37. What force holds protons and neutrons together in an atom?

(1) strong force (3) gravitational force
(2) magnetic force (4) electrostatic force

38. Which fundamental force is primarily responsible for the attraction between protons and electrons?

(1) strong (3) gravitational
(2) weak (4) electromagnetic

39. The energy produced by the complete conversion of 2.0×10^{-5} kilogram of mass into energy is

(1) 1.8 TJ (2) 6.0 GJ (3) 1.8 MJ (4) 6.0 kJ

40. In the equation $E = mc^2$, E may be expressed in

(1) newtons/coulomb (3) electronvolts
(2) joules/second (4) coulombs

41. If a deuterium nucleus has a mass of 1.53×10^{-3} universal mass unit less than its components, this mass represents an energy of

(1) 1.38 MeV (3) 1.53 MeV
(2) 1.42 MeV (4) 3.16 MeV

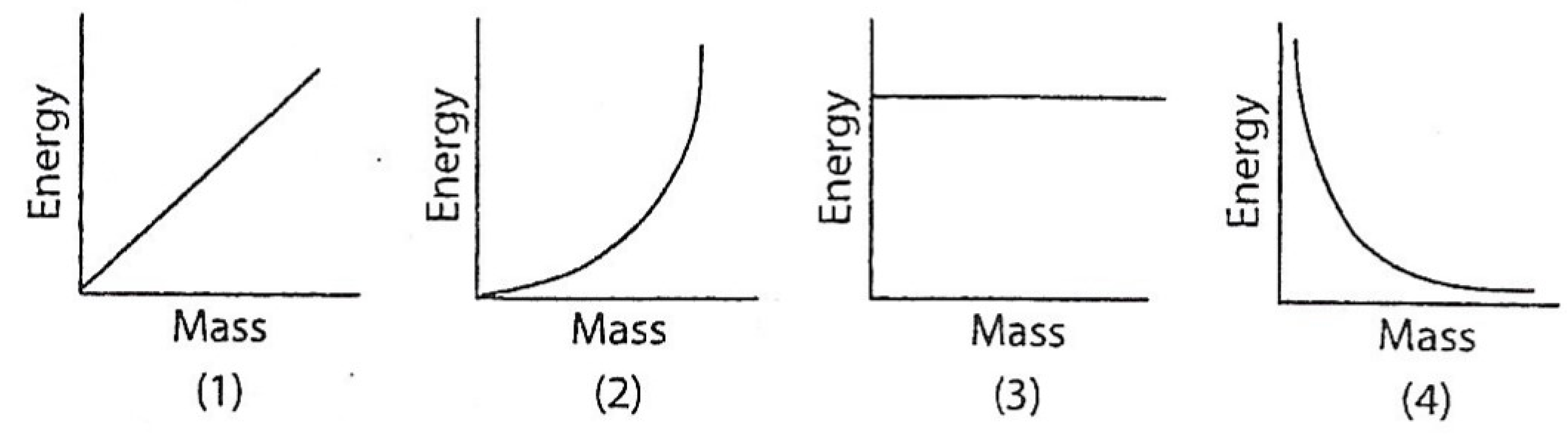
42. Calculate the amount of energy in joules that would be produced if 2.50×10^{-3} kilogram of matter was entirely converted to energy.

43. If the mass of one proton was totally converted into energy, the yield would be

(1) 2.79×10^{-38} J (3) 1.50×10^{-10} J
(2) 5.01×10^{-19} J (4) 9.00×10^{16} J

44. In a nuclear reaction, 9.90×10^{-13} joule of energy was released. Calculate the mass equivalent of this energy.

45. Which graph best represents the relationship between energy and mass when matter is converted into energy?



46. The chart below shows the masses of selected particles.

Particle	Mass
$^{235}_{92}U$	235.0 u
$^{138}_{56}Ba$	137.9 u
$^{95}_{36}Kr$	94.9 u
$^{1}_{0}n$	1.0 u

Consider the following equation.

$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{138}_{56}Ba + ^{95}_{36}Kr + 3^{1}_{0}n + E$

The energy E is equivalent to a mass of

(1) 0.2 u (2) 2.0 u (3) 2.2 u (4) 0.0 u

The Standard Model of Particle Physics

Today, particle physicists are in the process of building a model of the structure of the nucleus. The current model, called the **Standard Model of Particle Physics,** is a theory, not a law, that is used to explain the existence of all the particles that have been observed and the forces that hold atoms together or lead to their decay.

The Fundamental Forces in Nature

Force can be defined as a push or pull on a mass, or explained as a vector quantity causing an object to accelerate. In modern physics, scientists refer to particles as force carriers, because forces are brought about as a result of an exchange of particles.

There are four fundamental forces in nature: strong (nuclear), electromagnetic, weak, and gravitational. Table 6-1 gives an overview of the important characteristics of these four forces. The weak force, which has not yet been discussed, is another short-range nuclear force that is responsible for the decay of some nuclear particles.

Table 6-1. The Fundamental Forces of Nature

Force	Relative Strength	Range of Force
strong (nuclear)	1	$\approx 10^{-15}$ m
electromagnetic	10^{-2}	proportional to $\frac{1}{r^2}$
weak	10^{-13}	$<10^{-18}$ m
gravitational	10^{-38}	proportional to $\frac{1}{r^2}$

Electric and magnetic forces are often treated independently, but they are actually combined as electromagnetic force. The weak force has successfully been combined with the electromagnetic force to produce a single electroweak force. Grand unification theories (GUTs) attempt to add the strong force to this combination. Theories of everything (TOEs), which would combine gravity with all the other forces, are not developed at this time. Scientists continue to try to resolve questions and inconsistencies in the Standard Model in much the same manner as Thomson, Rutherford, and Bohr made changes and amendments to the model for the structure of the atom.

Classification of Subatomic Particles

Particles can be classified according to the types of interactions they have with other particles. If the force carrier particles are excluded, all particles can be classified into two groups according to the types of interactions they have with other particles. A particle that interacts through the strong nuclear force, as well as the electromagnetic, weak, and gravitational forces, is called a **hadron.** Protons and neutrons are hadrons. A particle that interacts through the electromagnetic, weak, and gravitational forces, but *not* the strong nuclear force, is called a **lepton.** A lepton has a mass less than that of a proton. Electrons, positrons, and neutrinos are classified as leptons. A **positron** is a particle whose mass is equal to the mass of the electron, and whose positive electric charge is equal in magnitude to the negative charge of the electron. A **neutrino** is a neutral particle that has little, if any, mass but does possess both energy and momentum. The *Reference Tables for Physical Setting/Physics* give the names, symbols, and charges of the six members of the lepton family. Ⓡ

The hadron group can be subdivided into baryons and mesons. A **baryon** is an elementary particle that can be transformed into a proton or neutron and some number of mesons and lighter particles. Baryons are also known as heavy particles because their masses are equal to or greater than the mass of a proton. A **meson** is a particle of intermediate mass. Mesons decay into electrons, positrons, neutrinos, and photons.

An antiparticle is associated with each particle. An **antiparticle** is a particle having mass, lifetime, and spin identical to the associated particle, but with charge of opposite sign (if charged) and magnetic moment reversed in sign. An antiparticle is denoted by a bar over the symbol for the particle. For example, an antiproton, the antiparticle of a proton p, is denoted by the symbol $\overline{p}$. Thus, the antiproton would be described as a stable baryon carrying a unit negative charge, but having the same mass as a proton. The positron, noted earlier, is thus the antiparticle of the electron. The antineutron, the antiparticle of the neutron, has the same mass as the neutron and is also electrically neutral. However the magnetic moment and spin of the antineutron are in the same direction, whereas, the magnetic moment and spin of the neutron are in opposite directions. An antiparticle exists for the neutrino; the two are identical except for their direction of spin. **Antimatter** is material consisting of atoms that are composed of antiprotons, antineutrons, and positrons.

The Quark Baryons and mesons are composed of more fundamental particles called quarks. A **quark** is one of the basic particles, having charges of $\pm\frac{1}{3}$e or $\pm\frac{2}{3}$e, from which many of the elementary particles may be built up. This implies that the charge on the electron is no longer considered to be the smallest nonzero charge that a particle may possess. The quarks are named *up, down, charm, strange, top,* and *bottom*. Every baryon is a combination of three quarks and every meson is a combination of a quark and an antiquark. An **antiquark** is the antiparticle of a quark, having electric charge, baryon number, and strangeness opposite in sign to that of the corresponding quark. An antibaryon consists of three antiquarks. The *Reference Tables for Physical Setting/Physics* give the names, symbols, and charges of the six members of the quark family. The quark content of a proton is *uud* (up, up, down) and the quark content of a neutron is *udd* (up, down, down). When quarks combine to form baryons, their charges add algebraically to a total of 0e, +1e, or −1e. When quarks and antiquarks combine to form mesons, their charges add algebraically to a total of 0e, +1e, or −1e.

Review Questions

Base your answers to questions 47 through 49 on information given in Table 6-1.

47. Express the range of the strong force in picometers.

48. Express the range of the weak force in nanometers.

49. How many times stronger than the gravitational force is the electromagnetic force?

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50. 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 51 and 52 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.

neutron → proton + electron + electron antineutrino + energy

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

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

53. A baryon may have a charge of

(1) $-\frac{1}{3}$e (2) 0 e (3) $+\frac{2}{3}$e (4) $+\frac{4}{3}$e

54. An antibaryon is composed of

(1) three quarks
(2) one quark and two antiquarks
(3) three antiquarks
(4) two quarks and one antiquark

55. What is the electric charge on a pion having quark composition $u\bar{d}$?

56. What is the electric charge on a particle having quark composition $d\bar{b}$?

57. A particle has a quark composition of *dds*. What is the charge on and classification of the particle?

(1) −1e, baryon (3) −1e, meson
(2) +1e, baryon (4) +1e, meson

58. A particle has a quark composition of $s\bar{u}$. What is the charge on and classification of the particle?

(1) −1e, baryon
(2) +1e, baryon
(3) −1e, meson
(4) +1e, meson

59. What is the mass of an antineutron in kilograms?