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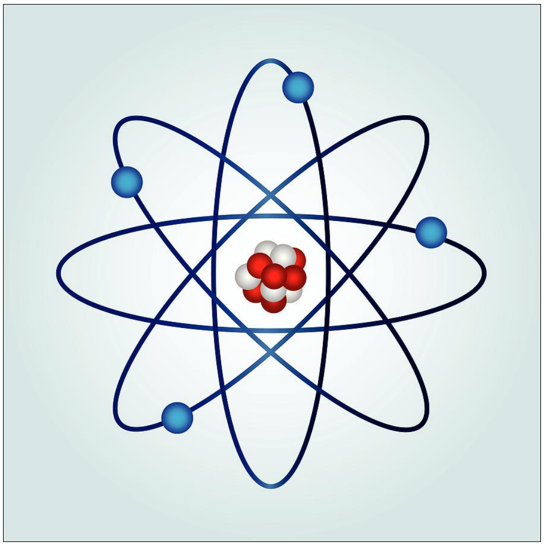
Name: ______________________________ Date: __________

Discovering the Strong Force



1 There are four fundamental forces in nature. The strong force is the strongest of these. It holds atomic nuclei together. Protons are positively charged. They are packed close together inside the nucleus. The protons strongly repel each other. The strong force has to overcome these strong repulsive forces. The strong force depends on an exchange of subatomic particles. These are called gluons. Unlike gravity, the strong force remains constant over distance. Many different scientists worked for decades to come up with the theory of the strong force.

2 Protons and neutrons were found long before gluons. British chemist Ernest Rutherford had evidence of protons in 1919. Rutherford also hypothesized that there were neutral particles in the nucleus of atoms. In 1932, James Chadwick found neutrons. He described their properties. Not long after, Eugene Wigner hypothesized that protons and neutrons are basically the same particle. Wigner thought that their difference was caused by a property called spin. However, these scientists could not explain how an atomic nucleus is held together.

3 Hideki Yukawa was a Japanese scientist. In 1935, he wrote papers about proton and neutron interaction. He said that the strong force was involved. Yukawa also hypothesized that a new subatomic particle was needed for the strong force. It would be exchanged between the particles attracted to each other. The gluon had not yet been found. Yukawa used his hypothesis to predict its mass. Yukawa was the first Japanese scientist to win a Nobel Prize.

4 In 1964, American physicists Murray Gell-Mann and George Zweig hypothesized the existence of quarks. They hypothesized that quarks come in six “flavors”. No free quarks had been observed. They hypothesized that protons and neutrons are made of different combinations of quarks. The strong force holds protons and neutrons together within a nucleus. The strong force is now thought to be an extension of the force holding the quarks together within a proton or neutron. In 1968, experiments at the Stanford Linear Accelerator Center found the first evidence of quarks. Scientists shot high energy electrons at protons. They analyzed the scatter angles. The scatter angles were different than if protons had a uniform interior. Instead, they showed that there were subatomic particles inside the protons. Over the years, all six “flavors” of quarks were found. Fermilab found the last quark in 1995. Gluons are the particles exchanged to transmit the strong force. They were finally found in 1979. There are eight different types of gluons.

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5 As with all scientific theories, the theory of the strong force began as a set of hypotheses. Over many years, many different scientists tested those hypotheses. They were refined as more was learned. Scientists from the United States, Britain, and Japan worked to understand the strong force. The Nobel Prize is one of the highest honors given to a scientist. Nobel Prizes were awarded to many different scientists for parts of this theory. They include Rutherford (1908), Chadwick (1935), Wigner (1963), Yukawa (1949), and Gell-Mann (1969). Years and years of evidence supported the hypotheses. Finally they were accepted as a scientific theory. Scientists are confident that the strong force theory can be used to explain natural phenomena. The theory can be used to make predictions.

6 Scientists are still researching the nucleus. Recent experiments describe how different quarks and gluons make up the proton. Until 2002, scientists thought that quarks only come together in twos and threes to form particles. Since then, experiments have found particles made of five quarks. Why are scientists still studying the nuclear strong force? Nuclear power uses the decay of heavy elements to make electricity. It makes highly radioactive waste. Scientists think it would help if we knew more about how the strong force works in the nucleus. We may be able to use different elements and produce less waste.

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1. Over what range does the strong force apply?

A Within the nucleus

B Within the electron

C Within an ion

D Within a thin slice of metal

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2. What are gluons?

A Subatomic particles that are created as part of strong force interactions.

B Subatomic particles that are involved only in weak interactions.

C Subatomic particles that are exchanged as part of strong force interactions.

D Subatomic particles that are manipulated directly in nuclear reactors.

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3. Which best describes the experimental evidence for subatomic particles such as quarks?

A Protons colliding with each other scatter elastically

B Electrons colliding with nuclei scatter at angles

C Protons colliding with nuclei are absorbed

D Free quarks were observed

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4. How did Hideki Yukawa's work contribute to the identification and characterization of the gluon?

A His experiments discovered gluons in collisions.

B He identified how the gluon interacted with quarks.

C He recognized that gluons were the strong force transfer particle.

D He predicted the gluon and its properties, inspiring others to search for it.

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5. Scientists from which nations were involved in discovering and describing the strong nuclear force?

A United States, Britain, and Japan

B Britain, Japan, and China

C United States, Japan, and Korea

D Japan, China, and Korea

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6. Which of the following statements regarding current research in nuclear processes is correct?

A Research on nuclear processes stopped with the discovery of the last quark in 1995.

B Current research may help improve electricity production from nuclear power plants.

C It is unlikely that any scientist currently working on nuclear processes will receive a Nobel Prize.

D Current research is most concerned with discovering the number of protons and neutrons in the nuclei of heavy atoms.