Article

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Nuclear Chemistry and Medicine: Why "Young-Earthers" Cannot Have It Both Ways

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Nuclear chemistry is the branch of chemistry that reflects our current understanding of the structure and chemical properties of the atom and its parts. Nuclear medicine applies nuclear chemistry to medical diagnoses and treatments. For example, radioisotope imaging and radioiodine therapy are successful medical applications of nuclear chemistry. We argue that the best explanation for the success of these medical applications is that our current framework of nuclear chemistry is, in the main, correct. We further argue that this framework also entails the prevailing models of radiometric dating, according to which the earth is approximately 4.6 billion years old. We thus conclude that "young-earthers" (those who think the earth is ten thousand years old or less) cannot have it both ways. That is, they need to either provide an alternative explanation for the success of nuclear medicine or accept a much older earth. Finally, we consider and reply to psychological, scientific, philosophical, and theological objections to our arguments.

Introduction

One underappreciated, but potentially important, tool for navigating tensions in science and religion dialogue is understanding the way in which scientific frameworks have applications that are appropriated across "party lines." Technological applications of scientific discovery produce smartphones, medical advances, and an ever-increasing number of conveniences that are appreciated and appropriated by those with differing perspectives on any hot-button science and religion issue. What is sometimes not recognized, however, is the connection between the piece of technology we can touch and see, and the scientific framework which made the creation of the technology possible.

For example, suppose that Sue gets thyroid cancer and her doctor prescribes radioiodine therapy as part of her treatment. Or suppose that Bob has symptoms of a gallbladder attack and his doctor recommends a radioisotope scan in order to give an image of the gallbladder that will aid diagnosis. Both of these features of modern medicine—radioisotope imaging and radioiodine therapy—are applications of a more fundamental framework of nuclear chemistry. But the applications of nuclear chemistry do not stop with medicine; the same scientific framework that results in radioisotope imaging and radioiodine therapy also generates radiometric dating, one of the pieces of information scientists use to determine that the earth is approximately 4.6 billion years old. Now it turns out

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that for religious reasons, Sue and Bob do not think that the earth is nearly that old—they think that it is much younger—somewhere between six thousand and ten thousand years old. Sue and Bob's experience with the benefits of nuclear medicine puts them in an intellectual tension, if not in an actual dilemma. On the one hand, they are benefiting from the application of a scientific framework which will assist doctors in treating their diseases. But on the other hand, that same scientific framework entails a result that conflicts with their religiously based beliefs about the age of the earth.

This article will show the way out of this tension; in it, we set out to do three things. First, we provide an accessible overview of the modern framework of nuclear chemistry and demonstrate the link between the science and the various applications it supports. Second, we present and defend two arguments that link the successful science of nuclear chemistry to certain applications of that science. Third, we consider and reply to several objections to our argument.

I. The Scientific Framework of Nuclear Chemistry

A. Modern Chemistry

Chemistry is the study of matter, the stuff out of which all physical objects are made. Going back to at least the pre-Socratic philosophers of ancient Greece, matter has been studied through careful observation, which includes classifying matter into constituent elements. One feature that separates modern chemistry from its roots in ancient Greek natural philosophy is the sophisticated tools we now have for observing and analyzing matter. Thus, a central feature of how chemists do their work is to subdivide elements into their constituent parts. In one sense, the story of modern chemistry is the story of greater and greater understanding of smaller and smaller things.

Chemistry as a discipline was making great strides by the end of the nineteenth century. Chemical reactions were an active area of research in university laboratories and in industry; chemists explored molecular structure in both organic and inorganic chemistry even before the discovery of the electron in 1897 by J. J. Thomson.[1] A year prior to Thomson's discovery, Henri Becquerel observed that uranium was emitting energy without interacting with any external source. While energy emissions had been previously observed, for example, in phosphorescence, what was new with uranium was the fact that the emission seemed spontaneous.[2] It was later understood that the energy emission is a result of change and decay in the nucleus. This spontaneous energy emission is radiation, a release of energy in the form of particles or electromagnetic waves.

Over the next few years, G. C. Schmidt, Pierre Curie, and Marie Curie worked with radioactive substances, discovering new elements such as radium and polonium. Ernest Rutherford and Robert J. Strutt figured out, before the turn of the century, that there were three types of radiation. Over the next decade, scientists catalogued nuclear radioactive chain reactions in which, through a process of radioactive decay, one element turns into another, which then turns into another. These early discoveries related to radiation occurred alongside the development of quantum mechanics. Since the 1930s, scientists have added to the knowledge about radioactivity, leading to the robust field of nuclear chemistry that has produced novel technology, including medical applications such as the ones utilized by Sue and Bob above.

B. Atoms and Isotopes

Chemists think of an element as a substance that is made up of one type of atom, in which an atom is the most basic unit of that element; the Periodic Table organizes the different types of known elements.[3] Each atom, regardless of the element, is made up of three types of particles: neutron, proton, and electron.[4] Elements on the Periodic Table are arranged in order of increasing atomic number; the atomic number is the unique number of protons in one atom of that element.[5] For example, a hydrogen atom has one proton, whereas a uranium atom has 92 protons. The structure of an atom is fundamental in explaining observed behavior of different elements and chemical reactions.

In 1913, Frederick Soddy discovered that an element can have more than one atomic weight.[6] Atoms of the same element always have the same number of protons, but can have a different number of neutrons. Soddy used the term "isotope" as a way of distinguishing between atoms of one element that differ in atomic weight. Isotopes are identified by their total number of protons and neutrons giving each type of isotope a unique mass,[7] and elements can be studied by understanding the properties of isotopes of that element. The framework of nuclear chemistry centers on this important principle of isotopes.[8]

C. Isotopes and Radioactive Decay

Some isotopes are unstable: this means that they will undergo a process of decay during which they will give off radiation. Isotopes that decay in this manner are called "radioisotopes." The radioisotope that starts the process of decay is called the "parent" and the new isotope that is formed is called the "daughter." Suppose you have some quantity of a radioisotope that is undergoing a process of decay. When the process begins, the ratio of parent to daughter in the sample is 100% parent, 0% daughter. The time it takes for the quantity of parent isotope in the sample to be reduced by half, by turning from parent to daughter, is called a "half-life." Isotopes decay following the same pattern, called a "rate law."[9] This means that the time span for a half-life for an isotope will be consistent throughout the process of decay. As a result, the time it takes for the percentage of parent isotope in the sample to decay from 50% to 25% will be the same amount of time it took for the percentage of parent isotope to go from 100% to 50%. All isotopes follow the rate law, though the time span for half-lives will vary according to each isotope.[10] The process of decay and the corresponding change in amount of the parent isotope can be measured as a function of time, as with the graph in figure 1.

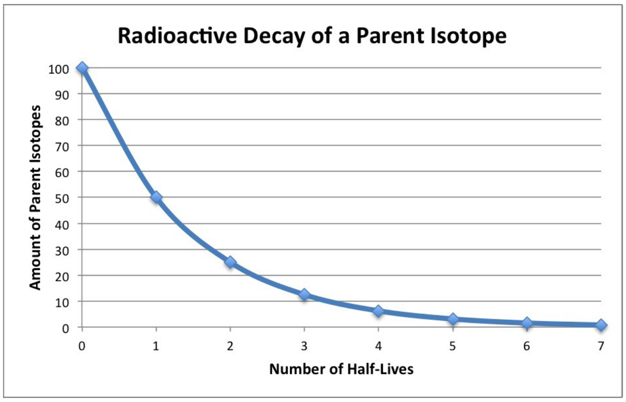

Figure 1: Radioactive decay of a parent isotope displaying exponential decrease of the amount of parent isotope over time.

Notice that the parent isotope curve begins at 100% and over time decreases toward zero. The graph represents the decreasing proportion of the parent isotope over time as the parent decays. The daughter isotope curve, as seen in the figure 2 graph, begins at zero and increases toward 100% over time. The line on the graph represents the increasing proportion of the daughter isotope as the parent isotope decays.[11] While the degradation rate looks the same for all decaying isotopes, what differs for each isotope is the length of its half-life.

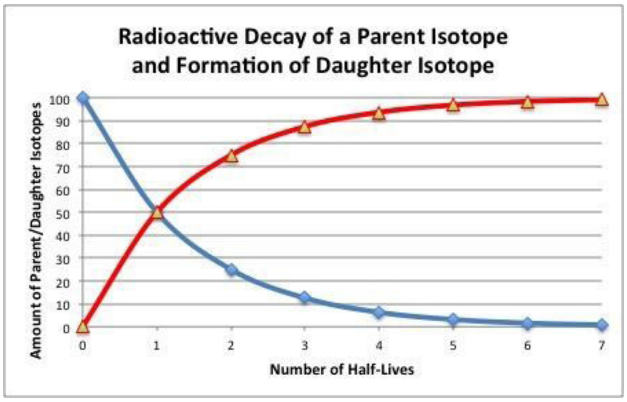

Figure 2: Radioactive decay of a parent isotope (diamond points) and formation of daughter isotope (triangle points). As the parent isotope exponentially decreases, the daughter isotope exponentially increases.[12]

D. Summary

In the nineteenth and twentieth centuries, chemists discovered the way in which atoms can emit energy, also called "radiation." Energy emission occurs because of certain changes in the nucleus of an atom. Atoms of one element can have different atomic weights, that is, nuclei of one element can differ in the number of neutrons while always having the same number of protons. Following Soddy, chemists use the term "isotope" as a way of distinguishing between atoms of one element that differ in atomic weight. Some types of radiation involve nuclear decay, in which changes in the nucleus result in an isotope of one element changing into another isotope (usually) of a different element. Regardless, the rate at which radioactive decay occurs is consistent for that element over time.

Simplifying even further, we can identify some key principles that constitute the framework of modern nuclear chemistry. First, nuclear chemistry is built on the understanding that the nucleus of atoms is composed of neutrons and protons. Second, atoms can emit energy due to changes in the nucleus. Third, atoms of an element can have different atomic weights called "isotopes." Fourth, some isotopes experience radioactive decay which occurs at a rate consistent for that element over time.

II. The Arguments

With the preceding overview of the basic framework of nuclear chemistry in hand, we are now in a position to present and defend the following two arguments: the framework argument and the radiometric dating argument.

A. The Framework Argument

Our first argument seeks to establish via inference that the best explanation that the basic framework of nuclear chemistry is correct.

The Framework Argument

1. We have successful radioisotope scans and radioiodine therapy.
2. The best explanation for the success of radioisotope scans and radioiodine therapy is that the basic framework of nuclear chemistry is correct.
3. Therefore, the basic framework of nuclear chemistry is correct.

1. *Defense of (1).* In the introductory section above, we gave hypothetical examples of Sue, who was diagnosed with thyroid cancer and requires radioiodine therapy, and of Bob, whose gallbladder symptoms prompt his doctor to require a radioisotope scan. Premise (1) merely states that radioisotope imaging and radioisotope therapy are a successful part of medical practice of the sort required by Sue and Bob. We will not spend a lot of time defending that claim—a cursory search of medical statistics shows the frequency with which these applications are used in diagnosis and treatment. For example, a 2013–2014 statistical report compiled by Britain's National Health Service (NHS) notes that during that year, imaging techniques arising from nuclear chemistry were utilized 446,365 times throughout Britain. Radioisotope imaging and radioiodine therapy fall under the category of nuclear medicine, which the NHS document describes as

> a branch of medicine and medical imaging that uses unsealed radioactive substances in diagnosis and therapy. These substances consist of radionuclides, or pharmaceuticals that have been labeled with radionuclides (radiopharmaceuticals). In diagnosis, radioactive substances are administered to patients and the radiation emitted is measured.[13]

The description of nuclear medicine continues, highlighting applications in both treatment and therapy:

> Nuclear medicine imaging tests differ from most other imaging modalities in that the tests primarily show the physiological function of the system being investigated, as opposed to the anatomy. It has both diagnostic and therapeutic uses, such as planning cancer treatments and evaluating how well a patient has responded to a treatment. It can be used with other diagnostic methods, including CT scans and MRI, where the images are superimposed to produce complex cross-sectional, three-dimensional scans.[14]

Nuclear medicine forms an integral part of various diagnostic and treatment protocols. Our knowledge of the structure of the atom and the framework of nuclear chemistry in which that knowledge is embedded makes this possible. In other words, we are able to conduct radioisotope scans and radioiodine therapy only if the broad principles of nuclear chemistry outlined above are correct. This leads us to claim, in (2), that the best explanation that we have for these highly successful medical applications is that the scientific framework on which they depend is correct. But why should we think that this is true?

2. *Defense of (2).* Defending "best-explanation" claims typically involves two steps: showing that the proposed explanation is indeed a good candidate for explaining the phenomenon in question, and then showing why this candidate explanation is better than the strongest rival explanations. In this section, we mainly do the former; we show how the principles of nuclear chemistry summarized at the end of Section I are linked with radioiodine therapy and radioisotope imaging.

2.1 *Radioisotope Imaging and Nuclear Chemistry*
A radioisotope used for a medical diagnosis, the kind that will be used in Bob's gallbladder scan, has three requirements. First, the chemistry of the radioisotope should be "versatile," meaning that the isotope can be combined with different chemicals that can control where in the body it goes. Second, as the radioisotope decays, it should give off the type of radiation that can escape the human body with minimal radiation exposure. Third, the radioisotope needs to have a relatively short half-life: something that will be sufficient to produce medical imaging, but will decay away at a predictable and consistent rate.[15]

A common radioisotope used for gallbladder malfunction is the metastable nuclear isotope, technetium-99m (Tc-99m) that is injected into the human body. Tc-99m fulfills all the requirements for diagnosis in the human body. In Bob's case, Tc-99m can be combined with a chemical compound that is recognized by the biliary system for uptake.[16] Then Tc-99m decays, giving off gamma radiation that can penetrate the human body. The radiation can easily escape the body, be captured by a gamma camera, and processed into an image.

The decay of Tc-99m gives a comparatively low dosage of radiation to the human body.[17] Finally, Tc-99m has a half-life of about six hours. This means that in less than two days, there is less than 1% of the original amount of Tc-99m left in the body. Tc-99m decays into technetium-99, then into stable ruthenium-99.[18] The chemistry and use of this radioisotope is well studied. As of December 2017, 40 million procedures involving Tc-99m are performed each year in the world, making it a routine, safe medical application of nuclear chemistry.[19]

Recall our brief description of basic aspects of nuclear chemistry.

i. Atoms are composed of protons and neutrons.

ii. Atoms emit energy as a result of changes to the nucleus.

iii. Atoms of one element may have different atomic weights described as isotopes.

iv. Certain isotopes experience consistent radioactive decay according to the rate law for that isotope.

The example of Tc-99m above described a chain reaction in which Tc-99m turned into Tc-99 which decayed into ruthenium-99. We can map this process since we know that atoms are composed of protons and neutrons.[20] Moreover, Tc-99m is used because it emits energy, which is a particular instance of (ii) above. And finally, our knowledge of how the body processes Tc-99m is a function of understanding isotopes and radioactive decay [see (iii) and (iv) above].

2.2. *Radioiodine Therapy and Nuclear Chemistry*
The standard treatment of thyroid cancer of the sort Sue has, is administration of the radioisotope iodine-131 (I-131) due to its nuclear chemistry. When I-131 decays into xenon-131, it gives off beta radiation, which destroys thyroid tissue cells, including any cancerous cells present. This is an ideal treatment because of the function of a thyroid and the half-life of the radioisotope. First, the thyroid uptakes most of the iodine in the body, regardless of the isotope. Decreasing the amount of stable iodine into the body prior to treatment will ensure that the thyroid will uptake enough of the radioactive I-131.[21] The half-life of this radioisotope is only eight days, and much of the radioisotope is excreted from the body naturally. Dosage studies of I-131, taking into account age, thyroid activity, half-life of the radioisotope in the human body, and additional factors, have been well documented.[22] Thyroid cancer is just one type of cancer that can be treated in this manner.

As we can see in the cases of both radioiodine therapy and radioisotope imaging, the chemistry involved in guiding the use of these applications depends on our more basic understanding of the nature of the atom, radiation emission, and the rate of radioactive decay for isotopes—principles that are part of the foundation of nuclear chemistry. Clearly, the accuracy of our current understanding of nuclear chemistry is an excellent explanation for the success of the applications described in (1). Thus, given our defense of (1) and (2) of the framework argument, we have a good reason to accept its conclusion that the basic framework of nuclear chemistry is accurate.

B. The Radiometric Dating Argument

The soundness of the framework argument allows us to create the following argument which supports radiometric analysis as a means of determining the age of certain objects.

The Radiometric Dating Argument

3. The basic framework of nuclear chemistry is correct.
4. If the basic framework of nuclear chemistry is correct, then we can successfully use radiometric dating for objects.
5. Therefore, we can successfully use radiometric dating for objects.

1. *Defense of (4): Carbon-14.* The same principles of nuclear chemistry that explain why medical applications are used successfully also explain how radiometric dating functions. Building upon the active research in nuclear chemistry in the first half of the twentieth century, radiometric dating for objects has been taking place since 1950.[23]

To illustrate how scientists use radiometric dating, we will consider two materials on Earth and how their ages have been assigned. Let us first consider the cloth wrappings from a mummified bull found in a pyramid in Dashur, Egypt.[24] Carbon-14 (C-14) dating was used to assign an age to the cloth wrappings. All living things (organic things) uptake carbon dioxide, and therefore isotopes of carbon can be found in living things. Most of the carbon is the isotope carbon-12 (C-12), but a small percentage of the carbon isotopes is C-14. Therefore, the carbon in living things exemplifies a particular ratio of C-14 to C-12, and when there is an uptake of new carbon, it is in the same ratio. Thus the C-14 to C-12 ratio in living things generally stays stable over time. When a living thing dies, no more carbon is taken into the body; however, the radioactive isotope C-14 decays into nitrogen-14. The C-14/C-12 ratio is beginning to decrease because the C-14 isotope is decaying, but no more carbon is being taken into the body. Therefore, mummy cloth wrappings made out of plant material (something once living) have a ratio of radioactive C-14 isotope to the stable C-12 isotope that is different from the ratio found in living things. Because C-14 has a half-life of 5,730 years and, like all isotopes, follows the rate law in its decay, the mummy cloth wrappings are estimated to be 2,050 years old. This value is consistent with historical records of when the pyramids were built.[25]

2. *Defense of (4): Potassium-40 and Argon-40.* Due to the relatively shorter half-life of C-14 and the nature of inorganic materials such as rocks, other isotopes are used for radiometric dating in geology. Let us now consider the rocks found on the Hawaiian Islands. Plate tectonics is the current scientific theory that explains continental drift by seafloor spreading. The surface of the earth consists of plates that are constantly moving; continents and oceanic crust make up these plates. Plate movement is measured and monitored by scientists. New crust is made through volcanic activity under the ocean at mid-ocean ridges. As magma enters the ocean, it is pushed away from the ridge (similar to a conveyor belt system), and old crust is pushed down into the mantle of the earth through a process called subduction. Plate tectonics explains earthquakes, volcanoes, and mountain building. The study of plate tectonics also helps in understanding the underwater volcanic activity called "hot spots"[26] and the resulting volcanic islands, as seen with the Hawaiian Islands. Hot spots are areas on Earth where hot mantle rocks rise to the surface of the earth, initiating volcanic activity. There is a hot spot currently underneath the island of Hawaii responsible for the active volcanoes on the island. There are eight main Hawaiian Islands that include fifteen volcanoes that form a chain in the Pacific Ocean, all on the Pacific plate.

Noting plate movement and using plate tectonics, it follows that the Hawaiian Islands are geographically oriented in order of age. The oldest island was formed by volcanic activity over the hot spot, then the plate shifted, moving the island west-northwest off the hot spot. Then another island was formed above the hot spot, moved north, and the process continues today.[27] Radiometric dating of the rocks on the Hawaiian Islands confirms this model. Potassium-40 (K-40) is a radioactive isotope that decays into two isotopes: calcium-40 (Ca-40) and argon-40 (Ar-40). Ca-40 is an abundant isotope in the earth's crust, so when measuring Ca-40 in a sample, it would be difficult to know if all of the isotope resulted from the decay of K-40. As a result, Ar-40 is measured because it is a much less common isotope found in rocks, and more importantly, it remains by itself, not interacting or bonding to anything else.[28] When rocks are formed by molten magma solidifying, the atomic clock starts on the radioactive isotope because all of the argon that was originally in the sample would have been released into the atmosphere. Only daughter Ar-40 will result in the sample now.[29] The half-life of K-40 is 1.25 billion years. The ratio of the parent isotope K-40 to daughter isotope Ar-40 has been measured, confirming that the geographic orientation of the Hawaiian Islands are in order of age. The islands going from south to north have increasing radiometric dates with the volcano on the most northern island of the chain being 3.8 million years old.[30] Radiometric dating of volcanic islands fits with the other data that make up plate tectonics, including volcanic activity and plate motion.

It is at this point that the question might be raised: How much confidence do we have in accurately knowing the half-lives of isotopes, even the ones that are over one billion years? The answer goes back to the fact that isotopic decay follows a first-order rate law with no exception being found by scientists. The half-life can be calculated measuring the amount of K-40 that decays into Ar-40 in a short amount of time, since the decay rate is measured and the rate law is applied. As this area of science has progressed over the last fifty years or so, scientists have compiled a growing body of evidence that the principles of nuclear chemistry can be accurately applied to radiometric dating.

C. Summary

Of course, a consequence of the conclusion of the radiometric dating argument is that we have a very good reason to think that the earth is over 4 billion years old, and not the much younger date of six to ten thousand years as is believed by those who hold to a "young earth." Young-earthers should feel a certain amount of epistemic pressure from the weight of a scientific claim endorsed by the scientific community concerning the age of the earth. Perhaps that weight can be mitigated, psychologically, by a young-earther who does not understand the science or have any connecting points to the science in her experience. However, folk like Sue and Bob, who have firsthand contact with the benefits of nuclear medicine, should feel an extra epistemic push toward accepting an old earth because the success of nuclear medicine depends on a scientific framework which also entails that the earth is very old. Young-earthers cannot have it both ways, at least with consistency. Young-earthers cannot accept the results of nuclear chemistry in one area, yet deny what it entails in another simply because those results do not fit with what they desire to be true.

III. Objections and Replies

In this section, we articulate and respond to seven objections that can be raised against our arguments. The first three are objections based on certain psychological factors that may be present among young-earthers. The next three are philosophical and scientific objections that might be raised regardless of whether one adopts a young earth view. The final objection is theological, and while it is specifically shaped in the context of this article as an objection in favor of a young earth view, the theological objection is a particular instance of a more general strategy adopted by those who wish to use theological arguments against scientific claims.

A. Psychological Objections

1. *The Ignorance Objection.* The ignorance objection amounts to a claim of plausible deniability: the objector states that she did not know that successful nuclear medicine depends on science that also confirms an old earth. However, this is not an objection so much as an explanation as to why one may have resisted the epistemic pressure from nuclear chemistry to this point. Moreover, after becoming acquainted with the framework and radiometric dating arguments, plausible deniability is no longer an option.

2. *The Psychological Burden Objection.* Similar to the ignorance objection, the psychological burden objection involves the objector's psychological self-reporting, in which the objector resists accepting an old earth because it would require giving up a host of beliefs that, to this point, have been quite important to her. The cognitive consequences of that kind of shift in beliefs is a burden that she feels is too great to bear.

Again, this is not an objection so much as an explanation as to why the objector is resisting change in beliefs. And while psychological pressure to resist proposition p is not (typically) a good reason or process that supports the belief that proposition p is false, the objector is to be commended for acknowledging the role that psychological pressure has in altering what we think is true about the world, and how we conduct our epistemic lives. Psychological research strongly suggests that human reasoning is subject to all sorts of biases which cause one to discount claims that contradict beliefs that are deemed important. Confirmation bias is a well-documented phenomenon, according to which we tend to seek out and endorse evidence that supports what we already believe to be true.[31] However, while psychological burdens can be heavy to bear, the weight can be mitigated over time.

3. *The Prudential Objection*. Although still motivated by psychological factors, the prudential objection is a slightly more principled objection than the previous two psychological objections. This objection takes a measured account of self-interest and counts the utility of serving one's self-interest as a reason for belief. Here the objector states something like the following:

> *It is not in my best interests to believe in an old earth—rejecting the young earth view would have serious negative consequences for me. I would probably get ostracized from my family and friends, and it is very possible that I could lose my job! As such, I have got strong prudential reasons to reject the key premises in both the framework argument and the radiometric dating argument.*

Some might initially respond to prudential objections with disdain, and claim that self-interest ought to have no role in one's quest for truth. However, we think that one ought not to be too hasty in rejecting prudential considerations out of hand. One reason is connected to our discussion of the psychological burden objection—namely, recognizing that influences of bias and self-interest are pervasive in reasoning; it is futile to assume that those influences are absent or easily overcome. Moreover, taking seriously the role of self-interest in our decisions about what to value, including beliefs about the world, can help reflective dialogue and informed decision making.

Another reason to take self-interest seriously pertains to the connection between self-interest and intellectual virtues in certain belief-contexts. For example, there are certain high-stakes situations in which what a cognitive subject believes is hugely relevant to her own self-interest such that, given the high-stakes circumstances, the agent is obligated both morally and intellectually to do more work than usual in seeking out evidence and engaging in intellectual best practices in order to support belief. Let us suppose that Bob is told that his daughter—whom he loves a great deal—may have been exposed to a life-threatening disease at a recent birthday party. The disease is such that it could be treated successfully but needs to be diagnosed quickly in order to have a reasonable chance of survival. Given Bob's great love for his daughter, it is in his best interest to believe that she did not contract the disease; he cannot bear the thought of losing her. Moreover, given the high stakes for both Bob and his daughter, Bob is obligated to do more than just casual intellectual work in determining whether his daughter has indeed been so exposed. Finally, suppose that Bob, in short order, amasses a large quantity of high-quality evidence that his daughter was not exposed to the potentially fatal disease. Bob calls every family at the party to see if any actually have the disease, and it turns out that none claim to have the disease—it seems to have been merely a rumor. But just to be sure, Bob takes his child to a physician who specializes in early diagnoses for this particular disease. All the testing turns out negative. So, here we have a situation in which prudential and evidential reasons coincide, and such that prudential reasons are epistemologically relevant in that prudential factors determine what is at stake epistemologically.

Notice the connection between prudence and evidence in the case of Bob's daughter: prudence alone is not enough. In terms of providing a basis for belief, prudential considerations do not lower or replace the requirement for best intellectual practice, including searching out good evidence. In fact, what high-stakes situations show is that prudential considerations can sometimes raise the standards for evidence. Thus, even if prudential reasons themselves do not directly confer justification, they can sometimes be relevant in determining whether some belief is justified.

Of all the premises in the framework and radiometric dating arguments, premise (1) which merely asserts that we have successful radioisotope imaging and radioiodine therapy is the least controversial. Thus, the most likely targets on the basis of prudential reasoning would be premises (2), (3), and (4), the content of which is:

2. The best explanation for the success of radioisotope scans and radioiodine therapy is that the basic framework of nuclear chemistry is correct.
3. The basic framework of nuclear chemistry is correct.
4. If the basic framework of nuclear chemistry is correct, then we can successfully use radiometric dating for objects.

Let's grant, for the sake of hypothesis, that one has strong prudential reasons for rejecting any or all of (2)–(4). Would that be a sufficient epistemological basis for rejecting any or all of these premises?

No. Let "PR*p*" stand for prudential support for *p*, and Let "EV*p*" stand for evidential support for *p*. Now consider the following list of possible combinations that define the relationship between prudential and evidential reasons for some proposition *p* believed by *S*:[32]

(A) *S* has strong PR*p* and strong EV*p*.

(B) *S* does not have strong PR*p* and does not have strong EV*p*.

(C) *S* has strong PR*p* and does not have strong EV*p*.

(D) *S* does not have strong PR*p* and does have strong EV*p*.

Of (A)–(D), only (A) and (D) put S in a strong epistemic position with respect to *p*. (A) shows the fortunate situation in which strong prudential and strong evidential support for p coincide. (D) reflects a situation in which S has strong evidential support for p, but no strong prudential support for p. However, (A)–(D) does not quite capture the right relationship between prudence and evidence as far as the young-earther is concerned. For that, we need to consider the following:

(E) S has strong PR~p[33] and does not have strong EVp.

(F) S has strong PR~p and strong EVp.

(E) accurately describes the young-earther for whom belief that the earth is young strongly serves their perceived self-interest, but is not in possession of the strong evidence for any one of a myriad number of propositions which support an old earth. We leave it an open question whether someone in situation (E) can be justified in believing ~p.[34]

(F) describes the young-earther who has come into contact with strong evidence for the claim that the earth is much older than she believes to be the case based on her religious views. Assuming that our previous sections provide strong evidence for the claim that the earth is old (as a consequence of the conclusion of the radiometric dating argument), (F) describes a young-earther who has read our article thus far.

Now let us return to the lesson from the case of Bob's daughter and the relationship between prudence and evidence: all things being equal, prudential support for ~p is not enough to undermine evidential support for p. In some cases, prudential support for p may have moral and intellectual implications for p's justification, but in those cases prudence increases, not decreases, the need for evidence. Thus, the prudential objection to the framework and radiometric dating arguments can be dismissed. Notice, however, that it is unlikely for young-earth objectors to advance one objection in isolation from the others. Thus, even if one is able to show that the prudential objection fails, one might still need to address the emotional and psychological burdens of the previous objections.

B. Philosophical and Scientific Objections

1. *The Anti-Realism Objection.* This objection to our argument arises from adopting some version of anti-realism with respect to science. One dominant issue in philosophy of science for the past several decades concerns the epistemic authority of science, particularly with respect to the picture science presents at the subatomic level. Though there are significant differences among philosophers within the scientific realist camp, scientific realists tend to think of the goals of science to include providing true descriptions and explanations of natural phenomena. This is why realists take the success of a scientific theory (where "success" is understood as success with respect to making novel predictions) as best explained by the truth or approximate truth of the theory—even when the theory involves postulating entities that are unobservable. While arguments based on the success of science are probably the strongest arguments in favor of scientific realism, the most common argument against scientific realism is based on lessons from the history of science. And again, while differences among historically sensitive anti-realists abound, one common feature is that they note that what was labeled "successful science" in previous periods in history—even successful with respect to making novel predictions—was later overturned; theories successful to some degree at one time were replaced by successor theories at a later time. This, so the objector says, should give us pause when looking at the epistemic status of current science, even the well-confirmed science of nuclear chemistry, and gives rise to the following objection to (3) of the framework and radiometric dating arguments. Recall according to (3):

3. The basic framework of nuclear chemistry is correct.

The anti-realist objector resists (3) with the following:

> *The theoretical content of science at any point in time is contingent and provisional, and the history of science is a graveyard of rejected theories—even theories that seemed to work well! Why have the confidence in the truth of contemporary nuclear chemistry even though it seems to "work"? The history of science gives us good reason to think our current science will probably be replaced at some point in the future, so I am perfectly within my rights to reject it (3).*

It is beyond the scope of this article to summarize all of the nuances in the realism/anti-realism debate in philosophy of science. We will merely note that much of what we say in our three responses to this particular objection reflects common realist strategies for responding to anti-realism in philosophy of science.

First, there is good reason to think that the history of science is not one of successive failed theories. According to Stathis Psillos:

> When a theory is abandoned, its theoretical constituents, i.e., the theoretical mechanisms and laws it posited, should not be rejected *en bloc*. Some of those theoretical constituents are inconsistent with what we now accept, and therefore they have to be rejected. But not all are. Some of them have been retained as essential constituents of subsequent theories.[35]

What we often see in exchanging one theory *T* for its successor *T** is that those truth-conducive theoretical constituents in *T* survive into the successor *T**. Thus, instead of history justifying skepticism about current science, it should actually give us greater confidence in current science because contemporary science has experienced the winnowing effect of theory revision over time.

This brings us to our second response to the anti-realism objection. Many of the high profile examples often cited in supporting historically based science skepticism involve examples from centuries ago. The shift from a Ptolemaic model of the solar system to a Copernican model that began in the sixteenth century is one such example. The development of the phlogiston theory of combustion in the seventeenth century and its eventual replacement in the eighteenth century is another such example. However, the experimental data supporting key components of physics, chemistry, and biology from the twentieth century and into the present day is of a quality and quantity vastly superior to the experimental support available at any other time in human history. This is not to say that contemporary science is beyond revision, either in principle or in practice. Rather, it is much, much more likely that revisions to current science will build upon the incredibly successful and precise theoretical framework of natural science that we have today, of which nuclear chemistry is a part.[36]

Our final response to the anti-realism objection is that (3), which appears as a premise in the radiometric dating argument, is also the conclusion of the framework argument. As such, the objector owes us a principled way of rejecting at least one of the premises of the framework argument. As we stated above, premise (1) which merely observes that we have successful radioisotope imaging and radioiodine therapy seems noncontroversial, in which case the objector will need to give us a reason for rejecting (2):

> 2. The best explanation for the success of radioisotope scans and radioiodine therapy is that the basic framework of nuclear chemistry is correct.

Until or unless the anti-realist objector can give us an equally good explanation for the success of radioisotope imaging or radioiodine therapy, (2) remains undefeated and (3) is secure.

2. *The Fluctuating Decay Objection*. According to the rate law, the rate of decay for an isotope will be uniform, and the duration of an isotope's half-life will be consistent throughout the process of decay. But the timescale being considered by radiometric dating goes into billions—a scale of time for which we, existentially, do not have a very good grip. As a result, the fluctuating decay objector asks,

> *How do we* know *the isotopes did not decay faster in the past? We cannot rule it out. There would not have been any human observers making observations and recording experimental results to confirm that isotope decay 4 billion years ago occurs at the same pace and in the same way as we observe today. And because we cannot rule out that possibility, we should not assume the uniformity that is prescribed by the rate law.*

However, while fluctuating rates of isotope decay at different times might be a possibility in logical space, it does not seem to be a live option in our concrete, physical space.[37] Science assumes that nature is uniform across spacetime. Uniformitarianism is the scientific principle that the natural laws and processes that we observe today were the same in the past. Working under this principle allows scientists to study the past in diverse disciplines, including geology, forensics, astrophysics, et cetera. If uniformitarianism is false, people could not trust that the world would work the same from one second to the next. As a result, it is more likely that the way isotopes decay is the same today as millions of years ago.

Moreover, the rate at which isotopes decay is directly related to the strength of both the strong and weak nuclear forces. So, an isotope of some element decaying at some previous time at a rate different from what we observe in the present would mean that the strength of the nuclear forces would have been different at that time as well. However, an ever-so-slight difference of the strength of nuclear forces would mean that elements could not form in the first place.[38] So, we would need some alternate story explaining how it is that the strength of nuclear forces, which bond the basic matter of the universe, could possibly change over time. Absent any reason to think that the rate of isotope decay changes over time, the fluctuating decay objection can be dismissed.

3. *The Environmental Interference Objection*. While the previous fluctuating decay objection was based on logical considerations, the environmental interference objection is somewhat more grounded in empirical observation. In our response to the previous objection, we stated that "fluctuating rates of isotope decay at different times might be a possibility in logical space, but these do not seem to be a live option in our concrete, physical space." However, that is not completely accurate. There are rare instances in which the rate at which an isotope decays can be very slightly altered as a result of being bonded to another substance. For example, it has been shown that beryllium-7, when surrounded with palladium atoms, can induce an "electron capture decay" so that the half-life changes.[39] Or we know that when isotopes are used in the body for medical treatments, the effective half-life is of importance, taking into account the biologic half-life.[40] There seem to be different half-lives for the same isotope. This gives rise to the following objection:

> *We DO see examples in which the length of an isotope's half-life will vary depending on environmental factors such as the isotope's being bonded to substances that impact the rate of decay. So, it is possible that thousands of years ago (but not more than 10,000) there were environmental factors that made the rates of isotope decay much different than what we observe today.*

The two environmental interference examples cited are two ways it seems that the half-life of an isotope can change. In the beryllium-7 example above, the state of the electrons around the isotope nucleus can be altered (as seen in bonding). The change in half-life is very small; in the beryllium-7 case, the half-life was made longer by 0.9%. Other cases in which the electron environment around the isotope can be altered, changing the half-life, have shown to be very small.[41] Other examples cited in this style of objection consider how isotopes decay in biological systems. Extensive studies are done involving isotopes used in medical applications with good reason. It is important to understand how anything taken into the human body will affect that living system. Any substance, whether it is a drug or an isotope in the body, has a half-life. A drug or an isotope each has its half-life, but when put into a living system such as a human body, metabolism and the environment can alter the kinetics of the drug or isotope. We have extensive studies noting how an isotope, say iodine-131, will decay in the human body. Whether we are considering an instance in which the electrons around the isotope nucleus are altered or an event when the isotope is put into a biological environment, these examples of radioactive decay are different than the radioactive decay considered in radiometric dating. The decay in radiometric dating is nearly constant in nature because it is in a physical, closed system without interference of a high-energy system.[42]

So, while there are some known cases of fluctuating half-lives for isotopes, it is worth noting that they are very specialized cases in which isotopes are interacting with certain forces, the influences of which can be measured and observed. Second, note that the observed rate of fluctuation is very small, and in no way is of the magnitude that could undermine the implication radiometric dating has for the age of the earth, as far as a young-earth perspective is concerned.

C. Theological Superiority Objection

The final objection we consider is motivated by the sense that theology is a superior and more reliable means of forming beliefs about the world than science, and so if theologically based beliefs contradict science, it is the science that must give way. Here the objector says something like the following:

> *Science is not the only way of forming beliefs about the world. In fact, we have the Bible which is God's word revealed to us. And because of who God is, including loving and all-knowing, we can have much more confidence in God's word than in science. Truths revealed by God are eternal and unchanging, whereas science changes all the time. As a result, it would be foolish to change or give up my Bible-based theology because of pressure from science. So, even though the science of nuclear chemistry seems to suggest an old earth, my Bible-based theology says the earth is young. So, the earth must be young.*

The objector seems to be employing an instance of the following argument schema:

The Mohler schema[43]

(a) According to science, *p*.

(b) According to my Bible-based theology, ~*p*.

(c) So, ~*p*.

This argument schema can be used for any area of science, and more importantly, for any substitution value for *p*. For example, it seems to be employed by Baptist seminary president Al Mohler in his response to the 2015 detection of gravitational waves predicted by Einstein's general theory of relativity.

On September 14, 2015, scientists at the Laser Interferometer Gravitational-Wave Observatory (LIGO) in Washington and Louisiana detected the ripple effects of two black holes colliding 1.3 billion years ago.[44] The landmark nature of this discovery earned the 2017 Nobel Prize in physics for three physicists who were instrumental in developing LIGO.[45] And more recently, physicists and astronomers were able to witness the gravitational wave effects of two neutron stars colliding around 130 million years ago.[46] In responding to the 2015 discovery, and its corollary that the universe is at least 1.3 billion years old, Mohler stated:

> Now to be candid, I don't believe that the world is 1.3 billion years old, certainly not billions of years old. I don't even believe that it is actually millions of years old. But one of the interesting things we need to note here is that the scientists who believe that, believe it because they are looking at certain patterns that, to their observation, tell them that. And what we need to note is this, if we ourselves were operating from a simply materialistic and naturalistic worldview, we would probably come to the very same conclusions.[47]

However, cautions Mohler, Christians need to approach announcements such as those coming out of LIGO from an intentional Christian worldview. From Mohler, this means being totally committed to the Bible and the historicity of events recorded in the Bible, including the biblical account of creation in the first chapters of Genesis. On Mohler's view, it is understandable for scientists who assume a secular, materialistic naturalism to interpret scientific data in a way that conflicts with the biblical account. For Mohler, secular scientists must assume that the universe tells its own explanatory story about its origins and operations. But because Christians operate according to a different "grand story," they will not be able to accept putative information that conflicts with their understanding of the universe.

Mohler's response to LIGO's detection of gravitational waves provides a template for a theologically motivated objection to the framework argument. On a Mohler-style stance, one can reject the claim that the best explanation for the success of radioisotope imaging and radioiodine therapy is the basic correctness of nuclear chemistry because it conflicts with the content of one's "biblical worldview." Appealing to the cognitive effects of sin, one can understand that fallible and finite human knowers can come to false conclusions about scientific claims and have an incomplete picture of the universe. A proponent of the Mohler stance will hold that those false conclusions are a natural consequence of secular scientists approaching their work from a secular, naturalistic worldview.

The theological superiority objection raises larger issues in epistemology in general, and religious epistemology in particular. However, as a response to the framework argument, more work needs to be done. In order for an appeal to theology to trump well-established scientific consensus, theological objectors need to either provide alternative explanations for the phenomena in question or present strong reasons for thinking that the science is incorrect. Consider the following three observations.

First, proponents of the Mohler schema need to account for the fact that many Christian scientists in physics, chemistry, and biology accept the mainstream conclusions of their secular counterparts in ways that are consistent with their Christian faith—even a faith that takes seriously the possible epistemic authority of the Bible. Thus, rejecting a scientific claim is not the only option available to someone who wishes to have a biblically informed Christian worldview.

Young-earthers who are prone to distrust mainstream science and scientists might deny what we have claimed about the possibility of there being authentic, Bible-believing Christians who deny a literal interpretation of biblical texts, an interpretation that they see as obvious. "Those 'Christians,'" the young-earther might say, "have compromised their faith in order to be accepted by their non-Christian colleagues—that is why they deny biblical truth." While it is natural to attribute negative motives to people who disagree with one's deeply held convictions (like the young-earther is doing in this hypothetical case), one should not assume that negative motives such as succumbing to professional peer pressure are involved simply because one accepts well-supported science. Many, many Christians in science who accept an old earth exhibit all of the external markers of Christian life and witness. Moreover, the charge of possibly letting peer pressure detract from truth could just as easily be leveled at the young-earther, as evidenced by our discussion of the psychological burden and prudential objections above.

In reviewing the LIGO data, Mohler sets up a strong dichotomy between a scientific explanation on the one hand, and a Christian worldview on the other: the faithful Christian, says Mohler, must choose. However, this is a false dichotomy—at least when it comes to accepting the results of either LIGO or nuclear medicine. Recall the Mohler schema:

(a) According to science, p.

(b) According to my Bible-based theology, $\sim p$.

(c) So, $\sim p$.

In order for the second premise of the Mohler schema to justify the conclusion, one's Bible-based theology should have more support than the scientific claim it is rejecting. But why should we think that is the case? Mohler himself made much about the fact that finite and fallible creatures need to check their confidence when it comes to conclusions we draw when "relying upon the world and our powers of observation to tell us the story of the universe."[48] But surely that should apply *in excelsis* to determining the content of a Bible-based theology.

Second, most theological traditions affirm epistemic authorities other than the Bible as important for Christians. Alongside scripture, the Wesleyan Quadrilateral names reason, tradition, and experience as possible sources of epistemic authority as well. The voices of theological tradition and one's own subjective experience carry epistemic weight—defeasible, but epistemic weight nonetheless. Similarly, if reason is a gift from God to aid creatures who bear God's image in making their way, reason (including science), too, should be acknowledged even by Christians as bearing epistemic weight—again, defeasible, but weight nonetheless.

Some, like Mohler, attempt to lift the Bible (and a Bible-based theology) as an epistemic authority over reason, tradition, and experience. Doing so may provide some internal justification for the Mohler schema's subordination of science to theology. However, there is no way either conceptually or practically to appropriate whatever epistemic authority the Bible may have without also engaging reason, tradition, and experience. Looking to "the Bible as a guide" is not done in a cognitive vacuum. Drawing theological conclusions from biblical texts requires several reasoning processes. These include drawing inferences from biblical texts to the meaning of those texts. They also include applying assumptions about the nature of the text itself to conclusions about what is being said. Moreover, each person will engage the biblical text from a particular interpretive vantage point that is influenced, at least in some ways, by the milieu of both tradition and culture. And finally, reading, interpreting, and reflecting theologically on biblical texts is engaged through the lens of subjective experience. There is no such thing as "the Bible alone," if that is intended to mean isolating biblical interpretation from reason, tradition, and experience. As a result, the biblical text and a Bible-based theology should not be placed in stark opposition to, say, reason. Rather, one should attempt to put all epistemic voices we have at our disposal in conversation with each other in order to determine how they can speak in harmony.

The voice of the Bible cannot speak in isolation—interpreting the Bible always brings the voices of reason, tradition, and experience along for the ride. Nor should the voice of the Bible be given the loudest volume, shouting and drowning out the others—at least if one wants to believe true things about most empirical phenomena. Science is built to do some things very well. The precision with which we are now able to understand events of cosmic magnitude such as those detected at LIGO, or the subatomic properties of radioactive decay which yield applications in medicine unimaginable a generation ago, should give theological objectors pause before easily dismissing scientific results merely because they conflict with one's version of biblical theology.

And third, the theological objector still owes us an alternative explanation for the success of medical applications such as radioisotope imaging and radioiodine therapy. We have claimed that the best explanation for the success of those applications is that the framework of nuclear chemistry that makes those applications possible is, in the main, correct. Until or unless the theological objector can give us a better explanation, the framework argument remains untouched.

Conclusion

Scientific understanding of the properties and structure of the atom provides the well-confirmed framework of nuclear chemistry. Nuclear medicine is the application of nuclear chemistry in service of medical diagnosis and treatment. Two such widely practiced applications are radioisotope imaging and radioiodine therapy, the success of which is best explained by the accuracy of the framework of nuclear chemistry. This framework also yields the application of radiometric dating of objects, according to which the earth is at least 4.6 billion years old. ♥

Notes

[1]Bodie E. Douglas and Darl H. McDaniel, *Concepts and Models of Inorganic Chemistry* (Waltham, MA: Blaisdell Publishing, 1965), 338.

[2]Energy emission in phosphorescence requires electrons to absorb energy from an external source prior to emitting energy in the form of visible light.

[3]Eric R. Scerri discusses how chemists think of "elements," whether that is "as simple substances that can be isolated and whose properties can be examined experimentally" or "as unobservable basic substances." Eric R. Scerri, "Some Aspects of the Metaphysics of Chemistry and the Nature of the Elements," *HYLE – International Journal for Philosophy of Chemistry* 11, no. 2 (2005): 135. The Periodic Table of Elements has changed over time, and there is still some debate about the arrangement of elements. See ____, *The Periodic Table: Its Story and Its Significance* (New York: Oxford University Press, 2006).

[4]The neutrons and protons are found in the nucleus of the atom while the electrons surround the nucleus in spaces called shells. Most of the mass of an atom is made up by the protons and neutrons that are packed together in the nucleus. Protons have a positive charge, electrons have a negative charge, and neutrons are neutral in charge. All neutrons have the same mass, regardless of which element's nucleus it is located in. The same is true for protons and electrons.

[5]Atoms combine to form molecules; some molecules are compounds and are composed of atoms of more than one element.

[6]Marion Clyde Day Jr. and Joel Selbin, *Theoretical Inorganic Chemistry* (New York: Reinhold Publishing, 1962), 369.

[7]Isotopes are called by their element name and mass, e.g., Carbon-12, with 6 protons and 6 neutrons.

[8]For example, when considering the elements present in paper, there is a certain amount of carbon. All materials that were once alive, even plants that make up paper, carry carbon. There are fifteen known carbon isotopes. Therefore, a sample of paper could be made up of different isotopes of carbon (but not all fifteen isotopes since many of them are unstable): this means that the atoms of carbon in the paper will probably have different numbers of neutrons.

[9]A rate law describes the relationship between the reaction rate (i.e., how fast reactants are converting into products) and the concentrations of the reactants and products. Rate laws can be experimentally determined for all chemical reactions and nuclear reactions. See Rate Laws, *LibreTexts* (2016), last updated June 23, 2019, https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Kinetics/Rate_Laws.

[10]Radioisotopes decay following a first order rate law. First order reactions have rates that are dependent on the concentration of one reactant and follow exponential decay. The half-life of a first order reaction is not dependent on the initial amount of reactant (in this case, the parent isotope). There are other types of rate laws (e.g., second order), but radioisotopes decay by first order only. See "First-Order Reactions," *LibreTexts* (2017), last updated June 5, 2019, https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry/Kinetics/Reaction_Rates/First-Order_Reactions.

[11]Thanks to an anonymous reviewer, it should be pointed out that the daughter isotope will increase to 100% only if it is a stable, not radioactive, isotope.

[12]While figures 1 and 2 are original, the graphs follow a standard way of representing half life. See, for example, David McConnell and David Steer, *The Good Earth: Introduction to Earth Science*, 4th edition (New York: McGraw Hill, 2018), 230.

[13]NHS England Analytical Services (Operations), "Diagnostic Imaging Dataset: Annual Statistical Release 2013/14," November 6, 2014, https://www.england.nhs.uk/statistics/wp-content/uploads/sites/2/2014/06/Annual-Statistical-Release-2013-14-DID-pdf-1118KB.pdf, 26.

[14]Ibid.

[15]"Radioisotopes in Medicine," World Nuclear Association, last updated February 2019, http://www.world-nuclear.org/information-library/non-power-nuclear-applications/radioisotopes-research/radioisotopes-in-medicine.aspx.

[16]Jayanth Keshavamurthy et al., "Cholescintigraphy," *Radiopaedia,* 2017, https://radiopaedia.org/articles/cholescintigraphy.

[17]As opposed to a high-energy beta emission. See "Radioisotopes in Medicine."

[18]Seven half-lives for Tc-99m is roughly 42 hours with 0.78% of the parent isotope left. Technetium-99 has a half-life of 211,000 years. There is no gamma ray emission during that decay into ruthenium-99. While the half-life of radioisotopes (called the physical half-life) can change slightly when placed in a biological environment (called the biological half-life), the effective half-life of Tc-99m is even less than its physical half-life. See "Technetium 99: A Pure Gamma Emitter Widely Used in Nuclear Medicine," *Radioactivity.eu.com,* February 20, 2018, http://www.radioactivity.eu.com/site/pages/Technetium_99.htm; and "Biological Half-Life," *EDP Sciences* (February 20, 2018), http://hyperphysics.phy-astr.gsu.edu/hbase/Nuclear/biohalf.html.

[19]"Radioisotopes in Medicine."

[20]The chain reaction that describes Tc-99m is as follows:

> Tc-99m with 43 protons and 56 neutrons gives off gamma radiation and decays into Tc-99 (same number of protons and neutrons, but they are no longer in their excited state).
>
> Tc-99 decays into ruthenium-99 which has 44 protons and 55 neutrons.

[21]"Information for Patients Administered Radioactive Iodine (I-131)," *U.S.NRC (United States Nuclear Regulatory Commission)* (2017), last updated May 28, 2019, https://www.nrc.gov/materials/miau/patient-release.html.

[22]Edward B. Silberstein et al., "The SNM Practice Guideline for Therapy of Thyroid Disease with ^{131}I 3.0*," *Journal of Nuclear Medicine* 53, no. 10 (2012): 1–19.

[23]"Radiometric Time Scale," *USGS*, last updated June 13, 2001, https://pubs.usgs.gov/gip/geotime/radiometric.html.

[24]H. E. Gove et al., "Radiocarbon Dating with Tandem Electrostatic Accelerators," *Radiocarbon* 22, no. 3 (1980): 785–93.

[25]"Radiometric Time Scale." We want to note that the earliest study on the mummy wrappings was done prior to the 1960s before a more accurate half-life of C-14 was established. Gove et al., "Radiocarbon Dating with Tandem Electrostatic Accelerators," measured and calculated the age of the mummy wrappings as 2,200 years old based on the then current data that C-14 had a half-life of 5,568 years.

[26]Hot spots have the technical name "mantle plumes."

[27]"Evolution of Hawaiian Volcanos," *USGS*, last updated April 12, 2017, https://volcanoes.usgs.gov/observatories/hvo/hawaiian_volcanoes.html.

[28]Argon is a noble gas.

[29]Scientists are aware that this is not a perfect process and that some argon does get left in the sample at solidification. Methods have been developed to correct for any argon that was present before daughter argon was formed. See Ian McDougall and T. Mark Harrison, *Geochronology and Thermochronology by the 40Ar/39Ar Method* (New York: Oxford University Press, 1988).

[30]"Evolution of Hawaiian Volcanos."

[31]Aiden P. Gregg, Nikhila Mahadevan, and Constantine Sedikides, "The SPOT Effect: People Spontaneously Prefer their Own Theories," *Quarterly Journal of Experimental Psychology* 70, no. 6 (2017): 996–1010.

[32]This is not an exhaustive list; for ease of simplicity, we have carved this region of logical space with broad strokes. Subdividing the categories in terms of having/not having strong support fails to account for having support of varying strengths or having no support whatsoever. We could certainly accommodate what we say in the sequel to take those nuances into account and nothing substantive would be changed—the main epistemological points carry through.

[33]"~p" is shorthand for "it is not the case that p."

[34]Though, depending of course on the circumstances which give rise to *S*'s belief that *~p*, it seems possible for *S* to have a measure of justification for *~p* given that she has no strong evidence for *p*.

[35]Stathis Psillos, *Scientific Realism: How Science Tracks Truth* (London, UK: Routledge, 1999), 108.

[36]See Eric R. Scerri, "Just How Ab Initio Is Ab Initio Quantum Chemistry?," *Foundations of Chemistry* 6, no. 1 (2004): 93–116, https://doi.org/10.1023/B:FOCH.0000020998.31689.16 .

[37]Except in rare circumstances to be discussed in the next objection.

[38]Note that the precise and limited values that could be had by the nuclear forces in order to give rise to a life-permitting universe is often a feature of fine-tuning arguments.

[39]B. Wang et al., "Change of the ^{7}Be Electron Capture Half-Life in Metallic Environments," *The European Physical Journal A – Hadrons & Nuclei* 28, no. 3 (2006): 375–77.

[40]Silberstein et al., "The SNM Practice Guideline for Therapy of Thyroid Disease with ^{131}I 3.0*."

[41]Christopher S. Baird, "Can the Decay Half-Life of a Radioactive Material Be Changed?," *Science Questions with Surprising Answers*, April 27, 2015, http://wtamu.edu/~cbaird/sq/2015/04/27/can-the-decay-half-life-of-a-radioactive-material-be-changed/. Physics gives an accessible general overview about the different ways that electrons around the isotope can be altered, changing the half-life.

[42]Thanks to an anonymous reviewer, it should be pointed out that even in the cases in which isotopes are bombarded by high energy particles, these cases are not relevant because the isotopes affected are not used for dating. These cases are also rare and well understood. For a more detailed discussion, see Roger C. Wiens, "Radiometric Dating: A Christian Perspective," *The American Scientific Affiliation*, revised 2002, http://www.asa3.org/ASA/resources/Wiens.html.

[43]Named for Albert Mohler, the president of Southern Baptist Theological Seminary for reasons that will become apparent below.

[44]Adrian Cho, "Gravitational Waves, Einstein's Ripples in Spacetime, Spotted for First Time," *ScienceMag.org*, February 11, 2016, http://www.sciencemag.org/news/2016/02/gravitational-waves-einstein-s-ripples-spacetime-spotted-first-time.

[45]"Press Release: The Nobel Prize in Physics 2017," *NobelPrize.org* [Nobel Media AB 2019, August 7, 2019], https://www.nobelprize.org/prizes/physics/2017/press-release/.

[46]Adrian Cho, "Merging Neutron Stars Generate Gravitational Waves and a Celestial Light Show," *ScienceMag.org*, October 16, 2017, http://www.sciencemag.org/news/2017/10/merging-neutron-stars-generate-gravitational-waves-and-celestial-light-show.

[47]Albert Mohler, "The Briefing 02-12-16," *AlbertMohler.com*, February 12, 2016, https://albertmohler.com/2016/02/12/the-briefing-02-12-16/.

[48]Ibid.