

How Science Deepens Our Understanding of Torah: (I) The Rainbow and the Photon and (II) Rain and Chaos

By: NATHAN AVIEZER

Abstract

Two examples will be given of how advances in science deepen our understanding of the words of the Holy Torah.

The first example relates to the rainbow. It states in *Beresheet* that after the Flood, G-d promised never again to destroy all mankind through a flood. The sign that G-d brings to seal His promise is the rainbow: “*I have placed my rainbow in the clouds as a sign of the covenant between Me and the Earth*” (9:13). Why is the rainbow the ideal choice for the sign of G-d’s faithfulness? Modern quantum physics provides the answer based on the photon, the quantum particle of light.

The second example relates to rain. It states in *Devarim* that since the water in Israel comes from rain, which is always uncertain, Israel requires G-d’s constant attention: “*A land (Israel) about which G-d always cares*” (11:12). However, recent advances in meteorology have led to accurate predictions regarding future rainfall. It thus seems that further advances in meteorology, using more powerful computers, will eventually eliminate all remaining uncertainties regarding future rainfall in Israel. Israel would then no longer require “G-d’s care,” a situation that contradicts the verses in the Torah. This contradiction has been resolved by the new science of chaos, which guarantees that accurate predictions of rainfall in Israel will always remain beyond the reach of meteorologists.

Nathan Aviezer is Professor of Physics and former chairman of the Physics Department of Bar-Ilan University. He has published 140 scientific articles on physics and was honored by being elected as a Fellow of the American Physical Society. In addition to his scientific work, Professor Aviezer has a long-standing involvement in the relationship between Torah and science, and is the author of three books: *In the Beginning, Fossils and Faith*, and *Modern Science and Ancient Faith*. He has also recently published a book on *parshat ba-sharu’a*, titled *Probing the Parsha*. Finally, his course at Bar-Ilan University on “Torah and Science” was awarded the prestigious Templeton Prize.

(I) The Rainbow and the Photon

“My Rainbow Placed in the Cloud”

The *Beresbit* narrative of the Flood relates that all human beings drowned, except for the family of Noah who were saved in the Ark. After the flood waters had receded and Noah and his family left the Ark, G-d promised that He would never again destroy the world by a flood and He gave a visual sign of His promise (*Beresbit* 9:12–15):

This is the sign of the covenant that I am establishing between me and all living creatures forever. My rainbow in the cloud will be the sign of the covenant ... When a rainbow appears in the clouds, I will remember the covenant ... *that there will never again be flood waters to destroy all creatures.*

These verses seem to imply that the rainbow first appeared after the Flood as a visual sign of G-d’s promise never again to destroy all humankind in a flood. However, the rainbow is a natural phenomenon that accompanies the rain. Sunlight is a combination of all colors. When it rains, the raindrops act as prisms that separate the sunlight into its various colors—the colors of the rainbow. In view of this scientific explanation, how can one understand the *Beresbit* verses regarding the divine origin of the rainbow?

These verses do not state that there had never been a rainbow before the Flood. Rather, the verses state that G-d designated the rainbow as His sign that as long as this natural phenomenon occurs, He will not destroy the world through a flood. I might say to a friend, “The sun rising in the east is my sign that you can always rely on my help.” These words do not mean that I am now creating the sun. Rather, they mean that I will *always* help my friend, just as the sun *always* rises in the east.

Why did G-d choose the rainbow as His sign to humankind that a destructive flood will never occur again? Why did He not choose a different natural phenomenon?

One might answer as follows: Rain is a common forerunner of a flood. Therefore, when it rains very heavily, people might fear that the heavy rain is the onset of another massive flood that will again destroy everything. Therefore, the rainbow that accompanies the rain will serve as a sign of G-d’s promise that a massively destructive flood will never occur again.

Elementary Particles

There is a deeper reason for G-d's choice of the rainbow as the visual symbol of His promise not to destroy the world through a flood. Science has shown that the rainbow has a unique feature that makes it the ideal choice to symbolize G-d's promise.

If one were to choose some object to symbolize permanence and stability, one might think of a mountain. Nothing seems more stable than a towering mountain. However, this is a delusion. The engineer of today can readily drill through a mountain to make a tunnel for a highway. If the need arises, giant earthmoving equipment can level entire mountains. Nowadays, engineers can take any object apart. Therefore, an object that symbolizes permanence should not be composed of smaller particles.

It was previously thought that the atom was an object that cannot be split into smaller particles. But scientists eventually discovered that the atom does consist of smaller particles, namely, electrons, protons, and neutrons. And it has since been learned that the proton and the neutron themselves consist of even smaller particles, called quarks. However, there do exist some particles that do not consist of smaller particles. Scientists call them "elementary particles." These are: electron, quark, neutrino, photon, gluon, and graviton. There are other elementary particles, but they are unstable. Of course, only a stable particle can be chosen to symbolize stability. The six elementary particles listed above are stable and do not consist of smaller particles.

Thus, there are six stable elementary particles that could be used to symbolize stability and permanence. However, five of the six stable elementary particles listed above can only be detected by means of scientific instruments. Therefore, they are not suitable to serve as G-d's sign to humankind, which of course has to be easily observable by human beings. The only exception is the photon, the particle of light.

The Photon

Throughout the nineteenth century, it was thought that light is a wave phenomenon, and scientists spoke of light waves. However, in 1900, Max Planck proposed the radical idea that light consists of a stream of particles, called "photons," from the Greek word for "light." Planck's idea marked the beginning of quantum theory, the theory universally used today to explain natural phenomena.

Planck showed that the idea of photons—particles of light—can explain some very puzzling features of light. The idea that light consists of photons was elaborated and clarified by Albert Einstein in 1905. Both

Planck and Einstein were awarded the Nobel Prize in Physics for their important contributions regarding the nature of light.

Unlike the other stable elementary particles, photons *can* be detected by the human eye without the need for scientific instruments. Thus, light would seem to be the ideal choice for G-d's sign of stability, His promise that He will never again destroy all life through a flood. But why a rainbow? Why not sunlight?

Sunlight

Light comes in many colors. The color of light corresponds to the energy of the photon. Red light consists of lower-energy photons, whereas blue light consists of higher-energy photons. There are photons of still higher energy that the human eye cannot see, such as ultraviolet light and x-rays. There are also photons of still lower energy that the human eye cannot see, such as infrared light and radio waves. However, G-d's sign for humankind must consist of photons having an energy that the human eye can see.

The color of sunlight is nearly white. The whiteness of sunlight is due to the fact that sunlight is a mixture of the light of many colors, ranging from red to blue, and the eye perceives this mixture as being white. White sunlight thus consists of many different types of photons, each with its own energy/color. As the sunlight passes through the atmosphere on its way to the surface of the Earth, some photons are scattered by the air molecules and thus removed from the sunlight. The observed whiteness of the sunlight results from the mixture of photons that are not scattered.

The observed color of sunlight would change if more photons of certain colors were removed. This happens at sunset, when sunlight becomes markedly reddish-orange.

At sunset, when the sun is close to the horizon, sunlight has to pass through a thicker layer of atmosphere to reach the observer. This causes most of the blue photons to be scattered out of the sunlight. (For technical reasons that will not be discussed here, blue light is scattered more strongly by the atmosphere than other colors.) The beautiful sunsets we observe are because most of the blue photons have been removed from the sunlight, leaving primarily reds, oranges, and yellows. Because the color of sunlight changes during the day, sunlight is unsuitable to serve as a sign of stability.

The Rainbow and G-d's Covenant

Is there any occasion when sunlight consists of a single color, rather than a mixture of colors? The answer is, yes! This occurs in a rainbow, when the raindrops act as prisms that separate the sunlight into its various colors. Each of the separated colors of the rainbow is a single color, consisting of identical photons whose color never changes. The rainbow is thus a visible symbol of the stability found in nature. Therefore, one can understand why the rainbow was chosen as the sign of G-d's covenant, as is written (*Beresbit* 9:9–11):

I hereby establish My covenant with you, with all future generations, and with all living creatures that are with you, including birds, cattle, and all the animals that were with you in the Ark. I am establishing my covenant with you that never again will all creatures be drowned by floodwaters; a flood that destroys the Earth will never occur again.

The above verses indicate that this covenant was not restricted to the Jewish people, as were later covenants (*Beresbit* 15:18, 17:11, *Shemot* 24:8, 31:16, 34:10, *Be-Midbar* 25:13, *Devarim* 5:2). This covenant was not even restricted to humankind. This covenant includes all living creatures.

The resplendent rainbow of photons will forever serve as G-d's visible sign of the constancy of nature.

(II) Rain and Chaos

'A Land About Which G-d Always Cares'

The holiday of *Sukkot* is immediately followed by the holiday of *Shemini Atzeret*, as is written (*Be-Midbar* 29:35):

On the eighth day, you shall have a solemn assembly, and you shall do no work.

In Israel, the holiday of *Shemini Atzeret* ("Solemn Assembly") marks the beginning of the rainy season. Therefore, starting from *Shemini Atzeret*, one begins to include the following words in the *Amidah* prayer: "You cause the wind to blow and the rain to fall." The special prayers recited on *Shemini Atzeret* include the "Prayer for Rain" and the moving hymns ("yotzrot") in which we ask G-d to bless us with life-giving rain. Since it is impossible to know in advance whether the coming year will be one of sufficient rain or one of drought, we pray to G-d for rain during the coming year.

In addition to these prayers for rain, there is an entire tractate of the Talmud—*Ta'anit*—that is devoted to the fast days and prayers that the Sages of the Talmud instituted to plead with G-d for rain in times of drought. The theme of turning to G-d for rain also appears in the Torah, in a passage that contains an interesting contrast between the Land of Egypt and the Land of Israel (*Devarim* 11:10–12):

The land you are going to inherit is not like the Land of Egypt from which you came, a land in which you can plant your seeds and water them by working (the ground) with your foot, as in a vegetable garden. In the land you are going to inherit ... you will drink water from the rain of the heaven. It is a land about which G-d always cares. The eyes of G-d are on this land from the beginning of the year until the end of the year.

These verses state that Egypt has a physical advantage over Israel. In Egypt, water is guaranteed by the yearly overflow of the Nile River (“*you can water your seeds by working (the ground) with your foot, as in a vegetable garden*”). But this physical advantage has a spiritual disadvantage, since the Egyptians are thus unaware of the important role that G-d plays in their lives. However, in the Land of Israel, the water is uncertain because it depends on the rain (“*you will drink water from the rain of the heaven*”), and one never knows whether or not it will rain. The uncertainty regarding rain is a spiritual advantage because it makes the people of Israel acutely aware of their complete dependence on G-d. This is an important element in developing our understanding of the constant influence of G-d in our daily lives (“*It is a land about which G-d always cares*”).

Predicting the Rain

Throughout history, there had always been great difficulty in predicting the weather. However, this situation changed dramatically in the last few decades. Today, scientists are able to predict accurately the probability of rain for a week in advance.

What made such predictions possible? The answer can be summarized in one word: *computers*. Before the age of computers, predicting the rain was based on the observed clouds, wind speed and temperature. These data enabled people to predict the weather and the likelihood of rain for only one day in advance.

What is the great difficulty in long-range weather forecasting? Meteorology, the science of weather forecasting, deals with properties of the atmosphere. The atmosphere is composed of a known mixture of gases (oxygen, nitrogen, carbon dioxide, argon and, of course, water vapor). The sources of energy for atmospheric processes are also known. More-

over, the equations that determine the interactions between the components of the atmosphere have been known for over a century. Finally, meteorologists now have advanced technology and sophisticated scientific instruments to help them in weather forecasting. In view of all this, it would seem straightforward to calculate the future probability of rain. Why is so difficult to make accurate long-range weather predictions?

The difficulty in predicting the rain stems from the fact that the weather is not a local phenomenon. The weather at any particular place is influenced by the atmospheric conditions over a vast area. For example, in order to predict the weather in Chicago, one must include in the calculation the detailed atmospheric conditions in half the United States! It is clearly impossible to perform such calculations by hand.

The Computer

All this changed with the development of the electronic computer. The computer of today is able to perform billions of calculations per second. The fantastic speed and enormous memory of a modern computer enables the meteorologist to predict the weather accurately up to a week in advance. The faster the computer, the more reliable is long-range weather forecasting.

The trend of developing even faster computers continues. Experience has shown that every five years, the speed of computers increases tenfold. Computer engineers are already designing the computer that will be able to perform trillions of calculations per second. Therefore, one may expect that the day will come when the computers of the future will enable meteorologists to accurately predict the rain for two weeks in advance, and then for a month in advance, and finally for an entire season in advance. It appears that eventually it will become possible to prepare for any location a detailed listing of which days will be rainy and which days will be sunny for an entire season in advance. What then will be the fate of our prayers for rain?

If one knows that the coming season will be blessed with plenty of rain, then prayers for rain would be unnecessary. One does not pray for the sun to rise every morning because it is known from the laws of physics that the sun **will** rise every morning. One never prays for something whose occurrence is known in advance through the laws of nature. The opposite is also true. If meteorological calculations would show that the coming season will be one of drought, then rain in that season would be an overt miracle, and it is forbidden to pray for an overt miracle (*Be-rakhot* 9:3).

The Problem

The above results pose a problem. This Torah passage quoted above states that the rainfall in the Land of Israel *cannot be known in advance*. However, if accurate weather predictions for an entire season become possible in Israel, then the rainfall in the Land of Israel *will be known in advance*. In other words, the situation in Israel will be identical to the situation in Egypt. How is one to resolve this seeming contradiction with the words of the Torah?

Chaos Theory

Recent scientific research has provided a resolution to the above contradiction. This research has shown that it will never be possible to accurately predict the weather and the rain for an entire season in advance. Moreover, this statement remains true even if future electronic computers can perform trillions of trillions of calculations per second!

The basis for this statement is *chaos theory*, which is a new and important branch of science.¹ The term “chaos” does not mean confusion or disorder. The science of chaos has clear and definite rules. Although the theory of chaos is quite complicated, it is easy to state the central idea. *A chaotic system is extremely sensitive to even tiny changes in the surroundings*. And it has been shown that the atmosphere is a chaotic system.

For a non-chaotic system, small changes in the surroundings will produce small changes in the system. However, for a chaotic system, even extremely small changes in the surroundings can produce enormous changes in the system. The sensitivity of chaotic systems to extremely tiny changes in the surroundings is called the *butterfly effect*.²

The Butterfly Effect

This term “butterfly effect” means that it is literally true that a single butterfly flapping its wings in Tokyo can significantly affect the weather in Jerusalem within about two weeks. In other words, extremely tiny changes in the atmosphere anywhere on Earth will produce a significant effect on the weather everywhere on our planet.

The time necessary for extremely tiny changes in the local surroundings to cause effects elsewhere depends on the chaotic system in ques-

¹ James Gleick, *Chaos, A New Science* (Viking Press, 1987).

² Jacques Laskar, *Nature*, vol. 338 (1989), pp. 237–238.

tion. For the atmosphere, this time is about two weeks.³ That is, if a butterfly flaps its wings, no significant changes in the weather will occur for about two weeks. Therefore, the much faster computers of the future will make it possible to accurately predict the weather for only two weeks in advance, before chaos sets in. Since one can never include into the meteorological calculations the flapping of the wings of every butterfly in the world, plus all other such tiny effects, long-range predictions of rain will never be possible.

The butterfly effect does *not* imply that butterflies can cause unusual weather conditions, such as rain or snow falling in Tel Aviv in August, because it never rains or snows in Tel Aviv in August. However, a typical January day in Tel Aviv can be either rainy or sunny. And a single butterfly flapping its wings in Tokyo can determine which of these two options will occur. This is the magic of chaos.

It therefore follows that, exactly as stated in the Torah, the Land of Israel will forever be “*a land about which G-d always cares ... from the beginning of the year until the end of the year.*” It will always be appropriate to pray to G-d for the rain that is needed for the land to yield its produce. ❧

³ David Ruelle, *Physics Today* (July 1994), p. 26.