87. How many protons and electrons are there in the element Thorium ? In the element Thorium, there are 90 protons and 90 electrons.
88. Including the Higgs Boson and the graviton, how many elementary particles are there in the universe as a whole ? Ans: Including the Higgs boson and the graviton, there are 18 elementary particles in the universe as a whole, and approximately 400 other particles can be constructed from these original 18 particles.
89. Why are the masses of most elementary particles, including the proton, the neutron, and the electron normally quoted in $MeV/c^2$? Ans: Because on a subatomic level, this is the most convenient way to do so in view of Einstein's equation $E = mc^2$.
90. How much does one cubic centimeter of nuclear material weigh ? Ans: Approximately $1.8 \times 10^{11}$ kg
91. What are the number of protons and the number of neutrons in a U-238 nucleus? Ans: The U-238 nucleus has 92 protons and 146 neutrons.
92. Write an equation that can be used to determine the minimum confinement energy of a nuclear particle if mass m of the particle and the confinement length $\Delta x$ are known. $E = \Delta p^2/2m = h^2/2m\ \Delta x^2$
93. Why does the neutron have a different rest mass than the proton ? Ans: Because it consists of two down quarks and an up quark, while the proton consists of two up quarks and a down quark.
94. What are two alternative formulations of the Heisenberg Uncertainty Principle ? Ans: $\Delta E * \Delta t \geq h$ and $\Delta p * \Delta x \geq h$
95. Write a simple equation that can be used to determine the confinement energy E of a particle if it has a velocity v that is some fraction of the velocity of the speed of light, and the confinement distance $\Delta x$ is known. Ans: $E = \Delta E = h/\Delta t = hv/\Delta x = (\% \cdot c\ h)/\Delta x$, where $v = \% \cdot c$.
96. Sometimes the radius of an atomic nucleus is expressed in the units of femtometers (fm). How large is a femtometer, and how many femtometers wide is the nucleus of a hydrogen atom ? Ans: A femtometer is equal to $1 \times 10^{-13}$ cm. From equation 1.35, the radius of an atomic nucleus is $R = 1.25\ A^{1/3} \times 10^{-13}$ cm, so a hydrogen nucleus with a value of A =1 must have a diameter of 2.5 fm or $2.5 \times 10^{-13}$ cm.

# Chapter 2

## Questions for Chapter 2

The following questions cover the material presented in this chapter, and in some cases, previous chapters as well. They are designed to test how well the student has acquired a working knowledge of the subject matter.

1. Name three fundamental conservation laws that all nuclear particles must obey. Ans: The Conservation of Mass and Energy, the Conservation of Momentum, and the Conservation of Charge
2. Name an additional conservation law that the protons and the neutrons inside of the nucleus of an atom must obey. Ans: The conservation of the Baryon number or the nucleon number: $B_{OUT} = B_{IN}$
3. What is the Law of the Conservation of Energy ? Ans: That the energy of the particles coming out of a reaction must be the same as the energy of the particles coming into a reaction: $E_{OUT} = E_{IN}$
4. What is the Law of the Conservation of Momentum ? Ans: That the momentum of the particles coming out of a reaction must be the same as the momentum of the particles coming into a reaction: $\mathbf{p}_{OUT} = \mathbf{p}_{IN}$
5. What is the Law of the Conservation of Charge ? Ans: That the charge of the particles coming out of a reaction must be the same as the charge of the particles coming into a reaction: $q_{OUT} = q_{IN}$
6. What is a Feynman Diagram, and what does it represent ? Ans: A Feynman Diagram is a graphical representation of the interaction of two particles that normally involves the exchange of third particle called a virtual particle
7. What is a simple equation for the momentum of a particle of mass m ? Ans: $\mathbf{P} = m_o \mathbf{v} / \sqrt{(1 - (v/c)^2)}$, where $m_o$ is the rest mass of the particle. Of course, at low speeds, this reduces to $\mathbf{P} = m_o \mathbf{v}$, which is the expected classical result
8. What is the equation for the energy of a Photon ? Ans: $E_\gamma = hf$, where h is Plank's Constant
9. If a photon is ejected from an atomic nucleus with the twice the energy of another photon, how do the frequencies of the two photons compare ? Ans: The higher energy photon has twice the frequency of the lower energy photon
10. Neutrinos are created in a nuclear reactor all of the time. What percentage of the energy do they carry away, and where does this energy go ? Ans: In fission reactions, neutrinos carry away approximately 5 % of the total energy produced. This energy is carried away into space, and is distributed somewhere between the stars
11. What is Plank's Constant, and who discovered it? Ans: Plank's constant is a fundamental constant of nature discovered by Max Plank in 1900. It has a value equal to $6.626 \times 10^{-34}$ joule–seconds. In electron volts, its value is $4.135 \times 10^{-15}$ eV-seconds.
12. What is a positron, and what is its corresponding matter particle ? Ans: A positron in the antimatter equivalent of the electron. It was discovered by Carl Anderson in 1932.
13. If there were such a thing as an anti-proton, and we shot one through a magnetic field at right angles to the field, what would we observe, relative to doing the same thing with a normal proton ? Ans: It would deflect with the same radius of curvature in exactly the opposite direction
14. What is the classical expression for the kinetic energy of a proton ? Ans: $KE = \frac{1}{2} m_o v^2$, where $m_o$ is the rest mass of the proton
15. What is the energy equivalent of one atomic mass unit or AMU ? Ans: 931.494 MeV
16. What symbol is sometimes used for the atomic mass instead of the AMU ? Ans: u

17. If a proton were traveling close to the speed of light, how would this equation change? Ans: KE = $m_o c^2 / \sqrt{(1 - (v/c)^2)} - m_o c^2$, where $m_o$ is the rest mass of the proton
18. In a classical sense, is the momentum of a particle a scalar or a vector quantity ? Ans: It is a vector quantity because it has both magnitude and direction
19. What is the "rest mass" of a matter particle ? Ans: The rest mass is the mass of the particle when the particle is completely at rest relative to the person who is measuring it (i.e., the observer)
20. What is an Electron Volt ? What is a KeV and an Mev ? Ans: An electron volt is a unit of energy equal to $1.60 \times 10^{-19}$ joules. 1 KeV is 1000 electron volts, and 1 MeV is 1,000,000 electron volts
21. What is the relationship between a photon's frequency and its wave length ? Ans: $\lambda = c/f$
22. Fill in the following sentence with the appropriate word or phrase: A photon with a wavelength of 10 centimeters is sometimes called a _____ wave. Ans: micro wave (see Figure 2.5)
23. How long does a neutron live inside the nucleus of an atom ? Ans: Essentially forever – if the nucleus happens to be stable
24. How long can a neutron live outside of the nucleus (e.g., what is its half-life) when it is free from the presence of the nuclear force field ? Ans: Outside of the nucleus of an atom, it has a half life of approximately 15 minutes
25. What is a photon with a frequency of $10^{+15}$ cycles per second called ? Ans: A visible light wave
26. What is a photon with a frequency of $10^{+18}$ cycles per second called ? Ans: An x-ray
27. What is a photon with a frequency of $10^{+22}$ cycles per second called ? Ans: A gamma ray
28. What is a photon with a frequency of $10^{+10}$ cycles per second called ? Ans: A microwave
29. Which one of these would you use to cook something in a microwave oven ? Ans: A photon with a frequency of $10^{+10}$ cycles per second (which happens to be a microwave)
30. If a neutron outside of the nucleus of an atom (also called a free neutron) were to decay into some other particles, what would these particles most likely to be ? Ans: A proton and an electron
31. What conservation laws would you use to predict the byproducts of the decay process ? Ans: The conservation of mass, energy, and charge
32. Does a radio wave have a higher energy or lower energy than a microwave? Ans: A lower energy because its frequency is lower
33. Who is Richard Feynman, and what did he do ? Ans: A Nobel Prize winning physicist who helped to perfect the nuclear theory of electricity and magnetism. His biography can be found at the following URL: www.feynman.com
34. At what frequency (in cycles per second) is a typical gamma ray emitted from a reactor core ? Ans: At a frequency of about $10^{22}$ cycles per second
35. What is an AMU, and why was it originally invented ? Ans: The AMU is a unit of nuclear measurement called the atomic mass unit. It was invented to compare the masses of common nuclear particles such as the proton, the neutron, and the electron
36. What is a neutrino, and how thick would a lead plate have to be to have a 50 % chance of stopping one ? Ans: The neutrino is a small ghostlike nuclear particle created in certain nuclear reactions. The lead plate would have to be about 1 light year thick to have a 5% chance of stopping one
37. If all of the momentum of a matter particle of mass $m_o$ and velocity v was transferred to a photon, what would the energy E of the photon be ? Ans: $E = pc = m_o vc / \sqrt{(1 - (v/c)^2)}$
38. What would be its wavelength ? Ans: $\lambda = c/f = h\, c/E = h\sqrt{(1 - (v/c)^2)} / m_o v$
39. What is the electrical charge of a Quark ? Ans: +1/3,-1/3, +2/3 or -2/3
40. What is the atomic weight of a proton in AMU's and in $MeV/c^2$? Ans: 1.00728 AMU = 938.28 $MeV/c^2$
41. What is the atomic weight of a neutron in AMU's and in $MeV/c^2$? Ans: 1.00866 AMU = 939.57 $MeV/c^2$
42. What is the atomic weight of an electron in AMU's and in $MeV/c^2$? Ans: 0.0005 AMU or 0.511 $MeV/c^2$
43. Does a photon have any rest mass ? Ans: No
44. There are two forms of radioactive beta decay – $B^-$ decay and $B^+$ decay. What particle is emitted in $B^+$ decay ? Ans: The positron, which has a charge of +1
45. By convention, how is the AMU defined ? Ans: By convention, one AMU is defined as exactly 1/12th of the rest mass of one electrically neutral atom of the isotope Carbon 12. Since Carbon 12 has exactly 6 protons and 6 neutrons, one AMU is exactly equal to the average atomic weight of one proton and one neutron, plus the small extra mass of half an electron. This also means that the proton has an AMU slightly less than the neutron.
46. At what speed does a matter particle have its least possible mass? Ans: When it is completely at rest (i.e., when the velocity is zero)
47. What is the difference in the atomic weight between a neutron and a proton ? Ans: The proton has an atomic weight of 1.0073 AMU, and the neutron has an atomic weight of 1.0087AMU. The difference in the atomic weight is 0.0014 AMUs
48. By what fundamental process can a neutron be converted into a proton and an electron ? Ans: By converting a down quark inside of the neutron into an up quark
49. Does a neutrino have any rest mass ? Ans: Yes, it has a small but finite rest mass on the order of about 0.25 eV
50. What charge does a photon have ? Ans: Zero
51. What charge does a proton have ? Ans: +1
52. Fill in the following sentence with the appropriate word or phrase: A photon with a wavelength the same size as a large building is sometimes called a _____ wave. Ans: radio wave (see Figure 2.5)
53. What types of particles require Maxwell's four equations of electricity and magnetism to predict their behavior ? Ans: Any one of a number of charged particles, including, protons, electrons, alpha particles, and positrons
54. What charge does a neutron have ? Ans: Zero - 0

55. Approximately how many times heavier is a neutron than an electron? Ans: A factor of approximately 2000 times heavier
56. What equation can be used to relate the energy of a photon to its momentum ? Ans: E = pc
57. What charge does an electron have ? Ans: -1
58. What is the name of the anti-matter particle that is the mirror image of the normal electron ? Ans: the positron
59. What is an alpha particle, and what is its mass in AMUs ? Ans: An alpha particle is an ionized helium nucleus with a rest mass of about 4 AMUs
60. When an alpha particle acquires two additional electrons, what does it then become ? Ans: A helium nucleus
61. What phenomenon did Einstein study in the 1920's that led to his first Nobel Prize ?Ans: The photoelectric effect
62. Write an expression for the kinetic energy of a matter particle in terms of its relativistic mass and its rest mass. Ans: KE = $mc^2$ - $m_oc^2$
63. What charge (or charges) can an Alpha Particle have ? Ans: Alpha particles normally have a charge of +2
64. What is a "first order" particle interaction ? Ans: An interaction in which a virtual particle such as a photon is exchanged only once
65. What particle is the carrier of the electrical force between the electrons surrounding the nucleus and the protons inside of the nucleus? Ans: The photon
66. What is the speed of a photon in empty space ?Ans: The speed of light c, which is approximately 186,000 miles per second, or 300,000,000 meters per second
67. There are two forms of radioactive beta decay – $B^-$ decay and $B^+$ decay. What particle is emitted in $B^-$ decay ? Ans: The electron, which has a charge of -1
68. What is the most commonly observed particle in a nuclear reactor core ? Ans: The neutron
69. What is the purpose of the Large Hadron Collider at CERN ? Ans: The stated purpose of building the LHC was to discover the Higgs Boson, which is sometimes called the "God particle"
70. What is the highest energy that any man made machine in existence today can give to a single particle ? Ans: About 8 trillion electron volts
71. What particle is the anti-particle of the electron, and what charge does it have ? Ans: The positron; +1
72. Using Maxwell's relationship between the energy and the momentum of a photon, show that the momentum of a photon is related to its frequency of vibration by p = hf//c. Ans: Maxwell's relationship says that E = pc. However, we also know that the energy of a photon is related to its frequency of vibration by the equation E = hf, where h is Plank's constant. Substituting this expression for the energy into the previous equation it immediately follows that by p = hf//c
73. If a helium nucleus is converted into a helium ion with a charge of +1, how many electrons must be emitted in this process to allow for the conservation of charge ? Ans: Just one
74. In quantum field theory, that particle is required to give a measurable mass to all of the other particles in the universe ? Ans: The Higgs Boson, which is sometimes called the "God particle"
75. What is a light year, and if it was converted into a distance, what distance would it represent ? Ans: A light year is the distance that a light wave travels in empty space in one year. It is approximately equal to 5.87 x $10^{12}$ miles, or 5878 Billion miles (9.46 x $10^{15}$ meters)
76. What is a virtual particle ? Ans: A particle that is temporarily exchanged between two matter particles to exchange a nuclear or electrical force
77. What is the name of the theory invented by Richard Feynman to describe the electromagnetic field, and which led to the discovery of the Feynman Diagram? Ans; Quantum Electrodynamics (Q.E.D).
78. What is CERN, and what do you think the letters represent ? Ans: The CERN Nuclear Research Center is located in the mountains outside the city of Geneva, Switzerland, near the border between Switzerland and France. Its name stands for the European Council for Nuclear Research
79. What is anti-matter, and how does it differ from ordinary matter ? Ans: A matter particle is the mirror image of an antimatter particle. Normally the only difference between them is that they have the opposite electric charge
80. Who discovered the particle called the positron ? Ans: Carl Anderson in 1932
81. What nuclear particle is its own anti-particle ? Ans: The photon
82. How is a positron different from an ordinary electron ? Ans: It has the opposite charge (+1), and is the antimatter equivalent of an ordinary electron, which has a charge of -1
83. What reactions in a nuclear reactor core lead to the creation of positrons ? Ans: The process of pair production can lead to the creation of a positron as well as the process of Beta decay
84. Fill in the following sentence with the appropriate word or phrase: According to electromagnetic theory, a _____ ray has the same wavelength as the diameter of the nucleus of an atom. Ans: Gamma ray
85. What reactions in a nuclear reactor core require the creation of a neutrino ? Ans: Primarily those involving radioactive Beta decay
86. What does the Second Law of Thermodynamics tell us about the direction of heat flow in a nuclear reactor? Ans: It tells us that heat must flow from a region of high temperature (the fuel rods) to a region of low temperature (the coolant).
87. What is the equation that relates the energy of a matter particle to its rest mass and then to its velocity dependent mass ? Ans: E = $m_o\ c^2/\sqrt{(1-(v/c)^2)}$ where $m_o$ is the rest mass of a particle, and c is the speed of light.
88. If a matter particle having rest mass of $m_o$ is travelling at approximately 86% of the speed of light, what would we measure for the mass m of this matter particle at that particular speed ? Ans: 2 $m_o$

89. What do you think the green fog was that surrounded the Eldridge during the Philadelphia experiment? Ans: Marsh gas or St. Elmo's fire. It most likely came from the electromagnetic radiation (in the form of microwaves) ionizing the sea water surrounding the ship
90. Who is the founder of the modern US nuclear navy ? Ans: Admiral Hyman Rickover
91. How many joules of energy are approximately equal to one electron volt ? Ans: $1.60 \times 10^{-19}$ joules
92. As it pertains to the nucleus of an atom, what is the Baryon number, and how is it conserved ? Ans: The Baryon number B is the total number of protons and neutrons (or nucleons) in the nucleus). It is conserved because a neutron can only be converted in to a proton, and vice-versa
93. In all nuclear reactions, does it necessarily follow that the number of neutrons going into a reaction must always be equal to the number of neutrons coming out of a reaction ? No. A neutron can sometimes be converted into a proton
94. Why does the mass of a nuclear particle (with the exception of the photon) increase as its velocity increases ? Abs: Because increasing the velocity of a particle increases its energy, and according to Einstein, a particle that has more energy also has more mass
95. What is the difference between a matter particle and a force particle? A matter particle has a defined rest mass and normally exists in the physical universe for a long period of time. Force particles are particles that are temporarily emitted and absorbed by matter particles to exchange a force.
96. Name the four fundamental forces of nature, and the force particles associated with each one of them. Ans: Electromagnetism- the photon; Gravity- the graviton; The nuclear force – the gluon; The weak force responsible for radioactive decay – the W boson
97. What fundamental nuclear property is conserved by the First Law of Thermodynamics ? Ans: The energy of the particles in a material, which is normally manifested in the form of heat
98. Who discovered the neutrino ? Ans: Fred Reines and Clyde Cowan at Hanford in 1953
99. What are some plausible explanations for the purpose of the neutrino ? Ans: Four possible explanations are presented in Section 2.17
100. What did the Philadelphia experiment attempt to prove ? Ans: That electromagnetic waves could be used to bend light waves. Unfortunately, this turned out not to be true
101. In addition to the fact that $E = pc$, what two assumptions did Einstein use to derive his famous equation $E = mc^2$ ? Ans: The conservation of linear momentum (which follows from Newton's Laws of motion) and the fact that the center of mass of a two particle system which is not acted upon by an external force must continue to remain stationary
102. Below what fraction of the speed of light is it generally acceptable to use the expression for the rest mass of a particle without making an error in the calculation of its mass or its momentum ? Ans: About 10 % of the speed of light, or 30,000,000 meters per second
103. What prestigious scientific journal refused to publish Enrico Fermi's original explanation for the process of beta decay, which occurs in nuclear fuel rods all of the time ? Ans: The Journal of Nature
104. At what kinetic energy does an electron become a relativistic particle ? Ans: At kinetic energies above about 5 KeV
105. What purpose does thee neutrino serve in the process of radioactive beta decay ? Ans: The neutrino is needed in the process of Beta decay to conserve energy and momentum in the reaction
106. If an electron and a positron happen to collide with each other in a reactor core, what happens during the collision ? Ans: They annihilate each other, and they are converted into pure energy (in the form of a photon) in the process
107. Name two important differences between a military reactor and a commercial power reactor. Ans: Military reactors are smaller and do not have to be refueled as frequently
108. What two famous equations are needed to predict the transport of particles in nuclear systems ? Ans: The Boltzmann transport equation and the neutron diffusion equation
109. What type of equation do the smoke particles in a room filled with dry air obey? Ans: A diffusion equation which is similar in form to the neutron diffusion equation
110. Fill in the following sentence with the appropriate word or phrase: According to electromagnetic theory, a _____ ray has the same wavelength as the diameter of an atom's electron cloud. Ans: X-ray
111. At what energy must an electron be treated as a relativistic particle in a reactor core ? Ans: At any energy over 5 or 10 KeV
112. If one calculates the velocity of a 10 MeV neutron using classical mechanics, how much error does this introduce into the calculation ? Ans: About 1.57 %
113. What nuclear particle led Einstein to discover his famous equation $E = mc^2$ ? Ans: The photon
114. It is a well known fact that the half life of a nuclear particle increases as it moves faster. Suppose that the half life of a nuclear particle is 1 second when it is measured at rest in a laboratory coordinate system. If it then starts to move at approximately 97% of the speed of light, what is its corresponding half-life in this case? Ans: About 4 seconds.
115. If someone tells you that time travel is possible today, what do you tell them ? Ans: That it is not possible today
116. Why did the Philadelphia experiment fail ? Ans: Because light cannot be bent by electric or magnetic fields.
117. At what velocity does an electron become a relativistic particle ? Ans: Above about $3 \times 10^7$ meters per second
118. Earlier in the chapter we showed that neutrons cannot be affected by the presence of electric or magnetic fields. Because of this, what two equations are required to predict the behavior of neutrons in a nuclear reactor core ? Ans: The neutron diffusion equation and the neutron transport equation