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Towards a Scientific Approach for Integrating Science's Outputs and Islamic Concepts—Part 2

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Abstract

The intellectual Muslim community lives in a dichotomy between faith and science. On one hand, the Islamic teaching tells us that knowledge brings us closer to God and substantiates our faith with rational evidence. On the other hand, the predominant western culture in scientific circles rejects the concept of believing in the unseen and classifies it under the topic of metaphysics, with all the negative connotations associated with this topic. As a result, the path of living according to faith and the path of scientific investigation grew divergent from each other, with no apparent point of intersection. This article is aimed at removing the obstacles erected by the empiricists in the scientific method, which hinder the integration of religious knowledge and scientific output in a unified

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framework. Our discussion of the scientific method from an Islamic perspective shows that rational and empirical faculties can be utilised to their fullest potential in a complementary manner. Emerging from the concept that religion and science are two valuable engines of human civilisation, an ideology-based approach for the study of natural systems can be adopted. This second part of the article sets the foundation for integrating induction and deduction in a unified framework.

Keywords
Ibn al-Haytham, deduction, induction, experimentation, metaphysics, scientific method, theory.

Introduction

As discussed in the first part of this article,[1] basing scientific investigation on a pure experimental approach precludes the integration of the inductive and the deductive approaches, which consequently puts the western practices of applied sciences in conflict with Islamic theology. To set the stage for such desired integration, the limits and assumptions of Bacon's method and Popper's notion of falsification have been critiqued. It has been also shown that reaching certainty is possible in dogmatic principles, as well as in some natural theories.

In this part of the article, Ibn al-Haytham's scientific method is presented as a bright example of capitalising on the points of strength of deduction and induction. The role of abstraction and insight in building theories is then analysed through the discussion of two remarkable physical discoveries. Lessons learned from these case studies are used to contrast deduction and induction in a logical and practical context. Finally, it is argued that incorporating the metaphysical dimension in

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[1] See Ahmed Mabrouk "Towards a Scientific Approach for Integrating Science's Outputs and Islamic Concepts–Part 1," *TAFHIM: Journal of Islam and the Contemporary World* 16, no. 1 (June 2023): 1—29.

the scientific investigation of natural systems enriches human experience and removes the barrier between divine-revealed knowledge and natural sciences.

Ibn al-Haytham: When Dogma Fuels Scientific Advancement

Centuries before Bacon (1561–1626 CE) and Locke (1632–1704 CE), and in a substantially different atmosphere where scientific research is promoted and encouraged by religious authority, Ibn al-Haytham (965–1040 CE) lived. Owing to his exceptional scientific talents and unique values, Ibn al-Haytham performed a pioneering work in physics and mathematics that distinguished him as one of the leading science makers in history.

On the personal level, Ibn al-Haytham was described as "a man of noble character, abstaining from worldly affairs, and naturally inclined to good causes."[2] With regard to his religion, he was regarded as "a pious worshipper who highly upholds the commands of his religion."[3]

Our analysis of his work is focused on exploring his scientific approach, particularly in comparison to that of Bacon. This analysis may show—as a secondary outcome—that his accomplishments did surpass others in time and value. It should be highlighted that Ibn al-Haytham's statements have been paraphrased in contemporary language in order to facilitate comprehension of his arguments. Moreover, some examples have been added to those he mentioned to further clarify his points.

Constructing Scientific Theories

As every human endeavour is initiated by a motive, Ibn al-Haytham was motivated with the desire to resolve the various conflicting views of his contemporary and past scholars regarding

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[2] Ibn Abī Uṣaybiʿah, *ʿUyūn al-Anbāʾ fī Ṭabaqāt al-Aṭṭibāʿ* (Cairo: Majmaʿ al-Wahbiyyah, 1882), vol. 2, 90.

[3] Ẓāhīr al-Dīn al-Bayhaqī, *Tārīkh Ḥukamāʾ al-Islām* (Damascus: Majmaʿ al-Lughat al-ʿArabiyyah, 1976).

theories of visual perception. He described his attitude toward these conflicting views as that of a reserved observer who believes that the truth can only be one and may have been missed by all involved parties.[4] Further, he attributed this contradiction to the different approaches, or alternatively the different scientific methods, adopted by the investigators. Such realisation accounts for the critical importance Ibn al-Haytham attached to the scientific method. From Ibn al-Haytham's point of view, a correct method would pave the road to reaching the truth, whereas a failing one would take the investigator farther away from it. It is thus natural to ask: "what is the most reliable way for reaching the truth?" Ibn al-Haytham answered this question saying, "I realised that I would not reach the truth except through views built over undoubtful sensual observations within a rational framework of inference."[5] Consequently, the effective method, according to Ibn al-Haytham, is "to start our research by observing the surrounding visual media, surveying their various conditions, and determining their major and minor characteristics."[6] This is meant to provide the original data based on which the research shall proceed. Diversifying the sensual observations and augmenting the volume of the initial data, Ibn al-Haytham affirmed, would decrease the chance of making mistakes in subsequent stages of research.

According to Ibn al-Haytham, a scientist has to analyse the collected data within a rational framework. The scientist should look for common features and/or repeatable patterns that connect the data to formulate general laws describing the phenomenon under investigation. Correlating the data for the sake of identifying repeatable patterns indicates Ibn al-Haytham's belief that natural phenomena follow universal laws within a coherent framework. Without such a framework, science would never manage to interpret nature or reveal its

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[4] Ibn Abī Uṣaybiʿah, *ʿUyūn al-Anbāʾ*, 91–92.

[5] Ibid., 92.

[6] Al-Ḥasan ibn al-Haytham, *Kitāb al-Manāẓir* (Kuwait: The National Council for Culture, Arts, and Letters, 1983), 62.

underlying principles.[7] In support of the concept of unity of nature, Ibn al-Haytham states that "the nature of minute parts and that of giant ones in the universe are the same as long as they share the same form."[8]

Ibn al-Haytham integrated experimentation and reasoning in his research in a way that demonstrated deep insight of the points of strength and weakness of each. He resorted to experiments to prove points which are not logically necessary and to confirm conclusions. He also used geometrical and mathematical analysis to formulate laws in quantitative terms. Moreover, Ibn al-Haytham utilised abduction to exclude potential scenarios in the course of developing proofs. Both experiments and mathematically proven arguments can build upon each other and thereby move research forward. For example, after Ibn al-Haytham established experimentally that light propagates in straight lines, he applied this outcome in his explanation of shadow formation. On another front, Ibn al-Haytham used an inductive analogy to link several disciplines. Because many mechanical processes can be observed with bare eyes, knowledge of mechanical systems constitutes a first order sensory knowledge. Ibn al-Haytham drew parallels between optical phenomena and mechanical ones. The reflection of light upon falling on mirrors was made analogous to the bounce back of an elastic ball from a rigid surface.

After reaching tentative conclusions, experiments are to confirm these conclusions and remove, to some extent, the doubt over the correctness of such theories. In the second part of *al-Manāẓir*, Ibn al-Haytham described in detail the design of his laboratory apparatus and his test procedures. Ibn al-Haytham called the process of experimentation *al-iʿtibār*, a Quranic term that refers to learning lessons and capitalising on experience. Ibn al-Haytham's use of this term indicated that experiments should be interpreted in a rational framework.

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[7] Mustafā Naẓīf, *Al-Hasan ibn al-Haytham wa Kushūfuhu al-Baṣariyyah* (Beirut: Markaz Dirāsāt al-Wiḥdah al-ʿArabiyyah, 2008), 119.

[8] Ibn al-Haytham, *Kitāb al-Manāẓir*, 81.

Ibn al-Haytham declared his admiration of Aristotle's deductive logic and his presentation style. From Ibn al-Haytham's perspective, the deductive logic is in line with the scientific model of research in which the scientist moves from a general rule to the cases that belong to this rule. This is consistent with the worldview of Ibn al-Haytham that nature can be modelled by a set of laws. Compared to Plato, Aristotle's writings were straightforward and more concrete.[9] It is important to note that despite Ibn al-Haytham's admiration for the Aristotelian line of thinking, he did not follow his research methodology. For Aristotle, reasoning-based conclusions are the chief outcome of scientific works. On the other hand, Ibn al-Haytham ranked experimentation so high that it occupies a central position in his research. Not only was experimentation a way of confirmation and an additional security measure against error, but it was an independent channel for learning about the world.

*Reflection of Light as Seen Through Experiments and Mathematic*s

The most advanced stage of optical research prior to Ibn al-Haytham was that of Ptolemy. Therefore, Ptolemy's findings represented the starting point of Ibn al-Haytham's research. The added value in Ibn al-Haytham's research can be seen on two fronts. First, he drew parallels between light reflection and collision of rigid bodies. Secondly, he provided a theoretical derivation of light reflection. When light falls on a highly reflective surface like a mirror, it acts like a ball falling freely on, or thrown toward, a surface, Ibn al-Haytham asserted. He conducted various experiments in which he varied the distance of the ball from the surface, the kinetic force of the ball, and the material of the surface.[10] These experiments showed similar results to those obtained upon varying the intensity and the

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[9] D. J. O'Connor, *A Critical History of Western Philosophy* (New York: The Free Press of Glencoe, 1964), 36–61.

[10] Mustafā Naẓīf, *Ibn al-Haytham wa Kushūfuhu*, 214–220.

reflective index of the surface. When a rigid surface, like iron, is replaced with a less rigid one, like wood, the ball bounces back a shorter distance. In a similar manner, when light reflects from a less reflective surface, it reflects with a lower intensity. The surface material, thereby, determines the coefficient of restitution for the surface impact. Seven centuries after Ibn al-Haytham, Newton (1643–1727 CE) reused the same factor in his study of rebounding.

It might be helpful to summarise the mathematical derivation conducted by Ibn al-Haytham for light reflection. It does show an instance of substituting experimentation with a more powerful deductive tool. The incident light can be decomposed into two components: a vertical component to the surface and a horizontal one. Upon hitting a highly reflective surface, the vertical component of the reflected light reverses direction but maintains its magnitude, while the horizontal component maintains both direction and magnitude. Because the vertical component alone propagates in the opposite direction to that of the incident light, the angle of incidence must be equal to the angle of reflection.[11] As seen, the mathematical proof stands formidable against invalidation due to its simplicity and reliance on a single assumption that the surface is highly reflective such that it does not absorb any portion of the energy of the incident light. This assumption accounts for the fact that the vertical component of the reflected light maintains its magnitude.

Cognition

Ibn al-Haytham differentiated between sensation and perception.[12] With sensation, he meant that the observer receives simple, basic qualities, such as illumination and colour. Perception, on the

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[11] Ibid., 225–226.

[12] Modern cognitive studies adopt the same classification. See, for example: Bruce Goldstein, *Sensation and Perception,* Eighth Edition (Belmont: Cengage Learning, 2010), 5–12.

other hand, requires further mental processing to complete the cognitive process. For example, an observer recognizes that he is looking at a transparent medium after seeing the objects behind this medium and realising that they are farther away from the observer. Only after performing these mental transactions, the observer classifies this medium as transparent. Perception was further sub-divided by Ibn al-Haytham into perception that is based on previous knowledge, or more accurately based on a stored pattern in memory, and perception that does not rely on such knowledge.[13] Ibn al-Haytham developed a rule of thumb to differentiate between the two types of perception. When we watch a familiar object, we only survey a few of that object's features. For example, it is sufficient for a mother to match a few features of the watched child with the image of her child in mind to recognize the child as her son. However, when we look at a rare, unknown animal, the cognition process covers most of the features of that animal. This means that the second sub-category of perception requires a longer time due to the more comprehensive feature survey.

Ibn al-Haytham put his theory of visual cognition into the broader context of human cognition. In *al-Manāẓir*, he discussed how the human mind is programmed to perform cognitive tasks unconsciously. In this regard, he mentioned the way toddlers perform cognition. There are two important implications of Ibn al-Haytham's consideration of visual cognition as a branch of human cognition. First, all sensory data, including visual, auditory, aromatic, and others are processed by the same cognitive faculty. Secondly, the various types of cognitive data undergo some sort of abstraction that enables the cognitive faculty to handle them through a unified approach. The role of abstraction will be further discussed in our later comparison between induction and deduction.

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[13] Ibn al-Haytham, *Kitāb al-Manāẓir*, 219–224.

Ibn al-Haytham identified twenty-two visual qualities that we receive in our cognition and discussed how each one is perceived in considerable detail.[14] For brevity, we outline a quality that involves intensive mental processing, namely the distance from the observer. Ibn al-Haytham stated that we estimate the distance of the watched object from us based on the existence of intermediate objects, which provide cues of the estimated distance and without which the estimated distance figure would be a mere conjecture.[15] Consider the case of a person in a flat desert trying to estimate the height of clouds. Such a person is not expected to give a reasonably accurate figure of this height. However, if mountaintops intercept the clouds, their height can be estimated with a higher accuracy. Additionally, the degree of accuracy increases when the object is relatively close to us and is flanked by other objects whose sizes are known to us beforehand. For example, the distance between an observer and a room's wall can be easily estimated when a carpet of known dimensions is covering the floor of the room.

Errors of the Sight

One of the valuable contributions of Ibn al-Haytham is his analysis of the causes of visual errors and the framework of analysing them. Ibn al-Haytham attributed all visual errors to a single general cause, with various ramifications, that one or more of the conditions required for unmistaken cognition is not fulfilled. The following is a list of the eight conditions he named: illumination, distance, facing the object, size of the object, object be non-transparent (opaque or partially opaque), existence of a transparent medium between observer and object, allowing enough time for cognition, and having a non-defected visual sense.[16] Each of these conditions has a range for proper

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[14] Ibid., 230–231.

[15] Ibid., 248–249.

[16] Ibid., 374.

cognition, with a midpoint designating optimum cognition. The coordinates of this midpoint are a function of the other conditions and the characteristics of the object. For example, a minute object and an object with fine patterns should be inspected from a short distance and under strong illumination. If the whole range of cognition for a condition is missed, we either do not see the object or perceive an unreal image of it.

Ibn al-Haytham classified visual errors into three categories. First category includes errors due to pure sensational factors. For example, we sometimes identify the colour of a dark blue fabric at night as black due to insufficient illumination. Second category includes errors due to lacking sufficient cues needed for cognition. For example, we may mistakenly recognise a distant fox in a jungle as a dog. Errors made in identifying letters during a sight test at the ophthalmologist fall into this category. Third category includes errors due to lacking associative cues in the surrounding environment. For example, if the observer and two distant persons stand on a straight line in a flat field, it becomes hard for the observer to estimate the distance between the two persons. Of particular interest is this category because it shows the collaborative nature of receiving visual cues and interpreting them by the mind. The following few examples are to further clarify the role of associative cues in cognitive processes. Due to lacking associative cues, the full moon appears as big as the sun despite the substantial difference in size and distance of the two from the earth. Also, a square tilted backwardly would appear as a parallelogram for the same reason. Similarly, we can only differentiate between a toy car and an actual car based on associative cues. Seeing a car on a carpet would lead us to classify it as a toy. This discussion shows that many visual cognitive tasks include a complex analysis of various cues. Sometimes the complexity of cognitive tasks reaches the point that the scene is considered a type of visual delusion that tricks our minds into interpreting them differently.[17]

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[17] Rudolf Arnheim, *Art and Visual Perception* (Berkeley: University of California Press, 1974).

A Physiological Model of the Eye

In order to develop a complete theory of vision, Ibn al-Haytham analysed the eye as a tool of vision, apart from anatomical aspects. In *al-Manāẓir*, Ibn al-Haytham described the different layers of the eye, starting with the outermost layer that receives light and ending with the nerve that carries visual data from the retina to the brain.[18] Ibn al-Haytham used geometrical analysis to determine the locations of two external points on the retina. He used this analysis to explain that our sight misses some details of the object's image when the points representing such details fall at the same retinal point. This is basically the concept of resolution, measured in the number of megapixels, applied in modern digital cameras. More importantly, Ibn al-Haytham used his model of the eye to invalidate one of the most common and long-standing misconceptions, among scientists and philosophers alike, that we see based on light rays emitted from our eyes. He instead showed that the eye is a passive receiver and collector of light from the surrounding environment, in one of his most crowning achievements that has set optical researchers on a straight path since the tenth century.

Models and Science

Models are mathematical representations of natural and man-made systems, aiming at capturing their functionalities and producing outputs that closely match the actual outputs of these systems.[19] Models are used to predict possible events such as models for weather forecasting, to understand and emulate some functions such as models of the human vision, and to verify that our design indeed implements the intent behind it such as models of semiconductor devices like phone chips.[20]

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[18] Ibn al-Haytham, *Kitāb al-Manāẓir*, 127–136.

[19] Stathis Psillos and Martin Curd, *The Routledge Companion to Philosophy of Science* (New York: Routledge, 2010), 385–395.

[20] Diran Basmadjian, *Mathematical Modeling of Physical Systems* (Oxford: Oxford University Press, 2003).

Obviously, the accuracy of a model depends on our level of understanding of the modelled system. The better we understand a system, the more accurate its model will be. Because models are usually simulated over digital computers, it is critically important that they are computationally efficient in order to achieve a reasonably low runtime over computers.[21] For this reason, models usually undergo functional and mathematical simplifications. Functional simplification entails the omission of one or more processes of the system that do not impact the system performance significantly, in order to reduce the number of computations. Mathematical simplification entails approximating nonlinear functions using linear ones, as well as ignoring the high order terms resulting from series expansion. For example, the sigmoid function used in modelling visual perception can be approximated by a piecewise linear model.

Models incorporate our deductive and inductive knowledge of the modelled system. First, mathematics, which is the interface between our understanding and computers, is a deductive tool. Secondly, theories and laws modelling the internal processes are a mix of deductive and inductive knowledge. Thirdly, empirical constants and measurements represented by the way of curve fitting represent inductive knowledge. Because of their mathematical formulation, models provide invaluable assistance in understanding systems and building devices. However, they come at the cost of computational complexity.

We dedicate the rest of this part of the article to two interrelated case studies, followed by a comparative analysis of deduction and induction. We first discuss the success of Dmitri Mendeleev (1834–1907 CE) in constructing his periodic table despite lacking enough knowledge of the inner structure of the atom. Afterwards, the journey of exploring the subatomic world is presented to show the dominant role of abstraction and

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[21] The simulation of the phase locked loop, which is the element responsible for generating the clock signal inside electronic devices, may take up to several weeks over fast computers.

insight in shaping our understanding of that subtle dimension of our world. The research of the atomic structure developed increasingly accurate atomic models that offered conclusive interpretation of the periodic table. We also discuss how the introduction of quantum theory, despite its divergence from common sense, explained the particle nature of light.

Mendeleev and the Triumph of Theory

Mendeleev was not the first chemist who tried to classify elements based on their similarities. Similar to other chemists, he noted the connection between the atomic masses of elements and their chemical properties. However, several factors set Mendeleev apart from other chemists. First, he arranged the elements into groups (vertical columns) in accordance to the similarity of their chemical properties. He did not try to force elements into patterns that do not match the chemical aspects like John Alexander Reina Newlands (1837–1898 CE) who devised the law of octanes based on an analogy to the notes in a musical scale.[22] Secondly, Mendeleev was objective enough to follow a single criterion in structuring his table. When the increasing order of the atomic mass of an element did not exhibit the expected similarity, he put a question mark next to that element. As such, Mendeleev's 1869 periodic table has been widely accepted and it is the most similar table to the modern table that is currently in use.

Mendeleev strongly believed in the periodicity of elements and organised his table in a way that reflects this periodicity. He internalised the characters and properties of similar elements within a family in his mind before knowing these elements. When none of the sixty-three elements known during his time fit in the correct position, he simply left a blank entry for this

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[22] The law of octanes, suggested by Newlands, states that when elements are aligned in order of increasing mass, every eighth element would have similar properties to the corresponding one in the previous octane, see Steven and Susan Zumdahl, *Chemistry,* Seventh Edition (Boston: Houghton Mifflin, 2007), 300.

"yet-to-discover" element, accompanied with a prediction of the atomic mass of this element. Not only did Mendeleev predict the atomic masses of some hypothetical elements, he also determined their chemical properties alongside their densities. In 1871, Mendeleev predicted the discovery of an element similar in properties to aluminium and accordingly left a blank position for it under aluminium. He predicted this missing element to have an atomic mass of 68 and a density of 6.0. In 1875, the French chemist Lecoq de Boisbaudran (1838–1912 CE) discovered an element (later called gallium) that seemed to fit in group III under aluminium, but with a density of 4.7. Due to the significant difference in the values of density, the French chemist initially denied that gallium should fit under aluminium. However, after reviewing his procedure of preparing the sample, he realised that air cavities were trapped in the sample, leading to a lower density value. Later, he obtained a density of 5.935, confirming the early prediction of Mendeleev. Holton and Brush commented on this saying: "Here we have one of the most remarkable cases in which the theory is (initially) more accurate than the experiment."[23]

In connection to the above comment, the remarkable success of the theory was due to its ability to foresee the chemical properties of elements *before* discovering the atomic structure that accounts to these properties. As the electron was discovered decades later in 1897, Mendeleev was unable to link the chemical properties of an element to the number of electrons in the atom's outermost shell. Now, we know that elements with the same number of outer shell electrons show similar properties. Since the group number in the periodic table indicates the number of outer shell electrons of all the elements of this group, these elements are simply similar in chemical properties. We also understand why chemical reactivity increases as we go down the

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[23] Gerald Holton and Stephen Brush, *Physics, the Human Adventure: From Copernicus to Einstein and Beyond* (New Brunswick: Rutgers University Press, 2006), 303.

table in group 1, whereas it decreases in group 7. The metals in group 1 react by losing an electron. As we go down the table, the number of shells around the nucleus increases, making it easier for the outer shell electrons to escape from the nucleus, and becomes more ready to react. On the other hand, elements of group 7 react by gaining or sharing an electron. As we go down the table, the number of shells increases, making it more difficult to gain an electron.

It is worth remembering that Mendeleev was unaware of any of the above explanations made in terms of the distribution of electrons inside atoms. Nowadays, it is customary for chemistry teachers to see the modern periodic table as a further development of Mendeleev's table, paying little attention to the significant contrast of the approaches of developing the two. While the modern periodic table directly benefited from the findings of the distribution of electrons around the nucleus, Mendeleev founded his table on deep insight of the properties of elements. Had Mendeleev had some knowledge of the inner atomic structure, he would not have to struggle with less concrete arguments, and surely a less degree of ingenuity would just be enough to reach the same results. This last argument points out the enormous power with which models endow to human understanding. It is our belief that a deep human knowledge should attempt to capture the essence of a real model of the subject matter as much as possible.

Exploring the Subatomic World

As mentioned before, Mendeleev did not know much about the inner atomic structure, which dictated his approach of relying on common trends across chemical properties. Even though scientific investigation about the atom started two millennia before Mendeleev, very little progress has been achieved up until his time. The search for the reality of the atom posed, and still poses, a big challenge for scientific research, partly because the atomic dimension is beyond the direct observations of the human senses. Furthermore, the chemical and physical properties of matter open a wide range of possibilities and only portray very sketchy models of the atom. The following discussion of the major discoveries pertinent to the atomic structure analyses the roles of experimentation and inference in building our knowledge of the atom.

The question of divisibility of matter arose among Greek philosophers. Leucippus (c. 500 BC) and his disciple Democritus (470–380 BC) concluded, based on logical arguments, that any piece of material can be further subdivided until ultimately small particles, which they called atoms, are obtained. These atoms are not divisible any more. They claimed that the characteristics of a material, such as softness and taste, are still maintained on the level of atoms. They also thought that compounds of different features can be prepared by mixing atoms of different materials.[24] Nowadays, it is accepted that the physical characteristics of a matter, such as elasticity and smoothness, cannot be observed on the atomic level. Apparently, Democritus was not referring to the same atom we currently refer to despite his use of the same term. It is worth noting that the doctrine of atomism, holding that every matter consists of quite small indivisible units, was not accepted by most Greek philosophers, including Aristotle who maintained that matter consists of four elements.

In 1803, Dalton indirectly verified the existence of atoms through the way chemical reactions occur.[25] John Dalton (1755–1844 CE) showed that in order to form a compound, the constituent elements of this compound must follow, by weight, a fixed and unchangeable proportions. For example, suppose that an atom of oxygen is 1.33 times as heavy as an atom of carbon, a carbon monoxide can be formed using 3 weight units of carbon and 4 weight units of oxygen.[26] With this law of definite

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[24] Isaac Asimov, *A Short History of Chemistry* (New York: Anchor Books, 1965), 13–14.

[25] Dalton acknowledged the impact of Democritus' work on his.

[26] Asimov, *History of Chemistry*, 75.

proportions, Dalton differentiated between a chemical reaction and a physical mixture, like a mixture of sugar and water, which does not abide by this law. If matter does not consist of atoms, each having a specific weight, the law of definite proportions would not hold. The main flaw of Dalton's proposition was that he thought only one atom of an element can combine with another atom of a different element. Interestingly, this flaw in Dalton's theory goes back to the very same limitation Mendeleev experienced, namely the electron was yet to be discovered. Had Dalton known that based on the number of outer shell electrons, a single atom may combine with two other atoms, such as when two atoms of hydrogen combine with one atom of oxygen to form water, he would not forward this invalid proposition.

In 1897, Joseph J. Thomson (1856–1940) discovered for the first time a subatomic particle—the electron. Thomson did not detect electrons inside atoms though, but rather when they were emitted from them. He devised a vacuumed cathode ray tube and released electrons from the cathode using a high potential difference. Both electric field and magnetic field were used to deflect the electrons in order to determine their charge and estimate their mass.[27] Upon discovering the electron, Thomson proposed his plum pudding model of the atom, in which he pictured the atom as a positively charged pudding in which electrons are embedded, like seeds in a watermelon. The uniform distribution of positive and negative charges throughout the atom was the most salient feature of that model.

In 1911, just less than two decades after introducing the plum pudding model, Ernest Rutherford (1871–1937), a highly skilled experimentalist, conducted an experiment that shattered the Thomson's model. Rutherford projected a beam of alpha particles (positively charged helium ions) into a thin gold sheet. According to the plum pudding model, most of the

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[27] See the apparatus used by J.J. Thomson in Raymond Serway and John Jewett, *Physics for Scientists and Engineers with Modern Physics*, Ninth Edition (Boston: Cengage Learning, 2014), 881.

particles should have bounced back upon hitting the uniformly distributed charges over the atom's space. However, most of the particles passed through the sheet unobstructed, and more interestingly without ripping the sheet. Only a low percentage of the alpha particles was deflected by a large angle, and even a lower percentage bounced back.[28] This experiment produced the following revolutionary outcomes. First, most of the atom's space is empty, which allows most of the particles to pass through. Secondly, most of the atom's mass is concentrated in a certain point, causing few particles to bounce back upon colliding this mass. Thirdly, this concentrated mass is positively charged, causing particles passing within close proximity to deflect.

In 1913, Neil Bohr (1885–1962) presented the first quantum interpretation of atomic particles, which classical physics failed to offer. If electrons, as negatively charged particles, orbit the nucleus, which carries positive charges, electrons should be attracted to the nucleus or indefinitely accelerate to avoid this attraction, leading eventually to the extinction of the atom as per classical physics. Bohr proposed that electrons orbit the nucleus in specific paths, the outer of which carries more energy, with *forbidden* energy zones in between. The concept of forbidden zones is the essence of quantum theory in physics and chemistry. Electrons can only undertake specific discrete values of energy, rather than smooth continuum energy values, as moving particles in classical physics would. When matter absorbs energy, like heat, an electron may jump up to a higher orbit and becomes more ready for chemical reactions. When matter loses energy, an electron may jump down to a lower orbit, emitting the energy difference between the two orbits in the form of photons, which are perceived by our eyes as light. Since this energy difference must be a specific value of energy, according to quantum chemistry, photons can only carry such a specific value of energy, or one of its multiples. This value of energy is actually Plank's constant. Energy associated with light, as represented by the number of photons, is basically a multiple

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[28] Ibid., 1299–1300.

of Plank's constant. Using Bohr's quantum interpretation of the behaviour of atomic particles, chemists were finally able to explain the periodic table based on a model showing the inner dynamic aspects of the atom.[29]

Light: Wave or Particles?

The study of light-related phenomena by Ibn al-Haytham established the fact that light behaves as a wave. A wave can be best described as a disturbance, not displacement, of the constituents of a matter due to the passage of energy. Waves on water bodies demonstrate interference, diffraction, and reflection. A wave splits into two waves upon passing around a rock, subsequently interferes and diffracts while going through a narrow opening and bounces back upon hitting a ship's wall. Light demonstrates the same three phenomena as Ibn al-Haytham showed. James Clerk Maxwell (1831–1879 CE) later reconfirmed the wave nature of light. Maxwell's equations mathematically formulated the wave-like light behaviour.[30] Scientists were satisfied with the wave-like nature of light as it corresponds to common experience of natural systems. However, that sense of satisfaction was disturbed by the failure of fitting several phenomena into the wave theory of light at the onset of the twentieth century. A quick look at these phenomena reveals that they all belong to the atomic level of matter.

Among others, the interaction of light with matter was an area where the wave nature of light was absent. Here, we discuss an application of this interaction, which is the photoelectric effect. The photoelectric effect refers to the stream of electrons, called photoelectrons, released from a metal plate exposed to light. As expected, the photoelectric effect was demonstrated experimentally in many laboratories around the world, with

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[29] It is important to realise that while Bohr's model is adequate to explain the periodic table, it was not adequate to explain the emission spectra of atoms carrying more than one electron.

[30] James Maxwell, *A Treatise on Electricity and Magnetism*, Third Edition (New York: Dover Publication, 1954), vol. 2, 247–262.

different procedures. The following experimental procedure clearly highlights the quantum nature of light. A metal plate was illuminated by four different light colours—red, yellow, green, and blue—each with varying intensity. The red light never released photoelectrons, no matter how strong the intensity of this light was. On the other hand, a dim blue light triggered the photoelectrons. It was also reported that increasing the intensity of the incident light did not result in increasing the kinetic energy of the photoelectrons. Moreover, there was no time delay between applying the light to the plate and the release of the photoelectrons. These observations are in clear contradiction to the wave theory of light. According to this theory, as the intensity of the incident light increases, the photoelectric current should increase too. It was also anticipated to observe an energy build-up mechanism based on which photoelectrons should commence after a period of time. As a result of the failure of the wave theory to explain the photoelectric effect, scientists, with great reluctance, had to search for an alternative theory, which happened to be the quantum theory of light.

The quantum theory of light introduced the granular nature of light, which pictures light as particles, each carrying a quantum of energy. For each type of metals, there is a threshold frequency, below which photoelectrons cannot be released. In the experiment described above, the red colour falls below this threshold frequency. Because electrons are attached to their nucleus using a quantised amount of energy, each electron absorbs an amount of energy that is just enough to escape from the atom and makes no use of the extra energy (it spills over). Therefore, the kinetic energy of the photoelectrons is not proportional to the light intensity. This also explains the absence of a delay mechanism for triggering the photoelectrons. Electrons follow a binary function in relation to energy absorption; they either receive the exact amount of energy they need (the quanta) or just ignore the entire amount. In other words, it is a discrete process manifesting the corpuscular behaviour of light.

The above discussion shows that the wave nature of light and its quantum nature are mutually contradictory and cannot coexist at the same point of time. This immediately raises the following question: which one represents the actual reality of light? Switching from one theory to another based on the application is not a satisfactory strategy. Many scientists regard it as merely a practical trick to resolve the contention. One attempt for resolving the wave-particle dilemma, which was awarded with partial acceptance despite its speculative nature, came from L. de Broglie (1892–1987 CE). In his doctoral thesis, de Broglie proposed that as light exhibits wave and particle behaviour, electrons, and perhaps all types of atomic particles, do the same, assuming the symmetry of nature.[31] When de Broglie's thesis was sent to Einstein for comments, he said that the idea has some merits without giving his final consent. Five years later, in 1929, de Broglie was awarded the Nobel Prize for his doctoral proposal. The only evidence that de Broglie presented was that the momentum of an electron can be expressed in terms of Plank's constant and its wavelength. De Broglie reasoned the matter as follows. Plank's constant comes from the quantum world and thus represents the particle nature, while the wavelength obviously embodies the wave nature.

A few years after forwarding de Broglie's postulate, the Davisson-Germer experiment, conducted in 1927, provided the first experimental support for this postulate.[32] In this experiment, a stream of electrons was applied to a nickel plate. The scattered electrons had a maximum value at a particular angle relative to the incident beam of electrons. The maximum and minimum intensity pattern was seen akin to the fringes produced by light diffraction. A word of caution is in order at this point. When one thinks of the diffraction pattern of electrons, it is inevitable

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[31] Louis De Broglie, *Matter and Light* (New York: Norton and Co Inc., 1939), 80–102.

[32] Raymond Serway and John Jewett, *Physics for Scientists and Engineers with Modern Physics*, Ninth Edition (Philadelphia: Cengage Learning, 2013), 1250.

to abandon the classical picture of diffracting sea waves. This picture has to be abstracted to its bare integrals, such that one holds on to measurable quantities. In this case, the diffraction pattern can be affirmed based on the maximum and minimum values of intensity.

A common question that usually arises in conjunction to the wave-particle duality is that if atomic particles, like electrons, exhibit wave properties, which are unobservable to us due to their minute sizes, why cannot we observe the wave properties of bigger bodies such as pebbles and marbles? De Broglie formula provides an escape-type of answer to this question. For bodies weighing a few grams, or above, and moving with a speed that is significantly lower than the speed of light, their waves would be much smaller than a micrometre, which precludes the observability of wave-related phenomena. If we manage to get rid of the classical mental pictures associated with daily-life phenomena, we can only seek measurable quantities that characterise the phenomenon after abstracting its dynamics.

As pointed out before, the switch to quantum physics was disturbing, even to its own founders, in particular Erwin Schrödinger (1887–1961). While classical physics offers the comfort of linking phenomena to our common experience, quantum physics does not. When Bohr attempted to achieve this comfort by introducing his planetarium model of the atom, which draws on similarity with the solar system, this model failed in explaining the orbital configuration of elements with more than one electron. A decade or so after Bohr, Werner Heisenberg (1901–1976) introduced his principle of uncertainty, which legalises our ignorance of the whereabout of the electron and asserts that we are not supposed to figure out where electrons are, as such an illusory nature of electrons is an innate feature of the universe.[33] After successive failing attempts, it became clear to scientists that classical notions and analogous cases

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[33] Werner Heisenberg, *Philosophical Problems of Quantum Physics* (Woodbridge: Ox Bow Press, 1979), 95–108.

have to be given up. An electron cannot be made analogous to a marble in motion because the former does not have a rest mass. In other words, an electron would vanish if it came to rest. Photons cannot be fully visualised as fast bullets because photons cannot be detected without swallowing them, whereas bullets can be visually inspected without changing their paths. Scientists came to the realisation that they have to use common language to describe processes beyond the limits of this language. Max Born (1882–1970) stated that this is indeed difficult because: "Common language has grown by everyday experience and can never surpass these limits.[34]

Nonetheless, we are compelled to adopt concepts and conclusions of quantum physics in recognition of its explanatory power of what we observe on the atomic level.

Deduction vs. Induction

Our discussions of the journey of interpreting the periodic table and the interim journey of exploring the subatomic world provide us with sufficient data to contrast deduction and induction. Deductive arguments use premises of general nature. Every premise can be a law or a theory. Accordingly, deduction serves as an instrument for generalisation. Mathematical logic is a type of deductive logic. It also excludes irrelevant factors and presents only the relevant factors, in its most abstract form, to formulate universal laws. For instance, geometry established that the angles of a triangle add up to 180°. This law holds valid irrespective of the lengths of the triangle's sides. The only relevant point is that there are three intersecting straight lines forming a triangle. Abstraction and generalisation are two important tools for building theories as well as for interpreting experiments. Our discussion of demonstrating wave properties by electrons showed that some experimental results cannot

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[34] Max Born, *Atomic Physics*, Eighth Edition (London: Blackie & Son Limited, 1969), 97.

be properly interpreted unless wave-related phenomena are abstracted and presented in the context of particle mechanics. The same concept is demonstrated during our discussion of the third category of visual errors presented by Ibn al-Haytham.

While abstraction and generalisation of deductive arguments serve greatly in connecting the world and explaining its modes of operation, the very same features also point to the limitations of deduction. It is too general to deal with peculiar aspects, for which induction is better suited. Deductive arguments are born general and later broken down to specific cases. Conversely, inductive arguments are born for individual cases and may later join other arguments to group various aspects of a phenomenon. Additionally, deduction also uses known facts to conclude unknown ones. It is thus not expected to bring us to a new *field* of knowledge. For this reason, the exploration of the quantum world capitalises on the inductive research. Before introducing the principles of quantum mechanics, deduction can only wander within the ambit of classical physics, without being able to cross the border to quantum physics.

On the other hand, induction suffers from all the limitations of sensorial experience. Our senses have a range of detectability, beyond which a stimulus would go undetected. Distant celestial bodies send us very coarse images lacking a lot of fine detail. Even worse, the images we receive are not recent. As a matter of fact, images sent by neighbouring galaxies represent how they were millions of years ago. Similarly, atomic particles are not directly observable by us. Furthermore, all types of human perception are subject to a great deal of delusion and errors such as those discussed by Ibn al-Haytham in his analysis of visual errors.

In the first part, we concluded our discussion of Mill's five inductive methods by the comment of Copi and Cohen regarding the inadequacy of induction for establishing proofs. They justified that by several practical difficulties encountered upon applying these methods. Some of these difficulties are:[35]

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[35] Irving Copi and Carl Cohen, *Introduction to Logic*, Thirteenth Edition (New Jersey: Pearson Education, 2009), 547–549.

1. In many cases, the application of these methods would not lead to a single outcome. For example, the method of agreement would not yield a single common circumstance, but several.
2. In complex phenomena, circumstances are too high in number, precluding the testing of all possible scenarios.
3. The phenomenon under investigation may be connected to unknown causes, or to causes escaping our attention. In such cases, the inductive method would mislead us by suggesting a pseudo cause.

To overcome the above difficulties, we have no option but to resort to insight and imagination to guess circumstances which are likely to have bearing on the issue and exclude those we think as irrelevant. By developing hypotheses about the likely circumstances, the scope of experiments could be narrowed down to a reasonable level. For this reason, Copi and Cohen suggested that these methods should be regarded as instruments, or plans, for testing hypotheses. Yet, the above third difficulty is the toughest of all because there is no structured approach for forcing the unknown to declare itself to our wits. The example given for the method of residues, in the earlier section about Mill in part one of this paper, about the peculiar trajectory of a spacecraft is an instance of this difficulty.

Theory vs. Experimentation

As deductive arguments connect many elements, theories also connect many events/instances based on a common mechanism. Accordingly, deduction and theory share the same essence at two different levels. Likewise, induction and experimentation reflect the sense of individuality. Because of this intimate relationship between deduction and theory on one hand, and induction and experimentation on the other hand, it is quite plausible to switch the comparison between deduction and induction to a corresponding comparison between theory and experimentation. We apply this concept to highlight the following important difference between theory and experimentation.

Experiments produce the net results of complex processes but fall short of explaining the underlying mechanism, for which theory is needed. To illustrate, mixing two elements can follow two different processes, but with apparently similar outcome, based on whether the output is a physical mixture or a result of a chemical reaction, as mentioned in our discussion of Dalton's work. The reliance of experimental interpretation on theory is not limited to natural sciences. Psychiatric diagnosis, among others, follows the same course of investigation. A psychiatrist could detect the apparent signs of abnormal behaviour. Figuring out the causes needs a deeper propping of the patient's history and should be guided by theories of troubled psychology.

The collaboration between theory and experimentation can turn out to be very useful in moving science forward. An experiment may discredit a theory and thus trigger further investigation, eventually leading to the introduction of a new variant of the theory. Likewise, a good theory could guide the scientist on where to look and what to expect. Sometimes, the domain of possibilities is so large and consequently the number of experiments to be conducted is prohibitively high, precluding the commencement of experimentation in the first place.

In the early nineteenth century, Uranus was the last known planet of the solar system. At that time, it was possible for astronomers to compute the orbit of a planet using the law of gravitation. Observations of Uranus matched the theoretical results for a while. However, by 1830, enough evidence accumulated that Uranus was deviating from its calculated orbit.[36] Several guesses were raised, some doubting the accuracy of the law of gravitation, and others suggesting the proximity of a massive body to Uranus, such as a comet or perhaps a new planet, which was pulling Uranus out of its calculated orbit. The possibility of discovering a new planet captivated several astronomers who used the law of gravitation to predict the location of this hypothetical planet. Owing to

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[36] Holton and Brush, *Physics, the Human Adventure*, 145.

their work, Neptune was discovered in 1846 at the location they predicted. The law of gravitation was thereby vindicated. A quite similar scenario led to the discovery of Pluto in 1930. Knowing the limited capabilities of telescopes at that time, such discoveries without the availability of calculated predicted locations would only be a stroke of exceptionally good luck. At present, our telescopes, on earth or the ones in outer space, can easily explore the solar system to its farthest borders, eliminating the possibility of discovering one more planet in the solar system. However, today's telescopes exploring galaxies would face the same limitations their predecessors faced within the solar system two centuries ago. It is only for a good theory to render the task realistic and shorten the path to a successful finding.

Metaphysical Dimensions in Scientific Research

As stated before, scientists used to be called natural philosophers because the ultimate purpose of their work was to reach the truth as embedded in our understanding of the various systems of the cosmos. Aristotle introduced the paradigm of the four causes to characterise the integrals of full knowledge. These four causes are the material cause, describing the triggers of an action; the formal cause, describing its form; the efficient cause, describing its dynamics; and the final cause, describing its purpose.[37] Al-Kindī (801–873 CE), an early Muslim Philosopher, affirmed that we can only obtain a full knowledge of a matter when we fully understand its causes.[38]

When the secularisation movement started at the hands of Bacon and Locke, among others, a major shift of the paradigm of the scientific explanation of natural phenomena took place.

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[37] These four causes and the historical background of developing its curtailed version in secularism was discussed in Mulyadhi Kartanegara, "Secularisation of Science and its Islamic Answer," in *First ISTAC International Conference on Islamic Science and the Contemporary World* (Kuala Lumpur: ISTAC, 2008), 1–12.

[38] Al-Kindī, *Rasā'il al-Kindī al-Falsafiyyah* (Cairo: Dār al-Fikr al-ʿArabī, 1950), 101.

Focus had been given to the material and efficient causes, while the formal and final causes were discarded. More precisely, signs of and references to divine acts had been obliterated from western scientific research. It is not entirely accurate to think that western research is mainly concerned with the current status of the cosmos, rather than of how the cosmos and life started, simply because research on the big bang theory and the claims of evolution are intensively studied and funded in the west. Removing the metaphysical, or the transcendental, dimension of scientific investigation was part of the rebellious reaction of the west to dogmatic thinking and the authority of religious figures.

The Qur'an encourages us to seek deep knowledge of matter in order that effects are attributed to their true causes, as it belittles the value of superficial knowledge. The Qur'an also discusses the issues of this world within a broader context of acknowledging the reality and standards of the Hereafter. With regard to superficial knowledge, God says, "They know but the outer (things) in the life of this world: but of the Hereafter they are heedless." (*al-Rūm* (*30*):*7*).

The mindset of Muslim scientists should address, with different degrees of detail, all the causes of natural phenomena. A full analysis of the phenomenon under study should be conducted such that the transcendental aspect is acknowledged. Newton's laws of motion, which exemplify the curtailed version of scientific explanation, supposedly explain planetary motion. If the very same laws are applied to understand how the planetary orbits were formed, an inevitable conclusion would have been reached that an external force must have initially set the planets in motion, with the precise appropriate velocities and relative positions needed to balance the gravitational forces between them. However, secular physicists are never willing to complete the analysis when it leads to God. Likewise, it is proven till today as a fact, and for good Muslims, that a living organism cannot be produced from a non-living one. However, secular scientists, following the principles of materialism, resist and resent moving forward to the conclusion that the divine power breathes the soul (life) into primitive tissues, causing them to breed and construct a full embryo in accordance with a predetermined genetic code.[39]

It is important to realise that transcendental aspects can, and should, be included in topics of natural sciences because they both follow the same logic. In particular, our belief in the divine attributes is grounded on the same logic we accepted for scientific explanation. We adopted the principles of quantum mechanics, despite their orthogonality to common sense, because of their abilities to explain the unobservable atomic world. Likewise, we believe in divine attributes, as they point to the extraordinariness of absolute perfection and unrestricted power, because of their explanatory power of how the universe came to existence and the way things function.

We conclude this discussion by giving an example that shows that the transcendental dimension can enrich human experience and link the rational faculty to the artistic and intuitive faculties. Philosophers often give the question of "will the sun rise tomorrow as it ever did?" as a typical example of the inductive logic through its reliance on the past experience to predict the future. If the inductive logic is strictly followed, the answer will indicate uncertainty about the future event since we have no control over the orbits of the sun and the earth. Now, let us see how this question is addressed in a religious context. God mentions the consistent succession of day and night, and of the sun and the moon as signs of His power and His uninterruptible maintenance of the universe.[40] When the sun rises from the west, rather than as always from the east, this will be a sign of a major recasting: the end of this world and the beginning of the Hereafter.[41] Now, we can answer the question

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[39] Several Quranic and Prophetic statements describe the stages of embryonic creation, see, for example: Maurice Bucaille, *The Quran and Modern Science-Colored* (Dubai: Islamic Information Center, 1995), 19–22.

[40] *Fuṣṣilat* (41): 37.

[41] In Islamic eschatology, the sunrise from the west is one of the ten major signs of the Day of Judgment at which the door of repentance closes and deeds cannot be altered.

in more depth. Unless the Hereafter is approaching, the sun will rise tomorrow. Despite the repeatability of the event, the sunrise scene is reminiscent of the fact that we still have a chance to add to our account of deeds. Apart from the consistency and precision, sunrise is imbued with beauty, reverence, and tenderness. Such meanings are too valuable to be overshadowed with material considerations.[42] Thinking should incorporate all human faculties, the rational as well as the artistic,

> Do they not look at the camels, how they are created? And at the sky, how it is raised high? And at the mountains, how they are fixed firm? And at the earth, how it is spread out?
> (*al-Ghāshiyah* (*88*): *17–20*).

Conclusion

This article presented ways for releasing scientific practices from the restrictive limits of empiricism. The logical frameworks of deduction and induction were analysed as two complementary tools for reaching truth. Ibn al-Haytham's work demonstrated his profound understanding of the complementary nature of these two tools.

Our comparison of quantum physics and classical physics showed that abstraction and insight are two indispensable agents for interpreting experimental results and for building theories in general. The complexity of natural phenomena, and in turn their mathematical models, renders the desire for comprehensive testing plans unrealistic. This motivates the use of insight-based and guess-based hypotheses. Finally, addressing the transcendental dimension of the behaviour of physical systems was shown, through practical examples, to enrich our understanding of the cosmos and to embrace all our rational, artistic, and intuitive faculties.

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[42] For an analysis of how scientific realisations give rise to religious reflections, see Philip Clayton, *Religion and Science: The Basics* (New York: Routledge, 2012), 67–83.

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