Arie Leegwater

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Dead Chemists Do Tell Tales: The Religious Shaping of Chemical Knowledge

Arie Leegwater

This article offers an analysis of the science-religion relationship in the thought and practice of two influential chemists: F. Wilhelm Ostwald and Charles A. Coulson, who lived during the formative period of modern chemistry (1870s–1950s). I examine Ostwald's program for an "allgemeine Chemie" and Coulson's program for quantum chemistry, explore the deeper implications/basic beliefs at stake in these developments, and suggest why the "received" interpretation of the relation of science and religion may be inadequate for an understanding of their work.

Keywords: Religion and cognitive beliefs, Wilhelm Ostwald, energetics (an "allgemeine Chemie"), Charles A. Coulson, quantum chemistry, history of science, religion and science.

What bearing do religious beliefs have on the development of chemical theories and practice? Does Wilhelm Ostwald's proposal of a chemical energeticism reflect in some way his positivistic outlook and his eventual elaboration of an atheistic monism? Does the "phasen-leer" (phase theory) as promoted by H. W. B. Roozeboom display his Dutch Reformed background? Was Linus Pauling's development of structural chemistry related at all to his western American devil-may-care attitude toward religion and his support of liberal causes? Does Charles Coulson's framework for quantum chemistry reflect his English Methodism? Posing the question in this way: how religion influences cognitive beliefs and affects practices in modern science such as late nineteenth-century and mid-twentieth-century chemistry makes us, as moderns, feel uncomfortable.

Arie Leegwater *(PhD in Chemistry, Ohio State University) is Professor of Chemistry Emeritus at Calvin University and a Fellow of the ASA. He taught courses in chemistry and history of science. He is also co-author of* Responsible Technology: A Christian Perspective *(Eerdmans) and a former editor of* PSCF *(2008–2011).*

Martin Rudwick, a historian of science, once perceptively commented,

> … the strength of the historian's empathy for religious beliefs often seems to be directly proportional to the space of time that separates him from them, fading away as one approaches the present day.[1]

However, over the past four decades or more, historians of science have paid increasing attention to religion and religious beliefs. These beliefs have even been allowed to play a role as one among many factors affecting the development of science.[2]

A historian may more easily detect the influence of religious beliefs when investigating a powerful and influential individual. One can then hopefully find the person (actor) reflected in their scientific work. One must look to the

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problems the scientist chooses to work on, the kind of mathematical argument that they bring to bear, the experimental evidence they marshal and the conceptual experiments they devise, to what they take as basic and what subsidiary, to what they find easy or evident and what they find difficult and in need of discussion, to what they perceive as the range and scope of the theory, both with respect to the subject proper and to its impingement on other areas. In short, such studies need to be sensitive to various traditions in which each individual finds their place—either by spirited reaction or quiet acceptance.

These questions will be further explored using two historical examples: the chemical practice of the German Nobel prize-winning chemist Wilhelm Ostwald (1853–1932) and the work of Charles Alfred Coulson (1910–1974), an English-Methodist quantum chemist and Rouse Ball Professor of Mathematics at Oxford University. More specifically, this article will

(1) examine Ostwald's program for an "allgemeine Chemie" (general chemistry) and Coulson's program for quantum chemistry,

(2) explore the deeper implications/basic beliefs at stake in these developments, and

(3) suggest why the "received" interpretation of the relationship of science and religion may be inadequate for an analysis of their work.

My aim will be to understand the scientists in action: their effort to religiously shape *chemical* knowledge. I do not aim to provide an historically detailed account of their subsequent cultural engagement and influence. Rather, I wish to pay attention to their contribution in a specific area of *chemical* science.

Wilhelm Ostwald and Energetics (*Energetik*)

Until recently, little attention has been paid to the daring assumptions and consequences of Wilhelm Ostwald's program of energetics (*Energetik*).[3] Ostwald, a German physical chemist, who was awarded the Nobel Prize in Chemistry in 1909 for his "works on catalysis as well as for fundamental investigations of chemical equilibrium and reaction velocities,"[4] was one of the most celebrated German scientists at the turn of the twentieth century. As a student in Dorpat (University of Tartu) and professor at the Riga Polytechnikum, he did extensive studies in chemical affinity (*Verwantdschaftslehre*). Of note were two lengthy series: "*Studien zur chemischen Dynamik*" (1884–1888) and "*Elektrochemischen Studien*" (1884–1888). He had also written a two-volume *Lehrbuch der allgemeinen Chemie* (1885/1887). In 1887, he founded (and co-edited with J. H. van't Hoff) the first physical chemistry journal, *Zeitschrift für physikalische Chemie, Stöchiometrie und Verwantdschaftslehre*. Clearly, Ostwald was a man of considerable talent: a skillful experimenter, an adept organizer, an excellent teacher, and a persuasive expositor.

In 1887, Ostwald was appointed to the only German university chair in physical chemistry in Leipzig. In his inaugural address, Ostwald drew a parallel between the Law of Mass Action "which rests on the persistence of matter, and chemical affinity laws, which rest on the persistence of chemical energy."[5] But, Ostwald was determined to go beyond simple parallel comparisons. He insisted that chemistry required extensive reform. It lacked the simple and general laws of mechanics that Heinrich Hertz claimed characterized much of physics.[6] Ostwald wanted to develop a general chemistry (an "*allgemeine Chemie*"), which would undergird all the subspecialties of chemistry. His aim was to be constructive, to reconstruct and reformulate the principles of chemistry along more general and intuitive lines. He considered a good chemical theory to be one that satisfied two requirements: (1) it should consist of functional relations among measurable quantities; and (2) it must provide a main or general law from which special laws referring to particular systems could be derived.[7] Chemistry should be cleansed of as many hypotheses as possible.[8]

Ostwald proposed a research program called *Energetik* (energetics) which drew its inspiration from the success of thermodynamics in describing the principal relationships in physical chemistry without resorting to atomic and molecular models. Ostwald held that the ills of late nineteenth-century physics and chemistry could be addressed by the simple expedient of discarding the model—and indeed all models—and reducing physics and chemistry to an account of the conservation and transformation of energy. The unification of chemistry and the establishment of an "*allgemeine Chemie*" could not depend on mechanics as the integrating and foundational theory, but rather requires generalized thermodynamics (or energetics) which appeals to observables and empirical data such as temperature, pressure, active mass (concentration), etc. Ostwald longed to give expression to his energetic vision so vividly described in his "conversion experience" in 1890:

> In the earliest morning hour I walked from my hotel to the zoological garden [Tiergarten], where I experienced in the sunshine of a marvelous spring morning a true Pentecost, an outpouring of the spirit over me … Everything regarded me with new unaccustomed eyes, and I felt as if I were experiencing all of these blisses and splendors for the first time … The thought process required for the general formation of the energetic conception of the world then took place without any effort—indeed, with positive feelings of bliss. All things looked at me as if I had just been placed in Eden, in accordance with the Biblical account of creation, and was now giving each thing its true name.[9]

This description, forty years after the event, could easily be an embellished account, particularly with all its biblical imagery. But this account, embellished or not, does indicate how serious Ostwald was in being an apostle of energy and how zealous he was in propagating his gospel of energy. The ontological key to understanding reality was at hand. Energy had received its "true name."[10]

Ostwald's focus on energy as the explanatory principle and final constituent of reality developed through various phases during 1887–1905: sequentially (1) a challenge to physical atomism (kinetic molecular theory), (2) a particular interpretation of thermodynamics and method of energy analysis, (3) a search for an alternative to chemical atomic theory, and finally (4) the formulation of "*eine Chemie ohne Stoffe*" (a chemistry without matter/substances).[11]

Initially, in Oswald's self-described period of "*Unbewusste* [unconscious] *Energetik*" (1887–1892), energy and matter had ontological parity. But soon thereafter (1893–1902), energy gained priority and supremacy—conceptually, methodologically, and ontologically. Matter, he argued, "is nothing but a complex of energy factors."[12] Energy has a right (besides space, time, and an intensity or capacity factor of energy) to be the central concept, since everything that happens is in the final instance nothing but a change of energy.[13]

It would take me too far afield to describe all the details of this energy doctrine. In brief, Ostwald formulated two laws of energetics: (1) "*Die Gesamtmenge* [total quantity] *der Energie ist konstant*," and (2) "*Zwei Gebilde, die einzelnen mit einem dritten in Energiegleichgewicht sind, sind auch einander gleich*" (Two systems that are in energy equilibrium with a third are also equal to each other—one of several formulations Ostwald used).[14] The first law was a restatement of the law of energy conservation. The second law of energetics attempted to answer the question as to when a transformation would occur.

One suggested solution incorporated the concept of intensity. Each form of energy—heat, chemical, electrical, volume, etc.—was assigned an intensity. If the intensities of a particular form of energy are equal in two different regions, no energy transfer will occur between these regions. If, on the other hand, the intensities are unequal, a state of non-equilibrium prevails, and thus the energy will flow from a region of higher intensity to a region of lower intensity until equilibrium is once again established. In addition to the intensity factor (i), Ostwald also assigned a capacity factor (c) to each energy form. The product of these two factors represents a given quantity of energy: $E = ci$. Ostwald identified five "*Arten* [kinds] *der Energie*": (1) mechanical energy, (2) heat, (3) electrical and magnetic energy, (4) chemical and internal energy, and (5) radiant energy. Ten paired combinations are possible, three of which Ostwald claimed were particularly important for chemical energetics: thermochemistry, electrochemistry, and photochemistry. The total energy of a system [*Gebilde*] is equal to the arithmetic sum of the individual energies.[15] Each system contains (*or is*) a definite amount of energy of one form or another.

The most penetrating criticisms of Ostwald's energetic interpretation and derivation of thermodynamic relationships came from Ludwig Boltzmann and Max Planck. Ostwald had kept them apprised of his approach well before the fateful 1895 Lübeck meeting of the Gesellschaft Deutscher Naturforscher und Ärzte. At the meeting, the confrères debated the energetics program at length. On the last day, Ostwald delivered his famous lecture, "*Die Überwindung des wissenschaftlichen Materialismus*" ("The Conquest of Scientific Materialism"),[16] proclaiming atoms to be nothing but "graven images" and atomic models to be, at best, heuristic devices.

> The job of science is to determine the relationships between aspects of reality, in the form of demonstrable and quantifiable parameters, so that when some of the parameters are known the others can be calculated. This goal cannot be achieved by setting up a hypothetical picture of the world but only by demonstrating the relationship between quantifiable parameters.[17]

After Lübeck, the leading physicists of the day (such as Ludwig Boltzmann and Max Planck) were quick to publish their concerns.[18] Their criticism can be summarized as follows: (1) energetics displays a poor, if not deplorable, mathematical development of arguments; (2) energetics as defended by Ostwald, (and Georg Helm) argues to extant thermodynamic relationships rather than providing their foundation; (3) energetics has no adequate concept of irreversibility (most irreversible processes were subsumed under radiant energy); and (4) energetics employs an ad hoc construal of volume energy (Volume Energy = Volume [capacity] x Pressure [intensity]). For example, the critics charged that the energeticists juggled mathematical formulae to "derive" results known in advance or employed formulae which made no sense when describing irreversible processes.

But Ostwald did not stop promoting energetics in chemistry, even after support for physical *Energetik* waned after Lübeck. He advanced studies directed toward finding an alternative to chemical atomic theory, and eventually "*eine Chemie ohne Stoffe*" (a chemistry without matter/substances).[19] Even when Ostwald "recanted" in 1905, admitting the existence of atoms based on the X-ray investigations in 1896 by W. C. Röntgen, he could still comment, "Energetics is not affected by these developments because, since it is the more general concept, it is not affected by whether atoms exist or not."[20]

After a year as an exchange professor at Harvard, Ostwald resigned his Leipzig chair in physical chemistry in 1906 and retired to his retreat, Landhaus Energie, in Grossbothen. He actively began to employ a much broader range of arguments: not only scientific and methodological, but also philosophical, and most centrally, religious. This latter characteristic is manifest in Ostwald's commitment to an energy principle of cosmic proportions. To understand this development of "cultural" energetics, some historical background is needed. Ostwald did not follow a humanistic curriculum in his gymnasium (high school) and University of Tartu education, but once he moved to Leipzig he began to participate in interdisciplinary dialogue with fellow academics. In the mid-1890s, he joined the Leipziger Positivisten-Kränzchen, a small group of positivists such as the historian Karl Lamprecht, the geographer Friedrich Ratzel, the psychologist Wilhelm Wundt, and the economist Karl Bücher.[21] As Matthias Neuber has argued,

> What these scholars had in common was the conviction that it should be possible to establish a unified field of natural and cultural sciences in the sense of some sort of *Gesamtwissenschaft* [a unified science].[22]

They rejected any form of Cartesian dualism in favor of a monistic conception of reality. Ostwald's application of energetics to cultural phenomena, particularly after his experience at the Lübeck meeting, entailed a monism (an ontology of energy), a naturalism, and in historical terms, an appeal to Auguste Comte's law of three stages of historical development: theological, to metaphysical, to positive (scientific). Energetics, as a positive science and an all-embracing worldview, philosophy, or secular religion would, in his view, ultimately replace Christianity.[23]

Already foreshadowed in his 1902 *Vorlesungen über Naturphilosophie* [*Philosophy of Nature Lectures*], Ostwald minced no words about the universal scope of his energetics: it would be an energetics complete with a theory of happiness, an encyclopedia of the sciences, a theory of spirituality, an energetic understanding of consciousness, an argument for Esperanto, supplemented by numerous monistic Sunday sermons, many of which exhorted listeners to conserve energy.[24] In 1911, Ostwald assumed leadership of the Monist League, founded by the biologist Ernst Haeckel in 1906. Ostwald, to his mind, had fulfilled his vision so vividly described in his conversion experience in 1890 to pure energetics: he considered to have given energy its *true* name.

Ostwald and Religious Belief

"[O]ne must come to the conclusion that energy—and only energy—is real."[25]

If one holds that religion is a way of life that people always engage in with their full existence (while faith is only one of a number of fundamental modes of being religious), a different way of understanding the relationship of science and religion may follow. As Robert Sweetman proposes in his holist account of the relationship of religion and scholarship: "… it acknowledges that socio-cultural endeavor can be religious; indeed, it denies that socio-cultural endeavor can ever be *irreligious*."[26] Then the question becomes, what religion or religions does Ostwald's scientific activity and practice bear witness to?

That question can be addressed in two different, but related, ways: an analysis of Ostwald's religious belief in his formulation of energy theory, and a critique of his reductionism in chemistry. First, Ostwald claims far more than that his energy doctrine is only a hypothesis, open to testing and potential verification. For Ostwald, "… one must come to the conclusion that energy—and only energy—is real. This is because energy is the only thing that must be part of every act and affects both the acted-upon as well as the actor."[27] This belief also funded his later monistic understanding of the mind/body problem:

> … the problem of the relationship between mind and body, which scientific materialism had left unsolved, … lost in the light of energetics its unapproachable character since both mind and body were subsumed in the higher-level concept of energy and hence the two must be intimately bound up with each other.[28]

This energy doctrine also undergirds Ostwald's reductive view of chemistry. The strength of Ostwald's energeticist account in chemistry, energy as a singular quantitative measure of physical interaction, is simultaneously its major weakness. The abstract mathematical description of energy and its various exchanges required the isolation, either theoretically or experimentally, of a physical system and a conscious purging of its typical properties and structure.[29] This neglect, or explicit *reduction*, that is, of subsuming typical properties as instantiations of a general energy law, ran counter to the major thrust of nineteenth-century chemistry, namely organic chemistry with its structural and stereochemical assumptions,[30] and later in the early twentieth century: valence theory, chemical bonding, and structure-reactivity relationships. For Ostwald, physical entities and their interactions are projected to be quantitatively measurable *energy* factors.

But in what sense is this view of energy a religious belief? In his book *Knowing with the Heart: Religious Experience and Belief in God,* Roy Clouser advances the idea that a belief is a religious belief when "it is (1) a belief in something as divine or (2) a belief about how to stand in proper relation to the divine, where (3) something is believed to be divine provided it is held to be unconditionally nondependent."[31] This third sense entails replacing God with a nondependent reality on which all else depends, that is, as scripture proclaims, "to call anything a god or an idol if it in *any* way replaces God"[32] Granted this understanding, Clouser concludes a materialist has a religious belief. Ostwald's core belief in energy certainly functions in a comparable manner.

In the end, Ostwald's energy considerations, both in theory and practice, served as a religion, as a substitute source of meaning and revelation. His "graven images" may not have been atoms, but rather they became energy and its many manifestations. Energy was something within creation which everything else depended on for its existence. St. Paul's confession of creation frames the context for any discussion of these matters:

> For in him all things were created in heaven and on earth, visible and invisible, whether thrones or dominions or principalities or authorities; all things were created through him and for him. He is before all things, and in him all things hold together. (Colossians 1:16–17, NIV)

By 1893, Ostwald regarded energy as a self-existent substance; he accords it divine status, and it is therefore a core religious belief whether this is acknowledged or not. As he stated: "… there is nothing more 'real,' that is more effective than energy. And, indeed, in this sense it could be defined as the only thing that is 'real' in the physical world."[33]

Charles A. Coulson as Student, Quantum Chemist, and Religion-Science Spokesperson

Charles A. Coulson (1910–1974) was an early participant in the English school of quantum chemistry who, after World War II, was also one of the leading English spokespersons for understanding science and religion.[34] During Coulson's lifetime, quantum chemistry went through a revolutionary process of development. Coulson played a significant role in bringing quantum approaches—in particular, the molecular orbital interpretation of the chemical bond—to the broader chemical community. But academic research in quantum chemistry is only one component of Coulson's work. Crucial to understanding Coulson's career was his missionary zeal in promoting an understanding of the chemical bond that wed the pictorial representation of bonds—so dear to structural chemists—to the increasingly complex mathematical descriptions of the chemical bond, while simultaneously advancing a view of the relationship of science and religion which placed the person as historical actor at the center of responsible engagement.

Recent scholarship has done little to examine how these two leading interests of Coulson were related.[35] As J. W. Linnett noted in a brief 1975 memorial notice in *Chemistry in Britain,*

> Many scientists thought of Coulson as a "double person"—a theoretical chemist and a man of the church; and they thought of these two as two immiscible and separate persons. This was not so, because, had it been, then his life would have been a dishonest one, and would have been totally incompatible with all the rest of our experiences.[36]

That Coulson's life displayed a unity of belief and action was displayed in a variety of ways. First, Coulson's belief in a personal religious experience, the role of a group's fellowship in confirming that experience, and a call to holiness affected Coulson's approach to his scientific coworkers, his research group and their activities, and his general promotion of science to a wider public. Secondly, when Coulson employed and presented his optimistic style of attacking scientific problems in quantum chemistry, replete with approximations and models, he displayed a concern for others, particularly chemists, who often displayed a prejudice against the utility of quantum mechanics. Thirdly, his emphasis on the wholeness or unity of personal experience shaped his view of the science/religion connection.

Coulson as Student:

"I came up … a mystic,
I went down a missionary."[37]

Coulson's style and approach in quantum chemistry, as well as in his view of life, involves the theme of giving and receiving which first arose from his student experiences. During the Easter term of 1930, his second year at Cambridge, Coulson received an invitation to attend group meetings organized by W. Harold Beales, minister of Wesley Methodist Church. Beales encouraged Cambridge student groups, of roughly ten students, to explore how best to communicate the Christian faith. He presented feeling, knowing, choosing (personal choice), doing, and belonging as essential marks of a Christian's experience.[38] The impact of this small intimate group on Coulson was indeed life changing. After a group retreat held in June 1930, he wrote:

> I learnt from the value of corporate action. You all remember Beales' description of the anthropological view of the group idea. It impressed me most marvelously … I began to see that Christianity for me must be something broader than my own self … I began to see that religion was something that got beyond you and God, it included everybody … I came up this term a mystic—I went down a missionary.[39]

Coulson wished to "come down" from himself to the "world of others."[40] In fact, soon afterward, Coulson became a Methodist lay preacher who often did the circuit with other group members on weekends at churches and chapels in the vicinity of Cambridge. His sermons and letters from this initial period in his life display a Wesleyan-Methodist concern with holiness (perfection), a need for fellowship, and a desire for social action. A call for social action was not so much driven by a sense of duty, but rather seen as a way of developing spirituality.

One would surmise there must have been a tension between Coulson's academic interests and his interest in social action. A glimpse of how Coulson resolved this tension is revealing:

> I was reading mathematics myself, and puzzled to know to what extent I should allow my love for the subject to dominate my future life. The two chief competing possibilities were represented in my mind by two people. One was a most distinguished mathematician [G. Hardy], with a worldwide reputation: he was a symbol of the life so wholly devoted to academic study that it merited the epitaph: "this man decided to know and not to live." The other was Alex Wood [Quaker physicist at Emmanuel College, Cambridge], symbol for me then, as now, of the life of a man whose service to God lies not only through his learning, but no less through his social conscience, his power among people,

> his simple Christian affection. If, in the end, my puzzle was solved, it was because this second man was so attractive that I felt I wanted to be a bit like him.[41]

Coulson as Quantum Chemist and Group Leader:

"Feet on the solid earth … head … in the clouds."[42]

In her book, *From Chemical Philosophy to Theoretical Chemistry,* Mary Jo Nye traces the tenuous relation between the disciplines of chemistry and physics and the eventual rise of quantum chemistry.[43] She argues that chemistry, over the nineteenth century, became a distinct and separate discipline from physics. But by century's end, a convergence took place that resulted in the creation of a new subdiscipline—physical chemistry, and by 1933, the creation of another—chemical physics. Discipline boundary demarcation inevitably led to debates about where the boundaries should be drawn, which proper methodology to invoke, what ontological commitments were proper to make, and what the character of theory should be like.

Quantum chemistry (1927–1940s) arose as a subdiscipline emerging from the introduction and employment of wave mechanics (from physics) to solve classical chemical valence problems. As this occurred, certain national styles developed. Often the German and American approaches to quantum chemistry have been pitted against each other.[44] Friedrich Hund, Walter Heitler, and Fritz London represent the German *gründlich* approach, replete with mathematical sophistication, concerted efforts to reduce chemistry to physics, and deep, even pessimistic, philosophical concerns about the nature of causality, wave-particle duality, visualizability, etc., but a step or two removed from the practicing experimental chemist.

Linus Pauling, Robert Mulliken, John Slater, and John Van Vleck represent the so-called American approach, more pragmatic and optimistic, more pictorial in its representation of molecules, cozy with the operationalism of the American physicist Percy W. Bridgman (Bridgman considered the meaning of a concept dependent on a set of operations or a method of measurement). For the Americans, especially the chemist Linus Pauling, the formulation of a rule-governed methodology replete with predictive power was considered far superior to any deep understanding of the physics of the chemical bond.

In contrast to either of these approaches, the English school of which Coulson was a leading figure consisted of applied mathematicians who wished "to enlarge the domain of applied mathematics so as to include quantum chemistry."[45] The qualitative work of Nevil Sidgwick (1927) on the concept of valency was followed in the 1930s by the more mathematically sophisticated approaches of John Lennard-Jones, Douglas Hartree, and Coulson. As Lennard-Jones's student from 1932–1936, Coulson wrote the first quantum chemistry thesis in the UK. It dealt with molecular-orbital theory. Rather than viewing molecules as aggregates of individual atoms, each linked to its nearest neighbor by bonds formed by electrons localized between two atomic nuclei, molecular orbital theory considers molecules as atomic nuclei with binding electrons. These electrons spread throughout the whole molecule in orbitals.

Coulson's stated wish of living for others is seen in how he presented quantum chemistry and its results to others. As an applied mathematician, Coulson was interested in making sure that his conceptual, mathematical, and pictorial expressions were translatable and understandable to the chemist. The true applied mathematician is someone with "his feet on solid earth, but his head must be in the clouds."[46] He stated as much in his famous 1952 textbook *Valence*:

> Contrary to what is sometimes supposed, the theoretical chemist is not a mathematician, thinking mathematically, but a chemist thinking chemically. That is why almost everything in this book should be understandable to a chemist with no mathematical attainment … Almost everything necessary can be put in pictorial terms.[47]

Accuracy was not the strength of the new quantum mechanics. Its strength lay in the understanding it gave of chemical processes. At times, chemistry appeared to be solving the applied mathematicians' problems rather than the other way around. *Valence* presented the molecular-orbital approach to bonding, which it favored, as well as the valence-bond theory. Its pages are replete with pictorial diagrams of molecular orbitals.[48]

Several elements in Coulson's approach to quantum chemistry reflected his stated wish of living for others:

1. Non-reductive emphasis: Coulson would not render his descriptions of molecules in pure mathematical terms. Rather he stressed the role and bridge function of applied mathematics. Although holding a chair in mathematics (and in theoretical chemistry during 1972–1974), he was determined to respect the given patterns and structures of creation, even when described mathematically, in terms that others, particularly chemists, could understand.

2. Personal element: Coulson was keen on recognizing and emphasizing the personal element involved in science. What are our models? For Coulson, they are all "products of our imagination" that are displayed and described by applied mathematics. He employed strategies which highlighted visual representation and metaphors in his effort to advance mathematics in a formerly non-mathematical science—chemistry. Coulson was fearful that computational chemistry, which employed computers for its sophisticated calculations would both minimize and mask the personal element involved.

3. Fairness in presentation: While promoting his own molecular-orbital approach in an early 1941 publication, Coulson strove to be fair in representing other approaches:

   > [W]e meet two different main avenues of approximation, known as the molecular orbital and electron-pair [valence bond] methods respectively. We confine ourselves here to the former of these … not because it is the better (neither is satisfactory, and the existence of the two complementary approximations is an indication of our partial failure to solve the problem).[49]

   Although quantum chemists continued to

   > discuss the relative merits and disadvantages of the valence bond and molecular orbital theory, mostly with the aim of choosing one of the two, Coulson argued for their *complementarity* and their mathematical equivalence when each method is adequately extended.[50]

   When Linus Pauling first reviewed *Valence*, he was hostile to Coulson's treatment even though the book presented Pauling's valence bond theory, but only after first discussing molecular orbital theory. Coulson went out of his way to mollify Pauling. After an exchange of letters between the two, an amicable understanding was reached. In the second edition of *Valence* (1962), Coulson, in fact, incorporated a number of Pauling's comments.[51]

In a 1950 BBC radio broadcast, "I Speak for Myself," Coulson reflected on his life's experiences: "To receive, and not to give, that would be to deny the common humanity that we all share. This is why, for me, it is such a high privilege to carry scientific research a stage further."[52] For Coulson, this theme of giving and receiving marked his life's path. He thought it applied even more intensely to interpersonal relationships for it reflects the sacrificial giving of Christ who says: "If man shall try to save his life, he shall lose it. But if he loses his life for my sake, he shall find it" (Matthew 10:39).[53]

Coulson's style of leading a research group demonstrates his desire to live for others. He was determined to create a sense of fellowship in his research group and department. Coulson held Tuesday morning coffee parties and also organized outings and picnics, all designed to entertain his students as well as the constant stream of foreign scientists who attended his lectures. He stayed connected with past students for years, "mainly by organizing reunion parties which he called 'centenaries' where several generations of students met to celebrate the publication of each new lot of a hundred pages by him and his associates."[54]

Another way that Coulson "lived for others" was through his summer schools in theoretical chemistry held in Oxford from 1955–1972. They became famous and a powerful influence in the worldwide dissemination of current scientific ideas and the further development of theoretical chemistry. In fact, Coulson insisted that one-half of the participants be from the Third World.[55]

Coulson on Science-Religion: "On the Mountain"

When delivering his 1951 Tilden Lecture, "The Contributions of Wave Mechanics to Chemistry," Coulson concluded his lecture with these words:

> You must surely have been struck by the way in which, all along, modern wave mechanics has taken up ideas of the past and refurbished them. How astonishingly fruitful have been those semi-formulated concepts of the classical chemists: and how necessary, in a sense, it has been for wave mechanics to give flesh and blood to the spirit which it has inherited … At every turn we have seen how wave mechanics has taken their work and has added to it the quality of a deeper understanding. That of course is always how science proceeds, building the past into the present and enriching it thereby.[56]

At first reading, it strikes one as a wonderful, literate summary of the development of wave mechanics in chemistry from 1926 to 1951. And yet, if we look more closely at the statement, particularly at the phrase, "give flesh and blood to the spirit which [wave mechanics] has inherited," a whole new vista is open to our view. Another horizon of experience and interpretation funds this description. Does it reflect Coulson's reading or narrative of nature? In this case, does it describe a Christian incarnational view? nature not read as organism, as magical, as mechanism, as an economy, or as an entangled bank, but as God's incarnational involvement with the earth. For Coulson, the scientific investigation of nature was considered to be a religious activity.[57]

When Coulson examined the relation of science and religion, he introduced an analogy of a mountain, Ben Nevis, as a basis for extending and clarifying his arguments. The artist, the poet, the historian—they each have their own perspective. Each person attempts to describe his encounter with the mountain in terms that make sense. To say, "Ben Nevis is a grassy slope," or to say, "Ben Nevis is a rocky mountain," may seem at variance, but it is equivalent to saying: "An electron is a wave and a particle." Which model or description you prefer depends on the problem you wish to solve. In a telling statement, illuminating the primacy of experience, Coulson remarked: "There is no conflict, nor can there be, since both descriptions start from the same basic origin—our experiences—and experience can never contradict itself."[58]

Science and religion, for Coulson, may exhibit complementary views and features of reality. But what does this imply for the position of Christianity? Is it just one among a variety of viewpoints, each equally valid, each equally true? Here Coulson admitted the analogy of the mountain broke down and displayed its limitations. Much of religion, taken as theology, he argues, can be considered as a view corresponding to art or science.[59] But, Coulson maintained, there are other elements of religion that cannot be thought of at all as "views."[60] He identified a non-discursive element that he was convinced could never be explained or adequately described, similar to Pascal's phrase: "The heart has her reasons, of which reason by itself knows nothing." As Coulson expressed it:

> To accept Nature as, in some senses, given: to receive the gift, and behave in a creaturely fashion towards it; to believe that it carries with it meaning and significance; and to seek, in reflection, what that meaning is—this surely is to act religiously. But in that event, religion is not merely one view of the mountain. It is some attitude which colors all the separate views, and gives them a depth which otherwise they would lack, more or less as a yellow filter reveals a pattern of clouds in a sky that without it appears pure blue.[61]

What then did Coulson mean by religion? For him, "Religion is the total response of man to all his environment."[62] The word *total* is crucial for Coulson's understanding of religion. By it, he meant to convey the whole person: thoughts, emotions, and human relationships. Similarly, the term environment includes everything, echoing the words of St. Paul, "all things in heaven and on earth." Coulson's favorite text was "The earth is the Lord's and all that is in it, the world, and all who live in it" (Psalm 24:1, NIV). The basic theme of his last sermon gave expression to this: God not only directs the play of our lives. He also built the theater in which they take place.[63] Let me conclude with a quotation by Coulson which, I think, captures his spirit and vision:

> Not until the power conferred by our knowledge has been recognized as God's gift, enabling his children to grow up into fully developed men and women; not until man's new independence is seen to be but the liberty of the children of God; not until man's patient observation of the world around has led him on to awe and then to worship; not until our science has shown us with what rich luster the heavens declare the glory of God, and the firmament shows His handiwork; not until then can human faith be as it was meant to be, nor human life fulfil its

proper destiny. Nor shall we see how all things are summed up in Christ, both things on earth and things in Heaven; and our hearts be so astonished at the splendor of God's creation that they grasp eternity in a moment of time, and are lost in wonder, love and praise.[64]

Concluding Reflections

What can we learn from this brief excursion into the life and work of two widely diverging chemists? One, that the view of the complementarity of science and religion, though enriching our purview, will not capture all the constitutive relationships between science and religion. In fact, it often does not take seriously enough the depth dimension of religion, its defining nature as to what it means to be human. We may "engage" science as active participants in its investigative regimen or as casual observers and commentators of its grand theories, but religion is not something we "engage." As Christians, we may participate in religious practices and worship services, but life lived before the face of God is religion for everyone. We need to assume a stance which allows us to get beyond viewing a person as a Christian and as a scientist. Only then will we do justice to a person such as Charles Coulson who desired to live as a Christian scientist.

This brief historical analysis also raises a more interesting question: must religion involve a form of theism? If we insist on this definition, we will miss the religious dynamic in thinkers like Ostwald. For the atheist Ostwald, at least, we can see a concerted effort to eradicate traditional religion by a substitute scientific religion, an *Ersatzreligion* as he himself called it. Religion, for him, is not irrelevant. It does not function as a factor or merely provide a context. It is the very ground for scientific practice and life in its totality with presuppositions that have a religious character.

Both scientists concentrated on existing features and modes of reality: for Ostwald, physical interaction was fundamentally energy exchange; for Coulson, molecular models, imaginatively generated by scientists, were best described in applied mathematical language, not hidden in pure mathematical terms. For Ostwald, reality was equivalent or reduced to energy and its manifestations. He desired to remake a monistic energetic world. For Coulson, the reality of the givenness of God's incarnational involvement with creation ruled, even while designing intricate mathematical descriptions.

Each responded in their own way to creational revelation. Each translated that revelation in ways that were markedly different. For Ostwald, science rules as a secular religion giving meaning and purpose to life; for Coulson, science is a form of worship, a religious activity deeply empowered by personal acts of giving and receiving.

Notes

[1]Martin J. S. Rudwick, "Senses of the Natural World and Senses of God: Another Look at the Historical Relation of Science and Religion," in *The Sciences and Theology in the Twentieth Century*, ed. Arthur R. Peacocke (Notre Dame, IN: University of Notre Dame Press, 1981), 245.

[2]As examples, see John Brooke and Geoffrey Cantor, "Biographical Narratives," in *Reconstructing Nature: The Engagement of Science and Religion* (Edinburgh, UK: T&T Clark, 1998), 247–81; and Steven Shapin, *Never Pure: Historical Studies of Science as if It Was Produced by People with Bodies, Situated in Time, Space, Culture, and Society, and Struggling for Credibility and Authority* (Baltimore, MD: Johns Hopkins University Press, 2010).

[3]See the three papers by Robert J. Deltete, "Wilhelm Ostwald's Energetics 1: Origins and Motivations," *Foundations of Chemistry* 9 (2007): 3–56, https://doi.org/10.1007/s10698-005-6707-5; "Wilhelm Ostwald's Energetics 2: Energetic Theory and Applications, Part I," *Foundations of Chemistry* 9 (2007): 265–316, https://doi.org/10.1007/s10698-006-9025-7; and "Wilhelm Ostwald's Energetics 3: Energetic Theory and Applications, Part II," *Foundations of Chemistry* 10 (2008): 187–221, https://doi.org/10.1007/s10698-008-9053-6.

[4]Deltete, "Wilhelm Ostwald's Energetics 1," 6.

[5]Wilhelm Ostwald, "*Die Energie und ihre Wandlungen*," in *Abhandlungen und Vorträge* (Leipzig, Germany: Veit & Company, 1904), 205.

[6]Heinrich Hertz, "All physicists agree that the problem of physics consists in tracing the phenomena of nature back to simple laws of mechanics," *Die Prinzipien der Mechanik in neuem Zusammenhange Dargestellt* (Leipzig, Germany: J. A. Barth, 1894), vii.

[7]See Arie Leegwater, "The Development of Wilhelm Ostwald's Chemical Energetics," *Centaurus* 29 (1986): 314–37; and Arie Leegwater, "The Chemical Audience for Wilhelm Ostwald's *Energetik*," paper presented at the XVIIIth International Congress of the History of Science, August 1–9, 1989, Hamburg and Munich, Germany.

[8]One of Ostwald's American students, Joseph E. Trevor, who studied at Ostwald's Leipzig Institute in 1890–1892, echoes this thought:

> … in this matter we stand for conservatism. We must not countenance the wild hypotheses which have so often disfigured chemistry. Facts are the things with which we must deal, and we must deal with them rigorously. Hypotheses are to be used with the utmost caution and discarded whenever possible. ["The Fundaments of Chemical Theory," in *Journal of the American Chemical Society* 15 (1893): 430]

[9]Wilhem Ostwald, *Lebenslinien: Eine Selbstbiographie,* vol. 2 (Berlin, Germany: Klassing & Co., 1926), 160. For another translation, see Robert Smail Jack and Fritz Scholz, eds., *Wilhelm Ostwald*, Springer Biographies (Cham, Switzerland: Springer International Publishing AG, 2017), 232, https://doi.org/10.1007/978-3-319-46955-3_21.

[10]There is a tension in Ostwald's view of the relation of matter to energy. Do material objects *contain* energy or are they ontologically *nothing more than* energy complexes? For an excellent analysis see Deltete, "Wilhelm Ostwald's Energetics 2," 267–68.

[11]Leegwater, "The Chemical Audience for Wilhelm Ostwald's *Energetik*." A point of clarification: The development of Ostwald's thought about energy makes it imperative to say that the historiographic tradition which regards energetics as being equivalent to (or by definition, equivalent to) anti-atomism needs to be challenged.

[12]Wilhem Ostwald, "Studien zur Energetik (I)," *Berichte über die Verhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig. Mathematische-Physische Klasse* 43 (1891): 275.

[13]Ostwald's disenchantment with the kinetic molecular theory (viewing it only as a heuristic device) alarmed George F. Fitzgerald, an Irish physicist. He was genuinely concerned about Ostwald's influence: "There is considerable risk that others, chemists especially, may be carried away by the arguments of one whom they rightly value as a leader in their domain when he descants positively about the realm of mechanics" (Fitzgerald, "Ostwald's Energetics," *Nature* 53, no. 1376 [1896]: 441, https://doi.org/10.1038/053487c0).

[14]Wilhem Ostwald, "Studien zur Energetik [I]," *Berichte über die Verhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig. Mathematische-Physische Klasse*, 43 (1891): 271–88 [Reprinted in *Zeitschrift für physikalische Chemie* 9 (1892): 563–78]; and Ostwald, "Studien zur Energetik [II], Grundlinien in der allgemeinen Energetik," *Berichte über die Verhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig. Mathematische-Physische Klasse,* 44 (1892): 211–37. See 211 and 214. [Reprinted in *Zeitschrift für physikalische Chemie* 10 (1892): 363–86].

[15]Ostwald, "Studien zur Energetik [I]," *Berichte über die Verhandlungen der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig. Mathematische-Physische Klasse* 43 (1891): 279–80.

[16]Wilhem Ostwald, "*Die Überwindung des wissenschaftlichen Materialismus*," in *Abhandlungen und Vorträge* (Leipzig, Germany: Veit & Company, 1904), 220–40.

[17]Jack and Scholz, eds., *Wilhelm Ostwald*, 242.

[18]Robert Deltete, "Helm and Boltzmann: Energetics at the Lübeck Naturforscherversammlung," *Synthese* 119, no. 1/2 (1999): 45–68, https://doi.org/10.1023/A:1005287003138.

[19]Leegwater, "The Chemical Audience for Ostwald's *Energetik*."

[20]Jack and Scholz, eds., *Wilhelm Ostwald*, 244.

[21]Roger Chickering, "Der 'Leipziger Postivismus,'" *Comparativ* 5, no. 3 (1995): 20–31, https://www.comparativ.net/v2/article/view/1442.

[22]Matthias Neuber, "Monism, Naturalism, and the 'Pyramid of the Sciences': Wilhelm Ostwald's Energetic Theory of Culture," *Historia Scientiarum* 28 (2018): 20, https://doi.org/10.34336/historiascientiarum.28.1_19.

[23]For an analysis of monism and its many manifestations in nineteenth-century Germany, see Todd H. Weir, *Secularism and Religion in Nineteenth-Century Germany: The Rise of the Fourth Confession* (New York: Cambridge University Press, 2014), 96–102, and the last chapter "Secularism in Wilhelmine Germany," 253–68. An earlier work edited by Todd H. Weir, *Monism: Science, Philosophy, Religion, and the History of a Worldview* (New York: Palgrave-Macmillan, 2012) is also valuable.

[24]See Wilhelm Ostwald, *Vorlesungen über Naturphilosophie* (Leipzig, Germany: Veit Verlag, 1902) and *Monistische Sonntagspredigten* (Leipzig, Germany: Akademische Verlagsgesellschaft, 1912). For an analysis of Ostwald's later influence, see C. Hakfoort, "Science Deified: Wilhelm Ostwald's Energeticist World-View and the History of Scientism," *Annals of Science* 49 (1992): 525–44, https://doi.org/10.1080/00033799200200441; and Jason Ānanda Josephson Storm, "Monism and the Religion of Science: How a German New Religious Movement Birthed American Academic Philosophy," *Nova Religio* 25, no. 2 (2021): 12–39, https://doi.org/10.1525/nr.2021.25.2.12.

[25]Jack and Scholz, eds., *Wilhelm Ostwald*, 236.

[26]Robert Sweetman, *Tracing the Lines: Spiritual Exercise and the Gesture of Christian Scholarship* (Eugene, OR: Wipf & Stock, 2016), 81.

[27]Jack and Scholz, eds., *Wilhelm Ostwald*, 236.

[28]Ibid., 244.

[29]See Richard M. Gunton, Marinus D. Stafleu, and Michael J. Reiss, "A General Theory of Objectivity: Contributions from the Reformational Philosophy Tradition," *Foundations of Science* 27 (2022): 941–55, https://doi.org/10.1007/s10699-021-09809-x; and D. F. M. Strauss, "The Significance of a Non-Reductionist Ontology for the Discipline of Physics: A Historical and Systematic Analysis," *Axiomathes* 20 (2010): 53–80, https://doi.org/10.1007/s10516-009-9081-4.

[30]For example, Victor Meyer thought that organic chemistry was "inspired by feeling and fantasy" rather than the "strict logic of physical chemistry," in Jack and Scholz, eds., *Wilhelm Ostwald*, 208.

[31]Roy Clouser, *Knowing with the Heart: Religious Experience and Belief in God (*Downers Grove, IL: InterVarsity Press, 1999), 24.

[32]Roy Clouser, *The Myth of Religious Neutrality: An Essay on the Hidden Role of Religious Belief in Theories (*Notre Dame, IN: University of Notre Dame Press, 1991), 18.

[33]Wilhelm Ostwald, *Lehrbuch der allgemeinen Chemie*. Zweite ungearbeite Auflage. II. Band, I. Teil: *Chemische Energie* (Leipzig, Germany: W. Engelmann, 1893), 471.

[34]David and Eileen Hawkin, *The Word of Science: The Religious and Social Thought of C. A. Coulson* (London, UK: Epworth Press, 1989), 24.

[35]Some recent publications displaying little, or perfunctory, mention of connections between Coulson's science and religion are Stephen G. Brush, "Dynamics of Theory Change in Chemistry: Part 2. Benzene and Molecular Orbitals, 1945–1980," *Studies in History and Philosophy of Science* 30, no. 2 (1999): 263–302, https://doi.org/10.1016/S0039-3681(98)00028-4; Kostas Gavroglu and Ana Simŏes, "Quantum Chemistry *qua* Applied Mathematics: Approximation Methods and Crunching Numbers," in *Neither Physics nor Chemistry: A History of Quantum Chemistry* (Cambridge, MA: MIT Press, 2012), 131–85. One exception is Ana Simŏes, "Textbooks, Popular Lectures and Sermons: The Quantum Chemist Charles Alfred Coulson and the Crafting of Science," *British Journal of the History of Science* 37, no. 3 (2004): 299–342, http://www.jstor.org/stable/4028426. Some publications that discuss the

science-religion interaction without mentioning the specific details of Coulson's science are Erwin N. Hiebert, "Modern Physics and Christian Faith," in *God and Nature: Historical Essays on the Encounter between Christianity and Science,* ed. David C. Lindberg and Ronald L. Numbers (Berkeley, CA: University of California Press, 1986), 424–47; David and Eileen Hawkin, *The Word of Science*; Alister E. McGrath, *The Foundations of Dialogue in Science and Religion* (Oxford, UK: Blackwell, 1998); and Peter J. Bowler, *Reconciling Science and Religion* (Chicago, IL: University of Chicago Press, 2001).

[36]J. W. Linnett, "Charles Coulson 1910–1974," *Chemistry in Britain* 11 (1975): 109.

[37]Coulson Address Box, Wesley House Archives, Cambridge, UK: "Giving and Receiving," A-94. 3.

[38]W. Harold Beales Papers, Wesley House Archives, Cambridge, UK: *A Group Speaks 1931*, 7–16.

[39]Coulson Address Box, "Giving and Receiving," A-94. 3.

[40]Coulson Papers [CP], Bodleian Library, Oxford, MS 19, A.19.1, "My Reactions at Home, June 1930," 1.

[41]Charles Coulson, "Contributions of Science to Peace," Alex Wood Memorial Lecture (London, UK: Fellowship of Reconciliation, 1953), 7.

[42]Charles Coulson, *The Spirit of Applied Mathematics* (Oxford, UK: Clarendon Press, 1953), 12.

[43]Mary Jo Nye, *From Chemical Philosophy to Theoretical Chemistry: Dynamics of Matter and Dynamics of Disciplines, 1800–1950* (Berkeley, CA: University of California Press, 1993).

[44]Kostas Gavroglu and Ana Simŏes, "The Americans, the Germans, and the Beginning of Quantum Chemistry: The Confluence of Diverging Traditions," *Historical Studies in the Physical and Biological Sciences* 25, no. 1 (1994): 47–110, https://doi.org/10.2307/27757735.

[45]Gavroglu and Simŏes, *Neither Physics nor Chemistry*, 191.

[46]Coulson, *The Spirit of Applied Mathematics*, 12.

[47]Charles A. Coulson, *Valence* (Oxford, UK: Clarendon Press, 1952), v.

[48]For a depiction of π atomic orbitals and π molecular orbitals, see Charles A. Coulson, "Quantum Theory of the Chemical Bond," *Proceedings of the Royal Society of Edinburgh Section A: Mathematics* 61, no. 2 (1942): 128, https://doi.org/10.1017/S0080454100006142; and Coulson, *Valence*, 224 and 226. Also see Gavroglu and Simŏes, "Quantum Chemistry *qua* Applied Mathematics," in *Neither Physics nor Chemistry,* 179. In the valence bond approach, molecules are viewed as aggregates of individual atoms, each linked to its nearest neighbor by bonds formed by electrons localized between two atomic nuclei. The number of bonds is equal to the element's valence or bonding capacity. The valence bond (VB) approach was vigorously promoted by Linus Pauling in the Department of Chemistry at the California Institute of Technology for two decades (1931–1951). Robert Mulliken in the Department of Physics at the University of Chicago published a number of papers during the same period but was not able to capture the attention of very many chemists. His approach was predicated on the belief that molecules were not what valence bond advocates thought they were. Molecules to Mulliken were not aggregates of distinct atoms, but things unto themselves, with their own behavior explicable only in molecular terms. Molecules can more profitably be considered as nuclei with binding electrons, these electrons being delocalized and spread throughout the whole molecule.

[49]Charles A. Coulson, "Quantum Theory of the Chemical Bond," *Proceedings of the Royal Society of Edinburgh Section A: Mathematics* 61, no. 2 (1942): 115.

[50]Gavroglu and Simŏes, *Neither Physics nor Chemistry*, 164.

[51]Ibid., 178–81.

[52]Coulson Address Box, "Giving and Receiving," A-94. 3.

[53]Ibid.

[542]S. L. Altmann and Edmund John Bowen, "Charles Alfred Coulson, 1910–1974," *Biographical Memoirs of Fellows of the Royal Society* 20 (1974): 84, https://doi.org/10.1098/rsbm.1974.0004.

[55]Coulson sensed a real mission to the "underdeveloped" world. He thought that the "overdeveloped" West bore special responsibilities, because it had the scientific know-how to help eradicate the immense problems of shortages of food, health care, and energy in the world. The West had to put its own house in order. His work as Chairman of OXFAM (1965–1971) and his work on the Central Committee of the World Council of Churches (1962–1968) give ample evidence of that conviction. During 1959–1960, he was Vice-President of the British Methodist Conference, the highest position a layperson can achieve in Methodist circles.

[56]Charles Coulson, "The Contributions of Wave Mechanics to Chemistry," The 1951 Tilden Lecture, *Journal of the Chemical Society, Part II* (1955): 2084, https://doi.org/10.1039/JR9550002069.

[57]Arie Leegwater, "Charles Alfred Coulson: Mixing Methodism and Quantum Chemistry," in *Eminent Lives in Twentieth-Century Science and Religion,* 2nd edition, ed. Nicolaas A. Rupke (Frankfurt am Main, Germany: Peter Lang GmbH, 2009), 73–103.

[58]Charles Coulson, *Christianity in an Age of Science,* Riddell Memorial Lecture (London, UK: Oxford University Press, 1953), 25.

[59]Christopher M. Rios, *After the Monkey Trial: Evangelical Scientists and a New Creationism* (New York: Fordham University Press, 2014) describes only Coulson's complementary view of science and religion on pages 87–89. Also see the exchange between Oliver R. Barclay and Coulson concerning the religious character of scientific practice discussed in Arie Leegwater's editorial, "On Boundaries: Let Science Be Science? Let Religion Be Religion?," *Perspectives on Science and Christian Faith* 61, no. 4 (2009): 209–10, https://www.asa3.org/ASA/PSCF/2009/PSCF12-09Leegwater.pdf.

[60]Coulson, *Christianity in an Age of Science,* 30.

[61]Ibid., 33.

[62]Charles Coulson, *Science and Christian Belief,* McNair Lecture (London, UK: Oxford University Press, 1955), 83.

[63]J. W. Linnett, "Charles Coulson 1910–1974," 109.

[64]Charles Coulson, "Science and Religion," *The Advancement of Science* 11 (1954): 332.