involve the possibility of an absolute rotation of matter, a model with a general rotation of all galaxies relative to what he calls the "compass of inertia". This model is non-isotropic as a consequence and thus both deviates from the usual field equations of general relativity, with their concommitant inertial ideas, and from the usual isotropic models of cosmic theorizing. The Gödel idea involves only local times defined by the motion of matter in various regions of the model which cannot fit together to give a single time-history for the entire universe. It thus avoids a singularity (a beginning) for the present universe at some past moment.

Omer and Heckmann discuss, on the other hand universes which are more complex than the homogeneous "fluid" models of radiation and matter commonly found in cosmological theory. Omer's model involves a general expansion, but with a velocity differing, at a given time, from place to place. Hence each region has its own beginning in a dense environment expanding toward what is known as a de Sitter state in infinite time. Heckmann postulates the presence of some shear and rotation everywhere in the motion of matter. His models seem, under certain conditions, to permit the evidence of a past time singularity.

There is no doubt that the above ideas suggest important future work in theorizing from novel directions. But we are forced to call them instrumentalistic because at present they are mere mathematical exercises and show little possibility of being tested in the foreseeable future. For they do not attempt to explain the origin of their unusual conditions nor do they give us any idea how to detect the inhomogeneities and anisotropies of the magnitude suggested. Those who look on them with favor, therefore, do so because they provide a means of avoiding a beginning for the entire present universe and in spite of their lack of likely testability. Philosophical or methodological predilections seem to be determinative in giving them serious consideration.

Turning, finally, to Popper's view that theories are to be seen as conjectures used for the purpose of severely testing their assumptions we shall not point out the very numerous applications of this principle by others in cosmology. Let me instead report rapidly some conclusions arrived at by the writer who used Popper's attitude in assessing some cosmological problems. First, and perhaps of most general interest, is the fact that there are indications that the steady-state models may be in trouble as may the traditional Einstein-de Sitter model and the kinematic relativity model of Milne. However, the whole question of the value permitted for the cosmological constant, indeed even whether it exists at all, and of the curvature permitted for various models is still wide open. Secondly, and of more methodological import is the need for denying the well-known pulsating models any serious scientific consideration and the same applies to a lesser degree to the venerable Lemaitre exploding atom thesis. These are simply untestable or involve too many *ad hoc* theses to be credible. Thirdly, the question of continuous and/or initial creation turns out to be both untestable, and thus outside scientific discourse, and also an unsuitable criterion for even philosophical choice among models. Finally, the entire question of the age permitted the universe by most models is quite uncritical for choosing among these.[35]

In the closing section it will be our purpose to point up the kind of controls which seem to operate, though they are of an unscientific sort, on the problem of choice among cosmological theories. It is these metascientific criteria which are influential both in choosing among the three views of theories discussed earlier and upon the detailed application of even Popper's laudable scheme. Of course we can only examine a few of the many influences of this type, but we shall attempt to center our remarks around a unifying thread which one might call religio-metaphysical.

Cosmology is perhaps one of the most interesting theoretical and empirical fields for the purposes of a paper such as this because it reveals the more abstract type of scientific thinker at work and because it is also closely related to matters of philosophical and religious concern. Its only rivals in this regard seem to be certain biological theories and the indeterminancy problems of microphysics. Consequently, such a science is most affected by ideological concerns which can operate upon the scientist and by the predispositions of the scientist himself.

The classic example of the former is the control upon cosmological speculation within Soviet Communism since here the ideology, unlike Naziism with its dominant sociological dogma, is restricted by an imposed metaphysic. Mikulak and others[36] have studied this problem most carefully. Mikulak notes that Engels set the tone of later dogma by espousing an uncreated universe consisting of innumerable worlds in infinite space, existing eternally and continually renewed by extinct stars falling together, heating up, and producing new stars. Codification of the basic aspects of this model was rapid so that theoreticians began to demand that science under dialectical materialism accept the following theses: (1) that there is an infinite space and an eternal universe; (2) that matter and motion are without beginning and are inexhaustible and indestructible; (3) that the universe cannot run down to a heat death; and (4) that one cannot extrapolate physical laws discovered locally or in closed system to the universe as a whole.

Imposition of these axioms was also rapid. By 1937-1941 Soviet philosophers were voicing intense criticism of those who utilized relativistic approaches in cosmology. They rejected what they felt was an implied creationism in these, the fictitious nature of their "curved" space,[37] their finitude, and their assumed "heat death". A report in 1938 went so far as to claim that fascist agents were at the root of attempts to infiltrate Soviet astronomy with such ideas and that astronomers could not remain indifferent to the ideological battle.

Again in 1948 a major conference was held to examine postwar cosmology in the light of the reigning ideology. Milne, Lemaitre, Eddington, and Jeans were criticized for extrapolating special relativity into the entire universe, and an expanding universe was held to be anthropomorphic. In fact a closed, expanding universe was taken to be the major ideological enemy of materialistic science! Mikulak concludes that such ideas have apparently set the tone for Soviet theory up to the date of his writing, since there was an almost complete absence of positive contributions in Russian literature to the concept of an expanding universe. This is still the case. Instead, Soviet cosmology prefers to stress ideologically "safe" problems and research so that, as a result, the literature is largely observational.

As examples of the biases offered by personal predilections in cosmology, we will note only certain dominant religious and metaphysical influences. Religious attitudes first become active in choosing among models already available for the choosing. Milne's choice was predicated on the thesis that God could not create a universe wtih finite and therefore arbitrary mass or with arbitrary laws.[38] Lyttleton and Hoyle both find the possibility of a creator in expanding models to be distasteful.[39] Similar religious criteria are apparent in Lemaitre and in several other Christian writers.[40] Secondly, religious attitudes are a factor in developing one's own model. Kepler exhibits such an influence, as do Leibniz and Newton in earlier astronomy, but Einstein or Milne or Hoyle are fine contemporary examples.[41]

A third role shows up in the varied interpretations of deductions from cosmic constructs. This very common, and probably inescapable, relating of science to one's philosophy has a vast literature.[42] It ranges from attempts to prove the existence of God from cosmological ideas to just as serious attempts to disprove the same idea and from attempts to argue to creation or purpose to opposition to these theses. Finally, religious pre-disposition affects the evaluation of test data itself. One problem here is the introduction, often surreptitiously of teleological terminology in describing empirical data. Terms such as "the plan of the universe", "the world is so constructed", and "the universe apparently purposes to" are rather easy to use but they tend to personify nature or beg the question they seek to answer.[43] The language in which we scientists formulate our conclusions and its images and analogies lead to exponents of varied philosophies assuming that their view is demonstrated or denied.

Another difficulty in the same area arises from arguing too much from one's data. Lecomte du Nouy's *Human Destiny* and Cressy Morrison's *Man Does Not Stand Alone* are classic examples, but cosmology provides many others. The danger lies, not in claiming to prove a theological thesis, for most arguments of this sort claim only a high probability for their conclusions, but in too quickly assuming that one knows all the principles in the area "modelled" and in not yet having sufficient data to ascertain if the model is significant. But there is equally the danger of arguing too little.[44] Because of a strong reaction to the restrictions enforced by historical religions, many scientists consciously or (worse) unconsciously claim an objectivity in their analyses which places value judgments, not out clearly where they can be analyzed, but into the realm of the intuitive, unrecognized, or haphazard. The extensive use of what are really *ad hoc* arguments to preserve cosmological theories in the face of contrary observational data is often based on an unspoken desire to protect a model in the face of the alternative of choosing other models really considered, rightly or wrongly, to have religious overtones of what the theoretician considers an objectionable nature.

We have stressed the role of religion, but similar comments might be made on more general metaphysical attitudes.[45] Questions of whether scientific language is adequate to express ideas on all fields, the demarcation of ontological concepts from hypothetical entities, the differing criteria of judgment in philosophy and science, the precise theoretical framework necessary for discussing scientific concepts, and of how one discovers when experiment will induce a change in an accepted idea so that what was inconceivable becomes "thinkable" all are pertinent here. So are current debates on metaphysical directives on science and the relation of theory construction to prior value judgments.

To this point we have shown both the various pre-theoretic views as to the character of theories together with certain consequences and also certain controls of other types which affect one's interpretation even within these perspectives. It seems apparent that cosmology finds these attitudes toward theory and the conditioning influences of religion and metaphysics operative to a high degree because of its close affinity to matters of rather deep human concern. But, in concluding, we might do well to suggest a few lessons to be learned from all of this.

The first of these is that stultifying biases to science, historically arising from religion and metaphysics, are least serious when operating in a Popperian view of the task of scientific theories. But, while it is less serious, its presence even there must be recognized. If instrumentalism cannot avoid a judgment of what we may loosely call a metaphysical sort even when it claims to be ontologically agnostic or even anti-metaphysical, because these claims are really themselves ideological and because the predictable character of an instrumentalist view of theories has implicit in it the implication of a predictable world of interrelated phenomena, the same kind of thing must affect a view which claims to seek the nature of reality. Can one ever claim only to attempt a description of nature without at the same time really assaying to understand or explain it in some more fundamental way?

This brings up a second point. For those retaining the more common historical attitude toward the Scriptures, as seen in the Judaeo-Christian tradition, the control of scientific theorizing by interpretations placed upon certain passages has long been notorious. It is, for scientists in this tradition, no escape from the tendency to repeat this to move either toward instrumentalism or essentialism. The former dichotomizes one's faith and scientific practice and the latter cannot help but leave one dogmatically affirming some theory apparently agreeing with a specific exegesis of Scripture while remaining stubbornly obscurantistic to alternative theories and their argument. Surely it is far better to treat one's science as conjectural and to bend every effort in the direction of its critical examination, all the time aiming at a knowledge of God's world which one's faith otherwise affirms.

But this necessitates an interplay of hermeneutics and scientific theorizing. Interpretations of Scriptural passages are often frozen into the pattern of past and frequently unsatisfactory, metaphysical theories or scientific ideas. One's theories as to what a passage means must remain sensitive to scientific advance. However, were we to say no more, this would leave us with no other criterion of correct exegesis in some parts of Scripture than that of current scientific theorizing and leave us endlessly subject to the charge of arbitrary *ad hoc* adjustment to preserve the writings we revere in the face of new concepts and hypotheses. Thus, while it would seem that Biblical scholars would do believing scientists, and indeed their own religion, a great service if they didn't usually appear to lag science by a generation or more but rather honestly stated just how broad the possibilities for scientific interpretation usually are in Scripture, this breadth does necessitate placing some exegetical boundaries. For if there are no boundaries, one's view of Scripture as authoritative is left appearing to be purely the product of faith, since no portions of it can be potentially falsifiable in the light of experience. To attract the critical modern mind, the Judaeo-Christian teachings must be open to possible disconfirmation by whatever is suitable evidence.

At present, as we remarked earlier, cosmology cannot do more than say that the ideas of creation and of an age for the universe are meaningful in different ways in different models. But they will never be directly testable as a logical analysis will show. Only as we falsify the models or otherwise reject them as poor scientifically, can we falsify what they entail, and this might include their ideas of origin and age. As yet this is frequently an open question awaiting future work. Also, it seems that hermeneutical principles permit a broad spectrum of cosmological possibilities. Consequently, the falsification or *corroboration* of Scripture by cosmology appears quite dubious in the foreseeable future. Other sorts of scientific studies are far more pertinent to that task.

Thirdly, and lastly, the relationship of theism itself to the Judaeo-Christian faith must be mentioned. The type of God taught in the Bible is one who need not have created any particular type of universe, and whose laws in any universe He did create would be solely the product of His nature and not otherwise determined. Consequently, whatever occurs in the universe, or even the non-existence of any universe, would of necessity bear witness to such a God. Of course, were there no world in which God might reveal Himself, there would be no knowledge of this fact by human beings; but whatever kind of universe seems best corroborated in science can never be used to falsify the Judaeo-Christian God.[46] Hence, while it is possible that we might falsify the Judaeo-Christian faith, and the Scriptures in which it is rooted, we cannot, oddly enough, falsify the existence of the God which that faith and those Scriptures logically presuppose.

Yet, in remarking on controlling principles in science, such as the cosmological principles or even Popper's own suggestion for how to look at theories, we have noted that, under certain conditions, they can be falsified by failure to aid in the derivation of usable scientific consequences. What then, is there about the nature of the Judaeo-Christian God that makes this different?

May we suggest that the difference lies in the fact that the faith in or denial of such a God is more primary (indeed to the point of being an ultimate commitment) than any Judaeo-Christian belief? For you see if I argue only the theory that "If God exists, then Judaeo-Christianity will be the case" and I find the consequent false, I would falsify my theory only if the antecedent were true. And if I argue only the theory that "If Judaeo-Christianity is the case then God exists" and I find the former false my theory will be true regardless of the truth or falsity of the latter. Hence, only if I claim on faith the truth of the biconditional thesis "that if God exists, then Judaeo-Christianity is the case and if Judaeo-Christianity is the case, then God exists" would the falsification of the religion I hold involve the falsity of the existence of the God I claim. I may always avoid this by arguing that this strong faith was erroneous, in which case the biconditional would still leave the truth of the existence of such a God as I claim possible. It is the kind of faith we have which is the determining factor here.

REFERENCES

1. Since then, the division he makes has been elaborated in his *Open Society and Its Enemies* (London: Routledge & Kegan Paul, 1957) and in various articles now compiled in his *Conjectures and Refutations* (London: Routledge & Kegan Paul, 1963). A recent discussion of Popper's views may be found in Mario Bunge (ed.), *The Critical Approach to Science and Philosophy*, Free Press, Glencoe, 1964.

2. K. R. Popper, *CAR*, p. 105. These ideas reveal two facets of Popper's use of the term "essence". The second argues that we can never be sure that whiteness is always characteristic of being a swan while the third implies that an *a priori* belief in anything as being necessary uniquely to swan-ness entails the belief in ultimate explanation and the premature cessation of questioning. Compare his *LSD*, pp. 430-341.

3. K. R. Popper, *CAR*, p. 107. See also his *LSD*, p. 252.

4. K. R. Popper, *LSD*, pp. 144-145.

5. *Ibid.*, p. 373. See also his "A Note on Berkeley as a Precursor to Mach," *CAR*, pp. 166-174 for a discussion of this in practice.

6. K. R. Popper, *CAR*, p. 111.

7. *Ibid.*, p. 113.

8. K. R. Popper, *CAR*, p. 114.

9. *Ibid.*, p. 115.

10. *Loc. cit.*

11. *Loc. cit.*

12. *Loc. cit.*

13. Popper thus believes in a world independent of theories, but claims that we can be certain only about characteristics it does *not* have and only reasonably confident in the correctness of descriptions arising from theories that have withstood severe testing. Where such theories overlap in their "realm of discourse" we presume that we are likely describing different facets or layers of complexity in reality.

14. K. R. Popper, *CAR*, p. 117.

15. See Derek Price, "Contra-Copernicus" in M. Clagett (ed.). *Critical Problems in the History of Science* (Madison: Univ. of Wisconsin Press, 1959) and Ralph Blake *et. al.* (eds.) *Theories of Scientific Method* (Seattle: Univ. of Washington Press, 1960), pp. 38-43.

16. See Kepler's *Epitome Astronomiea Copernicanae.*

17. Compare Edwin A. Burtt, *The Metaphysical Foundations of Modern Science* (New York: Humanities Press, 1951), p. 48.

18. Compare Max Jammer, *Concepts of Force* (Cambridge: Harvard University Press, 1957), pp. 203-208 and K. R. Popper, *CAR*, pp. 107-109, 166-174.

19. K. R. Popper, *CAR*, p. 171.

20. M. Jammer, *CF*, p. 205.

21. K. R. Popper, *CAR*, p. 173. Sources in Berkeley's writings are conveniently collated in this chapter.

22. Quoted in Philipp Frank, "Einstein, Mach, and Logical Positivism" in Edward Madden (ed.), *The Structure of Scientific Thought* (London: Routledge & Kegan Paul, 1960), p. 84.

23. Wm. K. Clifford, *The Common Sense of the Exact Sciences* (New York: Dover Publications, 1955) and K. Pearson, *The Grammar of Science* (London: Everyman's Library, 1937).

24. W. Clifford, *CSES*, p. LXV in Pearson's preface.

25. See his *Science and Hypothesis, trans. W.J.G.* (New York: Dover Publications, 1952), his "Principles of Mathematical Physics" reprinted in the *Scientific Monthly*, 82 (1956), 165-175, and Ernst Nagel, The *Structure of Science* (New York: Harcourt, Brace & World, 1961), pp. 260-267.

26. Compare Mary Hesse, *Forces and Fields* (London: Nelson, 1961), pp. 147-148.

27. Compare Alexandre Koyré, *From the Closed World to the Infinite Universe* (Baltimore: Johns Hopkins University, 1957), p. 234.

28. See E. W. Strong, "Hypotheses Non Fingo" in H. M. Evans (ed.), *Men and Moments in the History of Science* (Seattle: Univ. of Washington, 1959), p. 163. Compare Ralph Blake, "Isaac Newton and the Hypothetico-Deductive Method," in Ralph M. Blake *et al* (eds.), *TSM*, pp. 119-143.

29. This listing roughly generalizes Popper's ideas and those of the writer in his "Popper's Views of Theory Formation Compared With the Development of Post-Relativistic Cosmological Models", Boston University Graduate School Ph.D. dissertation. Much of the rest of this paper is distilled from small portions of the latter.

30. H. Bondi, "Review of Cosmology", *Mon. Not. Roy. Astron. Soc.*, 108 (1948), 104-120; H. Bondi & T. Gold, "The Steady-State Theory of the Expanding Universe," *Mon. Not. Roy. Astron. Soc.*, 108 (1948), 252-270; H. Bondi, *Cosmology* (Cambridge: Cambridge Univ. Press, 1952); and H. Bondi *et al*, *Rival Theories of Cosmology* (London: Oxford University Press, 1960).

31. See editorial, London *Times Science Review*, (Summer, 1961), 1-2; the report in *Discovery*, (March, 1961), 91-92; G. C. McVittie, *Fact and Theory in Cosmology* (London: Eyre & Spottiswoode, 1961), pp. 155-166; and the extensive analysis in the author's *PVTF*.

32. Fred Hoyle, "A New Model for the Expanding Universe," *Mon. Not. Roy. Astron. Soc.*, 108 (1948), 372-382; "On the Cosmological Problem," *Mon. Not. Roy. Astron. Soc.*, 109 (1949), 365-371; "Stellar Evolution and the Expanding Universe," *Nature*, 163 (1949), 196-198; "A Covariant Formulation of the Law of the Creation of Matter," *Mon. Not. Roy. Astron. Soc.*, 120, (1960), 256-262; and his *Nature of the Universe* (Oxford: Blackwell, 1960).

33. See T. H. Leith, *PVTF*, pp. 297-302, 313-339, 536-563.

34. Kurt Gödel "An Example of a New Type of Cosmological Solution of Einstein's Field Equations of Gravitation," *Rev. Mod. Physics* 21 (1949), 477 ff. . See also his paper in P. A. Schilpp (ed.), *Albert Einstein*, (New York: Harper & Bros., 1959), *II*, pp. 557-562. Also see discussion in J. L. Synge, *Relativity: The General Theory* (Amsterdam: North Holland, 1960), pp. 331-8 and G. J. Whitrow, *The Natural Philosophy of Time*, (London: Nelson, 1961), pp. 257-261. O. Heckmann's lectures in London are reported in *The Observatory*, 79 (1959), 130-131.

35. See my *PVTF*, pp. 313-339, 346-351, 545-586 for a detailed discussion on these points.

36. Maxim Mikulak, "Soviet Cosmology and Communist Ideology," *Sci. Mon.*, 81 (1955), 167-172; his "Soviet Philosophic-Cosmological Thought," *Phil. of Sci.*, 25 (1958), 35-50; David Joravsky, *Soviet Marxism and Natural Science, 1917-1932* (New York: Columbia University Press, 1961); and a continuing definitive source of analysis, *Studies in Soviet Thought*, a quarterly journal published by D. Reidel Pub. Co., Dordrecht, Holland.

37. However, this could be reinterpreted, for in 1957 Kolman argued that Lobachevsky's geometry was based upon a materialist view of the world whereby spatial forms and laws were established from the movement of material bodies existing independent of consciousness. See report in *Nature*, 179 (1957), 1176.

38. E. A. Milne, *Modern Cosmology and the Christian Idea of God* (Oxford: Clarendon Press, 1952).

39. R. Lyttleton, *The Modern Universe* (London: Hodder & Stoughton, 1956), pp. 205-206; and F. Hoyle in R. Thruelsen *et al*, *Adventures of the Mind* (New York: Vantage Books, 1960), pp. 180-181 and his *NU*, p. 100.

40. G. Lemaitre in R. Stoops (ed.), *La structure et l'evolution de l'univers* (Solvay Congress in Bruxells, 1958), pp. 5,7; R. E. D. Clark, *The Universe: Plan or Accident?* (London: Paternoster, 1961); and J. C. Monsma (ed.), *The Evidence of God in an Expanding Universe* (New York: G. P. Putnam's Sons, 1958).

41. Gerald Holton, "Johannes Kepler: A Case Study on the Interaction of Science, Metaphysics and Theology," *The Philosophical Forum*, 14 (1956), 21-33; H. G. Alexander (ed.), *The Leibniz-Clarke Correspondence* (New York: Philosophical Library, 1956); F. Hoyle in M. Stockwood (ed.) *Religion and the Scientists* (London: SCM Press, 1959), esp. p. 60; and Hoyle's Einsteinian Spinozism in *Man and Materialism* (London: George Allen & Unwin, 1957), pp. 72, 157.

42. See bibliography in my *PVTF*, pp. 501-502.

43. Compare A. J. Bernatowicz, "Teleology in Science Teaching," *Science*, 128 (1958), 1402-1405.

44. See Richard Rudner in P. Frank, *VST*, pp. 24-28.

45. See my *PVTF*, pp. 505-513.

46. Of course we are assuming the most consistent and best corroborated thesis as to what the Bible teaches regarding God. Alternatives seem to either argue to the character of God on other standards which must, by the nature of the case, eliminate this view of God to start with or to a thesis regarding revelation which flies in the face of much available evidence.

PROBABILITY AND GOD'S PROVIDENCE

CHARLES HATFIELD*

The models and images we (choose to) form of both the world and God are our most characteristic possessions. The models of the world continually shift, and they should, lest acceptance of an inadequate model discourage search for a better. The probabilistic nature of much of our knowledge of the world gives hope for a fresher understanding of the use God makes of it in his providential control over the universe, but the basic tension remains in trying to resolve the personal providence of God with the impersonal world which is the context of our life.

IS PROVIDENCE OUTMODED?

It is a commonplace observation that the enterprise known as science has much to its credit. When newspapers print whole pages on such technical subjects as modern mathematics and biochemistry, even if in semi-popular language, then it is safe to say that science is an integral part of the spirit of our age. More than one person of scientific bent, however, has had sobering thoughts about the role of science in human life, for the science of a given age invariably has a strong effect upon personal creeds. Preoccupation with science and its methodology means a focussing of attention upon knowledge and how we get it. Burtt thinks that "the central place of epistemology in modern philosophy is no accident; it is a most natural corollary of something still more pervasive and significant, a conception of man himself, and especially of his relation to the world around him . . . In the last analysis it is the ultimate picture which an age forms of the nature of its world that is its most fundamental possession." I believe that most Christians, while not wishing to detract from the importance of knowing the world about us, would feel constrained to amend this evaluation as follows: "it is the ultimate picture which an age forms of the nature of *God* that is its most fundamental possession." It is certain, of course, that the two pictures are *not independent* of one another.

I would like to illustrate the importance of science in determining the mental picture we have of the world by citing two personal testimonies. "Looking back I have seen clearly that at different periods of my life my mind became incarcerated within the narrow confines of some doctrine such as the scientific materialism of the last century, the idea advanced by Darwin that evolution occurred through the action of blind mechanical forces, or the equally pessimistic systems of psychology sponsored by Pavlov and Freud. And what is particularly apparent to me now that I have escaped from these mental prisons is that while confined in them I was completely satisfied with my surroundings. I firmly believed that the universe was a meaningless interplay of matter and forces, that life arose on this planet as an accident . . . I was equally ready to accept the view that thought was only a reflex action and that religion was 'humanity's great obsessional neurosis'. While under the spell of these ideas I looked upon all forms of human experience other than those which had been utilized by the sciences as being unproductive of knowledge. For me, the artist's preoccupation with beauty, the philosopher's search for fundamental principles and the religious man's quest of the divine represented nothing but man's innate desire to escape from a forbidding reality into a realm of fantasies and dreams. It is only now that I realize how often in the past I mistook tentative theories for absolute truths, and temporary resting-places for thought for permanent residences. It was not the inventors of these theories who were to blame for what had happened to me, but my own inability to understand the true function of science and the nature of the conclusions at which it arrives." (Kenneth Walker, *Meaning and Purpose, p. 7f)*

If our own memories do not contain some similar experiences, then it is probably only with a determined effort that we can capture some of the pathos of such conversion.

The second testimony is that of a physicist who became Executive Director of the Oak Ridge Institute of Nuclear Studies in 1947 and who was ordained Priest in the Episcopal Church in 1954: Dr. Wm. G. Pollard. Again it is the problem of just how God *could* work his purposes in the world that science describes in such detail. Dr. Pollard writes: "In my own experience of coming into the Christian ministry from an already established career as a physicist, this question has been the most crucial of all. To me it seems a much more difficult and decisive question than that of the existence of God. I found extraordinary difficulty, when I thought about events in scientific terms, in imagining any kind of loophole through which God could influence them . . . I could not see any point in the world as it is known in physics at which the hand of God could be thrust in and providence, as it is known Biblically, actually exercised." And this, despite the fact that the Biblical concepts had become just as real and solidly based as the scientific terms to which he had become long accustomed. "There was no escaping", he writes, "the sense I had of the reality of God's grace and providence, of His judgment and redeeming power in life and his-

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tory which lies at the core of the Biblical understanding. This reality could no more be denied than the reality of the world of electrons, atoms, and physical law which I knew in physics. Yet when I tried to put these two worlds together their apparent incompatibility baffled me . . . I had come to know two realities, each all = compassing and of universal scope, which were so firmly and broadly rooted in my own experience that it was unthinkable to give up or deny either of them." (Wm. G. Pollard, *Chance and Providence,* p.8) Our own experience of this issue may be lacking in such dramatic intensity, but for all that, the bafflement is to many not less real.

It is not only the scientist or the student of science who is confronted with the issue. The farmer who regards the rain as providentially sent to save his crops finds his simple belief challenged by the meteorological explanation of the falling of rain in terms of the physics of the movement of masses of air and water. The farmer's faith is thus in danger of being corroded by the science of his fellow man. The Good God has become for many "The Good Clouds" or "The Good Earth" which in turn becomes "The Good Natural Laws". It seems fair to suggest, in the light of the foregoing that part of the price we have paid for the science of the last 400 years has been the passing away of belief in the providence of God. In a survey of the history and destiny of man, Erich Frank says that "since the Renaissance the peoples of the Occident have taken an increasingly hostile stand against the religious interpretation of history, according to which mankind is guided by divine Providence. Modern man sees his destiny in this world; he has decided to take his fate into his own hands." (*Philosophical Understanding and Religious Truth,* p. 117)

GOD AS PROVIDENCE

I suppose that to those who know only its outer garment Christianity seems desperately intricate, if not downright inconsistent. In the main, however, it affirms that the solution of the world (sic) is extremely simple and astonishingly bold. Right in the center of the stage with all the lights of history and revelation focussed upon it and so glaring that we can hardly miss it, is the personal God: God the provider, guiding the vast galaxies as well as our own little planet with such a watchful care that nothing gets lost—not even a little chick-a-dee; and God the revealer who maintains constant and unremitting communication with every man, and that not in terms of his own pristine splendor, but rather on the level of and through the ways of human intelligence. Teilhard reminds us that in both St. Paul and in St. John we read that "to create, to fulfil, and to purify the world is, for God, to unify it by uniting it organically with himself. How does he unify it? By partially immersing himself in things . . . and then, from this point of vantage in the heart of matter, assuming the control and leadership." (*The Phenomenon of Man,* pp. 293f) But if we speak of God's "partial immersing of himself in things" it must be with care. In any case, we must avoid identifying the world with God as if they were the two sides of an equation. This were a confusion, than which none is greater, for it would make God the author and active agent for evil, relieving man of moral responsibility and thereby inducing false comfort. God is *not* the same as His world, but it is *his* world: his by creation and his because he constantly upholds it.

Christian faith is just as opposed, on the other hand, to deistic separation as it is to a pantheistic confusion of God and the world. If deism allows creation of the world by God, it also denies his continued access to it. It pictures God as walking away from what he had made, leaving it to fend for itself. The traditional image to describe succinctly this view is that of God as a clock-maker. It should not be supposed that deism and pantheism are completely discredited views and therefore of no concern. While Christian faith has little in common with either, they are both nevertheless positions which are constant temptations to men the world over. The image of the God of Scripture is more nearly provided by the modern science of cybernetics: that of the helmsman. Calvin suggests in a passage that still bears citation: "What is called providence describes God not as idly beholding from heaven the transactions which happen in the world, but as holding the helm of the universe, and regulating all events. Thus it belongs no less to his hands than to his eyes. When Abraham said to his son, 'God will provide' he intended not only to assert his prescience of a future event, but to leave the care of a thing unknown to the will of him who frequently puts an end to circumstances of perplexity and confusion. Whence it follows, that providence consists in action; for it is ignorant trifling to talk of mere prescience." (*Institutes,* Bk. I, Ch. XVI, p. 222) Again Calvin wisely observes, "The providence of God governs all things in such a manner as to operate sometimes by the intervention of means, sometimes without means, and sometimes in opposition to all means." (Calvin, ICR, Bk. I, Ch. XVII, p. 232)

In many and varied areas the Bible details to us the extent of God's providence: it extends over

a. the universe at large: Ps. 103:19; Eph. 1:11
b. the physical world: Ps. 104:14; Mt. 5:45
c. brute creation: Ps. 104:21, 28; Mt. 6:26
d. the affairs of nations: Job 12:23; Acts 17:6
e. man's birth and lot in life: Ps. 139:16; Gal. 1:15, 16
f. the seemingly accidental or insignificant things: Prov. 16:33; Mt. 10:30
g. the righteous: Ps. 4:8; 121:3; Rom. 8:28
h. his people in supplying their needs: Deut. 8:3; Phil. 4:19
i. those that pray, in providing answers: Ps. 65:2; Mt. 7:7
j. the wicked by punishment: Ps. 7:12, 13; 11:6

It is sometimes helpful to see in these varied actions of God three distinct elements: preservation, concurrence, and government. Let us look briefly at each of these.

1. *Preservation*—this encompasses both creation and God's continuous activity in sustaining and renewing the world. There is no evidence that God made anything to "work" by itself. More basic in theology than any datum of history, further back than sin, even beyond creation, is the absoluteness of God over his creation. He always gives himself top priority. This is not egotism, but honesty. He is but being true to himself as well as to us. The God of the prophets relays to us his word, "I am the first" (Isa. 41:4; 44:6; 48:12). The words foreknowledge, predestination, preparation, and pre-existence all bear upon the way in which God through and through, knew before it happened, actively prepared for and ante-dated all that he actually performed in the physical and psychical worlds. Nothing occurs without God willing it and willing it to happen beforehand. He called the prophet Jeremiah before he was born (Jer. 1:15) and the apostle Paul likewise was set apart before he was born (Gal. 1:15). Regarding the latter Warfield observes that "representations are sometimes made as if, when God wished to produce sacred books which would incorporate His will—a series of letters like those of Paul, for example—He was reduced to the necessity of going down to earth and painfully scrutinizing the men He found there, seeking anxiously for the one who, on the whole, promised best for His purpose; and then violently forcing the material He wished expressed through him, against his natural bent, and with as little loss from his recalcitrant characteristics as possible. Of course, nothing of the sort took place. If God wished to give His people a series of letters like Paul's, He prepared a Paul to write them, and the Paul He brought to the task was a Paul who spontaneously would write just such letters." *(The Inspiration and Authority of the Bible,* p. 155)

2. *Concurrence*—God concurs and cooperates in the use made of energies and capacities given to man, even though the use may be evil. He co-operates with men, but the moral responsibility for a deed is lodged with the doer. Even sinful acts are under his control. Sometimes he restrains men from evil deeds (e.g., *via* the dream of King Abimelech he warned against taking Sarah as a wife) but often he permits them to wallow for a season in their sin. His control is so complete that he can overrule the crime of selling a brother into slavery, making of the victim an instrument for their undeserved deliverance from famine. God does nothing by halves. A will to act is only half the act. God supplies continuously the power and energy to carry out what man projects.

3. *Government*—God orders the affairs and actions of his creatures not according to some external plan, but according to his own character and purposes, for the glory of his name and the welfare of man. He is not limited in means. He uses both ordinary and extraordinary. He allows *wide*, but *not unlimited* liberties to men. He permits one, hinders another, here directing, there determining. Here the essence of the word "providence" comes into focus. It is so named from *providere*, to see beforehand. All Scripture is but a brilliant mirror from which, in all directions, shines the watchful eye of God's loving care for his whole creation. If there is one aspect of providence which seems in need of further elucidation, it is the goal and purpose of God in it all. "Yahweh's intervention in the world," writes Edmund Jacob, "and his will to leave nothing outside his sovereignty give us the authority to speak of a biblical notion of providence which is exercised at the same time in creation and in history. The creation is maintained, not by virtue of autonomous laws, but by Yahweh's free will; its duration is eternal only in so far as Yahweh is pleased to preserve it. On the whole the biblical view is not directed towards the preservation of the world, but towards its transformation. The teaching of the prophets concerning creation is dominated by the hope of a new heaven and a new earth, so that they see in the present world, before all else, the signs of catastrophe, foreshadowing the great change." *(Theology of The Old Testament,* pp. 226ff)

Indeed, providence, when carried completely through to its fulfillment, becomes indistinguishable from redemption. Kierkegaard observes that "A *providence* is no easier to understand (to grasp) than *the redemption:* both can only be believed. The idea of a providence is that God is concerned about the individual and for what is most individual in him . . . The Redemption is the *continued providence* that God will care for the individual and for what is most individual in him in spite of the fact that he has lost everything." *(Journals,* No. 602)

The essence of providence can be put this way: God made the world all by himself, he makes it work continuously and cooperatively, and he makes it work his own gracious purpose which includes us. He made the world, made it to work, and made it to work toward a goal. Paul's quotation from the poet Aratus is close to this summary: "In him we live and move and have our being." (Acts 17:28a)

WHAT IS PROBABILITY?

Probability is a measure, or more accurately, a theory of measuring. It is a mathematical concept and likewise a concept that has to do with actual occurrences. As in the case of physical concepts we have for simplicity two modes of defining probability: one due to Laplace and called *a priori* or measure-theoretical probability; the other is due to Ellis, Cournot, and others, but is usually connected with the name of von Mises and called *a posteriori*, or more adequately the relative frequency definition. Margenau reminds us that "living science . . . owes its vitality to the fruitful interplay of two different modes of definition, one closely related to theory and law, the other to the rules of correspondence (between concept and data)." *(The Nature of Physical Reality,* p. 221) Time, for example, is defined operationally (Bridgman's term) by reference to clocks. This Margenau calls *epistemic* definition. Time is also defined as the independent variable in the equations of mechanics. The first of these is a connection or correspondence with observables. The second is in the construct field, linking together other constructs. We note, in passing, that in pure mathematics constitutive definitions play a greater role than in the applied sciences, because mathematics is more concerned to generate *systems,* for which direct epistemic definitions are not usually available.

The necessity of two kinds of definitions is inherent in science as it seeks to describe the world, for "without epistemic definitions", continues Margenau, "science degenerates to speculation; in the absence of constitutive definitions it becomes a sterile record of observational facts and its formulas take on the character of medical formulas. Physical laws must be regarded as mediators between the two types of definition for specific quantities." (Ibid., p. 243) "Instead of being pleased at Providence for equipping probability with both certificates it needs to enter science, the modern logician sometimes quarrels over which of the two is 'right'. Not seeing their connection through science, he mistakenly believes the two definitions to contradict each other." (Ibid., p. 253)

Laplace's definition takes the probability of an event to be the number of favorable cases divided by the total number of so-called "equipossible" cases. E.g., the probability of throwing a "4" with a pair of dice is 3/36 since there are three ways of forming a "4" (3 + 1, 2 + 2, 1 + 3) and there are 6 x 6 = 36 possibilities for combining the numbers on the dice without repetition. The probability of throwing other than a "4", is the complement of 3/36 with respect to 1, that is, 33/36. Laplace's formula is exact and involves no provision for assigning errors. This constitutive definition has difficulties. Right away, the case of an infinite number of possibilities puts us in trouble. The definition suggests no reasons for the "2" and the "5" to be equiprobable events in the case of throwing a single die. That the actual frequencies (in a real trial run) of "2" and "5" are very close to 1/6 for a large sample, is just as remarkable, but no more mysterious than that the formulas for falling bodies fit observed facts. The meaning of equipossibles is never clear and never prescribed by the Laplacian concept.

The frequency definition of probability has penetrated deeply into science. It begins with the simple observation that the frequency of an event sometimes shows a marked tendency to become more or less constant for large values of the number of trials. Thus the frequency of heads in 10,000 tosses of a coin would be very near ½. The "constant" in the definition is taken to be the limit of the sequence of numbers made up of the frequencies recorded after each throw or trial of the given event. This practical or epistemic definition is used in the determination of a variety of "probabilities", and now it will be seen that the word is ambiguous unless we can somehow reconcile them. Recent discussions of the meaning of probability by philosophers show little evidence of agreement. The divergence in views persists. It is an old old story of voluminous rhetoric and partisan tenacity. As with Job's comforters, there is a "darkening of counsel with words". Let it be clearly understood, however, that there is no difficulty in getting good agreement between the two values, even striking agreement. The frequency definition is used to find the probability that a molecule has a given velocity by *measuring* the density of molecules on a rotating disk; the probability for various energies of an atom at a certain temperature is obtained by measuring the distribution of spectral intensities which it emits. Life expectancy is found by a careful counting process.

It is clear that the frequency concept has its limitations: it is rationally barren. It is "hooked up" to data, it is true, but not to formulas that enable us to predict compound probabilities. It is simply too clumsy to refer all probabilities to inductive generalization, which is what the frequency concept amounts to. "The vital link", suggests Josephine Mehlberg, "between the mathematical theory of probability and the unusually valuable applications of this theory to observational data is unaccounted for both in the measure-theoretical and the limiting-frequency approach . . . probability as explored by the mathematician is a theoretical construct functioning in the empirical sciences as other theoretical constructs do." (*Current Issues in The Philosophy of Science,* AAAS, 1959, p. 295)

The typical investigator who employs probability studies a large number of repeated instances of behavior under similar circumstances and then expresses his findings in terms of certain norms; the probability of deviation from the norm in a future instance is then made on the basis of already developed theory. Such methods are used to determine the fish population of a lake, vocational fitness, population trends, crime incidence expectation; they are used to study industrial management, in psychological testing, and to study accident frequency, to name but a few applications. The last-named is made familiar to us through the grim holiday predictions of the National Safety Council. There is no stronger argument, its users feel, for the validity of the assumptions made in such statistical probabilities than the obvious and striking success of the techniques to which it leads. Here is a good example of the fact that people believe in science because "it works".

In the summer of 1960 a Minneapolis advertising agency sought the help of mathematicians in estimating the possible liability of a certain car manufacturer who was to provide the cars to be used as prizes in a cereal-sponsored contest involving a sweepstakes drawing. They sought to determine, at the "95 percent confidence level," how many cars they would give away, assuming a certain number of persons entered the contest by sending in cereal box tops. Without knowing any probability theory themselves the agency was willing to take our figures for the probable number of cars to be given away.

SCIENTIFIC DETERMINISM

A thoroughgoing causality or determinism seems to be inescapably characteristic of science. In physics, chemistry, astronomy, biology, physiology, and in a host of related disciplines it has seemed essential to regard observed events as dependent upon what are called natural laws. These natural laws, in a sense, *required* the particular outcome that was in fact observed. By determinism we mean here the common-sense notion that *all events are caused.* There are, broadly speaking, two recognizably distinct strains of determinism. Following the psychologist Paul Meehl, we distinguish between methodological determinism which is simply a working rule or practical orientation, and metaphysical determinism which is the radical thesis that is by nature an absolute ontological presupposition. Methodological determinism is the attitude which seeks (and even hopes for) laws in a given domain. If we discover laws that hold strictly, good enough; if they are at best probabilistic, we'll settle for even that, for they may prove useful. This kind of determinism is not merely a pet prejudice of atheistic scientists, but rather the expression of their hope or even faith that lawfulness *will* be found. It is an implicit working assumption to which we all hold pretty much as a matter of course. It is difficult to see how any rational person could find fault with such a policy of investigation. It is close to Hans Reichenbach's view of induction "he who wants to catch fish, while he has no assurance of success, must at least cast his net."

But to say that absolutely *all* events, including human psychological events, merely instantialize universal laws, and to hold this as an absolute which no empirical evidence can be permitted to gainsay is to assert a *personal creed,* and as such goes far beyond a working rule. It is a vast speculative generalization, which, while it represents an extrapolation from a large and impressive body of scientific knowledge, is nevertheless an *idealization,* and however suggestive it may be, the facts simply do not suffice to coerce all rational men to accept it. Scientific naturalism, which is another name for this view, is regarded by Meehl as a powerful foe to the faith. "Scientific naturalism", he writes, "(philosophically underpinned by logical empiricism) often in an unquestioned and even unstated form is today the strongest intellectual enemy of the church and among educated people gives the most powerful no to the church's proclamation." (Paul Meehl, *et al, What Then Is Man?,* p. 173)

THE STATISTICAL NATURE OF SCIENTIFIC KNOWLEDGE

We turn now to chemistry to illustrate the fact that much of our scientific knowledge is statistical in nature. I am indebted to Pollard for the data on radioactive iodine, a type widely used today in the treatment of certain thyroid disorders. Neither touch, taste, nor smell would tip you off as to the difference between this and ordinary medicinal tincture of iodine. But the nucleus of its atom has four more neutrons than an atom of ordinary iodine. The atoms of radioiodine can exist in alternative physical states in which one of the neutrons has changed into a proton by the process of radioactivity, and when this occurs, its nucleus changes into that of the gas xenon. Now every such atom has these two alternative states at any given time, but no known forces, either external or internal can eliminate the element of randomness from this picture. All we can state is the probability that a given atom of it will explode and change to xenon during a given period of time. This probability finds convenient expression in terms of *half-life.* The half-life of a radioactive substance is the time required for half of it to decay into some other. The half-life of radioiodine is eight days. Thus, if we should start with 16,000,000 atoms of it today, in eight days we should have only 8 million and in 16 days 4 million, etc., so that by six months we should have no more atoms than the fingers on each hand. We never know when a given atom is going to change, but we know empirically that a certain number will change in a given interval of time. Half-lives of radioactive substances vary from a very small fraction of a second up to 5 billion years.

We seem to be faced with a basic characteristic of atomic and molecular phenomena for which the theory of probability is indispensable. "The basic characteristic," relates Pollard, "which forced the transformation of classical mechanics into quantum mechanics was formulated by the German physicist Werner Heisenberg in his now famous *principle of indeterminacy* . . . For very small objects such as electrons of an atom, this indeterminacy becomes decisive and makes it impossible to specify both their position and their velocity simultaneously with precision. If either one is precisely known, then the other will be wholly indeterminate." Roughly put, the numerical product of the range of error in measuring the velocity of a particle with the range of error in measuring the position of the same particle is approximately (Planck's) constant. Here we must not be led astray. It is a *theory,* of course, and some very respectable physicists remain unconvinced (DeBroglie, Bohm, Einstein, and Planck), despite the championing efforts of Niels Bohr, Max Born, and Heisenberg himself. It has been one of the hottest debates in physics. More than once in the history of science a new theory started out as statistical, only to be replaced by a precise theory. The dispute is over whether the same will happen to quantum theory. If we assume that a precise law must exist, then the question becomes: "is the precise law statable in a human language?" Those who oppose the quantum theory allow that it has made a significant contribution to our knowledge of the world. They believe, nevertheless, that the theory will be superceded by a precise overall theory of microphysics. This is an issue not settled by majority vote or by prestigious proponents. It awaits the further development of science.

ON THE NOTION OF CAUSALITY

It is worth observing, suggests N. R. Hanson, that the concept of cause is not often used in actual practice in physics. The terms "cause" and "causal chain" have rarely occurred in the texts, treatises, and tracts of physics for the past 300 years. Be that as it may, one continues to suspect that the search for cause-effect relationships has been going on under other names.

A mere glance at the literature on causality shows that it is often associated wtih some notion of inherent necessity. Invariable succession is all some are able to make out of their observations. Max Planck, for example, understands it as a *regular connection* between cause and effect. He is quick to ask the inevitable question: "What constitutes this specific type of connection?" "Is there any infallible sign to indicate that a happening in nature is causally determined by another?" His approach to an answer to these questions is along the avenue of prediction. (Illustration: the farmer who wanted to demonstrate dramatically the virtues of fertilizer to the skeptical peasants spread his product so that the clover under its influence would spell out the letters, "THIS STRIP WAS FERTILIZED WITH CALCIUM SULFATE".) Planck defines an occurrence to be causally determined if it can be *predicted with certainty.* By the side of this definition or principle is another, which he calls a "firmly established fact": "it is never possible to predict a physical occurrence with unlimited precision." But even the invariable succession meaning of causality is useless, since we don't know of *any* particular succession that will always be invariable. Moreover, we need to treat the successions which have *not* been invariable. It is abundantly evident from the works of both philosophers and scientists that there is astonishingly small agreement on the meanings of some of the most commonly used terms.

For Margenau causality is simply the invariability of physical laws with time. "Causality holds if the laws of nature (differential equations) governing closed systems do not contain the time variable in explicit form." *(Nature of Physical Reality,* p. 405.) Whether we conceive of causality in terms of equations, or in terms of psychological certainty, or in some other terms, the Christian has long felt it is a helpful distinction to make between God as the primary cause of all in the providential sense and the secondary causes which in the physical sciences, at any rate, are completely impersonal. Mascall relates the secondary cause to probability, while reserving the absolute character of the primary cause. "To the secondary cause it belongs merely to determine that there is a certain probability of the event occurring, and even this, does only as a result of its conservation by the primary cause which is God. To the primary cause alone it belongs to determine whether the event shall occur, and when and where; the secondary causes have no part or lot in this. Thus the relative autonomy which God has given to his creatures does not in the least diminish his sovereignty; whether a particular event happens or not depends in the last resort upon his choice and upon it alone." *(Christian Theology and Natural Science,* p. 201)

Wittgenstein's treatment of cause has a radicality, if not an honesty, that blows in some needed fresh air. "Laws", he reminds us, "like the law of causation, etc., treat of the network and not of what the network describes." It's all quite legitimate to make a model of the world in our attempt to understand it. But then we must be sure to draw conclusions about the model rather than about the world. Here is where the confusion is sometimes the most subtle. The same care is needed in theology, for here too we are wont to exalt one attribute of God out of proportion and the model becomes an idol.

And let us be thoroughly honest about this matter of causality and necessity. Is it not true, as Wittgenstein asserts, that "a necessity for one thing to happen because another has happened does not exist. There is only *logical* necessity. At the basis of the whole modern view of the world lies the illusion that the so-called laws of nature are the explanations of natural phenomena." (See Gen. 8:22) Natural laws are themselves creatures of God, for he gave us the regularities of sun and moon, day and night, the seasons, the tides, to name but a few. They are, as the German language has it, *Ge-setze,* i.e., "settings". God *set* them to be. "They are limitations," Brunner observes, "for *our* freedom, not for His. His freedom is above all settings or laws, they are not fetters upon His action, and some day they shall be no more. For 'the frame of this world perishes'. The contingent is also the transient, the perishable, the non-eternal . . . natural laws are not absolutes, nor ultimates, they don't determine His purposes. Rather they are instruments, organs, servants of His will." *(Christianity and Civilization,* I, p. 23f)

Time was when an idea could be squelched by showing that it was contrary to religion. Result; theology became the greatest single source of fallacies. Today an idea can be discredited by being branded as unscientific. Likewise, science has become in its turn the greatest single source of error. Our use of the law of causality in our scientific endeavor must not obscure its nature as an approximation. It is neither true nor false. Rather, it is a hueristic principle, a most valuable and productive idea in understanding some particular aspects of the physical world.

CHANCE AND PROVIDENCE

In the shaping of history there are no laboratory controls. The most improbable event, from the point of view of our probability model of the universe may be precisely the one that occurred. We should see history as a succession of time-points, each of which in the hands of God can become a turning point of special significance. The appearance of chance and accident in history are to be welcomed because it is so far as we have been enabled to see, a permanent feature (until God sees fit to change it) of the world. Pollard even goes so far as to make the appearance of chance and accident in history the "key to the Biblical idea of Providence". (Pollard, Chance and Providence p. 66)

Even stronger is Pollard's assertion that it is "only in a world in which the laws of nature govern events in accordance with the casting of dice can the Biblical view of a world whose history is responsive to God's will prevail" (Ibid., p. 97). This seems to say that the Biblical concept of providence *requires* the laws of nature to have a form governed by the casting of dice. If so, it is going too far. As long as we know only *that* God works providentially and *not* precisely *how* he works—that is, we do not know all the *mechanisms* by which he carries out his will—and as long as the foundations of probability are not thoroughly understood, we must confine ourselves to more modest assertions. Indeed, Pollard elsewhere expressed himself more modestly: "It lies at the heart of the Biblical idea of providence that there be no method of verifying by means of controlled tests or experiments whether or not a particular event in the past occurred because God willed that that particular alternative should be selected on that particular occasion." (Ibid., p. 96) And a little later we read that "events in themselves share in both realities of order and providence" so that "the enigma of history resides in the fact that every event is at one and the same time the result of the operation of universal natural laws and the exercise of the divine will." (Ibid., p. 114)

There is a persistent demand on the part of many for some objective demonstration of the reality of God and the fact of His providential ordering *apart* from his self-revelation through personal agents: the prophets, angels, the apostles, but preeminently through Jesus Christ. But to the author this seems but a gossamer: wishful thinking at best. It is a quest which can only come full circle back to the original question. God is ever resistant to our efforts to convert a faith problem into a knowledge problem. But in the very nature of things faith problems have only faith answers. The message God gave to Isaiah for Ahaz was so pointed: "If you will not believe, surely you shall not be established." (Isa. 7:9)

We do well to heed the experience of others who have been similarly engaged in the harmonizing of a new discovery with Christian faith (should there be a need for it). C. S. Lewis reminds us, from quite a different context, of the periodicity of such issues when he writes that "Each new discovery, even every new theory, is held at first to have the most wide-reaching theological and philosophical consequences. It is seized by unbelievers as the basis for a new attack on Christianity; it is often, and more embarrassingly, seized by injudicious believers as the basis for a new defense. But usually, when the popular hubbub has subsided and the novelty has been chewed over by real theologians, real scientists, and real philosophers, both sides find themselves pretty much where they were before. So it was with Copernican astronomy, with Darwinism, with Biblical Criticism, with the new psychology. So, I cannot help expecting, it will be with the discovery of 'life' on other planets'—if that discovery is ever made." *(The World's Last Night)*

It seems to me that it is more accurate to say that the key to understanding Biblical providence is with the nature of God, as discerned in both his performed deeds in the world, along with his own interpretation of them. In any event, we *cannot* tie God's hands or deny him access to his own world by any particular model we make of the world. Whether we use the principle of determinism or of indeterminacy in our view of the world, God is necessarily above all. Whatever rapprochment we shall find between Providence and the concept of probability, there will likely be a residuum of mystery about God. In fact, I would venture to say that the probability of the mystery is 1! We need not believe that we moderns are the first to travel this road whose illumination is beyond our view. The Apostle himself, after a long and somewhat inconclusive discourse on the philosophy of history in general, and the destiny of his own fellow Israelites, in particular, is reduced to adoration: "O the depth of the riches and wisdom and knowledge of God! How unsearchable are his judgments and how inscrutable his ways! 'For who has known the mind of the Lord, or who has been his counselor? Or who has given a gift to him that he might be repaid?' For from him and through him and to him are all things. To him be glory forever." (Rom. 11:33-36) We should not claim to have explanations for everything. The acceptance of an inadequate explanation can discourage search for a better. Our scientific endeavor is not a contemplative repose in the sumptuous setting of knowledge already acquired, but it is an indefatigable quest that takes us up slopes never scaled before.

NOTES:

"Between the observations of science and a simple, direct interpretation of the Bible narrative there exists a harmony such as would be expected of a Book having the same Author as the physical world." F. Alton Everest, editor, *Modern Science and Christian Faith,* Scripture Press, Wheaton, Illinois. Reprinted by permission.

"There is an appreciable group of reputable men of science who are convinced of the inspired origin of the Bible and who find in it a stimulating, satisfying, and irreplaceable contribution to their scientific picture of the universe." F. Alton Everest, editor, *Modern Science and Christian Faith,* Scripture Press, Wheaton, Illinois. Reprinted by permission.

PROBABILITY CONSIDERATIONS IN SCIENCE AND THEIR MEANING

It is here investigated how probability considerations arise in science. The use of probability concepts in statistical mechanics and wave mechanics is discussed. The implications of the second law of thermodynamics are dealt with. The concept of "random event" is discussed, with special application to events in the biological domain. Caution is expressed against drawing unwarranted conclusions from the use of probability concepts in science. For example, it is shown that the use of probability concepts does not imply that the world is governed by chance.

1. *Introduction.*
Probability considerations are used in physics and in biology. In physics they occur in statistical mechanics, the theory of heat, in the atomic and subatomic domain, etc. In biology they occur in the theory of mutations, the theory of survival rates, etc.

This is often interpreted as meaning that the world is indeterministic and that many phenomena in nature are governed by chance. This in turn is sometimes thought to have religious consequences in that it poses the question how the concept of an omnipotent God can be squared with the concept of chance phenomena.

If a careful analysis is made of the occurrence of probability considerations in science, it is seen that science is incapable to decide whether or not the world is deterministic, nor can it deduce whether or not the world is governed by chance. Farflung philosophical and theological deductions based on these questions are thus without foundation.

Those working in science feel the need of explaining to the laymen *what* they are doing and *why* they are doing it. This is a legitimate part of their scientific work. They also have a legitimate interest in connecting *their* results to the results of others and in relating their field of endeavor to other fields. But if science is used in order to draw far-reaching philosophical or religious consequences from it, science is misused and misinterpreted and the minds of the laymen are confused.

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True enough, it is flattering to one's ego to proclaim that one is working at the burning issues that torment man's mind, but it is not what science tries to accomplish. It is much better if scientists modestly explain what science is all about, and what it has accomplished, especially if it is done in such a manner that the actual scope of science as well as the limitations of science become visible. We shall try to do this in this paper for the problem of probability considerations in science.

2. *The reasons for the occurrence of probability considerations in science.*
When studying physical phenomena, the world around us is represented by a "model". This "model" is often an idealized situation in which disturbing influences are eliminated. For example, in the formulation of the laws of motion, one extrapolates first to the case of zero friction, since the laws of motion then attain their simplest form. Having formulated the "laws" governing the idealized case one can afterwards improve the model by taking the effect of the disturbing influences (in our example the effect of friction) into account. Usually they are taken into account one by one.

This procedure is followed because we live in a very complex universe. If everything in the universe interacted strongly with everything else, science would be extremely complicated. Fortunately, most of the interactions are extremely weak, so much so, that one can often start with a model in which only *one* interaction is taken into account. Next this simple model is improved by introducing other interactions as small disturbances of the model. Often only few of these interactions need to be taken into account for a reasonably accurate description of a whole range of phenomena.

The "model" can be described in a causal fashion. That is, if one knows the laws governing the model and if one knows the initial conditions of the system under consideration, then one can predict the future behavior of the system for long times. I purposely did not say "for all times", because there are cases where a branch of mathematics, known as perturbation theory, must be used. When that is the case, it may happen that the predictions of the theory become inaccurate for very long times. This is, e.g., the case in the theory of planetary motion.

The "models" by which we represent reality are fully determined. Is the world around us also fully determined? We will never know, for in order to do so we must know the laws with unlimited accuracy and the initial conditions with unlimited accuracy. But in all our measurements our accuracy is limited. Some methods of measurements are more accurate than others, but all methods of measurement have in common that there is some limitation to the accuracy. It is for this reason that the deterministic program can never be *fully executed,* it can only be *approximated.* This is one of the reasons for probability considerations in science.

Probability theory offers a way out of this difficulty. One determines the value of a physical quantity x in a large series of n independent measurements and then evaluates the quantities

$$\bar{x} = \frac{x_1 + x_2 + \ldots\ldots x_n}{n} \quad \& \quad \sigma = \sqrt{\frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots.(x_n - \bar{x})^2}{n}}$$

Then the most probable value of x is $\bar{x}$ and the probable error in this average is $0.6745\ \sigma/\sqrt{n}$

The difficulty is that it takes an infinite number of measurements to obtain unlimited accuracy and there is not enough time for that. Moreover, the above procedure implies that all the errors introduced in the measurement are of a *random* nature and that no systematic errors are involved in the measurements.

Since we cannot know the laws with unlimited accuracy or the initial conditions with unlimited accuracy, we cannot predict the future of the system with unlimited accuracy. For that reason all our predictions contain a certain margin of error, sometimes larger, sometimes smaller, but never absent. This is one reason for the occurrence of probability considerations in science and this occurs in *all* our predictions.

Since there is no fundamental law against making measurements more accurate, this occurrence of probability considerations in science is non-fundamental. It merely indicates that the estimate of the last decimal of the individual meter readings is subject to error. It does not mean that the *world* is governed by chance; only our estimate of the last decimal is.

In some cases there are limitations of a more fundamental nature. We can list them as follows:

1. Systems can be so complex that it is humanly impossible to know all the initial conditions with sufficient accuracy to make accurate predictions at a microscopic level. In view of what was said before, this means that one can only make statistical predictions about macroscopic quantities.

2. When one pushes the accuracy of the measurements farther and farther one comes to limitations set by the atomistic structure of matter. The meter readings are not constant in that case but fluctuate around an average value. This sets a limit to the accuracy of the measurements that has nothing to do with the accuracy of meter readings as such.

3. In the atomic or sub-atomic domain there are limitations set by quantum effects. These effects make it impossible to know all the initial conditions with arbitrary accuracy and as a consequence many predictions must be of a statistical nature.

We shall now discuss these three possibilities in greater detail.

As an example of the first possibility consider the following problem taken from the kinetic theory of gases. A cubic foot of gas at atmospheric pressure contains about 10^{24} (1 million billion billion) molecules. This number is so huge that one can never hope to know the initial conditions of all the molecules. And to predict the future motion of the molecules accurately, one would have to know all the initial conditions *extremely* accurately; since the slightest error in the initial condition of *one* molecule might make it uncertain whether or not a certain collision will take place.

But fortunately physical measurements are not performed at the *microscopic* level but at the *macroscopic* level. The quantities one is interested in are the average pressure of the gas, the average volume of the gas or the average temperature of the gas. These average quantities can be calculated in a relatively simple manner. For example, the average pressure of the gas is the average force per unit area on the wall. And this average force comes about because of the collisions of the individual molecules of the gas and the wall. These quantities are *average* quantities and hence statistical considerations apply.

Apart from this, the same situation mentioned before applies to this case. One starts with the simplest of models and then gradually improves it. In first approximation one can neglect the interactions of the molecules, and one then obtains the simple gas law. Next the various interactions between the molecules (finite volume of the molecule, the attractive force between molecules at short distance) are taken into account. Finally one ends up with a rather accurate prediction of all the macroscopic properties of the gas. The success of the theory comes about because one ignores the microscopic picture to a major extent and applies statistical considerations.

This does not mean that the mircoscopic picture is not there, of course. As a matter of fact, many manifestations of the microscopic behavior can be made observable. For example, if one makes very accurate pressure measurements, one finds that the pressure fluctuates around an average value. These fluctuations can be observed with a very sensitive microphone which transforms the pressure fluctuations into electrical signals that can be amplified electronically and made audible as a hissing sound (noise) by feeding the amplified signal into a loudspeaker. The theory can give the mean square value of the pressure fluctuations and again, that is exactly what the measurements yield. The spontaneous pressure fluctuations can then be accounted for.

As an example of the second possibility consider the measurement of small electric currents with a sensitive galvanometer. Here the limit is set by the small current fluctuations in the electric circuit of which the galvanometer forms a part; these fluctuations are caused by the random motion of the electrons in the conductors of the circuit. As a consequence, the galvanometer reading is not steady but fluctuates around an equilibrium value. If the current to be determined is small in comparison with these current fluctuations, it cannot be measured. There is here a limitation set, not by our inability to estimate the last decimal of a meter reading accurately but by the spontaneous fluctuations of the galvanometer deflection.

In the atomic or sub-atomic domain the problem arises that one cannot know the initial conditions at a given time with deliberate accuracy. According to Heisenberg's uncertainty principle the product of the inaccuracy Δ x in the *position* of an atomic or sub-atomic particle and the inaccuracy Δ p in the *momentum* of that particle exceeds the value h/ (2 π, where h is Planck's constant. As a consequence one cannot predict the future with complete accuracy; the inaccuracy in the final result reflects the inaccuracy in the initial conditions. In other words atomic theories give probabilities of events.

At first sight this case seems different from the first case. There one purposely ignored a major part of the information to make the problem soluble. Here it is physically impossible to know the initial conditions with deliberate accuracy. But in either case the same end result occurs: the theory cannot give accurate predictions but yields probabilities.

Let this be illustrated with the case of α—decay of radio-active nuclei. In this radioactive decay the nuclei emit helium nuclei (α —particles) at a certain rate. Apparently the α —particle is present in the nucleus and bound to the nucleus, for otherwise the nuclei would decay instantaneously. How then can the α —particle escape? Classically speaking, it cannot, but from the wave-mechanical point of view escape is possible.

To understand this we represent the radio-active nucleus by the following model. A marble oscillates in a bowl without friction with so little energy that it cannot reach the rim of the bowl. Hence according to the laws of classical physics the marble should stay in the bowl forever. But in fact the motion of the α —particle in the nucleus must be represented as a *wave* motion. If in our picture the motion of the marble is considered as a wave motion, then the wave does not have to pass *over the rim* of the bowl, but can pass *through the wall* of the bowl. In the radioactive nucleus the "wall of the bowl" is thin enough to give this event a certain probability. In other words the theory gives the *rate* of radioactive decay. This example also shows how the statistical character of the predictions made by wave mechanics occurs.

There are two equivalent ways of interpreting Heisenberg's uncertainty principle. One way represents the motion of a particle as the motion of a wave packet. Heisenberg's uncertainty principle then follows directly from the consideration of these wave packets. Another way looks more at the physics of measurements in the atomic or sub-atomic domain. For example, if one wants to measure the *position* of a particle accurately, one uses a γ —ray microscope. The particle scatters γ —ray light into the microscope and thus becomes observable. But in doing so, the particle receives momentum from the scattered quanta and hence its momentum *after* the measurement differs from its momentum *before* the measurement. If one works out the details, one ends up with Heisenberg's uncertainty principle.

3. *Spontaneous fluctuations and random events.*
We encountered fluctuations in various instances already. They could be amplified by many more examples. Practically everywhere in physics one encounters spontaneous fluctuations of one form or the other.

These spontaneous fluctuations appear to us as *random*. The reason is that we cannot observe at the microscopic level. If we could, we would *see* the microscopic phenomena and the spontaneous fluctuations would thereby find their causal explanation. As long as one observes at the *macroscopic* level, the causes of the fluctuations escape our notice and they appear as random.

The occurrence of random phenomena does not indicate that the world is governed by chance. Rather it is an indication that one is operating at a level of investigation that is disturbed by phenomena occurring at a deeper lying level. At the microscopic level everything has its causal explanation; at the macroscopic level this is not the case.

If the explanations of Heisenberg's uncertainty principle are taken seriously, it would seem that the randomness encountered in the atomic domain is of a different nature. But Bohm has suggested that this is not the case. He has proposed that in atomic experiments the observations are disturbed by phenomena occurring at a deeper lying level so that the observations show random fluctuations. These phenomena at a deeper lying level he proposes to describe by "hidden" variables. If one could *know* these hidden variables, a strictly causal description of the observations could be given. Since one does not know them, the phenomena appear as random.

This randomness shows itself in the case of so-called "elementary events", such as a collision between an electron and a particle, the radioactive decay of a nucleus, the transition of an atom from a higher energy state to a lower energy state, etc. The theory cannot predict *when* an elementary event is going to occur; it only can predict the *rate* of occurrence. Our description of atomic phenomena does not penetrate into the nature of things. Our predictions are as causal as Heisenberg's uncertainty principle permits, and beyond it we cannot go. There is, however, no justification for calling elementary events "events without a cause", as is sometimes done. For we do not know whether or not the event has a cause, it merely *appears* to us as random.

If Bohm is correct, then the hidden variables are responsible for the random behavior in the atomic domain. His proposal has the merit that it provides continuity and that it parallels phenomena in the atomic domain with other known microscopic phenomena. It also makes one more cautious not to ascribe great philosophical significance to modern atomic theories.

In my opinion any interpretation of Heisenberg's uncertainty principle, including Bohm's, is optional. One can take it or one can leave it. All that really matters is that the *equations* upon which Heisenberg's uncertainty principle is based *are maintained.* If somebody feels better by adopting Bohm's proposal, let him go ahead. If somebody feels better by rejecting Bohm's proposal, he may do so. In my opinion it is unwarranted, however, to draw sweeping philosophical or religious conclusions from Heisenberg's principle, since this is a misuse of science that obscures the scope and the goals of science.

4. *The second law of thermodynamics.*
The second law of thermodynamics states the general direction into which processes will go spontaneously. We give here its formulation in terms of probability concepts as follows: "A closed system, left to itself, will go spontaneously from a less probable to a more probable situation."

Let us illustrate this with some examples. A hot body to which no heat is supplied will cool down to the temperature of its environment, since it is more probable that heat is distributed evenly than that it is concentrated in one body. If a gas line is opened for a short time interval, then the gas, which is at first concentrated near the opening, will gradually distribute itself evenly through the room, since a uniform distribution of the gas is more probable than its concentration in some small volume of space.

If one measures carefully, one finds that the temperature of the cooled-down body is not *exactly* equal to the temperature of its environment but fluctuates around it. In the same way the distribution of the gas molecules through the room is not *exactly* uniform, but the concentration in a small volume element of the room fluctuates around its equilibrium value. Large deviations from equilibrium, though not impossible, are extremely unlikely, however. The second law of thermodynamics predicts the tendency to reach the equilibrium condition but does not explain the spontaneous fluctuations around equilibrium.

The second law predicts the *future* of many systems but it cannot predict the past. For if one tries to do that, one obtains that the system must have come from a state of *larger* to a state of *smaller* probability. The reason lies in the words "left to itself." A system "left to itself" in the past is a system to which nothing was done earlier. If that is the case, then the improbable state at time zero must have come from a very improbable spontaneous fluctuation. If one does not want to accept this, and there is no reason why one should, then one must conclude that the second law cannot always predict the course of *past* events.

5. *Random phenomena in the biological domain.*
We shall not dwell upon the pros and cons of the theory of evolution; that I gladly leave to others. There are two aspects of the theory that have a bearing on our subject: the occurrence of mutations and survival rates.

It is presently well known that mutations are caused by a rearrangement of molecular groups in the chromosomes. In some cases a molecular group breaks loose and reattaches itself to another part of the chromosome. In other cases a chromosome breaks and the broken-off part is connected to another chromosome. Both processes alter the genetic code and thus change the outward appearance of the organisms in question. Such mutations can either occur because of the thermal vibrations of the molecules, or by ionization caused by γ-rays, electrons from radioactive decay or cosmic ray particles.

In the first case molecule groups are shaken loose by the thermal agitation of the molecules and they reattach themselves somewhere else. In that case the mutation rate has a very characteristic temperature dependence that gladdens any physicist's heart. In the second case the ionization results in a break-up of the chromosome followed by a subsequent rearrangement of its parts. In that case the mutation rate is proportional to the intensity of the incoming radiation.

Both processes are treated at random, and for a very good reason. Both processes involve the events of ionization and thermal dissociation, and one can argue that they are elementary events describable by wave mechanics. But even if they could be described on a classical basis, one could not predict in advance *when* an ionizing particle would strike a chromosome or *when* a molecular group would be shaken loose by thermal agitation. It is not warranted to call these processes "without cause", nor do they indicate that biological events at the molecular level are *governed* by chance. We can only say that these events *appear* to us as random, as long as we do not fully observe at the microscopic level.

Next something about survival rates. A salmon lays about 20,000 eggs, I have been told. And of these eggs only two need to reach maturity to supplant the parents from which they came! All the others are eliminated either because the egg does not develop or is eaten or because the young salmon is eaten or dies before reaching maturity. These processes, are to be treated as *random* processes, not because they are elementary events in the wave-mechanical sense but because one cannot predict in advance, other than on statistical terms, what will happen to the individual eggs.

We conclude therefore that the random processes in biology partly reflect our ignorance about the future and partly indicate our inability to overcome Heisenberg's uncertainty principle.

6. *Conclusions.*

It has been argued that the statistical considerations open up the possibility for the occurrence of miracles. For statistically there are no impossible events; there are only probable and improbable events. It is thus possible that something occurs that goes against the existing order and against common experience. If such phenomena are called "miracles", then such miracles *can* and even *must* occur if one waits long enough. These miracles are thus very rare spontaneous fluctuations. They occur by the "grace of statistics", whereas biblically speaking they occur by the "grace of God". That is a step backward rather than forward.

It has been argued that the second law of thermodynamics points toward a creation. For if the present improbable state of the universe is not caused by a spontaneous fluctuation, then an improbable initial condition must have been *set* in the past. If one calls this "creation", then the Creator thus introduced looks more like a retired engineer than like the God of which the Bible speaks.

It has been argued that Heisenberg's uncertainty principle allows the human will to be free and allows God to act in His freedom. Now, Planck's constant is a very small quantity. Does this mean that the human will only has rather narrow limits of freedom and that God may not be so *very* free? I maintain that Heisenberg's principle has nothing to do with the human will nor with God's freedom. God is free because He is God.

Statistical considerations are extremely useful in science but their limitations should not be overlooked and one should not draw far-reaching conclusions from them. What *we* consider random is not necessarily random *in fact*, nor is it necessarily random *in God's sight*. To bear this in mind prevents unwarranted sweeping conclusions drawn from science.

NOTES:

"Where then does science belong in the life of a Christian? Since science has for a long time been exploited by those who are not Christians, and since it is often taught in secular universities and, sad to say, in some Christian colleges as if there were no God, should not the Christian turn from science to busy himself in what is often called "full-time" service? By no means, for a Christian in his laboratory can serve God in full-time service as a scientist." Roger J. Voskuyl in *Modern Science and Christian Faith*, Scripture Press, Wheaton, Illinois. Reprinted by permission.

FROM THE CONTRIBUTING EDITORS

CHEMISTRY

"Art for art's sake" is a phrase which indicates that art is to be enjoyed or pursued as an end in itself. That is the end of the road.

Some Christians deny this view. From them we hear either (1) art is to be avoided unless it is specifically Christian or (2) a motive for pursuing art other than "art for art's sake" must be found. This deeper motive must be related to the Christian faith. Thus there is a lively dialogue among many who are able to speak with authority concerning art.

We scientifically-minded Christians might consider whether "science for science's sake" is enough. Even unbelievers ask themselves, "Why do we carry out research?" Perhaps Christians can give a meaningful answer to this question.

Certainly the practical aspect of science is worthy of study by the Christian, but what is the relation between the Christian faith and the fundamental principles of science? My thesis is that "science for science's sake" is not enough.

Consider, for example, the "pattern" the investigator finds in creation. For the chemist or physicist the existence of this pattern means that the more we learn of atomic and molecular structure and the nature of chemical reactions, the more we see the pieces fit together. While we say the pattern we find indicates that creation is "orderly," is it proper to imply that the concept of order is itself *not* part of creation? The key idea here is that the concept of order is in the mind of man and this mind is made by God.

To the extent the mind of man is not clouded by the effects of sin, the concept of order we speak of is also part of the creation of God. Then when we say there is a pattern in creation we really mean that the concept of order in our minds is the same as the order of the material universe. In other words, God made the mind of man and the material universe to harmonize.

Two of the consequences of this harmony are of special interest. One is that God uses this means to reveal infinitely more of His creation to us than would otherwise be the case. Thus, we can generalize from observed facts by formulating natural laws. We have so much confidence in this concept that we predict sizes and electronic configurations of atoms even before their discovery. Without this order or pattern our observations would be isolated—virtually meaningless—and there would be no science. Whatever there is of science is a consequence of the harmony between the concept of order in our minds and the rest of the created universe.

Another consequence of this harmony is the intellectual satisfaction we receive from our study of creation. God has not only caused us to see a pattern in His creation, but He has also constituted us so that the existence of the pattern pleases us. Believer and unbeliever alike find beauty in the simplicity of nature when the first principles are understood. "Beauty in nature" is a phrase we almost automatically use when we think of what the mountain-climber or the forest ranger sees. When such persons are Christians, they praise God for their opportunities to observe such things. Yet, if David were writing psalms now he would surely praise God for the magnificance, beauty, and simplicity of number theory, quantum mechanics, and the periodic classification of the elements.

THE CHRISTIAN CHEMIST

If the Christian chemist praises God for the simplicity of the periodic classification, he ought to praise Him even more when he has a detailed understanding of this classification. Perhaps we who teach chemistry should approach the subject in this way. In my own experience, sophomore chemistry students in an inorganic chemistry course are able to understand the link between the periodic classification and quantum mechanics on the one hand and specific chemical properties on the other. These Christian students respond to the idea that God has made His universe basically simple.

Here are some typical examples of chemical facts which these students learn to trace back to simple principles.

(1) Most compounds of the first transition group elements are colored. Usually, the color is caused by a transition within the 3d level. The transition can occur because ligands split this energy level. The existence of the level and its splitting are explained by the existence of quantum numbers and the appropriate use of the Schrodinger equation. The Schrodinger equation is a consequence of basically simple assumptions, one of which is the assumption that the electron has wave-like properties. These few assumptions, the students learn (or, at least, they are told!), are the basic assumptions of chemistry. In this satisfying simplicity Christian students see the hand of God in creation.

(2) Hafnium and zirconium are so similar chemically that hafnium was "hidden" in what was thought for many years to be pure zirconium. Their chemical similarity stems from similar atomic sizes and outer electronic configurations. The size similarity is a consequence of the lanthanide contraction, which in turn is predicted by the building-up principle. Both the building-up principle and the outer electronic configuration can be predicted with proper use of the Schrodinger equation. As before, another complex matter can be reduced to a small number of fundamental assumptions.

(3) There is a much larger chemical difference between a second-row element and its third-row congener than between elements of the third and fourth rows, or the fourth and fifth, etc. As an example, the fluorine-chlorine chemical difference is large compared with the chlorine-bromine and bromine-iodine differences. The two reasons for this phenomenon are directly traced to the Schrodinger equation and to the wave principle and other simple principles upon which it is based. First, the valence shell of second-row elements is the four-orbital L shell, with a maximum coordination number consequently no more than four. In the succeeding rows there is not such a severe limitation. Second, the energy level of a shell is roughly inversely proportional to the square of the principal quantum number, n. While this rough rule is of principal use in comparing the shells of one atom, it also has some use in comparing the outer shells of different atoms. Thus, $1/n^2$ changes three times more between $n=2$ and $n=3$ than between $n=3$ and $n=4$.

These are not examples which fortuitously have the same simple explanation. Rather, the discipline of chemistry is mature enough so that it is now possible to perceive that all chemical facts will be explained in some such way. Is it not possible that the beauty of simplicity in what God has created is better understood by chemists than non-chemists? Should not each science yield something special, calling forth praise to God, for the benefit of the scientist in that field?

RUSSELL MAATMAN

SOCIOLOGY

THE CHURCH AND RACE: AN EXPERIMENT ON FUTILITY. The social conscience of the church has often been aroused to speak out in opposition to the ills of society. Though its voice has usually been clear and often strident, its hand has not always been effective or compelling in its actions. While the church continues to be stirred, perhaps its day of accomplishment in such questions is drawing to a close.

As one of the institutions of society, the church must work, eventually, through its constituent members. It may form policy concerning social problems and it may summon agencies to fulfill programs, but in the final analysis, it is the layman who is depended upon for support in his daily actions. It is at "the grass roots" level where all such programs gain the nourishment for increased strength and vitality. The question is whether the church can gain adequate support from its congregations to turn policy into effective, if not efficient, action.

There is much in the literature of social science to suggest that the church, in attempting to have the layman execute its programs, is indulging in a futile experiment in the area of racial integration. A study of a small New York town reports that the policy of ecumenicalism initiated by the National Council denominations is not supported by the local congregations. In fact, there is often sabotage of such values for the purpose of preserving local congregational differences.[1] An anthropologist notes that the early administrators in Africa had commendable plans which were based upon the understanding of and respect for the natives, but that the meeting of immediate needs prevented the fulfillment of these high ideals.[2] A sociologist, in his celebration of Marx, suggests that revisionism among Marxists is the result of the inability to apply the philosophical principles of Marxism to the problems of the concrete society.[3] The main thesis of a classic in political science affirms that once liberal and reform elements obtain power in office, the need to maintain a bureaucratic structure causes them to become conservative and oligarchic, thus preventing the accomplishment of their original goals.[4] Similarly, a study of a Canadian cooperative movement showed that when a new reform government attempted to put its program into action, an entrenched Civil Service sabotaged the plans and prevented any significant reforms from taking place.[5] In each case, the drafting of resolutions and the projection of goals were easily accomplished. Nevertheless, they were not fulfilled because of the inability and reluctance of those who were finally responsible for their performance. It is with a knowledge of such failures that the church must reassess its attempts at racial integration.

Before one can obtain a clear perception of the situation, however, it is necessary to ask the currently unpopular question of whether the church has been effective in the integration movement.[6] A Harvard sociologist has aggressively raised the issue and concluded that the church has not only failed in its efforts, but also that it has little chance for success under present circumstances.[7] The question was particularly difficult for Pettigrew to ask since, in providing the answer, it was necessary for him to raise a finger of condemnation at his own Episcopal church. The evidence is damaging and illuminating: an Episcopal school in Georgia refuses, on racial grounds, to accept the son of Martin Luther King; an Episcopal academy in Little Rock accepted only white Episcopalians when the public schools were closed; an Episcopalian rector in Deerfield took a vacillating stand while initiating the turbulent events surrounding the now well-known efforts at integrated housing in that community. Apparently a denomination which has been most influential in its pronouncements is unable to keep its own house in order.

It is not the Episcopalians alone, however, who live in that house. The conditions preventing effectiveness are generalized and can be found on any denominational level. Pettigrew cites four major reasons for the church's failure. In attempting to resolve the institutional dilemma between organizational and idealistic goals, preference has been given to such immediate and concrete needs as members and money. The freedom and individualism, sanctioned and nourished by the church, has been fed back into efforts to create a local congregation in the image of its members, *i.e.* white, middle-class, suburbanites. In advocating moderation as representative of the conciliatory and mediating role of the church, a position of relativism has been cultivated resulting in ineffectiveness. Since attitudes and behavior are not always in agreement, the church, in trying to change the thinking of its congregations on the question of integration, has not always been successful in changing their behavior. The need then is to reverse the pattern and advocate direct action which will slowly erode discriminatory and prejudiced attitudes.

What Pettigrew has to say is important but not necessarily because of the militant posture which he assumes. The data he summons reveals a new area in which the basic social principle of the inability to convert policy into an effective program may be found. Hopefully, the elucidation of more precise social forces may be possible by a comparison of the causal factors apparent in each separate case. It is clear that Pettigrew did not have as his main goal the following of this scientific principle.

Nevertheless, the sincerity and commitment of church integrationists notwithstanding, one could seriously question whether they could be any more successful than the Marxist or the supporter of ecumenicalism. Although Pettigrew is correct in not accepting the simplistic and naive view that it is only necessary to remove apathy, it should not be readily assumed that the pattern is reversible as Pettigrew states. Certainly a greater degree of sophistication of knowledge is needed before such results are possible.

Of course, Pettigrew is committed to such a view because it is apparent to him that the involvement of the church in such social action is one of its proper functions. It could be suggested here that, given such responsibilities, the church will always revert to those bureaucratic tendencies which motivate it to resolve dilemmas in favor of "members and money."[8] The needs of the individual, however, are different. It is, perhaps, on this level of the church's constituent members that attempts at integration become most viable.

1. Vidich, Arthur and Bensman, Joseph, *Small Town in Mass Society*, Doubleday Anchor, 1960
2. Turnbull, Colin M., *The Lonely African*, Doubleday Anchor, 1963
3. Mills, C. Wright, *The Marxists*, Dell Books, 1962
4. Michels, Robert, *Political Parties*, Dover Publications, 1959
5. Lipset, Seymour M., *Agrarian Socialism*, University of California Press, 1950
6. It should be noted here that such a statement does not raise the question for the individual Christian.
7. The major references here will be based on Thomas Pettigrew "Wherein the Church Has Failed in Race," *Religious Education*, Jan.-Feb. 1964, Vol. LIX. See also E. Campbell and T. Pettigrew, *Christians in Racial Crisis: A Study of the Little Rock Ministry*, Public Affairs Press, 1959 and E. Campbell and T. Pettigrew, "Racial Crisis and Moral Dilemma: A role Analysis of Little Rock Ministers", *American Journal of Sociology*, 1959, Vol. 64.
8. This "iron law of oligarchy", to which Michels refers in his *Political Parties*, would seem to hold today, even in religious organizations as has been shown in other studies.

RUSSELL HEDDENDORF

BOOK REVIEWS

THE BOOK REVIEW EDITOR COMMENTS

This being the first edition in which I have actually edited the Book Review Section (I cannot claim the previous two listed under my name) I want to compliment the previous editor Walt Hearn for his indefatigability in enlarging this section and setting up guidelines and policies and finally for enlivening this section by his own viewpoints.

These same general policies as outlined under Book Reviews in JASA 14(4) 1962 (Dec.); 15(4) 1963 (Dec.) will be followed until new and better ideas are forthcoming. Briefly, any book will be considered for review which deals directly with the encounter between science and Christian faith or that deals with current theological, social, ethical or educational problems about which every scientist who is a Christian should be thinking. The length of the average book review should be not more than 500 words. This will enable a coverage of more books in this section. However, occasionally a larger review will be accepted if it is of such vital interest and extensiveness to justify a more detailed coverage. The editor, with fresh memories of painful slashing and rewriting of his own articles by critical reviewers, hopes, in turn, to be merciful, realizing that there is more than one acceptable way of presenting a subject.

I may also make comments, as did the previous editor, which will likewise reflect my own bias and any unsigned material should be assumed to be of this origin.

Readers are cordially invited to send in names of books for review; volunteer to write a review; and give comments and criticisms so that this section may be most helpful and enjoyable.

Dying embers of *The Genesis Flood* fire are still around. Another criticism of previous criticisms has been received by the editor. Do you want it or have you had enough? This whole episode of criticism and countercriticism has been very interesting and has reminded me: (1) that people do read this Book Review Section (2) that reviewers (also scientists in general) must be accurate and concise in their communications, and (3) that personal biases do influence the arrangement and interpretation of scientific information.

This article in my possession is from Dr. John N. Moore, Associate Professor, Dept. of Natural Science, Michigan State University, who has studied one of the references (Spieker, E.M., Bull. Am. Ass. Pet. Geol. 40:1769, 1956) used in *The Genesis Flood* which a former critic has accused as being "lifted out of context and misapplied." Dr. Moore supports the author's use of the reference to point out the weaknesses of the geological time scale and to show that there is no actually identifiable boundary between the Cretaceous and Tertiary. If you should like to keep the fire going and want to hear more of this review let the Book Review Editor hear from you.

Marlin Kreider, Book Review Editor

PHYSICIST AND CHRISTIAN—A DIALOGUE BETWEEN THE COMMUNITIES, by William G. Pollard; Greenwich, Conn.: Seabury Press, 1961. xiii, 178 pp., $1.65 paperback.

All knowledge comes through community—this is the theme that runs through Dr. Pollard's book. As a well-respected member of two communities, physics and Christianity, he relates how his insights in these two areas have developed. He is both a Ph.D. physicist, acting as executive director of the Oak Ridge Institute of Nuclear Studies, and an ordained priest in the Protestant Episcopal Church. In an earlier book, *Chance and Providence,* he gives his views on God's action in a world governed by scientific law.

In the first part of *Physicist and Christian,* the primary focus is on the nature of community and its function in physics and Christianity. The latter part deals with the relationship of community to acquiring knowledge within both of these fields.

If one's conception of physics is solely that of classified subject matter, then one will find disturbing the suggestion that "physics is what physicists do"; but from the perspective of physics being a community of disciplined, imaginative human beings working together, this idea has profound implications. For example, the author writes that he became a physicist by grace not by works or knowledge in a way completely analogous to the way one becomes a Christian.

He deals with several incorrect or irrelevant contrasts commonly found in comparisons of science and religion: facts vs. faith, public vs. private knowledge, impersonal vs. personal knowledge. Faith is just as essential an element of science as of Christianity; there is personal, passionate participation in knowing in science as well as in Christianity; science has its orthodoxies, heresies, creeds, and beliefs; science exercises its authority and discipline over members of its community.

In his discussion of science and Christianity as communities, he uses several viewpoints found in the book, *The Little Community,* by anthropologist Robert Redfield. These ways of studying community include examination of social structure, a typical biography of a community member, the type of person produced by the community, the world view or outlook on life held by its members, its history, and the community within various communities. Untouched by this approach are important areas of content and subject matter: also serious questions about verification, revelation, nature and supernature require attention. But their treatment is always affected by the community within which such insights and understandings have been acquired. Thus the author defends his prior emphasis on community.

After a discussion of the reality of spirit and the reality of the supernatural, Dr. Pollard concludes that the "contingency of nature implies that which is transcendent to nature—namely the existence and reality of supernature" and that our experience of reality is both conceptual and non-conceptual. He cautions that science does not lead us to a knowledge of God or even to the recognition of his existence. "We are absolutely dependent for our knowledge of God on his initiative in revealing himself to us through Israel and Christ."

He concludes his book with chapters on knowledge and the problem of revelation. He adapts Margenau's perception plane-concept field diagrams to depict his views of three kinds of knowledge: conceptual knowledge from experience, non-conceptual knowledge from experience, and knowledge from encounter.

He stresses three aspects of revelation in the Biblical sense: (1) revelation arises exclusively out of the kind of knowledge called "knowledge by encounter"; (2) revelation takes place in community rather than with individuals in isolation; and (3) the role of the Holy Spirit in revelation. He completes his discussion with the consideration of the place of Christ in the process by which revelation takes place.

He compares knowing truth in physics and Christianity in dealing with the problems of revealed knowledge and the authority of the Bible. The difficulty again is the common assumption that scientific truth alone is capable of verification. "It is not possible for anyone but a physicist to really know the truth of physics; everyone else has to take it on faith. Equally so it is not possible for anyone but a fully involved and committed Christian to really know the truth of Christianity."

Some readers will welcome and others will shrink from the statement: "One small portion of the Bible which has received attention out of all proportion to its length as a result of theories of verbal and propositional revelation is the creation story of Genesis . . . Our task today, if we would be true to the spirit and method of the Bible itself, is not to attempt to make fifth-century B.C. Babylonian cosmology conform with twentieth-century A.D. science but rather to illuminate our scientific view of the world in the same way that the Biblical authors illuminated theirs."

Just as no man is an island, so no community of men is an island. This book should help one in the understanding of the nature and mission of the community to which he belongs. It should stimulate one to explore better ways to communicate the Good News to men now separated by the boundary lines of other communities.

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Some of the ideas expressed in ***Physicist and Christian*** were also expressed by Dr. Pollard in his article "Science As a Community" published in this *Journal* 15(2):38, 1963 (June). (M.K.)

EDITORIAL

FACTORS IN FUTURE IMPACT OF CHRISTIANITY

A panel of fifteen prominent evangelical scholars gave their forecasts in *Christianity Today* (October 9) about "what factor, more than any other, is likely to decide Christianity's influence upon the secular thought of the next decade."

Six of the fifteen (including Carl F. H. Henry and Bernard Ramm), thought theological considerations would be determinative. Two (Edward J. Carnell and James P. Martin) listed the application of love to social as well as churchly concerns. Two (John H. Gerstner and W. Stanford Reid) thought honest facing of the intellectual problems of the day the most decisive factor.

Merrill C. Tenney stressed the role of the laity. Wilbur M. Smith emphasized the need for "a mighty outpouring of the Holy Spirit," but was not optimistic. Gordon H. Clark mentioned the sovereignty of God, and wasn't very optimistic either. W. C. Robinson thought school prayers the decisive factor, while James S. Stewart held out for "a radical return to the basic creed of the early Church: Jesus is Lord; for this destroys the false antimony between 'sacred' and 'secular' and reveals the whole of life, including its 'secular' thought and science and culture, as Christ's domain."

Is there any significance in this grouping of answers? Maybe. It should be noted that all these men are theology professors (except Carl Henry, who was for a number of years). This may account for theology's prominence among the pressing concerns. But while six voted for theology, nine didn't. One can't help wondering why some prominent pastors and evangelists weren't consulted in this survey. Would Billy Graham for example, or Martin Luther King agree that theology is the crucial issue?

Nobody in this sampling listed either Christian education or evangelism as the decisive factors. Such surveys used to turn up several and sometimes a majority of votes for evangelism as the key. It is true that in this poll evangelism came in as an important by-product of: *(a)* love (Carnell); *(b)* revival (Smith); *(c)* militant laity (Tenney); and *(d)* Lordship of Christ (Stewart). But it may be important that evangelism is no longer offered unfailingly as the cure-all. We may be digging now beneath the blanket clichés.

History should convince us that theological orthodoxy was never in itself the solution. It has often co-existed with social wickedness, as in colonial New England, present-day Mississippi, and South Africa (to name a few prominent but by no means exhaustive examples). *Sound doctrine must be integrated with social concern.* (Only two of the above theologians saw this as the crux.) Unless people see love among Christians, and love applied in large doses to social relationships, our churches will increasingly become exclusive clubs, and our theology an antique curio preserved in wax for the amusement of coming generations.

James W. Reapsome, Editor, *The Sunday School Times*, Nov. 7, 1964. Reprinted by permission.

LETTERS TO THE EDITOR

GEOLOGY AND THE DAYS OF GENESIS

(William F. Tanner, Sept., 1964)

One cannot but agree with Tanner's span theory since any other opposing interpretation could not survive the scrutiny of scientific method. The linear magnitude of a Genesis "day" is not as important as the fact that the creative process has had no terminus. To elaborate on only one element of Tanner's paper, that is the probable meaning and character of the "firmament" as used in the Genesis account, it appears that an understanding of the nature of the firmament can be postulated by consideration of both the Biblical references and cosmogonical theories. Thus, comparison of primitive models of Earth with the planet Venus is a valid approach.

My model of the primitive Earth includes an envelop surrounding the Earth very similar to the cloud cover of Venus at the present time. This envelop or transluscent blanket corresponds with and is identical to the firmament. It acted as a barrier to the escape of most of the water vapor being driven out of the cooling Earth, and contributed to the attenuation of ionizing radiation from space. Additionally, the greenhouse effect was uniform over the entire surface of Earth. The great mists (Genesis 2:6) were perhaps in fact the escaping water from the cooling Earth. The watering effect referred to in the same passage corresponded in all probability to the condensation of some large fraction of this water during the solar night. Some water vapor undoubtedly escaped through the firmament to space; some was retained in the firmament itself. In this model the function of the firmament was to provide an energy balance zone between the daytime and nighttime thermal regimes.

Relating this concept to the Genesis flood, the "windows" referred to in Genesis 7:11 correspond to the disruption of the thermal balance (cooling) in the atmosphere and the release of huge quantities of condensed water vapor; that is, the firmament (or heaven) was opened. Note that the term window has survived to the present day, where it denotes a favorable launch period for interplanetary space flights. In Genesis 8:2 the windows in the firmament were "stopped" (closed) and clouds formed, Prov. 8:28, corresponding to what Tanner refers to as Atmosphere III. Prior to the close of this period during the prediluvian era the transition atmosphere (Tanner's No. II) existed.

The significance of the firmament is not diminished by the above analysis or inconsistent with Hebrew translation, since regardless of its gaseous or structural composition the firmament must certainly have been formed from "out of" the primitive Earth.

REFERENCES

1. Mintz, Y., "Planetary Atmospheres," Transactions, American Geophysical Union, Vol. 44, No. 2, June, 1963.

2. Barabashev, N.P., "Venus," A Chapter from *Issledovaniye fixicheskih uslovii na lunye i planetakh* (Investigations of the Physical Conditions of the Moon and Planets). Kharkov, 1952. Rand Corp. Memorandum RM-3194-JPL, June, 1962.

3. Johnson, R.W., "The Venus Terrain," General Electric Company, Technical Information Series Report No. R62SD153, 1962.

4. Kellogg, W.W. and Sagan, C., "The Atmospheres of Mars and Venus," National Academy of Sciences, Publication 944, Washington, 1961.

5. Sonett, C.P., "A Summary Review of the Scientific Findings of the Mariner Venus Mission," Space Science Reviews, Vol. 2, 1963, pp. 751-777.

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