

The Creative Dialogue Between Human Intelligibility and Reality—Relational Aspects of Natural Science and Theology

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ABSTRACT

Theology and natural science ask very different questions and use different procedures with respect to the common Universe being explored. Nevertheless, both human activities are grounded epistemologically in "faith seeking understanding." It is therefore not surprising that creative theologians and natural scientists have employed similar, qualitative, mathematically-structured relationship analogies to describe different aspects of the Universe in which both live. As a particular example it is interesting to note that 1986 is the centennial of not only the theologian Karl Barth but also the physicist Niels Bohr. These pioneering thinkers made use of what corresponds to *complementarity relational analogies* in their respective disciplines. In doing so they were apparently not aware of each other's work although there is evidence they were both influenced by reading the theologian, Søren Kierkegaard. Furthermore Barth argued that what is similar to *complementarity* may be an imprecise description of a much richer type of *differential relationship analogy*. Such differential analogies are found to play a functional role in natural science as well. Examples are given from both fields of similar relationship analogies, complementarity and differential in character. It is suggested that such similarities point toward an underlying unity in the thought patterns of theologians and natural scientists.

INTRODUCTION

How can we best understand a situation or object of reality in which two concepts that are not at the same conceptual level appear to be hierarchically related to one another thereby forming a unitary structure? What are we to do if further investigation reveals that we are confronted with a situation or reality structure in which we have to use two concepts that are mutually exclusive, and yet both of them necessary for a complete understanding of the phenomenon under investigation? As men and women explore the very complex, subtly structured Universe they live in, such situations and reality structures are often encountered. These phenomena are bipolar in character with both conceptual poles being bound together in a reciprocal relationship that creates a unitary structure. This essay looks at examples of such relational structures as found in natural science and in theology and suggests differential and complementarity analogies that can lead to further understanding of such complex phenomena. The essay also suggests that theology, properly understood as a science, and natural science have

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employed such relational analogies, this being indicative of underlying unities in the thought patterns of both natural scientists and theologians as they struggle to understand the Universe they both live in. Such conceptual unity is consistent with Judeo-Christian teachings on creation. These teachings emphasize that the Universe (including human observer-interpreters), with its rich, varied structure that forms the common basis of experience for theologians and scientists alike, was created and is sustained by a personal God who entered into its space-time flow in specific concrete situations.

A differential integrative relationship often is a most appropriate analogy for partially but truthfully representing the complex unity intrinsic to many objects or representations of reality that have a bipolar character. Such a differential integrative relationship consists of reciprocal asymmetric relations between two poles, the reciprocal relations between the poles maintaining a unitary structure that represents the complex unity intrinsic to the object and the representation of the object as the object shows forth to us. The key features of a differential integrative relationship or, alternatively, a differential unitary relational structure, are as follows:

1. The two poles, natures, aspects,... (the ... represent other appropriate terms) of the same object, person, discipline,...are conceptually understood in contexts appropriate to different levels of being-activity, i.e., there is a hierarchical structure that consists of two levels, the conceptual level and a "higher" level or metalevel. Thus the two poles, natures, aspects,...are qualitatively asymmetric as one pole,...is "higher" in that it manifests some quality that cannot be explained in terms of the properties of the "lower" pole,....
2. The differential integrative relationship consists of reciprocal asymmetric relations between the two poles,... The asymmetric character of the relations maintains the qualitatively distinct nature of the poles,...., while their reciprocity creates a unitary structure.
3. The poles, natures, aspects,...are asymmetric in character for they represent different levels of being-activity.
4. The asymmetric relations between the poles,...are an intrinsic aspect of each pole's,...reality.
5. The relationships between the poles,...and the poles,...themselves are in general dynamic in character.

This differential integrative relationship analogy (DIRA) is shown in figure 1 where the arrows represent the *pair of relations* that constitute a reciprocal relationship. The reciprocal asymmetric relations and the two poles, natures, aspects,...represent a unitary structure embodied in both the "object" of reality and its representation. The differential integrative relationship analogy is such a *representation*. In this relationship analogy we see that the poles, . . . are reciprocally related in hierarchical (asymmetry existing) rather than in additive fashion. Thus the poles,...are distinct yet inseparable, the reciprocal relations maintaining a superior-inferior distinction.

It is interesting to note that some unitary reality structures of bipolar nature are also characterized by the poles best being defined in terms of language contexts

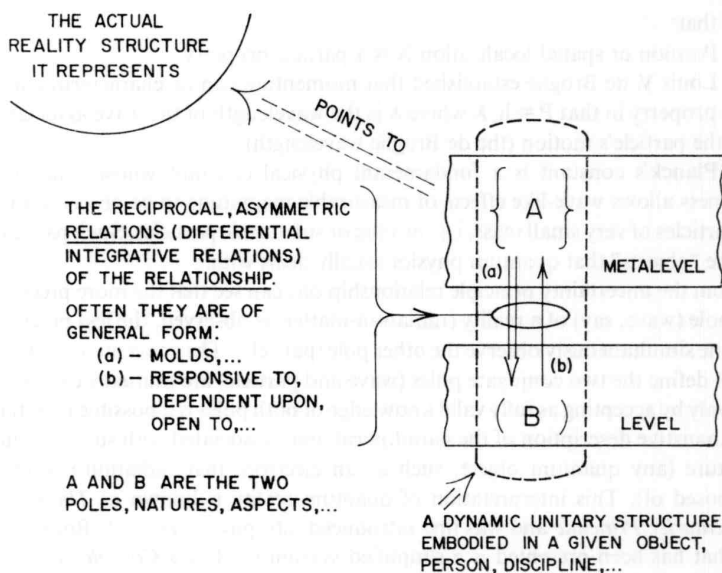


Figure 1. The differential integrative relationship analogy (DIRA). Note that the poles A and B and the asymmetric relations between them constitute a "circular" feedback loop. This "circular" feedback loop is an interaction between levels in which the top level "reaches" downward toward the bottom level and influences it, while at the same time responding to the bottom level. Out of the dynamic nature of the poles and the asymmetric relations between them that constitute the "circular" feedback dynamic, differentiated unitary structure emerges.

that are mutually exclusive with respect to each other. For such unitary reality structures whose hierarchical structure is faithfully represented by a differential integrative relationship analogy a complementarity relationship analogy is helpful in pointing to the mutually exclusive nature of the two poles. A complementarity relationship was found useful by the physicist Niels Bohr¹ as a means of representing the paradoxical unity associated with the wave and particle aspects of the quantum objects that constitute radiation-matter. He also argued that complementarity relationship analogies would be helpful in resolving wholistic antinomies at other levels of reality, i.e., a favorite example being the example of a human attempting simultaneously to be an actor and a spectator with respect to a particular situation he or she is immersed in.² With respect to the wave and particle aspects of quantum objects the mutually exclusive nature of the two poles can be looked upon as a consequence of Heisenberg's Uncertainty Principle, $\Delta X \Delta P \geq h$ ³ where

ΔX = the uncertainty in a measurement of position X,

ΔP = the uncertainty in a simultaneous measurement of the particle's momentum P defined as the product of its mass and its velocity,

h = Planck's constant.

Note that:

1. Position or spatial localization X is a particle property.
2. Louis V. de Broglie established that momentum can be characterized as a wave property in that $P = h/\lambda$ where λ is the wavelength of the wave associated with the particle's motion (the de Broglie wavelength).
3. Planck's constant is a fundamental physical constant whose numerical smallness allows wave-like effects of measurable magnitude to be observed only for particles of very small mass, i.e., atomic or subatomic particles. Such particles are the "objects" that quantum physics usually deals with.

From the uncertainty principle relationship one can see that the more precisely one pole (wave, say) of a reality (radiation-matter) is observed, the less precisely can one simultaneously observe the other pole (particle). The conceptual contexts which define the two conjugate poles (wave and particle) are mutually exclusive. Yet, only by accepting as fully valid knowledge of both poles is it possible to obtain an exhaustive description of the paradoxical unity associated with such a reality structure (any quantum object, such as an electron, that radiation-matter is composed of). This interpretation of quantum reality is known as *The Complementarity Principle* and was first introduced into physics by Niels Bohr.

What has been presented is a simplified version of Bohr's *Complementarity Principle* found in many good physics textbooks. Christopher B. Kaiser⁴ has carefully analyzed all of Bohr's writings on wave-particle complementarity and found that they contain an element of hierarchy between the wave and particle poles of the bipolar unitary structure, the quantum object. Kaiser argues that Bohr viewed the wave and particle poles of a quantum object to be in a transcendent relationship, the wave pole representing a different conceptual level than the particle pole and vice versa. William G. Pollard⁵ has argued that the full unity intrinsic to such a structure is not adequately portrayed by a complementarity analogy alone for, ultimately, the wave associated with a quantum object manifests itself in a mathematical space and is never observed directly in nature. The wave's manifestation in this mathematical space "transcendent" to three-dimensional space and time "controls" the particle whose presence is observed directly in physical space-time. Thus, according to Pollard, as contrasted to Bohr, the complementarity framework is no longer followed as the quantum object does not directly appear in physical space-time as a particle or wave depending upon the observational environment. Note that Pollard's argument is also based on asymmetric structuring of wave and particle poles.

In order to do full justice to the rich complexity of quantum reality, I would suggest that a differential integrative relationship as well as a complementarity relationship analogy is required for a comprehensive understanding of the bipolar unitary reality structures found in the quantum domain. Indeed in representing such structures a complementarity relationship may be a "projected" aspect of the more complete differential integrative relationship. By "projection" is meant a "flattening out," a "projecting" into a "lower" dimension, or a forming of an approximation of the more complex relational analogy. Both relationship analogies point beyond themselves to what for us is the inexhaustible richness of

the reality structure itself, which is only dimly perceived. A plausibility argument is now outlined as to how with respect to quantum physics this "projection" of one relationship analogy into another takes place:

1. In modern physics, the wave pole of a quantum object is represented by the state function (commonly called the wave function) which exists in a multi-dimensional configuration space. This mathematical space is transcendent with respect to three-dimensional space and time. The wave function⁶ is never observed directly in physical space-time since it is a *complex* function (having an imaginary number component) the square of which is proportional to the probability of finding the particle in a certain region of space-time.

2. From the Uncertainty Principle perspective the complementarity relationship between particle and wave poles of a quantum object can be expressed as between position and momentum, both usually assumed to be particle-like properties in a classical perspective.

3. All observations with respect to both position and momentum take place in three-dimensional space and time.

4. Through the de Broglie equation, ($p=h/\lambda$) it is possible to interpret the quantum object's momentum as a wave property. But the wave characteristic of a quantum object is only fully expressible in relationship to what we consider to be a transcendent configuration space; it "controls" (by means of the probability interpretation) particle behavior whose effects are observed in physical space-time.

5. Thus the complementarity of a quantum object's position and momentum, both observationally defined by apparatus existing in physical space-time, depends upon a wave that manifests itself in mathematical configuration space, which can be thought of as transcendent to physical space-time.

6. From this perspective, complementarity of position and momentum comes about when the wave character of a quantum object conceptually defined at a "higher" (mathematical) dimension is "projected" into a "lower" (physical) dimension where apparatus exists to observe it.

This plausibility argument from quantum physics suggests that a complementarity relationship is a result of the two-level character (in quantum physics—transcendent configuration space and physical space-time) of the differential integrative relationship making possible the "projection" of characteristics of the "higher" dimension into the "lower." I would assume this to be true for other contexts in which both types of relationship analogies are found useful in representing bipolar unitary structures. I would also assume that both relationship analogies and probably others are needed to represent faithfully the richly diverse yet unitary character of bipolar structures that exist in different regions of reality. All analogies are at best only imperfectly faithful representations of reality, i.e., they reflect in a partial way key components of the reality beyond them and to which they point. Epistemological confusion results when it is forgotten that reality is always pointed to and never grasped in its entirety; its inexhaustible richness⁷ can only be known in part by finite humankind (theologically one could say, . . . by a both finite and sinful humankind). Differential integrative and complementarity relationship analogies are both intended to focus primarily on

the unitary character of the bipolar reality that they point to beyond themselves. In some form these kinds of analogies are found in the writings of M. Polanyi⁸, N. Bohr⁹, and C. F. von Weizsaecker¹⁰ to cite a few representative examples.

A final word on the complementarity analogy. Bohr's complementarity perspective, developed in quantum theory, will be a faithful representation of bipolar reality structures (or objects) in situations where the conditions of observation associated with each pole limit the knowledge that is available in a simultaneous observation of the other pole. The intertwining of observer (in general—or observing apparatus in the particular case of quantum objects) and the bipolar object in such situations must be acknowledged in the context of the *whole* observational situation; for such situations, conjugate pairs of properties associated with the object under study are observationally defined in "complementary" context. These observational contexts are "complementary" even though their conceptual structures are mutually exclusive, for they are jointly necessary—or complement each other—in providing an exhaustive description of the physical situation. Accordingly, as the observer-knower focuses on one observational context, simultaneous knowledge of the other observational context fades out; knowledge of the latter is then only possible indirectly, i.e., in memory. For an exhaustive understanding in such complex situations, the observer as knower must engage in a dialectic, circling back and forth between the two complementary conceptual contexts. The dynamic nature of such dialectical circling is necessary to be faithful to the diverse yet unitary character of the bipolar reality structure that is being pointed to. This understanding of complementarity as a circular relationship is similar to C. F. von Weizsaecker's efforts in both extending and modifying Bohr's complementarity interpretation of the wave and particle properties associated with a quantum object. Harold P. Nebelsick concisely summarizes von Weizsaecker's contribution as follows:

... It may, therefore, be necessary to realize that we now have to do with complementarity at two different *levels*. Building upon Bohr's Theory of Complementarity, in which he held the mutually exclusive understanding of the location and momentum of the particle together in the mind, von Weizsaecker has spoken of a concept of "circular complementarity" wherein it is necessary to allow our concepts of the different aspects of nature to be mutually and continually corrective. We must think of the one even as we focus on the other or, hold on to the one (hold it in our memory,) [*parentheses mine*] as we *walk through* the other. In addition, we have to do with a mind-matter circular complementarity, a complementarity in which mind and matter are partners in the selection—revelation process (or *selection-discovery* process,) [*parentheses mine*]. As mind attempts to understand and conceive of matter, so matter determines the parameters of such conceptions.¹¹

One possible form of the circular complementarity relationship analogy (CCRA) is shown in figure 2.

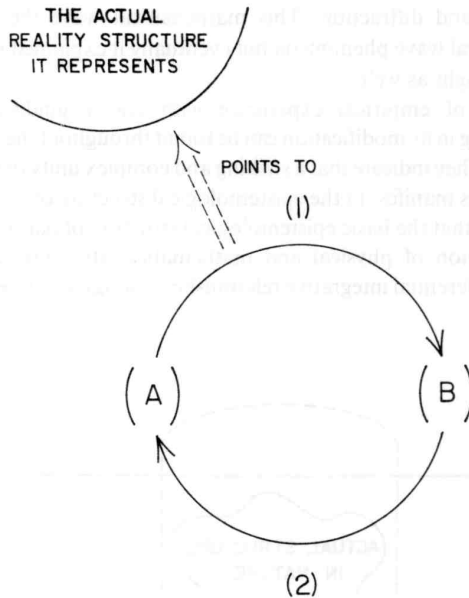


Figure 2. A circular complementarity relationship analogy (CCRA). (A) represents the set of observational concepts associated with one pole of a bipolar unitary structure; (B) represents the complementary set of observational concepts associated with the other pole of the unitary structure.

(1) As B is "listened to," knowledge of A fades out; A is known only indirectly, in memory.

(2) As A is "listened to," knowledge of B fades out; B is known only indirectly, in memory. As one circles back and forth between the sets of observational concepts associated with each pole, exhaustive knowledge emerges.

DIFFERENTIAL INTEGRATIVE RELATIONSHIPS IN NATURAL SCIENCE

When the historical development of natural science is examined one is constantly struck by the fact that truly creative advances have taken place when theoretical and empirical factors mutually modify each other. In this interplay creative advances often occur when mathematically expressed theoretical insight is guided by empirical experience of physical reality. This leads to modification of the original concepts and emergence of new theoretical insight. A few examples will illustrate the point. Newton developed the differential calculus as a theoretical framework for his famous laws of motion under the impact of quantitative, empirical studies of physical motion which were done by a host of earlier observers as well as by himself. Similarly, modern optics emerged when the study of interference patterns observed in mechanical waves, i.e., ripple patterns on the surface of water, stimulated mathematically inclined physicists to develop sophisticated mathematical tools which could adequately model the complexity of

wave interference and diffraction. This mathematical wave theory not only explained mechanical wave phenomena but eventually it explained many aspects of the behavior of light as well.

Such examples of empirical experience with reality guiding theoretical formulation resulting in its modification can be found throughout the development of natural science. They indicate that a striking and complex unity of the empirical and the theoretical is manifest in the epistemological structure of natural science. This unity suggests that the basic epistemological structure of natural science is a differential correlation of physical and mathematical structures and may be represented by a differential integrative relationship analogy as figure 3 illustrates.

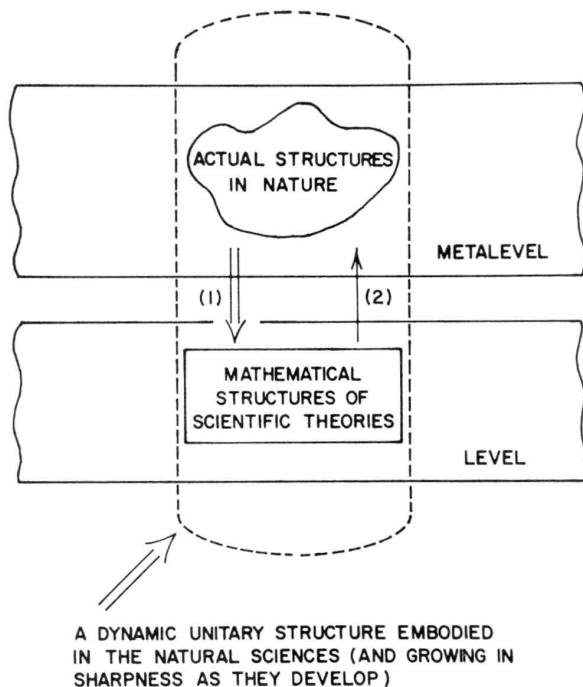


Figure 3. The epistemological structure of natural science, a differential unity of physical and mathematical structures. The integrative relations are as follows:

- (1) Control, sustain, reveal, suggest, . . .
- (2) Are dependent upon, are open to, point beyond to, . . . The epistemological level structure of natural science:

Metalevel-The empirical aspects of natural science.

Level-The theoretical aspects of natural science.

Such a unitary structure was termed by J. C. Maxwell "embodied mathematics," in which the mathematical ideas are presented to the human mind in an *embodied* form, as systems of entities and laws that are physically analogous to actual structures of nature (say systems of lines or forces), and not as merely *symbol systems* which neither convey the same mathematical ideas nor readily adapt themselves to explanations of actual physical phenomena. By physical analogy is meant a partial similarity between the laws of one science and those of another which make each of them illustrate the other. Such physical *clothing* of one's mathematical concepts can suggest meaningful physical interpretations of mathematical quantities when they are used in order to explain new physical phenomena; thus greater insight into physical problems is provided than can be obtained by formal analysis of analytic formulas. Maxwell's "embodied mathematics" is an activity in which one physically *clothes* mathematical concepts so that they may best provide the "opportunity of awakening those powers of thought which every fresh revelation of nature is fitted to call forth."¹² Lastly, let us note that the very success of this dynamic epistemological structure points beyond itself to an ontological unity which may also be differential in character.

This epistemological unity stresses that actual physical structures manifest in human experience of external reality ultimately judge (control, sustain) all mathematical theories. But such mathematical theories are not abstracted from experience of physical reality or chosen at random from available mathematical knowledge. Rather we look for mathematical structures rooted in personally held notions of beauty and elegance that will reveal "hidden" patterns capable of uniting the very complex surface regularities observed in actual experience of nature. That such informal methodology works has been attested by many creative scientists. To quote J. C. Polkinghorne: "However, it is interesting that such notions of economy and elegance, especially when expressed in mathematical form, have frequently proved valuable guides to a better understanding of the physical world. It is a recognized technique in elementary particle physics to seek theories that are compact and mathematically beautiful in the expectation that they will be the ones realized in nature. . . ."¹³ Indeed, it can be argued that the explanatory success of natural science is due to this fact "that mathematics, which essentially is the abstract free creation of the human mind, repeatedly provides the indispensable clue to the understanding of the physical world."¹⁴ Note the possibility exists that such "inventive" processes are revelatory in character. Mathematicians work under the compulsion of a rich variety of patterns embodied in nature. Such patterns are encountered in the totality of the mathematician's experience as a whole person. As Michael Polanyi has pointed out, this tacit indwelling of revelatory encounter with the rich patterns present in physical reality is a motivating component of the most abstract mathematical research. It is interesting to note that Albert Einstein also viewed his own scientific discoveries as rooted in inventiveness for he said, "For the creation of a theory, the mere collection of recorded phenomena never suffices—there must always be added a free invention of the human mind that attacks the matter."¹⁵ Again, Einstein's insight into his own creativity is consistent with the revelatory character

of acts of discovery if it is recognized that all creaturely freedom is never autonomous, but is, rather a freedom in relationship to reality. Inventiveness is an imaginative act and imagination properly understood is not set in distinction to sensory perception but in continuity with it. As Michael Polanyi has put it, imagination feeds upon experience and allows us to understand the world.

Our conceptual imagination, like its artistic counterpart, draws inspiration from contacts with experience. And like the works of imaginative art, the constructions of mathematics will tend therefore to disclose those hidden principles of the experienced world of which some scattered traces had first stimulated the imaginative process by which those constructions were conceived.¹⁶

In other words, we do not impose forms upon reality; ultimately reality always reveals (unveils) itself to us imposing its form upon all human cognition. Scientific creativity, understood in this context, is a free, responsive formulation arising out of empirical interactions with physical reality (often taking place at a tacit level). From a Judeo-Christian theological perspective such creativity is really *sub-creativity*, i.e., creativity under God, a creativity within the realm of nature using the potentiality in nature to create new entities. Scientists are not creating out of nothing as God did, but merely discovering possibilities that reside in what God has already made. In comprehending these possibilities we bring them into reality through insight and logic, a wedding of imagination and reason. In this way we are really bringing potentialities into being.

Polanyi's fundamental insight is that progress, in even a supposedly very abstract discipline like mathematics, has its origins in acts of discovery due to interactions of the human mind with physical reality (often at a tacit level) rather than in detached, purely inventive acts of the human mind. In the following extended quote from Roger Penrose, Rouse Ball Professor of Mathematics at Oxford University, Polanyi's insight is shared and further developed through consideration of the impact that physical space has on basic mathematical concepts including simple and complex N-dimensional geometries. In this quote Penrose, a physicist who has made important contributions to general relativity and elementary particle physics, elegantly reaffirms the physicist's basic faith in the existence of a deep correlation between the working of physical reality and the laws of the human mind. To quote Professor Penrose:

One of the most fruitful sources of *mathematical intuition* is *physical space*. For not only does physical space provide us with the *basic concepts* of *Euclidean geometry*, but it also gives us a *pictorial framework* for *visualizing* the very much *more general types of space* that occur continually throughout mathematics. Moreover, it was the *picture of physical space* that led to those key ideas of *mathematical analysis: continuity and smoothness*. Indeed, even the very basic *mathematical notion of real numbers* originated from *measurement of*

spatial separation—and of *time intervals* too, these being, as Albert Einstein's relativity has told us, geometrical quantities again, whose measurement is essentially bound up with that of space. So it comes as a shock when we also learn from relativity that our now cherished notion of Euclidean geometry does not, after all, describe physical space in the most accurate way. Yet, from these Euclidean beginnings, a more subtle and flexible geometry, known as differential geometry, has grown to maturity. It is in terms of this geometry that Einstein's theory finds expression. And now, more than sixty years after general relativity was first put forward as a daring original view of the world, the theory stands in excellent agreement with observation. So if we wish to understand how the world is shaped, we must come to terms with this theory. . . .

The physical theory of general relativity could not have evolved were it not for the work of many generations of mathematicians (in particular, Carl Friedrich Gauss and Bernhard Riemann) who were able to free geometry from its earlier imprisonment in Euclidean rigidity. But this debt to pure geometry that relativity had owed has now been amply repaid. For many of the ideas of the modern subject of differential geometry received their initial stimulus from concepts arising from Einstein's general relativity.

Thus we have, in the physics of relativity and in the mathematics of differential geometry, a supreme example which illustrates how physics and mathematics can enrich one another. Here we can begin to see something of that profound interplay between the workings of the natural world and the laws and sensitivity of thought—an interplay which, as knowledge and understanding increase, must surely ultimately reveal a yet deeper interdependence of one upon the other.¹⁷ [*Italics added.*]

A wide spectrum of evidence exists that lends further support to Polanyi's basic insight that all successful imaginative constructs of the human mind have a component of their origins rooted in the revelatory character of physical reality. Thus human cognition is a discovery rather than an inventive process. Further corroborating evidence from the natural sciences is now cited.

James Clerk Maxwell's truly great success as a mathematical physicist was, in no small part, due to his unusual ability to visualize mathematical operators and operations in a physical, often geometric, manner. In the course of developing his famous four partial-differential, vector equations that describe the electromagnetic field, he imagined space to be filled with vectors (arrows of different length and direction) that could be rotated by a suitable mathematical operator (The Curl). He also envisioned that vector-filled space as an imaginary fluid whose "sources" and "sinks" could be represented by another mathematical operator (The Divergence). Contemporaries were astounded by his ability to solve difficult

problems in mathematical analysis by making use of geometric analogies rather than long algebraic calculations. In his writings Maxwell stressed the usefulness of finding physical analogies with respect to mathematical operations, at the same time, carefully pointing out the limited, partial character of truth contained in any analogy. It is interesting to note that Maxwell's epistemological caution is similar to that expressed by the early church fathers, Athanasius and Hilary. Thomas F. Torrance has argued that his caution stemmed from his deep commitment to and knowledge of Christian theology.¹⁸

In a recent book Philip Kitcher¹⁹ attacks the widely held view that mathematical knowledge has its origin in experiential encounter with reality, which possesses a rich rather than impoverished structure. Professor Kitcher's argument may be summarized as follows:

... Mathematics (usually,) [*parenthesis mine*] is taken to be different from the natural sciences, independent of empirical evidence or the work of previous generations. Kitcher proposes an alternative approach, linking mathematics to natural science and portraying mathematics as a body of knowledge that evolves through its history. Specifically, he contends that the knowledge of contemporary mathematicians is grounded in the knowledge of their teachers and *that* knowledge, in its turn, derives from the wisdom of prior communities, ultimately descending from primitive mathematical knowledge which was acquired perceptually (in encountering physical reality,) [*parentheses mine*] by our remote ancestors.²⁰

Professor Kitcher's book is very carefully argued with ample historical and philosophical documentation; it poses serious questions for all who look upon mathematics as a purely *a priori* endeavor.

Lastly, Hans Christian von Baer, professor of physics at the College of William and Mary, in a recent article²¹ provides further confirmation of Polanyi's thesis that reality *reveals* itself to the scientist actively engaging it, "listening to it speak." Von Baer argues that a

CAT scanner's operation is a model for the way we solve scientific problems, and perhaps even for the way we perceive and reason. The machine is just one solution to what physicists call the inverse problem, a problem common to such disparate endeavors as prospecting for minerals, charting the earth's core, analyzing crystal, dissecting atoms—indeed, any effort to map and measure an object that cannot be seen. Regardless of the materials involved, the solution is the same: A stream of subatomic particles (or, *mutatis mutandis*, of radiation) is beamed toward the unknown target. The projectiles either are absorbed or they bounce off, and by carefully correlating the results of many encounters, one can detect a pattern and deduce from it the shape of the target. It is this backward tracing of the particle's path that gives the inverse method

its name. Of course, tracing hundreds of projectiles involves a volume of calculation only a fast digital computer can manage, which is why most practical uses for the inverse approach are quite recent. . . .

Yet it seems strange to think of the solution of inverse problems as a new approach in physics. The task of deducing reality from the observable data is the quintessential procedure of empirical science. If the inverse method is a novelty, then what have physicists been doing all these centuries? In a word, they have been guessing. (Such guessing becomes a viable possibility only when the scientist is completely immersed in his or her experience of reality's rich structure; i.e., the scientist must allow reality to "speak" as she or he "listens" to what is beyond oneself.) [*Parentheses mine.*] They have begun with observations, to be sure, and proceeded to discover the unknown—but not systematically. Rather, they have been jumping to conclusions before solving a single equation....

This direct approach (make a guess and see how it fits) rather than the inverse method, is a time-honored way of answering questions in science. Guided by intuition, imagination, and inspiration, . . . the trial-and-error approach is fundamental to scientific thinking, as Richard Feynman, a Nobel Laureate in physics, explained in *The Character of Physical Law*,

"In general, we look for a new law by the following process. First we guess it. Then we compute the consequences of the guess to see what would be implied if this law that we guessed is right. Then we compare the result of the computation to nature, with experiment or experience, compare it directly with observation, to see if it works. If it disagrees with experiment it is wrong. In that simple statement is the key to science."

The contrast between the direct and the inverse methods is poignantly illustrated by the story of the discovery of the structure of deoxyribonucleic acid. The crucial clues were the symmetrical but seemingly meaningless patterns of dots and streaks that appeared on X-ray photographs of crystallized DNA. James D. Watson, in *The Double Helix*, the highly personal account of how he and Francis Crick came to find the solution, praised Linus Pauling for demonstrating the advantage of a good guess over painstaking analysis of those photographs. In 1951, Pauling had shown that many proteins contain parts that are helical in form. "The helix had not been found," wrote Watson, "by only staring at X-ray pictures. . . . In place of pencil and paper, the main working tools were a set of molecular models superficially resembling the toys of preschool children." Watson and Crick, like Pauling, had built a

Tinkertoy-like model first, and only then did they compare their predictions with the photographs.

The Double Helix also tells the sad story of Rosalind Franklin, who produced the wonderfully sharp photographs of DNA that were essential to the discovery of its structure, but who failed to interpret them correctly because she disdained the use of models. Franklin attempted to deduce the structure of the DNA molecule from her photographs, and she was undone by her unwillingness to turn the inverse problem around. (She was unwilling to think in terms of physical analogies intuited from her whole-person scientific experience, not just the X-ray photographs. I would speculate that her prior research had been done with a segment of the scientific community attuned to postivistic methodology.) [*Parentheses mine.*]

Of course, Watson and Crick, like Rutherford and Pauling, had guessed correctly, and that made all the difference. But how did they guess? The best theorists, it would seem, get through the boring business of calculating forward faster than anybody else. By accelerating the process of trial and error, they have a better chance of hitting the right solution. Yet if that were the whole story, there would be no distinction between the idiot savant and the creative genius. Blind guessing, Feynman wrote, "is a dumb man's job." And he went on to trace the ways in which inspired hunches have come to him, and to provide guidelines for eliminating wrong assumption. But the real nature of scientific creativity, and of genius, remains elusive.

Perhaps the inverse approach has something to do with it. In a *Feeling for the Organism*, Evelyn Fox Keller's biography of the geneticist Barbara McClintock, who won a Nobel Prize in 1983, McClintock described being told about the discovery of corn plants near her laboratory with traits that seemed to defy the rules of heredity. She thought about the mystery, and suddenly the answer came to her. So great was her excitement and surprise, she said, that she ran out to the field and actually shouted "Eureka! Now, why," she asked, "did I know, without having done a thing on paper?"

The answer, for McClintock, lies in her long experience. She has a profound feeling for the organism, and this is not simply a matter of knowing more about her subjects than anyone else does. In all the years she has worked with corn plants, she believes, her mind has been analyzing far more information than she was aware of. (She even goes so far as to compare this subconscious process with the work of a computer.) Perhaps, then, a scientist's sudden flash of intuition is actually the solution of an inverse problem of years' standing, patiently

worked through by the subconscious. (Polanyi would argue that scientific intuition is a direct consequence of the scientist *indwelling*, i.e., tacitly absorbing, all her or his experience of external reality. Such tacit knowledge, according to Polanyi, may or may not take place at the subconscious level." [*Parentheses mine.*]²²

Thus the success of natural science is rooted in a remarkable epistemological unity as manifested by the marriage of physical and mathematical structure. Such epistemological unity is suggestive of an ontological unity resulting from the differential integration of intelligibility and the actual structures existing at all levels of created reality, i.e., the Universe. Figure 4 illustrates this unity. To explore

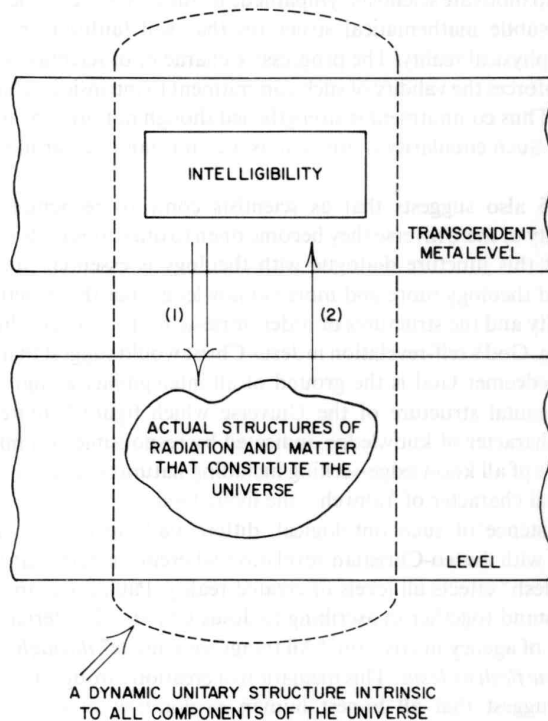


Figure 4. The ontological structure of natural science, a differential unity of intelligibility and the physical structures that constitute the Universe. The integrative relations are as follows:

- (1) Controls, sustains, . . .
- (2) Are dependent upon, are open to, point beyond to, . . .

A level structure intrinsic to the Universe which the surprising success of natural science points to:

Transcendent Metalevel-A surprising intelligibility consisting of lawful patterns similar to those of human thought (and going beyond current human thought).

Level-The physical structures of our space-time Universe.

further implications of this suggested unity, let us now turn to the theological dimension of human existence.

A THEOLOGICAL PERSPECTIVE

The differential grounding of epistemological intelligibility in a deeper ontological intelligibility is illustrated in figure 5. Such differential grounding can be biblically characterized as a covenantal structure intrinsic to the Universe. Its reliability is a consequence of the faithfulness of God and cannot be proved but is recognized as one commits oneself to its existence. Such commitment has motivated and continues to motivate scientists sympathetic to Judeo-Christian theology to search for more subtle mathematical structures that will faithfully represent deeper aspects of physical reality. The progressive character of scientific knowledge that results reinforces the validity of such commitment to intrinsic intelligibility hidden in nature. Thus commitment is strengthened though not proven, as the argument is circular. Such circularity is nonvicious, i.e., it is not circular in a self-defeating way.²³

Figure 5 also suggests that as scientists come to recognize such intrinsic intelligibility of the Universe they become open to questions of its meaning and its source. At this juncture dialogue with theology is essential, for both natural science and theology more and more acknowledge that the structures of human intelligibility and the structures of order intrinsic to the Universe have something in common. God's self-revelation in Jesus Christ would suggest that the love of the Creator-Redeemer God is the ground of all intelligibility as figure 5 illustrates. This covenantal structure of the Universe which figure 5 represents and the personal character of knowledge, indicated by responsible commitment being a component of all knowledge-seeking including natural science, are reflections of the personal character of Yahweh—the living God.

The existence of such ontological, differentially-structured unity is indeed consistent with Judeo-Christian revelation wherein the fact that the "Word has become Flesh" effects all levels of created reality. Paul, John and the author of Hebrews stand together in ascribing to Jesus Christ—the eternal Word of God some kind of agency in creation: "All things were made" *through the eternal Son who became flesh in Jesus*. This mediation of creation through Jesus Christ would strongly suggest that all honest human exploration of reality, scientifically, artistically, ...can result in actual discoveries. For the Universe we are exploring owes its origin to a God who made it with direct reference to one who was to become incarnate in it as a fellow human being. Is it not reasonable therefore to find that the Universe is indeed a proper place for human beings to use their senses, minds and imaginations in the expectation that they will not be deceived in doing so? Is not the intelligibility of the Universe a result of the continual creativity of the Creator-Redeemer God as He sustains all reality?

An affirmative answer to these questions can keep alive and restore the confidence that is essential to the motivation of all exploratory activity.

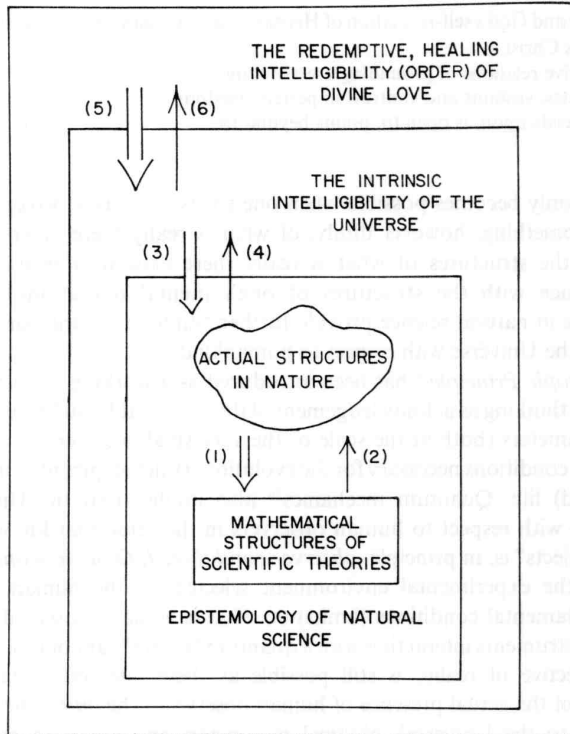


Figure 5. *The Theological Grounding of Natural Science*

The following schema provides a theological perspective with respect to the success of natural science in enabling human observer-knowers to understand the Universe, non-living and living.

Description of the Schema

A. The epistemology of natural science is a unity of physical and mathematical structures in differential integrative relationship as follows:

- (1) Control, sustain, reveal, suggest, . . .
- (2) Depend upon, are open to, point beyond to, . . .

Thus what is represented is an epistemological unity incarnate (in the sense of embodied in) in the natural sciences, growing in sharpness as they develop.

B. The epistemology of natural science is differentially grounded in (or embedded in) a "deeper" ontological order — the intrinsic intelligibility of the Universe which manifests itself at all levels of created reality. This differential grounding establishes a unity of epistemology and ontology incarnate in (integral to) the space-time Universe (which includes intelligent, human observer-knowers). The integrative relations of grounding are as follows:

- (3) Controls, sustains, . . .
- (4) Depends upon, is open to, points to, . . .

C. This unitary epistemological-ontological structure is differentially grounded in a "deeper" uncreated order — the redemptive healing intelligibility of divine love. Such a differential grounding establishes a profound unity between uncreated (eternal) and created reality (timebound) which can be heard by the "ear" of faith open to the truth revealed in

natural science and God's self-revelation of His nature as love manifest in space-time in the incarnate Jesus Christ.

The integrative relations of grounding are as follows:

- (5) Creates, sustains and controls in perfect freedom.
- (6) Depends upon, is open to, points beyond to.

Exploration only becomes possible when one trusts that one's perceptions can experience something, however dimly, of what is really there independent of oneself and the structures of what is really there exist in a relationship of correspondence with the structures of one's mental operations.²⁴ Recent developments in natural science provide further "hints" as to the participatory character of the Universe with respect to humankind.

*The Anthropic Principle*²⁵ has been introduced as a working hypothesis into cosmological thinking as acknowledgement of the remarkable "fit" between basic physical parameters (both at the scale of the very small and very large) of the Universe and conditions necessary for the evolutionary development of intelligent (carbon-based) life. Quantum mechanics²⁶ also implies that the Universe is participatory with respect to human observers in the sense that knowledge of quantum "objects" is, in principle, *observer-conditioned*. *Observer-conditioning* means that the experimental environment selected by the human observer imposes fundamental conditions (limits) on what is actually observed, i.e., the measuring instruments interaction with a quantum "object" cannot be ignored. A realist perspective of reality is still possible as these interactions take place independent of the actual presence of human observers. The *anthropic evidence* with respect to the Universe's physical parameters and quantum mechanics' recognition that understanding of quantum "objects" is always *observer-conditioned* together reinforce the notion that humankind participates in fundamental ways in the Universe's very existence and evolutionary development. This participatory character of the Universe with respect to humankind can be looked upon as one facet of Judeo-Christian theology's recognition that both physical reality and human observers were created and are sustained by a God who *entered into His own creation*.

Lastly let me make one further suggestion with respect to the underlying unity that biblical and scientific knowledge point to, often in complementary ways. The "participatory" Universe is in harmony with Thomas F. Torrance's insight that the success of the scientific enterprise points to the Universe being ontologically grounded in a redemptive, healing intelligibility rooted in divine love.²⁷ If this is true, the nature miracles of Jesus—the calming of the sea, the feeding of hungry multitudes, the turning of water into wine at the wedding feast—may be understood as illustrations of God's sovereign loving intelligibility manifest in His rule over the entire Creation. Indeed it is quite fitting that the One the gospel writers witness to as the "Word became flesh" should guide physical processes continually sustained by Him in such a way as to benefit concrete members of the human race. These miracles, rather than being intrusions of God into natural processes no longer dependent on His sustaining activity, were concrete

manifestations of God's redemptive intelligibility as He continually sustains all the natural processes of the Universe to ultimately benefit humankind. Thus, the knowledge of the Creator-Redeemer God that Jesus reveals to us through the nature miracles complements the knowledge of the participatory intelligibility of the Universe revealed to us by modern science. This latter, created intelligibility enables humankind, as priests of creation, to fulfill their unique individual and communal roles in the redemptive plan of the loving, Creator God who continually sustains all.

THEOLOGY — "A THANKFUL AND HAPPY SCIENCE"²⁸

Our discussion has centered upon differential relationship analogy as a way of pointing to natural science's unified epistemological unity in an ontological intelligibility and to suggest how such grounding appears in the light of Judeo-Christian theology. At this point it is appropriate to ask in what sense is theology itself a science, and do relationship analogies play a role in its thought patterns.

The mature opinion of Karl Barth, the century's ablest theologian, on the scientific character of theology is particularly instructive. His comments give us a deep, humility-embedded insight into the true nature of scientific activity.

Evangelical theology is concerned with Immanuel, God with us! Having this God for its object, it can be nothing else but the most thankful and happy science.²⁹ Dogmatics (theology,) [*parentheses mine*] is the science in which the church with the state of its knowledge at different times, takes account of the content of its proclamation critically, that is, by the standard of Holy Scripture and under the guidance of its confessions. . . . by science we understand an attempt at comprehension and exposition, at investigation and instruction, which is related to a definite object and sphere of activity . . . all sciences are attempts which by nature are preliminary and limited. Wherever science is taken in practice completely seriously, we are under no illusion that anything man can do ever will be an undertaking of supreme wisdom and final art, that there exists an absolute science, one that as it were has fallen from Heaven. . . . In every science an object is involved and a sphere of activity. In no science, is it a matter of pure theory or pure practice; on the one hand, theory comes in, but also, on the other hand, practice guided by this theory. So by dogmatics, too, we understand this two-fold activity of investigation and doctrine in relation to an object and sphere of activity. . . . We must always be putting the question "What is evidence?" Not the evidence of my thoughts, or my heart, but the evidence of the apostles and prophets, as the evidence of God's self-evidence. Should a dogmatics lose sight of this standard, it would be irrelevant dogmatics.³⁰

Theology in Barth's view is not a *closed deductive system*, but rather an *open reasoned response* motivated by gratitude for what God has revealed of Himself in

Holy Scripture and His Universe which includes human observers. Theology and natural science are thus both seen to be open reasoned responses in their respective explorations of different and distinctive domains of a common reality. Accordingly, one might expect to find epistemological affinities between theology and natural science, i.e., there may be an underlying unity in the thought patterns of theology and natural science. In the light of this last point, it is interesting to note that 1986 is the centennial of not only Karl Barth but also Neils Bohr, the pioneering physicist. Bohr developed the *Principle of Complementarity* as he came to recognize that physical reality always reveals what can be known of its intrinsic structure by means of an interaction between objects of nature and the observer—through the observing apparatus chosen by the observer. He recognized that the wave and particle aspects of matter do not directly describe what a quantum object is; they rather, describe the nature of the relationship between the object and the experimental apparatus used to observe it. Furthermore both wave and particle aspects of the object-observer relationship are required for exhaustive understanding, but both wave and particle aspects cannot be simultaneously observed due to the mutually exclusive character of their experimental, observational contexts. Out of grappling with such problems, Bohr's complementarity thinking arose. It is noteworthy that Barth developed what corresponds to a complementarity understanding as he wrestled with the similar problem of how God reveals himself to humankind by means of interacting with humankind in the events of space-time history. Thus both of these thinkers made use of what corresponds to a complementarity analogy in their respective disciplines of theology and natural science. It is worth noting that in doing so the two thinkers were apparently not aware of each other's work. Although there is evidence both were influenced by the theologian, Sören Kierkegaard.³¹

Barth,³² to cite one example, made use of what corresponds to a complementarity perspective in his discussion of:

1. The relation in the Old Testament between Yahweh's old and new covenants with Israel (Exodus 19 and Jeremiah 31).

2. The relation in the Old Testament between the predictions of salvation and predictions of disaster by the prophets.

3. The relation in the New Testament, synoptic and Johannine traditions, with respect to the humanity and deity of Jesus Christ..

Both pairs of concepts associated with relations (1) through (3) are scripturally taught and must be taken into account in order to have exhaustive knowledge of the rich complexity of God's dealings with humankind. However, misunderstandings will arise if we attempt to measure one in terms of the other, or seek to balance the one by the other; for the pair of concepts of each relation are defined in mutually exclusive contexts. What Barth suggests we do is listen to both but not at the same time; as one tunes in or hears one, the other can only be heard indirectly, by faith. By circling back and forth between the two concepts of these relations, holding one concept in memory (i.e., by faith) as we listen to the other, exhaustive knowledge emerges as the circular complementarity relationship analogy of figure 2 suggests.

Furthermore, a plausible argument can be made from Barth's writings that he saw what is similar to circular complementarity as an imprecise description of a much richer type of relationship. In discussing the knowability of the Word of God and faith,³³ he suggests with respect to the theology of the Reformers that relating Word and Faith in what corresponds to the conceptual framework of circular complementarity is an *imprecise description* of a much *richer relationship* between Word and faith. In this richer relationship, Word "controls" faith, faith is utterly dependent upon the Word of God, i.e., God's existence and self-revelation. This latter conceptual relationship is suggestive of the differential integrative relationship analogy. It is thus plausible to interpret Barth as saying that what corresponds to both complementarity and differential integrative relationships point beyond themselves to the inexhaustible richness of God's self-revelation in Jesus Christ with the complementarity relationship analogy being a "projected" aspect of the fuller differential integrative relationship analogy.

In addition, there are other of Barth's theological discussions that may be understood from the perspective of the differential integrative relationship analogy. As one example, Barth characterizes the Holy Spirit as *binding together* the "invisible," indwelling presence of the risen Jesus Christ and the "visible" community of believers to form a dynamic, unitary structure incarnate in the people of God, the Church.³⁴ The Holy Spirit accomplishes this binding together by creating and sustaining what corresponds to differential relationship in which the presence of Christ continually *molds* the believing community while, reciprocally, the believing community is continually *responsive to* and *open to* their Lord. The differential integrative relationship analogy of figure 1 represents this insight of Barth if pole A is taken to be the risen Christ and pole B is the community of believers with the differential relationship that binds both together into a unitary structure being an ongoing activity of the Holy Spirit.³⁵

The very fact that one can use such mathematically structured analogies, complementarity or differential, in character, borrowed from natural science's thought patterns, in describing theological thought is indicative of underlying unities existing between theological and scientific thinking. As a natural scientist, it greatly strengthens my conviction that theology can be thought of as a science.

SOME COMMENTS ON THE APPROPRIATENESS OF ANALOGIES IN NATURAL SCIENCE AND THEOLOGY

All analogies³⁶ are meant to point beyond themselves toward a limited domain of external reality. They are considered successful if they faithfully "mirror" a key aspect of that limited domain. If successful, the insight that they give us can be thought of as partial, non-exhaustive truth concerning external reality. This forming of mental analogies seems to be part of the mind's creative activity. Einstein commented that thinking in images was a key aspect of his scientific creativity. Earlier I argued that such analogies arise in the mind through experience of external reality. It is appropriate to use analogies in science if:

- a. One does not think of the analogies *as realities in themselves*.

b. Rather, one thinks *through* the analogies to the realities they refer to, that is, point beyond to themselves to.

In Michael Polanyi's terminology, we indwell images and analogies to help us "focus" upon and better understand the realities that they point to.

Calvin made essentially the same point when he suggested that the Bible is like a pair of spectacles that helps a person focus on the reality it points to—the living God, Immanuel, God with us. Note that the Bible contains a multiplicity of analogies with respect to God's existence, nature and actions. The rich variety of biblical representations may serve to make us more fully aware that knowledge of God is inexhaustible. Any one analogy provides a partial, limited nature of God and can even lead to error if considered apart from its particular, biblical context. In both theology and natural science it is important clearly to understand the context in which an analogy is embedded.

Notes

1. Niels Bohr, *Atomic Physics and Human Knowledge* (New York: Science Editions, Inc., 1961), in particular the essays "Light and Life," pp. 3-12 and "Discussion with Einstein on Epistemological Problems in Atomic Physics," pp. 32-66.

2. Aage Petersen, "The Philosophy of Niels Bohr" in *Niels Bohr—A Centenary Volume*, edited by A. P. French and P. J. Penny (Cambridge: Harvard University Press, 1985), pp. 299-310.

3. A precise, non-technical description of The Uncertainty Principle is contained in *The Quantum World* by J. C. Polkinghorne (London: Longwood Group Limited, 1984), pp. 44-59.

4. Christopher B. Kaiser, "The Logic of Complementarity in Science and Theology," Ph.D. Thesis, The University of Edinburgh, 1974, in particular chapter 2, "Bohr's Use of Complementarity in Atomic Physics," pp. 49-72. Available on microfilm from the University of Chicago, the Joseph Regenstein Library, Dept. of Photo Duplication, 1100 East 57th St., Chicago, IL 60637.

5. William G. Pollard, "Rumors of Transcendence in Physics," *American Journal of Physics*, 52 (Oct 1984): 877-881.

6. Polkinghorne, pp. 40-41.

7. Michael Polanyi's profound discussion of the personal character of all knowledge is based upon his definition of reality "as that which may yet inexhaustively manifest itself" (*Knowing and Being*, p. 141). He arrives at this definition from a detailed examination of the process of scientific discovery. See:

a. Michael Polanyi, *Personal Knowledge* (Chicago: The University of Chicago Press, 1958).

b. Michael Polanyi, *Knowing and Being*, edited by Marjorie Frene, (Chicago: The University of Chicago Press, 1969).

c. Drusilla Scott, *Everyman Revived—The Common Sense of Michael Polanyi*, (Sussex, U.K.: The Book Guild Limited, 1985). This book is an excellent, very readable overview of the work of Michael Polanyi.

- d. Dr. W. Jim Neidhardt, "The Open-Endedness of Scientific Truth," *Interdisciplinary Biblical Research Institute*, 1982. Obtainable from IBRI, P.O. Box 423, Hatfield, PA 1940.
8. Polanyi, *Knowing and Being*, pp. 152-155. Polanyi's concept of dual control is a form of differential relationship.
9. N. Bohr. Complementarity is discussed.
10. C. F. von Weizsaecker, "Komplementaritaet und Logik," *Die Naturwissenschaften* 42 (1955): 521-529, 545-555. Circular complementarity is discussed.
11. Harold P. Nebelsick, "Theological Clues from the Scientific World," *Journal of the American Scientific Affiliation* 38 (1986): 110-121. The relationship of von Weizsaecker's "circular complementarity" is a complex subtle issue not yet fully resolved. For additional discussion of this issue see:
 - a. von Weizsaecker, "Komplementaritaet und Logik."
 - b. Kaiser, pp. 137-142.
 - c. Max Jammer, *The Philosophy of Quantum Mechanics* (New York: John Wiley & Sons, 1974), pp. 102-104. Professor Nebelsick, I believe, has correctly assessed this complex situation in suggesting that von Weizsaecker's "circular complementarity" is an enlargement of Bohr's Theory of Complementarity as applied to quantum systems.
12. Richard Olson, *Scottish Philosophy and British Physics, 1750-1800* (Princeton: Princeton University Press, 1975), in particular the section "Embodied Mathematics and Physical Analogies," pp. 299-312.
13. J. P. Polkinghorne, *The Particle Play* (Oxford: W. H. Freeman and Company, 1979), p. 2.
14. *Ibid.*, p. 125.
15. Heinz R. Pagels, *The Cosmic Code* (New York: Simon and Schuster, 1982), p. 58.
16. Polanyi, *Personal Knowledge*, p. 46.
17. Roger Penrose, "The Geometry of the Universe," in *Mathematics Today*, edited by Lynn Arthur Steen, (New York: Vintage Books, 1980), pp. 83-84.
18. Olson, "Thomas Brown and William Hamilton: The Relativity of Scientific Knowledge and the Triumph of Simplicity and Analogy," pp. 125-153, "Culmination of the Tradition: Metaphysics and Method in the Works of James Clerk Maxwell," pp. 287-335. Martin Goldman, *The Demon in the Aether* (Edinburgh: Paul Harrison Publishing Co., 1983). Hilary's discussion on the use of analogies in order to better understand God's nature is similar to Maxwell's discussion on the use of analogies to reveal further truth with respect to physical reality. See "On the Trinity—Book I," contained in *St. Hilary of Potiers—Select Works*, edited by the Rev. W. Sonday, (Grand Rapids: Wm. B. Eerdmans Publishing Company, 1979), pp. 45-46. Thomas F. Torrance, "Christian Faith and Physical Science in the Thought of James Clerk Maxwell," in *Transformations & Convergence in the Frame of Knowledge*, (Eerdmans, 1984), pp. 215-242.
19. Philip Kitcher, *The Nature of Mathematical Knowledge*, (London: Oxford University Press, 1983).
20. *Ibid.*, book jacket.
21. Hans Christian von Baer, "The Inverse Problem," *The Sciences* (Nov/Dec 1985): 13-14.
22. *Ibid.*
23. Thomas F. Torrance, "Classical and Modern Attitudes of Mind" and "The Status of Natural Theology," in *Reality and Scientific Theology* (Edinburgh: Scottish Academic

Press, 1985), pp. 1-63. See also Thomas F. Torrance, *Divine and Contingent Order* (Oxford: Oxford Press, 1981).

24. Colin Gunton, *Enlightenment & Alienation* (Grand Rapids: William B. Eerdmans Publishing Co., 1985). The ideas expressed in this paragraph are a major theme of the book.

25. George Gale, "The Anthropic Principle," *Scientific American* 245 (1981): 154-171. Henry T. Simmons, "Redefining the Cosmos," *Mosaic* 13 (March/April 1982): 16-22. W. Jim Neidhardt, "The Anthropic Principle: A Religious Response," *Journal of the American Scientific Affiliation* 36 (1984): 201-207.

26. Polkinghorne, *The Quantum World*. Richard H. Bube, "Reality According to Quantum Mechanics," *Journal of the American Scientific Affiliation* 1 (1984): 37-38. Fritz Rohrlich, "Facing Quantum Mechanical Reality," *Science* 221 (No. 4617, 1983): 1251-1255.

27. This theological position has been succinctly summarized by Thomas F. Torrance as follows:

"Now it is to *man* himself that we are to look for help at these crucial junctures (those junctures where physical theories reach their limits and point beyond themselves to a transcendent source of intelligibility), [*parenthesis mine*], it must surely be to man who is tuned in to the Central Order of all things, to God himself whose being is the ultimate ground of all contingent existence and whose love is the power of all contingent order. And yet, strongly, man is the one creature within the universe who straddles more than any other the boundary between order and disorder, for somehow, quite unexplicably, he has become alienated in his mind from God, disorderly in himself and is an infectious source of disorder in nature. This does not mean that man is deprived of his central role in the created universe, but rather that he may mediate order only as he himself is reconciled to God and healed of his own personal and inter-personal disorder. As the priest of creation he is not a means of order in himself, but can only mediate order from the transcendent source of order-beyond himself." T. F. Torrance, *The Christian Frame of Mind* (Edinburgh: The Handsel Press, 1985), pp. 46-47. This theological perspective is carefully worked out in the book's third chapter, "Man, the Mediator of Order," pp. 29-47.

28. Karl Barth, *Evangelical Theology: An Introduction* (Grand Rapids: William B. Eerdmans Publishing Co., 1963), p. 12. An excellent overview of K. Barth's position on theology as a science is contained in Harold P. Nebelsick, "Karl Barth's understanding of Science," to be published in 1986 in a centenary volume for Karl Barth. For a reprint write the author at Louisville Presbyterian Theological Seminary, 1044 Alta Vista Road, Louisville, KY 40205.

29. K. Barth, *Ibid.*, p. 12.

30. Karl Barth, *Dogmatics in Outline* (New York: Harper & Row, Publishers, 1959), pp. 9-14.

31. Harold P. Nebelsick, *Theology and Science in Mutual Modification* (New York: Oxford University Press, 1981), pp. 159-166. Barth's indebtedness to Kierkegaard is well known. The possible influence of Kierkegaard on Bohr's thought is discussed in:

- a. Russell Stannard, *Science and the Renewal of Belief* (London: SCM Press Ltd, 1982), pp. 165-166.
- b. Gerald Holton, *Thematic Origins of Scientific Thought* (Cambridge: Harvard University Press, 1973), pp. 144-149.

32. Karl Barth, *Church Dogmatics I/1*, edited by G. W. Bromiley, and T. F. Torrance, (Edinburgh: T. & T. Clark Ltd., 1975), pp. 179-181.

33. *Ibid.*, pp. 230-236.

34. Karl Barth, *Church Dogmatics IV/3.2*, edited by G. W. Bromiley and T. F. Torrance, (Edinburgh: Clark, 1962), pp. 742-762.

35. This suggests that a vital aspect of the Holy Spirit's redemptive role toward all of Creation, human and non-human, is the binding together by means of reciprocal relationship components of ontological and epistemological configurations to form unitary structures. In figure 1, the "imperceptible" relationship with its reciprocal, asymmetric relations between "more perceptible" poles may be viewed as an ongoing manifestation of the Holy Spirit. From this perspective it is the Holy Spirit that inspires scientists into an awareness of the often unexpected correlations between physical and mathematical structures that results in the epistemological unity of natural science illustrated in figure 3. Thus integrative relations (1) and (2) of figure 3 emerge through the inspirational activity of the Holy Spirit in the thought processes of natural scientists. *The Westminster Confession of Faith* points toward such a role for the Holy Spirit in Chapter IX — *Of the Holy Spirit*, paragraph 2, where it states: "He is the Lord and Giver of life, everywhere present, and is the source of *all good thoughts* and holy counsels in men (*italics added*)."

36. R. Olson, "Thomas Brown and William Hamilton: The Relativity of Scientific Knowledge and the Triumph of Simplicity and Analogy," pp. 125-153, "Culminating of the Tradition: Metaphysics and Method in the Works of James Clerk Maxwell," pp. 287-321. See also Thomas F. Torrance, *Theological Science* (London: Oxford University Press, 1969). Vern Sheridan Poythress, "Science as Allegory," *Journal of the American Scientific Affiliation* 35 (No. 2, 1983): 65-71. Poythress, "Newton's Laws as Allegory," *JASA* 35 (No. 3, 1983): 156-161. Poythress, "Mathematics as Rhyme," *JASA* 35 (No. 4, 1983): 196-202.

ACKNOWLEDGEMENTS

The author wishes to thank Harold P. Nebelsick, Thomas F. Torrance, Lee Wyatt, and James E. Loder for numerous stimulating suggestions with respect to this essay. Any misunderstandings contained within are, of course, my sole responsibility and not theirs. The author also wishes to thank New Jersey Institute of Technology for granting him a sabbatical leave to work on this project and Louisville Presbyterian Theological Seminary for appointing him visiting scholar, fall term, 1985.

