Name: ______________________________ Period: ____________

Modern-Standard Model

1. The strong force is the force of
   1. repulsion between protons
   2. attraction between protons and electrons
   3. repulsion between nucleons
   4. attraction between nucleons

2. The tau neutrino, the muon neutrino, and the electron neutrino are all
   1. leptons
   2. hadrons
   3. baryons
   4. mesons

Base your answers to questions 3 and 4 on the information below.

A lambda particle consists of an up, a down, and a strange quark.

3. A lambda particle can be classified as a
   1. baryon
   2. lepton
   3. meson
   4. photon

4. What is the charge of a lambda particle in elementary charges?

5. According to the Standard Model, a proton is constructed of two up quarks and one down quark (*uud*) and a neutron is constructed of one up quark and two down quarks (*udd*). During beta decay, a neutron decays into a proton, an electron, and an electron antineutrino. During this process there is a conversion of a
   1. *u* quark to a *d* quark
   2. *d* quark to a meson
   3. baryon to another baryon
   4. lepton to another lepton

6. Which statement is true of the strong nuclear force?
   1. It acts over very great distances
   2. It holds protons and neutrons together
   3. It is much weaker than gravitational forces
   4. It repels neutral charges

7. Which combination of quarks could produce a neutral baryon?
   1. *cdt*
   2. *cts*
   3. *cdb*
   4. *cdu*

8. A meson may *not* have a charge of
   1. +1e
   2. +2e
   3. 0e
   4. -1e

Base your answers to questions 9 and 10 on the information and equation below.

During the process of beta (β^-) emission, a neutron in the nucleus of an atom is converted into a proton, an electron, an electron antineutrino, and energy.

$$\text{neutron} \rightarrow \text{proton} + \text{electron} + \text{electron antineutrino} + \text{energy}$$

9. Based on conservation laws, how does the mass of the neutron compare to the mass of the proton?

10. Since charge must be conserved in the reaction shown, what charge must an electron antineutrino carry?

11. Protons and neutrons are examples of
    1. positrons
    2. baryons
    3. mesons
    4. quarks

12. The force that holds protons and neutrons together is known as the
    1. gravitational force
    2. strong force
    3. magnetic force
    4. electrostatic force

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Modern-Standard Model

Base your answers to questions 13 through 16 on the passage below and on your knowledge of physics.

More Sci- Than Fi, Physicists Create Antimatter

Physicists working in Europe announced yesterday that they had passed through nature's looking glass and had created atoms made of antimatter, or antiatoms, opening up the possibility of experiments in a realm once reserved for science fiction writers. Such experiments, theorists say, could test some of the basic tenets of modern physics and light the way to a deeper understanding of nature.

By corralling [holding together in groups] clouds of antimatter particles in a cylindrical chamber laced with detectors and electric and magnetic fields, the physicists assembled antihydrogen atoms, the looking glass equivalent of hydrogen, the most simple atom in nature. Whereas hydrogen consists of a positively charged proton circled by a negatively charged electron, in antihydrogen the proton's counterpart, a positively charged antiproton, is circled by an antielectron, otherwise known as a positron.

According to the standard theories of physics, the antimatter universe should look identical to our own. Antihydrogen and hydrogen atoms should have the same properties, emitting the exact same frequencies of light, for example. . . .

Antimatter has been part of physics since 1927 when its existence was predicted by the British physicist Paul Dirac. The antielectron, or positron, was discovered in 1932. According to the theory, matter can only be created in particle-antiparticle pairs. It is still a mystery, cosmologists say, why the universe seems to be overwhelmingly composed of normal matter.

Dennis Overbye, "More Sci- Than Fi, Physicists Create Antimatter," New York Times, Sept. 19, 2002

13. The author of the passage concerning antimatter incorrectly reported the findings of the experiment on antimatter. Which particle mentioned in the article has the charge incorrectly identified?

14. How should the emission spectrum of antihydrogen compare to the emission spectrum of hydrogen?

15. Identify one characteristic that antimatter particles must possess if clouds of them can be corralled by electric and magnetic fields.

16. According to the article, why is it a mystery that "the universe seems to be overwhelmingly composed of normal matter?"

17. The particles in the nucleus are held together primarily by the
    1. strong force
    2. gravitational force
    3. electrostatic force
    4. magnetic force

18. Baryons may have charges of
    1. +1 e and +4/3 e
    2. +2 e and +3 e
    3. -1 e and +1 e
    4. -2 e and -2/3 e

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Modern-Standard Model

19. The charge of an antistrange quark is approximately
    1. $+5.33 \times 10^{-20}$ C
    2. -5.33×10^{-20} C
    3. $+5.33 \times 10^{20}$ C
    4. -5.33×10^{20} C

20. Which fundamental force holds quarks together to form particles such as protons and neutrons?
    1. electromagnetic force
    2. gravitational force
    3. strong force
    4. weak force

21. What is the total number of quarks in a helium nucleus consisting of 2 protons and 2 neutrons?
    1. 16
    2. 12
    3. 8
    4. 4

Base your answers to questions 22 and 23 on the statement below.

The spectrum of visible light emitted during transitions in excited hydrogen atoms is composed of blue, green, red, and violet lines.

22. What characteristics of light determines the amount of energy carried by a photon of that light?
    1. amplitude
    2. frequency
    3. phase
    4. velocity

23. Which color of light in the visible hydrogen spectrum has photons of the shortest wavelength?
    1. blue
    2. green
    3. red
    4. violet

24. What are the sign and charge, in coulombs, of an antiproton?

25. A deuterium nucleus consists of one proton and one neutron. The quark composition of a deuterium nucleus is
    1. 2 up quarks and 2 down quarks
    2. 2 up quarks and 4 down quarks
    3. 3 up quarks and 3 down quarks
    4. 4 up quarks and 2 down quarks

26. Which particles are not affected by the strong force?
    1. hadrons
    2. protons
    3. neutrons
    4. electrons

27. A tau lepton decays into an electron, an electron antineutrino, and a tau neutrino, as represented in the reaction below.

$$\tau \rightarrow e + \bar{\nu}_e + \nu_\tau$$

On the equation above, show how this reaction obeys the Law of Conservation of Charge by indicating the amount of charge on each particle.

28. Compared to the mass and charge of a proton, an antiproton has
    1. the same mass and the same charge
    2. greater mass and the same charge
    3. the same mass and the opposite charge
    4. greater mass and the opposite charge

29. Which fundamental force is primarily responsible for the attraction between protons and electrons?
    1. strong
    2. weak
    3. gravitational
    4. electromagnetic

30. A subatomic particle could have a charge of
    1. 5.0×10^{-20} C
    2. 8.0×10^{-20} C
    3. 3.2×10^{-19} C
    4. 5.0×10^{-19} C

31. A particle that is composed of two up quarks and one down quark is a
    1. meson
    2. neutron
    3. proton
    4. positron

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Modern-Standard Model

Base your answers to questions 32 through 34 on the passage below.

For years, theoretical physicists have been refining a mathematical method called lattice quantum chromodynamics to enable them to predict the masses of particles consisting of various combinations of quarks and antiquarks. They recently used the theory to calculate the mass of the rare B_c particle, consisting of a charm quark and a bottom antiquark. The predicted mass of the B_c particle was about six times the mass of a proton.

Shortly after the prediction was made, physicists working at the Fermi National Accelerator Laboratory, Fermilab, were able to measure the mass of the B_c particle experimentally and found it to agree with the theoretical prediction to within a few tenths of a percent. In the experiment, the physicists sent beams of protons and antiprotons moving at 99.999% the speed of light in opposite directions around a ring 1.0 kilometer in radius. The protons and antiprotons were kept in their circular paths by powerful electromagnets. When the protons and antiprotons collided, their energy produced numerous new particles, including the elusive B_c.

These results indicate that lattice quantum chromodynamics is a powerful tool not only for confirming the masses of existing particles, but also for predicting the masses of particles that have yet to be discovered in the laboratory.

32. Identify the class of matter to which the B_c particle belongs.

33. Determine both the sign and the magnitude of the charge of the B_c particle in elementary charges.

34. Explain how it is possible for a colliding proton and antiproton to produce a particle with six times the mass of either.

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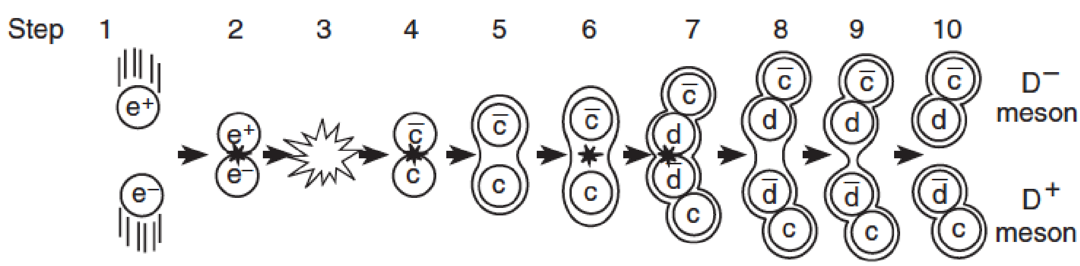
35. The diagram below represents the sequence of events (steps 1 through 10) resulting in the production of a D^- meson and a D^+ meson. An electron and a positron (antielectron) collide (step 1), annihilate each other (step 2), and become energy (step 3). This energy produces an anticharm quark and a charm quark (step 4), which then split apart (steps 5 through 7). As they split, a down quark and an antidown quark are formed, leading to the final production of a D^- meson and a D^+ meson (steps 8 through 10).



Adapted from: Electon/Positron Annihilation http:/www.particleadventure.org/frameless/eedd.html 7/23/2007

Which statement best describes the changes that occur in this sequence of events?
1. Energy is converted into matter and then matter is converted into energy.
2. Matter is converted into energy and then energy is converted into matter.
3. Isolated quarks are being formed from baryons.
4. Hadrons are being converted into leptons.

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Base your answers to questions 36 and 37 on the table below, which shows data about various subatomic particles.

Subatomic Particle Table

Symbol	Name	Quark Content	Electric Charge	Mass (GeV/c^2)
p	proton	uud	+1	0.938
$\bar{p}$	antiproton	$\bar{u}\bar{u}\bar{d}$	–1	0.938
n	neutron	udd	0	0.940
λ	lambda	uds	0	1.116
Ω^-	omega	sss	–1	1.672

36. Which particle listed on the table has the opposite charge of, and is more massive than, a proton?
   1. antiproton
   2. neutron
   3. lambda
   4. omega

37. All the particles listed on the table are classified as
   1. mesons
   2. hadrons
   3. antimatter
   4. leptons

38. According to the Standard Model of Particle Physics, a meson is composed of
   1. a quark and a muon neutrino
   2. a quark and an antiquark
   3. three quarks
   4. a lepton and an antilepton

39. A particle unaffected by an electric field could have a quark composition of
   1. css
   2. bbb
   3. udc
   4. uud

40. A helium atom consists of two protons, two electrons, and two neutrons. In the helium atom, the strong force is a fundamental interaction between the
   1. electrons, only
   2. electrons and protons
   3. neutrons and electrons
   4. neutrons and protons

41. A lithium atom consists of 3 protons, 4 neutrons, and 3 electrons. This atom contains a total of
   1. 9 quarks and 7 leptons
   2. 12 quarks and 6 leptons
   3. 14 quarks and 3 leptons
   4. 21 quarks and 3 leptons

42. A top quark has an approximate charge of
   1. -1.07×10^{-19} C
   2. -2.40×10^{-19} C
   3. $+1.07 \times 10^{-19}$ C
   4. $+2.40 \times 10^{-19}$ C

43. The composition of a meson with a charge of -1 elementary charge could be
   1. $s\bar{c}$
   2. dss
   3. $u\bar{b}$
   4. $\overline{ucd}$

44. In a process called pair production, an energetic gamma ray is converted into an electron and a positron. It is not possible for a gamma ray to be converted into two electrons because
   1. charge must be conserved
   2. momentum must be conserved
   3. mass-energy must be conserved
   4. baryon number must be conserved

45. An antibaryon composed of two antiup quarks and one antidown quark would have a charge of
   1. +1e
   2. -1e
   3. 0e
   4. -3e

46. Which force is responsible for producing a stable nucleus by opposing the electrostatic force of repulsion between protons?
   1. strong
   2. weak
   3. frictional
   4. gravitational

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Modern-Standard Model

Base your answers to questions 47 through 50 on the information below.

Two experiments running simultaneously at the Fermi National Accelerator Laboratory in Batavia, Ill., have observed a new particle called the cascade baryon. It is one of the most massive examples yet of a baryon -- a class of particles made of three quarks held together by the strong nuclear force -- and the first to contain one quark from each of the three known families, or generations, of these elementary particles.

Protons and neutrons are made of up and down quarks, the two first-generation quarks. Strange and charm quarks constitute the second generation, while the top and bottom varieties make up the third. Physicists had long conjectured that a down quark could combine with a strange and a bottom quark to form the three-generation cascade baryon.

On June 13, the scientists running Dzero, one of two detectors at Fermilab's Tevatron accelerator, announced that they had detected characteristic showers of particles from the decay of cascade baryons. The baryons formed in proton-antiproton collisions and lived no more than a trillionth of a second. A week later, physicists at CDF, the Tevatron's other detector, reported their own sighting of the baryon...

Source: D.C., "Pas de deux for a three-scoop particle," Science News, Vol. 172, July 7, 2007

47. Which combination of three quarks will produce a neutron?

48. What is the magnitude and sign of the charge, in elementary charges, of a cascade baryon?

49. The Tevatron derives its name from teraelectronvolt, the maximum energy it can impart to a particle. Determine the energy, in joules, equivalent to 1.00 teraelectronvolt.

50. Calculate the maximum total mass, in kilograms, of particles that could be created in the head-on collision of a proton and an antiproton, each having an energy of 1.60×10^{-7} joule. [Show all work, including the equation and substitution with units.]

51. What is the quark composition of a proton?
    1. uud
    2. udd
    3. csb
    4. uds