**Questions 42-52 are based on the following passage and supplementary material.**

This passage is adapted from Brian Greene, “How the Higgs Boson Was Found.” ©2013 by Smithsonian Institution. The Higgs boson is an elementary particle associated with the Higgs field. Experiments conducted in 2012–2013 tentatively confirmed the existence of the Higgs boson and thus of the Higgs field.

Nearly a half-century ago, Peter Higgs and a handful of other physicists were trying to understand the origin of a basic physical feature: mass. You can think of mass as an object’s heft or, a little more precisely, as the resistance it offers to having its motion changed. Push on a freight train (or a feather) to increase its speed, and the resistance you feel reflects its mass. At a microscopic level, the freight train’s mass comes from its constituent molecules and atoms, which are themselves built from fundamental particles, electrons and quarks. But where do the masses of these and other fundamental particles come from?

When physicists in the 1960s modeled the behavior of these particles using equations rooted in quantum physics, they encountered a puzzle. If they imagined that the particles were all massless, then each term in the equations clicked into a perfectly symmetric pattern, like the tips of a perfect snowflake. And this symmetry was not just mathematically elegant. It explained patterns evident in the experimental data. But—and here’s the puzzle—physicists knew that the particles did have mass, and when they modified the equations to account for this fact, the mathematical harmony was spoiled. The equations became complex and unwieldy and, worse still, inconsistent.

What to do? Here’s the idea put forward by Higgs. Don’t shove the particles’ masses down the throat of the beautiful equations. Instead, keep the equations pristine and symmetric, but consider them operating within a peculiar environment. Imagine that all of space is uniformly filled with an invisible substance—now called the Higgs field—that exerts a drag force on particles when they accelerate through it. Push on a fundamental particle in an effort to increase its speed and, according to Higgs, you would feel this drag force as a resistance. Justifiably, you would interpret the resistance as the particle’s mass. For a mental toehold, think of a ping-pong ball submerged in water. When you push on the ping-pong ball, it will feel much more massive than it does outside of water. Its interaction with the watery environment has the effect of endowing it with mass. So with particles submerged in the Higgs field.

In 1964, Higgs submitted a paper to a prominent physics journal in which he formulated this idea mathematically. The paper was rejected. Not because it contained a technical error, but because the premise of an invisible something permeating space, interacting with particles to provide their mass, well, it all just seemed like heaps of overwrought speculation. The editors of the journal deemed it “of no obvious relevance to physics.”

But Higgs persevered (and his revised paper appeared later that year in another journal), and physicists who took the time to study the proposal gradually realized that his idea was a stroke of genius, one that allowed them to have their cake and eat it too. In Higgs’s scheme, the fundamental equations can retain their pristine form because the dirty work of providing the particles’ masses is relegated to the environment.

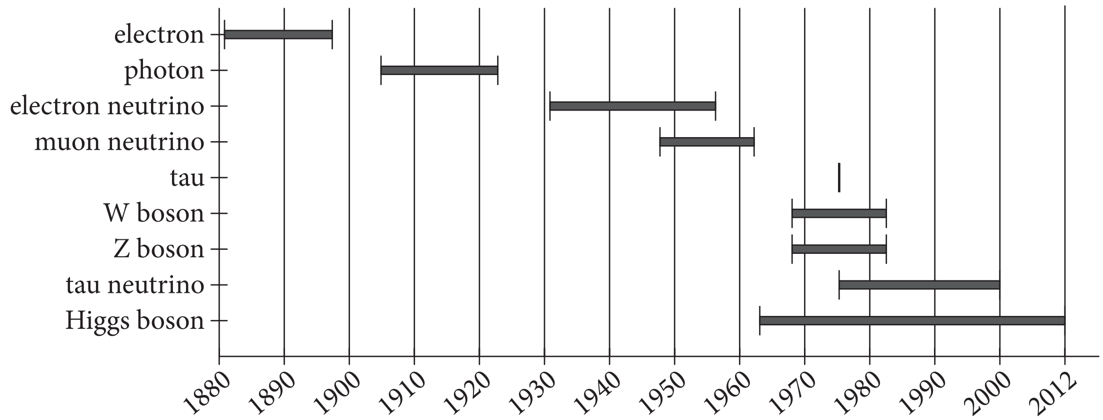
While I wasn’t around to witness the initial rejection of Higgs’s proposal in 1964 (well, I was around, but only barely), I can attest that by the mid-1980s, the assessment had changed. The physics community had, for the most part, fully bought into the idea that there was a Higgs field permeating space. In fact, in a graduate course I took that covered what’s known as the Standard Model of Particle Physics (the quantum equations physicists have assembled to describe the particles of matter and the dominant forces by which they influence each other), the professor presented the Higgs field with such certainty that for a long while I had no idea it had yet to be established experimentally.

On occasion, that happens in physics. Mathematical equations can sometimes tell such a convincing tale, they can seemingly radiate reality so strongly, that they become entrenched in the vernacular of working physicists, even before there’s data to confirm them.



CONTINUE

Years from Introduction of Concept of Particle to Experimental Confirmation




Adapted from the editors of *The Economist*, "Worth the Wait." ©2012 by The Economist Newspaper Limited.

**42**

Over the course of the passage, the main focus shifts from

A) a technical account of the Higgs field to a description of it aimed at a broad audience.

B) a review of Higgs's work to a contextualization of that work within Higgs's era.

C) an explanation of the Higgs field to a discussion of the response to Higgs's theory.

D) an analysis of the Higgs field to a suggestion of future discoveries that might build upon it.

**43**

The main purpose of the analogy of the ping-pong ball (line 40) is to

A) popularize a little-known fact.

B) contrast competing scientific theories.

C) criticize a widely accepted explanation.

D) clarify an abstract concept.

**44**

The author most strongly suggests that the reason the scientific community initially rejected Higgs's idea was that the idea

A) addressed a problem unnoticed by other physicists.

B) only worked if the equations were flawless.

C) rendered accepted theories in physics obsolete.

D) appeared to have little empirical basis.

**45**

Which choice provides the best evidence for the answer to the previous question?

A) Lines 30-32 ("Instead . . . environment")

B) Lines 46-48 ("In 1964 . . . mathematically")

C) Lines 48-53 ("Not . . . speculation")

D) Lines 67-70 ("The physics . . . space")





CONTINUE

46

The author notes that one reason Higgs's theory gained acceptance was that it

A) let scientists accept two conditions that had previously seemed irreconcilable.
B) introduced an innovative approach that could be applied to additional problems.
C) answered a question that earlier scientists had not even raised.
D) explained why two distinct phenomena were being misinterpreted as one phenomenon.

47

Which choice provides the best evidence for the answer to the previous question?

A) Lines 36-39 ("Push . . . mass")
B) Lines 43-45 ("Its interaction . . . field")
C) Lines 55-63 ("But . . . environment")
D) Lines 78-83 ("On occasion . . . them")

48

Which statement best describes the technique the author uses to advance the main point of the last paragraph?

A) He recounts a personal experience to illustrate a characteristic of the discipline of physics.
B) He describes his own education to show how physics has changed during his career.
C) He provides autobiographical details to demonstrate how Higgs's theory was confirmed.
D) He contrasts the status of Higgs's theory at two time periods to reveal how the details of the theory evolved.

49

As used in line 77, "established" most nearly means

A) validated.
B) founded.
C) introduced.
D) enacted.

50

What purpose does the graph serve in relation to the passage as a whole?

A) It indicates that the scientific community's quick acceptance of the Higgs boson was typical.
B) It places the discussion of the reception of the Higgs boson into a broader scientific context.
C) It demonstrates that the Higgs boson was regarded differently than were other hypothetical particles.
D) It clarifies the ways in which the Higgs boson represented a major discovery.





CONTINUE

51

Which statement is best supported by the data presented in the graph?

A) The W boson and the Z boson were proposed and experimentally confirmed at about the same time.

B) The Higgs boson was experimentally confirmed more quickly than were most other particles.

C) The tau neutrino was experimentally confirmed at about the same time as the tau.

D) The muon neutrino took longer to experimentally confirm than did the electron neutrino.

52

Based on the graph, the author's depiction of Higgs's theory in the mid-1980s is most analogous to which hypothetical situation?

A) The muon neutrino was widely disputed until being confirmed in the early 1960s.

B) Few physicists in 2012 doubted the reality of the tau neutrino.

C) No physicists prior to 1960 considered the possibility of the W or Z boson.

D) Most physicists in 1940 believed in the existence of the electron neutrino.

# STOP

**If you finish before time is called, you may check your work on this section only.**

**Do not turn to any other section.**