Chapter 2
Eddington's Limits of Knowledge: The Role of Religion

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2.1 Thinking About Science and Religion

When thinking about the limits of scientific knowledge, religion is often invoked. Religious ideas are outside science, perhaps; or religious dogma constrains what science can know. We must remember, though, that science and religion are not abstract categories. Science is done by scientists, and religions only exist in the practices and beliefs of their membership. So, one way to think about science and religion is through the individuals involved. Many scientists are, and have been, religious. Does that matter? Is there any role for religion when we are talking about science?

This is an empirical question, and we need to look for evidence to understand what is happening. A.S. Eddington, as a religious scientist deeply concerned with the limits of knowledge, may be a helpful case study. He engaged with a range of scientific disciplines, was thoughtful about the philosophical implications of his work, and wrote extensively on science and religion. He was also active at a time of profound shifts in the role of religion in the western world, and he can help us understand some of those transitions.

One of the advantages of looking closely at an individual is that we are immediately pulled away from very broad terms such as ‘science’ and ‘religion.’ Eddington was not just ‘religious,’ he was a Quaker at a very particular time and place. We cannot assume ‘religion’ means something general like belief in God. For example, if we are concerned with sources of religious truth, we must distinguish between divine inspiration, scriptural literalism, and the apostolic succession. These are all sources of religious knowledge, but adherents of different traditions (or even the same traditions in different eras) might disagree profoundly about their significance.

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We need to be specific about what beliefs and practices we are interested in. For Eddington's case, we need to understand something about late 19th-century/early 20th-century Quakerism. The Quakers are a small Protestant sect dating back to the 17th century that emphasizes the presence of God within everyone, and a related embrace of mysticism, pacifism, and social activism. They are distinctive for their rejection of clergy, rituals, and many of the outward trappings of organized religion. Even scripture, while valued, takes second place to personal religious experience. Eddington himself was a product of a particular historical manifestation of the Quakers: the so-called 'Quaker renaissance' of the late Victorian period, which was characteristic of liberal theological movements of the time.

This movement was a result of a new generation of Quakers debating how to react to the march of modernism: science, history, industrialization, urbanization, pluralism. They decided to embrace modernism, with all of its flaws, but to try to invest those modern views with religious values. The question of how to interface with science was particularly fraught. One Quaker leader wrote:

> This theory of the detachment of science and religion from one another never has been a working theory of the universe; the two areas must overlap and blend, or we are lost [5, p. 219].

Eddington learned how to be a Quaker from exactly this group. He was taught from a young age that a scientist could not separate his religious beliefs and practices from his work. He became what one influential Quaker called a 'practical mystic': someone who lived and worked in the temporal world but who was still in direct experiential contact with spiritual forces.

2.2 Types of Interactions

Once we have established the specific religious categories we are interested in, we can start asking more detailed questions. In what ways might we imagine these religious categories interacting with scientific work? We are focused here primarily on conceptual issues, and this discussion will address four broad categories (with some overlap) that can help shape scientific concepts and methods: restriction, inspiration, natural theology, and values.

2.2.1 Restriction

We often think about religious thought functioning as a bias against certain scientific concepts. This was not particularly an issue for Eddington, but Quakers of earlier generations were hostile to Darwin and notions of human evolution. Human evolution is perhaps the classic example of an idea resisted for religious reasons. Even beyond caricatures such as Creation Scientists, well-respected productive scientists such as William Thomson (Lord Kelvin) found themselves unwilling to accept natural selection [11].

However, this sort of restriction sometimes happens in more subtle ways. Religious beliefs often involve ways of thinking and acting, not just statements of fact about the material world. Michael Faraday was famously skeptical of hypothetical reasoning and speculative theory, a position likely linked to his idiosyncratic theological positions regarding humility before God [1].

2.2.2 Inspiration

If we accept that religion can shape scientific thinking in negative ways, it should come as no surprise that the opposite can happen as well. A theological viewpoint may provide a scientifically useful idea, or make a particular theoretical perspective more appealing. To take our earlier example, Kelvin's religious beliefs were a critical part of how he engaged with the second law of thermodynamics. He felt that there was strong scriptural support for a universe which was gradually running down, and saw entropy as an affirmation of a divinely created universe. Similarly, Maxwell was convinced that the Christian God had designed the laws of nature with unity and simplicity in mind. This was a major stimulus for his research program that would eventually unify electricity, magnetism, and light [6, 10].

In Eddington's case, we can see this at work in his embrace of the implications of quantum physics. As a Quaker, he believed strongly in the reality of free will and the ability of humans to make meaningful choices in the world. He had already rejected determinism, so he was particularly receptive to quantum indeterminism. It is important to note that this was not a matter of him thinking that quantum physics had proved his religious beliefs to be true. Rather, his religious beliefs provided a receptive environment in which the oddities of the quantum world were expected and welcome.

2.2.3 Natural Theology

A related, though distinct, process is referred to as natural theology. This describes practices and beliefs involved with the idea that scientific study can reveal religious truths. It is sometimes described as the assertion that there is a book of nature just as there is a book of scripture, and both should be studied to learn about God. This was a common motivation for scientific practice before the twentieth century, particularly in Britain. Natural theology was often concerned with questions of proof—can science provide evidence for God's existence, or the truth of the Bible? The hope (usually unfulfilled) was that science could so surely demonstrate divine creation and foresight that every atheist would be forced to capitulate.

Eddington, like most Quakers of his generation, rejected the reasoning of natural theology. For them, proof was not an important issue in religion. Religion was an ongoing, always developing realm of human experience, and should not be expected to provide certainty. When Eddington became well known as a religious scientist, he bemoaned being pressured to use science to prove the truth of Christianity. He complained that believers were constantly asking him to provide a scientific silver bullet to use against skeptics. In response, he disclaimed that he could no more force belief into an atheist than he could ram a joke into a Scotsman [4, p. 336]. Proof was simply not a part of his theology.

Quakers talked to God not through nature, but through direct, individual, internal experience. Eddington tried to illustrate this through a quote from scripture. In the first book of Kings, God came to communicate with Elijah:

> And he said, Go forth, and stand upon the mount before the LORD. And, behold, the LORD passed by, and a great and strong wind rent the mountains, and brake in pieces the rocks before the LORD; but the LORD was not in the wind: and after the wind an earthquake; but the LORD was not in the earthquake: And after the earthquake a fire; but the LORD was not in the fire: and after the fire a still small voice And, behold, there came a voice unto him, and said, What doest thou here, Elijah? [2, pp. 25–26].

God was not to be found in meteorology, seismology, or physics, but inside oneself, through mystical experience. Eddington was deeply religious but rejected the claim of natural theology that God should be invoked in science.

2.3 Science and Values

The previous types of interactions became less prevalent and influential in the practice of science in the twentieth century. All of them are largely concerned with the truth claims of religion—did God create the world? In what way? Are humans separate from the natural order? However, both religion and science are more than a collection of truth claims. Both are also collections of values—attitudes, preferences, ways of thinking or acting. Tolerance is a value. Precision is a value. Some values appear in both religious and scientific contexts, and can provide a way for both traditions to interact in interesting ways. In analogy to chemical bonding, I call these *valence values* [9, pp. 5–7]. The fact that they are shared can bring together otherwise disparate practices. Valence values are the best way to understand Eddington's work as a religious scientist, particularly his thinking on the limits of science. In this section I will examine two groups of values that, for Eddington, were important in both science and religion: pacifism, and open-minded seeking.

2.3.1 Pacifism and Internationalism

The Quakers are perhaps best known for their pacifism and commitment to internationalism. That value is rooted in a religious principle called the peace testimony. Their 'belief of the potentiality of the divine in all men' led them to reject war and violence in all its forms. Attacking another person was, essentially, attacking God. The Quaker Renaissance saw an important shift in their pacifism. Whereas previous generations simply refused to fight, Eddington's generation felt called to be activists for peace—working constantly to prevent conflict and repair rifts between nations.

This was particularly important for Eddington due to the way the scientific community reacted during World War I. After the outbreak of war, British scientists rejected anything that looked German. Foreign members were thrown out of the Royal Society, astronomical telegraph lines were cut, scientific societies refused to send journals to enemy countries. Eddington was one of the very few British scientists who resisted these moves. He protested jingoism in science both on practical grounds (the lines of latitude and longitude do not obey national boundaries) and higher ideals (the pursuit of truth is sacred beyond any patriotic feuds).

Unlike most of his colleagues, Eddington maintained communications with scientists in enemy and neutral countries. This meant that he was the only person in Britain to hear about Einstein's new theory of general relativity in 1915. Eddington was excited by the theory's scientific and philosophical significance, and even further when he learned that Einstein was himself a pacifist. Promoting Einstein and his ideas could promote world peace and refute the racist stereotypes that were fueling wartime hatred.

This helps us understand the intensity of Eddington's efforts to carry out the 1919 eclipse to test Einstein's prediction of light deflection. It required exactly the international cooperation that Eddington had argued was fundamental to the spirit of science: German theory, British observers, Brazilian and Portuguese sites. Further, it was an opportunity to bring a peace-loving, insightful German to prominence in both science and society and thus weaken the prejudice that had shattered international science. To Eddington the expedition was not only part of his duty as a scientist (it would test a theory of radical physical implications), but he felt a linked duty as a Quaker (it would help repair international relations by bringing together the German and British scientific communities) [7, 8].

Eddington used the spectacular publicity surrounding the expedition to lay out his case for repairing international relations both inside and outside science. To do so, he adopted the techniques used by Quaker relief workers during and after the war. For him, Einstein and relativity were his contribution as a Quaker to world peace. The key strategy was to build intellectual relationships, and to humanize the enemy—to show that they were just like us, and suffered just as much from war. Eddington's religious values were key to this scientific project, and drew stark contrast with his British colleagues who did not share his pacifist perspective.

2.3.2 Seeking

Eddington's scientific work was also shaped by a Quaker attitude toward knowledge called 'seeking'. This is an outlook on religious experience that emphasizes constant exploration and searching for new things. Seeking is essentially an anti-dogmatic position: do not look for complete certainty, because that leads to stagnation. This is derived from the Quakers' mystical practices. If you talk to God every day, you need to always be receptive to new knowledge. In contrast, a fundamentalist who emphasizes unchanging scripture comes to value stability and certainty over novelty. Quaker seeking embraces progress despite uncertainty, and resulted in a kind of mystical pragmatism. Whatever tools were useful for spiritual progress were to be celebrated, even if their ultimate meaning was unclear.

Eddington argued that this sort of attitude was not just useful in religion, but also in science. Particularly in his work on stellar physics we can see Eddington constantly emphasizing this need to embrace incomplete knowledge and to reject complete certainty as a goal. He began work on stellar astrophysics before many of the fundamental nuclear processes were understood, and investigators had been continually frustrated in their efforts to model the interiors of stars. Many physicists, such as James Jeans, argued that if they did not know every principle at work there, and every detail of the star's history, they could know nothing at all about what was happening. Eddington instead shaped his work around the idea that we can use incomplete, uncertain theories to solve specific problems. He became famous at the Royal Astronomical Society for his shrewd use of assumptions, approximations, and outright guesses to evade difficult theoretical problems and arrive at some useful conclusion. This is the sort of methodology that led to his development of the mass-luminosity relation, one of the first real inroads to understanding stellar structure. This eventually provided traction on the problem of stellar energy, even as the full understanding of fusion was over a decade away. Some, like Jeans, complained that this partial knowledge should not really count as science. In contrast, Eddington tried to convince colleagues that exploring a new problem, even incompletely, was valuable unto itself. His case was that tentative knowledge was welcome as long as it led to progress [9].

This represented an extension of Eddington's Quaker attitude toward religious knowledge, in which fundamental certainty (such as inerrant scripture) was far less important than maintaining a living, transforming faith and a direct experience of God. Certainty was not to be sought after in either science or religion. In one of his best-selling books, Eddington wrote:

> In science as in religion the truth shines ahead as a beacon showing us the path; we do not ask to attain it; it is better far that we be permitted to seek You will understand neither science nor religion unless seeking is placed in the forefront [2, pp. 22–23].

He said science and religion were similar in that they were both an unending quest. Further, this urge to seek was the deepest expression of human nature—science came from as profound a root as religion.

2.4 Experience

The most important of Eddington's valence values for our discussions here was that of *experience*. Quakers had a distinctive way of thinking about how humans experience the world, and this informed Eddington's approach to relativity and quantum physics. In his extensive writings on relativity he always emphasized the role of the observer. His epistemological emphasis eventually developed into his 'selective subjectivism.' This essay will look at the roots and implications of this framework as opposed to the framework itself.

In interpreting relativity, Eddington particularly stressed the observer's role in making measurements. He even elevated measurability (or he sometimes wrote, 'metricality') to be the very marker of scientific knowledge. The essence of relativity was, he said, simply a rigorous treatment of this idea. What are we measuring, and how do we measure it?

Pushing this even further, Eddington wanted to distill these observations to simple relations. He drew extensively on his intellectual genealogy. His reading of Karl Pearson helped shape his emphasis on the role of conscious minds in organizing distinct sense impressions. He explicitly credited Bertrand Russell as his most important philosophical influence, and it is not difficult to see that philosopher's structuralism in Eddington's work.

Eddington's definition of science was essentially Einstein as filtered through Pearson and Russell. Exact science was simply the symbolic analysis of pointer readings collected during space-time events (that is, intersections of world-lines). Thus science was limited to a structural relationship of symbols and binary events. Relativity and quantum mechanics were the pinnacle of modern science because they embraced this operationalism and discarded deterministic materialism. Even further, both theories acknowledged the importance of human consciousness.

Eddington contended that this move, the rigorous analysis of the act of observation, was the foundation of scientific inquiry. He stressed that observation was the human mind selecting data from the four-dimensional universe (what Eddington called 'the World'). And the selection process was not passive. Rather, our minds chose which elements of reality were important and worth analyzing. The World was a vast soup of space-time events which could be sliced up and perceived in many different ways. The observer's selection of a particular slice results in their perception of certain laws, such as conservation of mass. Our minds like permanence, so they select for conservation laws that create that effect. Einstein's law of gravity came directly from these selection effects. The laws of physics were therefore created by human observation. This 'closed cycle' of physics, in which the mind both creates and discovers natural laws, gave humanity and human experience a renewed place of importance. Eddington stressed that this demonstrated that our world was fundamentally idealistic, and the rigid materialism beloved of skeptics was no longer tenable.

This left humanity with two worlds of experience: one metrical, one non-metrical. The world of science was completely metrical. It could only speak about the measurable aspects of reality. But there were aspects of human experience that were not quantifiable (love, beauty). Relativity's emphasis on measurements and coincidences acknowledged a world beyond that of measurable science. Eddington illustrated this with his famous tale of two tables [4]. He described himself sitting and writing at two different tables. One was the table of science. It was mostly emptiness, made of atoms whirling to and fro, without any substance or stability. The other was the table of ordinary experience. It was solid and steady. Science could only describe the former; a person could only write on the latter. The solid table came from the direct experience of our consciousness. The scientific table was filtered through pointer readings and abstract symbols. The scientific table was, therefore, far less *real* than the other. This is the root of 'Eddington's challenge' as discussed by Huw Price at the conference that inspired this volume. We have a sense of time provided by our ordinary experience, and a sense of time provided by scientific analysis. Are they compatible? Should one be valued over the other?

Eddington contended that this sort of ordinary experience was really *spiritual* experience. This spiritual world was the one in which everyone actually lived. It was the world marked by our intuitive convictions of experience and consciousness. Spiritual reality and scientific reality were separated by the border of metricality. Relativity's emphasis on measurement thus acknowledged the reality of spiritual experience.

This was, Eddington thought, good for both science and religion. Emphasizing the role of direct experience affirmed the spiritual life and created modern physics. He wrote that this spiritual outlook would benefit science:

> The anti-materialistic attitude of religion would certainly be an advantage to modern science. It would help a man to see certain possibilities, to entertain certain speculations, which the old materialists, who regarded the universe as composed of little billiard balls, would have difficulty in grasping [2, pp. 50–51].

This emphasis on the spiritual value of experience was particularly Quaker. Eddington's attack on materialistic critiques of religion was typical of British liberal theology. It was notably Quaker, though, in emphasizing individual, non-dogmatic experience. For Eddington, both the metrical and spiritual worlds were empirical:

> The scientist and the religious teacher may well be content to agree that the value of any hypothesis extends just so far as it is verified by actual experience [4, p. 222].

The scientific and spiritual worlds were quite different, but they both emerged from the same values.

It is important to note that this was not a replacement religion—Eddington did not want anyone to worship covariance. Neither did he think that relativity confirmed Quakerism. Rather, his argument was that this interpretation simply opened up a space in which an individual's own religious experience could be accepted on its own terms without scientific critique.

Despite this, it is common to see Eddington quoted as saying 'religion first became possible in 1927' (referring to the development of Heisenberg's uncertainty principle). The quote is usually presented to support the claim that quantum physics proved the validity of religion. Amazingly, this is exactly the opposite of the meaning of Eddington's actual statement. The original quote reads as follows:

> It will perhaps be said that the conclusion to be drawn from these arguments from modern science, is that religion first became possible for a reasonable scientific man about the year 1927. If we must consider that most tiresome person, the consistently reasonable man, we may point out that not merely religion but most of the ordinary aspects of life became possible for him in that year [4, p. 350].

He was very clear that 1927 made nothing new possible for religion. Instead, modern physics was just providing reassurance to religious people that their experiences of the spiritual world could be valid on their own terms. Eddington expected everyone to go on having religious experiences just as they always had been. Relativity provided the critical first step by recognizing the importance of mind and consciousness, but any further religious guidance had to come from direct individual spiritual experience. What modern physics did was make a particular kind of religion more plausible—Quakerly experiential religion. Scripturalists and High Church advocates were given little help.

2.5 Information and Interaction

Two of the themes of this volume are information and interaction, each critical concepts for understanding Eddington's limitations of science. The role of "interaction" is very clear—Eddington's entire epistemology of science is built on intersections of world-lines and the interaction of the mind with the World. Considering the role of 'information' is both more hazy and perhaps more rewarding. Eddington certainly uses metaphors and terms that evoke modern senses of information theory: observations are 'sets of signals passing along our nerves,' and pointer readings are 'code messages' that have no meaning without a conscious observer [3, p. 6]. Deciphering the messages of the outside world is a metaphor he returns to again and again. The scientific observer is one who tries to decode the patterns seen in those messages.

In an important sense, Eddington denied that there is any scientific reality to the physical world other than what we can discern from these signals. He reduces those signals to their most primitive forms—pointers read by a one-eyed observer with no color vision. He would not have used the term, but we can think of his observations as bits. To Eddington, this reduction of the entire scientific world to bits was the foundation of the geometrization of physics begun by Einstein. In this sense, Eddington might have said that information is distinctive of physical science, but not experience generally. The non-metrical world of spiritual experience could not be reduced to bits the same way. Regardless, understanding both categories was a matter of epistemology, which perhaps does put information at the root.

2.6 Conclusion

There are many ways of thinking about science and religion. This essay has examined some modes that are useful for understanding Eddington's approach to the limits of science. Even in situations such as this where the importance of religion is clear, it is rarely the sole explanation. Religious beliefs and practices necessarily interact with many other factors.

The case of Eddington shows that sometimes we do see real interactions between religion and science. This can make some ideas more plausible (quantum physics); some ideas less (determinism); some approaches better (seeking), some worse (nationalism). Sometimes there is no direct interaction even where we might expect it. For example, Eddington's religiosity did not seem to have any links to his cosmological work on the beginning of the universe. This should not be a surprise. Quakers of his generation were not particularly interested in questions of creation and Genesis. Finding that sometimes science and religion interact does not mean they always do.

Further, these interactions are historically situated. They appear in some times and places and not others. What we see with Eddington is distinctive of early twentieth century liberal theology. We would not expect to see the same valences in nineteenth century Britain, which was dominated by robust institutional religion. It is also different today. The strong Protestant fundamentalism in modern America has completely different values than Quakerism, and generally struggles with science. And it will be different in the future. We need to be careful about how we generalize. When talking about science and religion, we need to pay attention to the particulars.

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