"The Fullness Thereof": The Significance of the Higgs Mechanism in Jewish Thought and Theology

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He has coauthored papers searching for evidence of extra-dimensions, low-scale gravity and micro black holes in the most energetic events available at the LHC. This includes a search for strong gravity in multijet final states produced in pp collisions at $s\sqrt{}=13$ TeV using the ATLAS detector at the LHC (*https://arxiv.org/abs/1512.02586*) and a search for low-scale gravity signatures in multi-jet final states with the ATLAS detector at $s\sqrt{}=8$TeV (*https://arxiv.org/abs/1503.08988*).

Currently he is independently developing a novel technique for discovering other BSM signals (e.g., R parity violating supersymmetry). His MSc was done in the quantum optics lab in the BINA Center for Nanotechnology, Bar-Ilan University, where he had completed a BSc with honors. While at Bar-Ilan he was an instructor for the quantum mechanics 1 and 2 courses. He now lectures at the Davidson Center for Science Education.

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ABSTRACT

Our fundamental understanding of matter has been revolutionized in the past century. This revolution reached a climax in 2012 with the discovery of the Higgs boson — the proof of the mechanism that generates particle masses. The conclusion, with regard to our understanding of matter, is that there is no such thing as "matter." The first section of this article is devoted to explaining the scientific theory, while the second section delves into the theological meaning of this new paradigm. The science content below was published in a previous article in Hebrew by Daniel Turgeman, "Light, Matter, and the Higgs Boson." 2016. Galileo Journal for Science and Thought, vol.210, March, pp. 20–27.

INTRODUCTION

As we experience it, there is a clear divide between light and matter. Matter has mass, is bounded in local space, and is conserved (what might be called the "law of conservation of matter"). Light, on the other hand, is massless, spreads over space, and has the ability to be created and annihilated. This clear divide began to crack with Einstein's famous equation $E=mc^2$ and ultimately collapsed with the discovery of the Higgs boson in July 2012. In this article, I shall try to elucidate the physical theory behind the Higgs mechanism and its deeper meaning in relation to Jewish thought and theology.

PART ONE: PHYSICS

The Law of Conservation of Matter

Ever since Lavoisier, it has been known that in any chemical reaction the products of the reaction must be of the same mass as the reactants. If the measured mass of the products is not equal to that of the reactants, then one must search for the missing mass in other elusive products that had not been recognized. Indeed, this is basically the way that oxygen was discovered. Matter can change form but it can never appear or disappear. In this paradigm, the very question "What is the origin of mass?" is illegitimate. That is because "origin of mass" means that mass was created from something that is not mass — a statement that contradicts the law of the conservation of matter described above.

E=mc²

The publication of Einstein's Theory of Special Relativity in 1905 caused this paradigm to shift. This is because $E=mc^2$, which can be written as $m=E/c^2$, i.e. the mass of a body equals its energy divided by the speed of light squared. A spring will be more massive when compressed than when loose because of its additional potential energy, and any object will be more massive when it is hot than when it is cold, because of its additional thermal energy. In reality, the added mass in these examples is negligible, but for the proton this is far from so. The proton is composed of three elementary particles called "quarks." Like a compressed spring, these quarks are bounded together by a very strong force called "the strong force." Because of this energy the mass of a proton is 100 times larger than the mass of its constituent quarks. The same goes for the neutron. The fact that almost all the mass of the matter that we experience comes from its protons and neutrons (because its electrons are 2,000 times lighter than the protons and neutrons) brings us to the understanding that almost all the mass of the matter we experience is in fact energy. This is a very dramatic conclusion. Dramatic, but not a total revolution of the way we understand the world. That is because the elementary particles (the quarks and electrons) have their own intrinsic mass. At least that is what we once thought, but it turns out that even that is not true. In order to explain how even the elementary particles do not have an intrinsic mass we must first become acquainted with what goes on in particle colliders like the Large Hadron Collider at CERN.

In particle colliders particles are accelerated to speeds of 99.999998% the speed of light. Those particles are then brought to collide, head on, inside huge detectors that record the products of those collisions. The purpose of colliding the particles is not to break them open and find out what they're made of. Rather, they are brought to collide in order to create new particles, different kinds of particles that weren't in the original particles. For example, from a proton-proton collision may pop out electrons or muons or Higgs bosons or other particles that weren't in the protons initially. How does that happen? Here, too, we use Einstein's equation $E=mc^2$, but now with energy we *create* mass. But how does that happen? What is the mechanism? This question requires

a brief introduction to quantum field theory, from which we will be able to touch upon the role of the famous Higgs boson.

Quantum Field Theory

In order to describe reality, physicists have been able to formulate a theory that encompasses both quantum mechanics and special relativity. This formulation gave rise to the need to describe the fundamental ingredients of matter as fields[1] that permeate all of space. Particles are actually excitations in the fields, like a wave on the surface of the water. An electron is an excitation in an "electron field" and a quark is an excitation in a corresponding "quark field." These fields permeate all space, and that is the reason that a particle here on Earth is completely identical to that type of particle anywhere else in the universe. Both are excitations in the same field. These "particles" (= excitations) have the ability to interact with other "particles" (=excitations), and even directly with other underlying fields. That was an ultra-short introduction to Quantum Field Theory (QFT). QFT is a framework which, together with the definition of which fields exist and what their precise interactions are, makes up the "Standard Model" for describing nature.

Now we can already comprehend how electrons can pop out of a collision of protons. Energy from an excitation in one field is transferred to another field and thus excites it, creating new "particles." The ability of particles to transform into one another is hard to reconcile with a simplistic picture of particles being small, ball-like objects, but it does befit the understanding that particles are excitations in fields.

Let There Be Mass

Simplistically, it was thought that excitations/particles could have an intrinsic mass of their own, but it turns out that they cannot. (See Appendix 1.)

The reader will surely exclaim, "But particles *do* have mass!"

The answer is that particles surely *act as if* they had mass, but it is just an effective phenomenon and not an intrinsic trait. The phenomenon of mass arises from the interaction of the particles with the

1. A field is a quantity that has a value for each point in space.

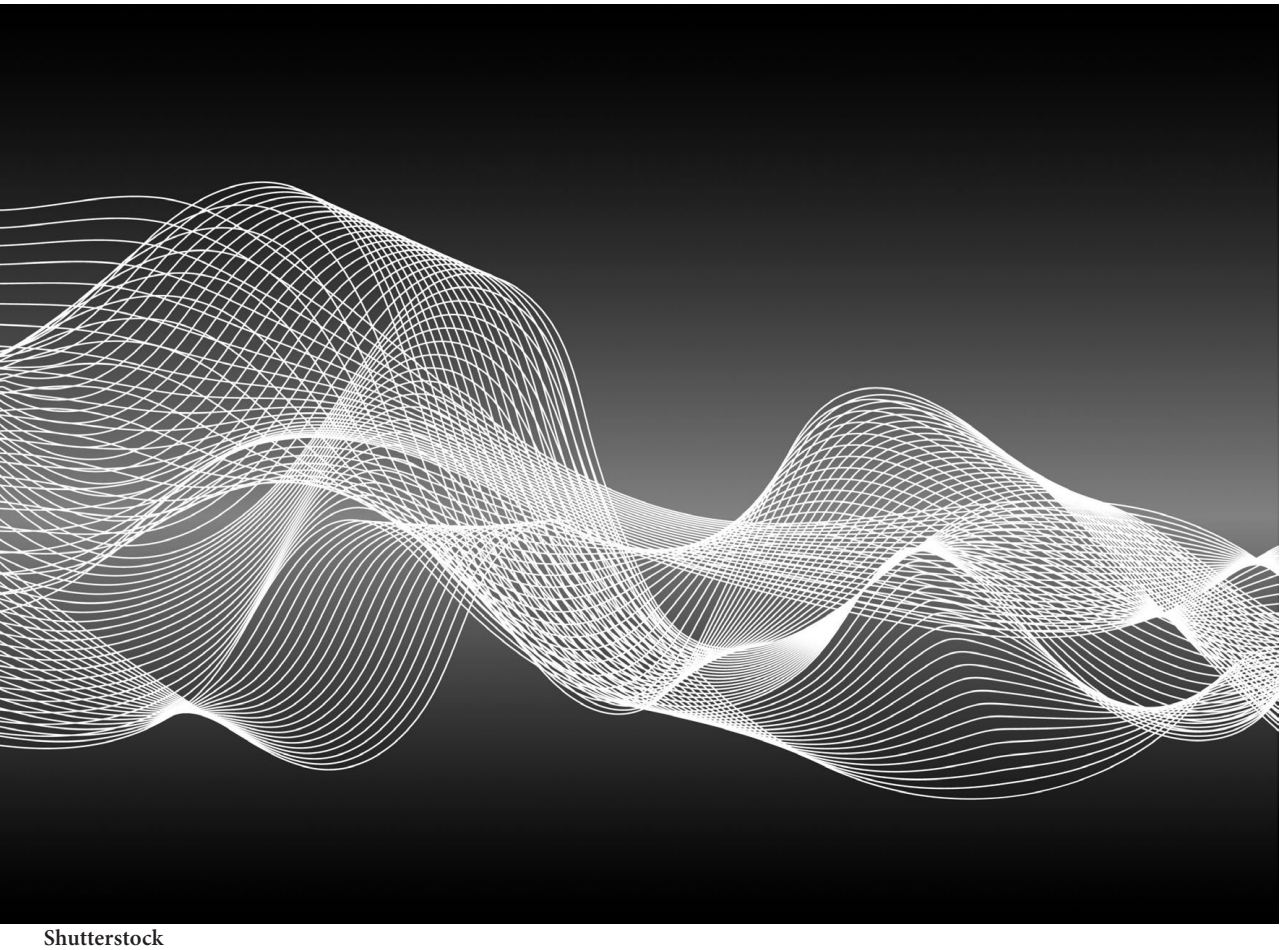

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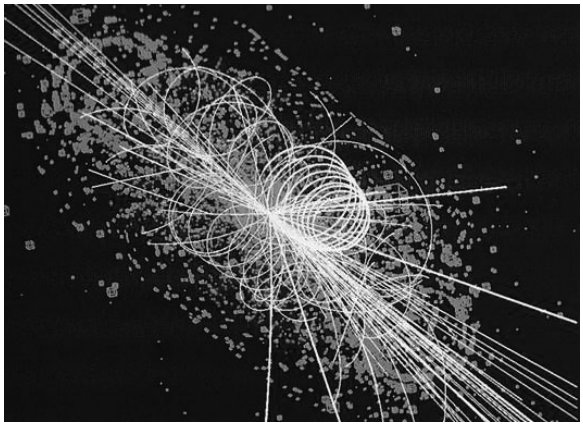
Figure 1. According to quantum field theory, the field that permeates all of space is the fundamentally existent entity, while "particles" are only excitations in that field.

Higgs field. (See Appendix 2.) Different types of particles have different masses because of the strength of their interaction with the Higgs field. The photon is massless because it does not interact with the Higgs field. The electron is light because it interacts with the Higgs field only weakly. Heavier elementary particles, like the top quark, which is 300,000 times more massive than the electron, are heavy because they interact strongly with the Higgs field.

A popular analogy is that of different bodies swimming in water. A slippery fish will swim fast because it barely interacts with the surrounding water. A man wearing a coat will swim slowly because of the drag, i.e., the large amount of interaction of the coat with the water. So, too, all of us are swimming in the "Higgs field sea." Particles interacting weakly with the Higgs field are less massive, and particles interacting strongly are more massive.

In July of 2012 production of the Higgs particle was discovered at the Large Hadron Collider in Switzerland. The Higgs particle is the excitation of the Higgs field and the footprint proving that the field exists.



A collision event at the Large Hadron Collider.

THE DEEPER MEANING

There Is No Such Thing as "Matter"

To summarize, the particles that constitute matter have no intrinsic mass. Mass is only an effective phenomenon caused by interactions between fields. Furthermore, according to Quantum Field Theory, the

field that permeates all of space is the fundamentally existent entity,[2] while "particles" are only excitations in that field. The clear conceptual divide between light and matter presented at the beginning of this paper turns out to be a misconception. Reality acts as if these differences exist, but by doing so hides its true face. Matter resembles light that can undergo interactions with the Higgs field, more than anything "material." From all the above, it turns out that there is no such thing as "matter." In a sense, one can say that the world we live in is more like an image made of light than a bunch of particles.[3]

It is important to emphasize that without the Higgs mechanism described above these conclusions could not arise. Neither quantum mechanics, nor relativity, and even not quantum field theory without the Higgs mechanism could have led us to these conclusions.

Indeed, the quantum revolution has greatly changed the way we view matter and the laws governing it, but in quantum mechanics the mass of a particle has remained a "given intrinsic property of matter." Furthermore, it doesn't make a difference which way you look at the Schrödinger equation (the equation that governs the evolution of a particle in time according to quantum mechanics), you are still left with the same particle. There is no creation or annihilation of particles in quantum mechanics. Matter remains intrinsically massive and the law of conservation of matter still holds.

Relativity has shown us that there is a relation between matter and energy, but the mechanism is still missing. The equation $E=mc^2$ doesn't explain how it is that the massive particles we see are actually energy. It just states that this is so. Furthermore, it can be argued that even this is an overstatement. The equation only relates the conversion ratio

2. It should be noted that ontologically it may be that the real fundamental entity is something deeper, for instance, string theory in ten dimensions where the strings are glitches in the fabric that makes space-time. In any case, the understanding of "particles" as little balls has been rejected. Reality acts as if it were excitable fields but it may well be that it is something even farther from our simple imagination.
3. The difference between our world and an image made of light is that the latter is made up of photons which do not interact with one another, and the former is made up of the quark and electron fields which do interact with one another. Therefore one is able to pass one's hand through an image made of light but not through a wall.

between mass and energy, but one can still choose to look at mass as something that stands in and of itself (just as foreign currencies stand in and of themselves).

Also, the fantastic reality according to quantum field theory by itself does not suffice. I recall while taking my first course in QFT how puzzled I was by the concept that massive particles pop out from a field. I entertained myself with the thought "Let there be a quantum field of cows; cows can just pop out of the quantum vacuum." Obviously, this is an exaggeration, but it sounded like the gist of what QFT was saying: creation of massive particles from fields. Only after understanding that "particles" really do not have intrinsic mass but rather receive their effective mass through the Higgs mechanism, does the picture of reality become clear.

It could be said that a philosophical argument could have been made even before understanding the Higgs mechanism: If particles do indeed appear from fields, then they cannot possess an intrinsic mass; their mass must be some sort of effective phenomenon. This argument is not compelled by the equations, but rather compelled from a philosophical point of view.

To summarize, only after completely understanding that mass is an effective phenomenon of interactions between fields can one understand and depict in the mind's eye how and why the masses of elementary particles are nothing but energy. This conclusion affects the way we conceive the world we live in also from a Jewish theological perspective, as will be expounded upon next.

PART TWO: JEWISH THOUGHT AND THEOLOGY

"World of Deceit"

I have learned from my rabbi, Rabbi Kobi Dana, that the epithet "world of deceit" does not mean that this world has evil fraudulent intentions. This epithet means that this world does not express or reflect its true essence. In Hebrew, the same root (*ʿolam*) is used for both "world" and "hidden." The "hiddenness" comes to play in relation to good and evil, holy and secular, and spiritual and material. The basis of this viewpoint is that, in spite of all the evil and material that we may see, the root of all

is truly holy, good, and spiritual. When we experience something bad, we *believe* that it is for some greater unseen good, and we bless "Baruch Dayan HaEmet" ("Blessed is the Judge of Truth"). So too, Judaism has held for millennia that the material world conceals its true spiritual basis. Until now this has been a *belief*, now we *understand* how this is truely so. Although the quantum fields are not "spiritual," they disprove the conception that the base of this world is matter.

From this philosophical-theological argument, we may make *a scientifically falsifiable prediction*. Based on the Jewish belief that the world is not founded on the material, we may predict that the masses of particles to be discovered in the future will also not be intrinsic but rather effective phenomena. This holds true when the nature of dark matter will be discovered and when the complete theory of the light neutrino masses will be understood. These are particles that we have not mentioned so far in this paper as they are not a part of the matter familiar to us in our everyday lives. Nonetheless, based on the conception that all of creation is linked from the spiritual to the material like a chain, it is necessary that these particles also do not have any intrinsic mass.

Unity of G-d

Matter has been perceived conventionally as something inanimate and "dead," such that even if in the distant past it was created by the Creator, now it is independent and disconnected from Divinity. Yet the Jewish principle of G-d's unity does not add up to mere monotheism. According to Rabbi Isaiah Ha'Levi Horowitz, the overriding statement of Deuteronomy 4:39, "Know this day, and lay it to thy heart that the L-rd He is G-d in heaven above and upon the earth beneath; there is none else," does not state that there is no other god, but rather that there is nothing other than G-d (*Shlah*, *maamar rishon* from *Ṣeser Maamarot*).

This obligates us to look at everything, even inanimate matter, as being perpetually vitalized by the L-rd, life of worlds. In the words of Rabbi Shneur Zalman of Liadi:

> The force of He Who acts, on he who is acted upon, is perpetual to

> vitalize and keep in existence […] This is what the Ari said that *also in the inanimate such as rocks, soil and water is a type of vitality.*
>
> (*Tanya*, *Iggeret Ha'Kodesh*, chap. 25)

From the point of view that matter is made of massive particles similar to tiny billiard balls, it is hard to understand how and from where the Creator continues to vitalize the creation. It has been advocated that the electrostatic forces giving all materials their structure show that there is a vitality vitalizing all matter at every moment. Yet this view still leaves the elementary particles as inanimate objects that exist by themselves. But, after we understand that there are only fields that spread over all space and what we call "particles" are only excitations in these fields, we may say that the world is closer to a kind of hologram than an ensemble of particles. This great revelation makes it possible for our generation not only to believe, but also to know and to understand how it is possible to continually vitalize the substance of all matter. This is because the particles do not exist in and of themselves, but rather they are branches that are perpetually brought into existence from the fields that are their roots.

This physical description is exceptionally reminiscent of how Rabbi Moshe Ḥaim Luzzatto (the Ramḥal) describes reality:

> One of the great principles that we [the rabbinical tradition] have on this subject is that parallel to all the inferior things that be, there are non-material forces above, that from them chain down and come out, in a certain order of succession that His wisdom decreed, these inferior things that be, them and their instances. It turns out that those forces are the roots of all these inferior things that be and *the inferior things that be are branches and consequences of those forces*, and are connected one to another like links of a chain.
>
> (*The Way of G-d*, chap. 5)

It is hard to imagine a better way to describe reality in the language of Ramḥal's time. Indeed, today we describe the elementary particles not as existent in and of themselves, but rather as branches and consequences of quantum fields.

As stated above, this description has been completed philosophically only after we have understood the Higgs mechanism. How are

we to have understood "the elementary particles not as existent in and of themselves, but rather as branches and consequences of those fields" if the particles had their own intrinsic trait of mass? It is as if we were to say that a "billiard ball field" that permeates all space causes the spontaneous creation of massive billiard balls. This description is unacceptable and even laughable. Furthermore, even if we were to accept this odd description, from the moment a massive billiard ball would be created, we would look at it as something that now stands in and of itself. This is similar to the "common conception" cited by the Shlah above, that after creation of something out of nothing it stands and exists in and of itself. Beforehand, there was no massive particle and now there is a particle with an intrinsic mass. Yet, after we have understood that mass is not an intrinsic property but rather an effective phenomenon of an interaction between fields, the road is now paved to understand how the particles that make up everything we experience are in a state of being perpetually revitalized from their root. This is beautifully expressed in the prayer *Nishmat Kol Ḥai*:

> בּוֹרֵא כָּל הַנְּשָׁמוֹת, רִבּוֹן כָּל הַמַּעֲשִׂים, הַבּוֹחֵר בְּשִׁירֵי זִמְרָה מֶלֶךְ אֵל **חַי הָעוֹלָמִים**
>
> Creator of all souls, Master of all deeds, Who chooses musical songs of praise — King, Unique One, **G-d, *Life of all worlds*.**

"Came" or "Comes" To Be?

A halakhic consequence of this way of looking at the world arose around 400 years ago. Rabbi Manoaḥ Hendil advocated that the accurate vocalization of the common blessing on food

> ברוך אתה ה' אלוקינו מלך העולם שהכל נהיה בדברו

should be "Blessed are You, G-d…through Whose word everything *comes* to be," instead of "…everything *came* to be."(In Hebrew this is a difference in vocalization rather than spelling.)

Rabbi Hendil's rationale was to thank G-d for bringing everything into being, perpetually in the present. In this way this blessing joins all other blessings that are in the present tense, like "…Who brings forth bread from the land." In accordance with Rabbi Hendil, great religious authorities such as the Vilna Gaon (*Maʿase Rav* 76) ruled to

pronounce the blessing in the present tense. Rabbi Yeḥiel Mikhel Epstein ruled:

> It seems to me that the way the blessing is written encapsulates also the present. This is because the Holy One, blessed is He, renews always the acts of creation and creates always and in every moment, that His providence does not pause even for one moment. Therefore we use an expression that encapsulates all tenses…
>
> (*Ḥarukh Ha'Shulḥan*, *Oraḥ Ḥaim* 167:7)

We see here that this worldview is so ingrained in Jewish theology that great halakhic authorities ruled to change the more popularly accepted vocalization of the blessing. The truth is that the original vocalization also may be understood as pertaining to the present, and the new one as actually pertaining to the future.[4] Therefore, the original common vocalization may still be used, holding the view that G-d creates everything perpetually.

Rabbi Zeev Yavets held a different view:

> Of course, they [who use the original vocalization] are correct because this is a blessing for all of existence and *how can one fathom that everything comes to be perpetually in the present* by His word? Behold the entire world was already made in the six days of Creation and doesn't receive its existence at present. Therefore, there is no doubt that the correct vocalization is "came to be."
>
> (*Responsa*, part 1, chap. 94)

It seems obvious that Rabbi Yavets's physical view of the world influenced his ruling. Our eyes see that "One generation passes away, and another generation comes; and the Earth abides forever" (Ecclesiastes 1:4), so how can one fathom that everything comes to be perpetually in the present? This point of view forced the understanding of the blessing as pertaining to the past. Our generation, however, has been enabled

4. Uriel Frank, "Error Corrections and Erroneous Correctors" (in Hebrew). 2011. http://www.lif.ac.il/maim/chumrot_uriel_273.pdf, pp. 302–304 (accessed 13 Aug. 2017).
אוריאל פרנק. תשע"א־תשע"ב. "חומרות, הידורים ושיבושים בלשון העברית: על תיקוני שגיאות ועל שגיאות מתקנים." *מים מדליו, שנתון המכללה הדתית למורים ע"ש ליפשיץ*, גיליון 22–23, עמ' 273–320.

to reveal the foundations of the universe. We now know that it is not only fathomable, but rather it is really so: Through His word everything *comes* to be, also in the present.

Moral-Theological Implications

Belief in the creation of the world is one of the foundations of Jewish faith because of its deep and encompassing significance. Belief in perpetual creation shares the same significance. Rabbi Abraham Isaac Kook writes of creation:

> The complete novelty of Creation, with no prior matter and no entity at all, bases the idealistic thinking that there is no true reality other than the absolute good.
>
> (*Ariflei Tohar* 49)

This knowledge infuses belief in this world and a confidence in its complete perfection to come, writes Rabbi Kook:

> For since there is no general or particular reality that exists other than from the hand of G-d, Maker and Creator of all, and He, Blessed be He, is the source of righteousness and morality, therefore there is no possibility that righteousness and morality will not be realized…
>
> (*Olat Raiyah*, part 1, p. 114)

> …the Israelite principle that the foundation and root of the world is from absolutely nothing — not from any mass and force, but only from an act of G-d — [means that] since all comes from G-d's omniscient word, everything leads to Him.
>
> (*Shmoneh Kvatsim*, *kovets* 5: 143)

https://he.wikisource.org/wiki/שמונה_קבצים_קובץ_ה#.D7.A7.D7.9E.D7.92

(accessed 13 Aug. 2017)

This is how Rabbi Kook defines the significance of the creation of the world. Although Christianity may declare its belief in the Bible, Rabbi Kook says that it "stray[s] after the eternity of matter [a philosophical view of matter existent independent of and prior to the creation by G-d]" (ibid.). That is because Christianity talks about redemption *from* the world and has given up on rectifying it, whereas Judaism believes

in the Divine origin of the universe and the ability to repair and perfect the world (*tikun ọlam*).

Rabbi Kook upholds that the belief in the eternity of matter, or the view that matter is independent from G-d, blocks G-d's light from appearing in this world:

> …as for the deceiving opinion that there always was eternal matter… [if this were so] there couldn't be a way for the creations to have an internal relation with their Creator, may He be Blessed, because according to this misconception the material foundation would be apart from Him, but it (matter) is the foundation of the inner existence of all created beings. Thus he who errs in this opinion is like one who has no G-d, because he is unable to elevate his soul to recognize his Owner from his own internal existence…
>
> (*Ẹin Ayah, Brakhot* 132a)

Just as the opinion that matter was never created blocks one from recognizing the Creator in his own internal existence, so too does the opinion that matter is currently closed and inanimate. Therefore, there is great moral-theological significance in understanding the discoveries of modern physics. We have expelled the dark heavy clouds of idolatry; we are now dispelling the lighter clouds of materialism.

APPENDIX 1: NO INTRINSIC MASSES

As stated in the text, particles are excitations in fields. Theoretically, one can ascribe to them a mass in the equations that govern their motion. In the equations one can write:

[kinetic term] + [mass term] + ["interaction with other fields" term]

The mass term will look like:

$$m \cdot f$$

where f represents a field and m its mass. For the massless photon, for example, m=0. When writing the mass term as so, the mass is just a given — an intrinsic property of the field being described. Here the

reader may ask: Philosophically, how is it that something with mass can spontaneously be created from something without mass? The equations might allow for it, but something seems amiss…

The answer is that indeed this is not the whole story. All experiments performed give rise to a clear conclusion that in reality it is not possible to write a mass term. In short: the existence of a mass term is plausible under a certain condition, a condition of symmetry, that it turns out that nature does not fulfill. If nature would have obeyed this symmetry condition, we could have written a mass term and understood that mass is a given — an intrinsic property of the particle. Yet, since nature has shown us that it possesses a certain asymmetry, then it is not possible to write the mass term, because it depends on a symmetry that is nonexistent.

A more detailed explanation of this can be found in footnote 4 of my Hebrew article:

http://www.daat.ac.il/daat/mahshevt/maamarim/turgeman.pdf.

APPENDIX 2: PARTICLE MASS GENERATION VIA INTERACTION WITH THE HIGGS FIELD

We will again show the general equation in a schematic form:

[kinetic term] + [mass term] + ["interaction with other fields" term]

We have seen that there cannot be a mass term. Now let's take a look at the interaction term. The interaction term between two fields will look like:

$$g \cdot f_1 \cdot f_2$$

where f_1 and f_2 represent two different fields and g is a constant that represents the strength of their interaction. This term is responsible, for example, for the reception of radio waves by the antenna in your car. The photons of the radio waves interact with electrons in the antenna and drive them at different frequencies. In any case, ever since the 1970s the standard model foresaw a mechanism that enabled bestowing mass to particles via the interaction term. If there would be a field, let's call it

the Higgs field and denote it H, which interacts with all other particle fields:

$$g \cdot H \cdot f$$

(For example $g_e \cdot H \quad e$ would be the interaction term of strength g_e between the Higgs field and the electron "e", and $g_t \cdot H \cdot t$ would be the interaction term of strength g_t between the Higgs field and a quark of type t.) And, if by a certain mechanism (called spontaneous symmetry breaking) the value of this field would become fixed around a certain value, let's call it "v," then the interaction term will take on the form and effectively act as a mass term:

$$\begin{array}{c} g \cdot H \cdot f \\ \downarrow \\ g \cdot v \cdot f \\ \downarrow \\ (g \cdot v) \cdot f \\ \downarrow \\ \text{“m”} \cdot f \end{array}$$

where now the mass "m" of the particle is really nothing other than $g \cdot v$, the interaction strength between the particle and the Higgs times the value around which the Higgs has become fixed. We have obtained something that looks and acts like a mass term without it really being a mass term. The meaning of this is astounding: *There no such thing as "mass."* All the mass of the most elementary particles that make up what we call matter is only an effective phenomenon of interactions between fields.