Final Exam Review **3.Modern Physics** **Name**

Multiple Choice and FREE RESPONSE

1. The photon model of light is more appropriate than the wave model in explaining

   A) interference
   B) refraction
   C) polarization
   D) photoelectric emission

2. Which phenomenon best supports the theory that matter has a wave nature?

   A) electron momentum
   B) electron diffraction
   C) photon momentum
   D) photon diffraction

3. Experiments performed with light indicate that light exhibits

   A) particle properties, only
   B) wave properties, only
   C) both particle and wave properties
   D) neither particle nor wave properties

4. Which phenomenon is best explained by the particle nature of light?

   A) interference
   B) the Doppler effect
   C) polarization
   D) the photoelectric effect

5. Light demonstrates the characteristics of

   A) particles, only
   B) waves, only
   C) both particles and waves
   D) neither particles nor waves

6. If the mass of one proton is totally converted into energy, it will yield a total energy of

   A) 5.1×10^{-19} J
   B) 1.5×10^{-10} J
   C) 9.3×10^{8} J
   D) 9.0×10^{16} J

7. How much energy would be produced if 1.0×10^{-3} kilogram of matter was entirely converted to energy?

   A) 9.0×10^{13} J
   B) 3.0×10^{16} J
   C) 9.0×10^{16} J
   D) 3.0×10^{19} J

8. The total conversion of 1.00 kilogram of the Sun's mass into energy yields

   A) 9.31×10^{2} MeV
   B) 8.38×10^{19} MeV
   C) 3.00×10^{8} J
   D) 9.00×10^{16} J

9. What is the total energy released when 9.11×10^{-31} kilogram of mass is converted into energy?

   A) 2.73×10^{-22} J
   B) 8.20×10^{-14} J
   C) 9.11×10^{-31} J
   D) 1.01×10^{-47} J

10. A tritium nucleus is formed by combining two neutrons and a proton. the mass of this nucleus is 9.106×10^{-3} universal mass unit less than the combined mass of the particles from which it is formed. Approximately how much energy is released when this nucleus is formed.

    A) 8.48×10^{-2} MeV
    B) 2.73 MeV
    C) 8.48 MeV
    D) 273 MeV

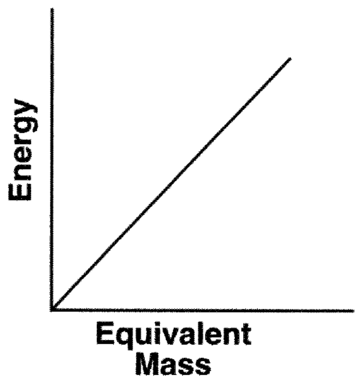
11. What is the energy equivalent of a mass of 1 kilogram?

    A) 9×10^{16} J
    B) 9×10^{13} J
    C) 9×10^{7} J
    D) 9×10^{7} J

12. Approximately how much energy would be generated if the mass in a nucleus of a $^{2}_{1}H$ atom were completely converted to energy? [The mass of $^{2}_{1}H$ is 2.0 atomic mass units.]

    A) 3.2×10^{-19} J
    B) 1.5×10^{-10} J
    C) 9.3×10^{2} MeV
    D) 1.9×10^{3} MeV

13. The graph below represents the relationship between energy and equivalent mass from which it can be converted.



The slope of this graph represents

A) c **B) c^2** C) g D) g^2

14. What is the energy equivalent of a mass of 0.026 kilogram?

A) 2.34×10^{15} J **B) 2.3×10^{15} J**
C) 2.34×10^{17} J D) 2.3×10^{17} J

15. When 2.0 x 10^{-16} kilogram of matter is converted into energy, how much energy is released?

A) 1.8 x 10^{-1} J **B) 1.8 x 10^{1} J**
C) 6.0 x 10^{-32} J D) 6.0 x 10^{-8} J

16. An atom changing from an energy state of –0.54 eV to an energy state of –0.85 eV will emit a photon whose energy is

A) 0.31 eV B) 0.54 eV
C) 0.85 eV D) 1.39 eV

17. Which formula may be used to compute the energy of a photon?

A) $E = hf$ B) $E = mg\triangle h$
C) $E = \frac{1}{2}mv^2$ D) $E = FS$

18. The wavelength of photon *A* is greater than that of photon *B*. Compared to the energy of photon *A*, the energy of photon *B* is

A) less **B) greater**
C) the same

19. When incident on a given photoemissive surface, which color of light will produce photoelectrons with the greatest energy?

A) red B) orange
C) violet D) green

20. Which characteristic of electromagnetic radiation is directly proportional to the energy of a photon?

A) wavelength B) period
C) frequency D) path

21. Which transmits the energy in a light beam?

A) electrons **B) photons**
C) protons D) neutrons

22. Which electron transition between the energy levels of hydrogen causes the emission of a photon of visible light?

A) $n = 6$ to $n = 5$ B) $n = 5$ to $n = 6$
C) $n = 5$ to $n = 2$ D) $n = 2$ to $n = 5$

23. Which color light has photons of the greatest energy?

A) red B) yellow
C) green **D) blue**

24. A quantum of light energy is a

A) photon B) photoelectron
C) lumen D) spectra

25. In which part of the electromagnetic spectrum does a photon have the greatest energy?

A) red
B) infrared
C) violet
D) ultraviolet

26. The threshold frequency in a photoelectric experiment is most closely related to the

A) brightness of the incident light
B) thickness of the photoemissive metal
C) area of the photoemissive metal
D) work function of the photoemissive metal

27. The threshold frequency of a metal surface is in the violet light region. What type of radiation will cause photoelectrons to be emitted from the metal's surface?

A) infrared light
B) red light
C) ultraviolet light
D) radio waves

28. In the photoelectric effect, the speed of emitted electrons may be increased by

A) increasing the frequency of the light
B) decreasing the frequency of the light
C) increasing the intensity of illumination
D) decreasing the intensity of illumination

29. When a source of dim orange light shines on a photosensitive metal, no photoelectrons are ejected from its surface. What could be done to increase the likelihood of producing photoelectrons?

A) Replace the orange light source with a red light source.
B) Replace the orange light source with a higher frequency light source.
C) Increase the brightness of the orange light source.
D) Increase the angle at which the photons of orange light strike the metal.

30. A metal surface emits photoelectrons when illuminated by green light. This surface must also emit photoelectrons when illuminated by

A) blue light
B) yellow light
C) orange light
D) red light

31. Base your answer to the following question on the information below.

Light of constant intensity strikes a metal surface. The frequency of the light is increased from 6.0×10^{14} cycles per second to 9.0×10^{14} cycles per second. Photoelectrons are emitted by the metal surface when the frequency reaches 8.0×10^{14} cycles per second.

As the frequency of the incident light increases, the photons striking the metal surface increase in

A) number
B) energy
C) speed
D) wavelength

32. The threshold frequency for a photoemissive surface is 6.4×10^{14} hertz. Which color light, if incident upon the surface, may produce photoelectrons?

A) blue
B) green
C) yellow
D) red

33. When photons with an energy of 3.0 electron-volts strike a photoelectric surface the maximum kinetic energy of the emitted photoelectrons is 2.0 electron volts. What is the work function of the surface?

A) 1.0 eV
B) 0.67 eV
C) 1.5 eV
D) 5.0 eV

34. The threshold frequency for a photoemissive surface is 4.0×10^{14} hertz. What is the work function of this surface?

A) 1.2×10^{-19} J
B) 2.6×10^{-19} J
C) 6.0×10^{14} J
D) 6.1×10^{47} J

35. Photons with a frequency of 1.0×10^{20} hertz strike a metal surface. If electrons with a maximum kinetic energy of 3.0×10^{-14} joule are emitted, the work function of the metal is

A) 1.0×10^{-14} J
B) 2.2×10^{-14} J
C) 3.6×10^{-14} J
D) 6.6×10^{-14} J

36. Which determines the number of electrons emitted by a photoelectric material?

A) intensity
B) color
C) frequency
D) wavelength

37. A certain photoemissive material with a work function of 1.3×10^{-19} joule is exposed to incident photons with an energy of 3.3×10^{-19} joule. The maximum kinetic energy that an ejected photoelectron can attain is closest to

A) 1.0×10^{-39} J **B) 2.0×10^{-19} J**
C) 3.0×10^{-19} J D) 4.0×10^{-19} J

38. Photons with energies of 3.9×10^{-19} joule strike a photoemissive surface whose work function is 2.9×10^{-19} joule. The maximum kinetic energy of the ejected photoelectrons is

A) 1.0×10^{-19} J B) 7.5×10^{-20} J
C) 7.0×10^{-19} J D) 1.2×10^{-18} J

39. The work function of a certain photoemissive material is 2.0 electronvolts. If 5.0-electronvolt photons are incident on the material, the maximum kinetic energy of the ejected photoelectrons will be

A) 7.0 eV B) 5.0 eV
C) 3.0 eV D) 2.5 eV

40. As the frequency of photons incident upon a photoemissive surface is increased, the maximum energy of the photoelectrons

A) decreases **B) increases**
C) remains the same

41. Protons and neutrons are examples of

A) positrons **B) baryons**
C) mesons D) quarks

42. According to the Standard Model of Particle Physics, a meson is composed of

A) a quark and a muon neutrino
B) a quark and an antiquark
C) three quarks
D) a lepton and an antilepton

43. The particles in a nucleus are held together primarily by the

A) strong force B) gravitational force
C) electrostatic force D) magnetic force

44. The strong force is the force of

A) repulsion between protons
B) attraction between protons and electrons
C) repulsion between nucleons
D) attraction between nucleons

45. What fundamental force holds quarks together to form particles such as protons and neutrons?

A) electromagnetic force
B) gravitational force
C) strong force
D) weak force

46. Baryons may have charges of

A) +1e and $+\frac{4}{3}$e B) +2e and +3e
C) –1e and +1e D) –2e and $-\frac{2}{3}$e

47. What is the total number of quarks in a helium nucleus consisting of 2 protons and 2 neutrons?

A) 16 **B) 12** C) 8 D) 4

48. A meson may *not* have a charge of

A) +1e **B) +2e** C) 0e D) –1e

Base your answers to questions **49** and **50** 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

49. Which particle listed on the table has the opposite charge of, and is more massive than, a proton?

A) antiproton B) neutron C) lambda **D) omega**

50. All the particles listed on the table are classified as

A) mesons **B) hadrons** C) antimatter D) leptons

51. The quarks that compose a baryon may have charges of

A) $+\frac{2}{3}e, +\frac{2}{3}e, and - \frac{1}{3}e$
B) $+\frac{1}{3}e, -\frac{1}{3}e, and + \frac{2}{3}e$
C) –1e, –1e, and 0
D) $+\frac{2}{3}e, +\frac{2}{3}e, and, 0$

52. Which combination of quarks produces a neutral baryon?

A) cts B) dsb **C) uds** D) uct

53. Which force is responsible for producing a stable nucleus by opposing the electrostatic force of repulsion between protons?

A) strong B) weak
C) frictional D) gravitational

54. An antibaryon composed of two antiup quarks and one antidown quark would have a charge of

A) +1e **B) –1e** C) 0e D) –3e

55. The composition of a meson with a charge of –1 elementary charge could be

A) $s\bar{c}$ B) dss C) $u\bar{b}$ D) $\bar{u}\,\bar{c}\,\bar{d}$

56. A deuterium nucleus consists of one proton and one neutron. The quark composition of a deuterium nucleus is

A) 2 up quarks and 2 down quarks
B) 2 up quarks and 4 down quarks
C) 3 up quarks and 3 down quarks
D) 4 up quarks and 2 down quarks

57. Compared to the mass and charge of a proton, an antiproton has

A) the same mass and the same charge
B) greater mass and the same charge
C) the same mass and the opposite charge
D) greater mass and the opposite charge

58. A particle that is composed of two up quarks and one down quark is a

A) meson B) neutron
C) proton D) positron

59. A particle unaffected by an electric field could have a quark composition of

A) *css* B) *bbb* C) *udc* D) *uud*

60. A lithium atom consists of 3 protons, 4 neutrons, and 3 electrons. This atom contains a total of
    - A) 9 quarks and 7 leptons
    - B) 12 quarks and 6 leptons
    - C) 14 quarks and 3 leptons
    - **D) 21 quarks and 3 leptons**
61. 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
    - A) *u* quark to a *d* quark
    - B) *d* quark to a meson
    - **C) baryon to another baryon**
    - D) lepton to another lepton
62. Which combination of quarks could produce a neutral baryon?
    A) *cdt* B) *cts* **C) *cdb*** D) *cdu*
63. Which combination of quarks would produce a neutral baryon?
    A) uud **B)** udd C) $\overline{\mathrm{u}}\overline{\mathrm{u}}\mathrm{d}$ D) $\overline{\mathrm{u}}\mathrm{dd}$
64. A baryon may have a charge of
    A) –1/3 e **B) 0 e**
    C) + 2/3 e D) + 4/3 e
65. Which of the following gives evidence for the quark structure of baryons?
    - A) Baryons only have charges that are integral multiples of the electron charge.
    - **B) The neutron has a magnetic moment.**
    - C) Baryon number is conserved in all reactions.
    - D) The force that holds nuclei together is very strong.
66. A particle is known to only contain up and charm quarks, what can be its charge?
    A) +2 e B) +1 e C) 0 e D) –1 e
67. A particle is known to only contain down and strange quarks, what can be its charge?
    A) +2 e B) +1 e C) 0 e **D) –1 e**
68. Which of the following reactions does not affect a baryon's charge?
    - A) An up quark changing into a strange quark.
    - B) A strange quark changing into a bottom quark.
    - C) A top quark changing into a charm quark.
    - **D) A down quark changing into a strange quark.**
69. Which of the following contains quarks?
    A) beta particles **B) alpha particles**
    C) positrons D) gamma rays
70. How many quarks are there in an alpha particle?
    A) 3 B) 4 C) 8 **D) 12**
71. Which of the following happens in the production of beta radiation?
    - A) An up quark changes into a down quark.
    - **B) A down quark changes into an up quark.**
    - C) An up quark changes into a strange quark.
    - D) A down quark changes into a strange quark.
72. A baryon has a charge of –1 e. It CANNOT contain
    A) an up quark. B) a down quark.
    C) a strange quark. D) a bottom quark.
73. Which of the following has the same charge as a neutron (udd)?
    A) proton (uud) B) sigma (Σ) (uus)
    C) xi (Θ) (uss) D) omega (Ω) (sss)
74. What is the charge on an anti-down quark?
    A) $+\frac{1}{3}e$ B) $+\frac{2}{3}e$ C) $-\frac{1}{3}e$ D) $-\frac{2}{3}e$
75. An upsilon (U) particle contains a bottom quark and an anti-bottom quark. It is
    - A) a baryon with charge +1 e.
    - B) a meson with charge +1 e.
    - C) a baryon with charge 0 e.
    - **D) a meson with charge 0 e.**
76. Which of the following statements is NOT true about the proton?
    - A) It is a baryon.
    - B) It is a hadron.
    - C) It contains 3 quarks.
    - **D) It is a meson.**

77. One variety of delta (Δ) particle has a charge of +2 e. What is a possible quark configuration for it?

    A) uuu B) uud C) udd D) ddd

78. What is a possible charge for a baryon, but not for a meson?

    A) +2 e B) +1 e C) 0 e D) –1 e

79. A baryon contains at least one charm quark. Which may NOT be its electric charge?

    A) +2 e B) +1 e C) 0 e **D) –1 e**

80. Which of the following CANNOT be the charge on a meson?

    A) 1 e **B) $\frac{2}{3}$ e** C) 0 e D) –1 e

81. Which of the following particles is NOT made of quarks?

    A) proton **B) electron**
    C) pion D) neutron

82. The omega (Ω) particle is made up of 3 strange quarks. It is

    A) a baryon with charge +1 e.
    B) a meson with charge +1 e.
    C) a baryon with charge –1 e.
    D) a meson with charge –1 e.

83. What is the quark composition of a proton?

    A) uud B) udd C) csb D) uds

Base your answers to questions **84** through **86** on the information below and on your knowledge of physics.

Tritium is a radioactive form of element hydrogen. A tritium nucleus is composed of one proton and two neutrons. When a tritium nucleus decays, it emits a beta particle (an electron) and an antineutrino to create a stable form of helium. During beta decay, a neutron is spontaneously transformed into a proton, an electron, and an antineutrino.

84. What fundamental interaction is responsible for binding together the protons and neutrons in a helium nucleus?

85. What is the total charge, in elementary charges, of a proton, an electron, and an antineutrino?

86. What is the total number of quarks in a tritium nucleus?

Base your answers to questions **87** and **88** on the information below and on your knowledge of physics.

An electron traveling with a speed of 2.50×10^6 meters per second collides with a photon having a frequency of 1.00×10^{16} hertz. After the collision, the photon has 3.18×10^{-18} joule of energy.

87. Name *two* physical quantities conserved in the collision.

88. Determine the energy in joules of the photon before the collision.

Base your answers to questions **89** through **91** on the information below.

Auroras over the polar regions of Earth are caused by collisions between charged particles from the Sun and atoms in Earth's atmosphere. The charged particles give energy to the atoms, exciting them from their lowest available energy level, the ground state, to higher energy levels, excited states. Most atoms return to their ground state within 10. nanoseconds.

In the higher regions of Earth's atmosphere, where there are fewer interatom collisions, a few of the atoms remain in excited states for longer times. For example, oxygen atoms remain in an excited state for up to 1.0 seconds. These atoms account for the greenish and red glows of the auroras. As these oxygen atoms return to their ground state, they emit green photons $(f = 5.38 \times 10^{14}\ \mathrm{Hz})$ and red photons$(f = 4.76 \times 10^{14}\mathrm{Hz})$. These emissions last long enough to produce the changing aurora phenomenon.

89. Explain what is meant by an atom being in its ground state.

90. Calculate the energy of a photons, in joules, that accounts for the red glow of the aurora. [Show all work, including the equation and substitution with units.]

91. What is the order of magnitude of the time, in seconds, that most atoms spend in an excited state?

Base your answers to questions **92** through **95** 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

92. 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.]

93. 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.

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

95. Which combination of *three* quarks will produce a neutron?

Base your answers to questions **96** through **98** on the information below.

A photon with a wavelength of 2.29×10^{-7} meter strikes a mercury atom in the ground state.

96. Based on your answer to the question above, state if this photon can be absorbed by the mercury atom. Explain your answer.

97. Determine the energy, in electronvolts, of this photon.

_______________________ **eV**

98. Calculate the energy, in joules, of this photon. [Show all work, including the equation and substitution with units.]

99. The energy required to separate the 3 protons and 4 neutrons in the nucleus of a lithium atom is 39.3 megaelectronvolts. Determine the mass equivalent of this energy, in universal mass units.

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Base your answers to questions **100** through **103** on the information below.

As a mercury atom absorbs a photon of energy, an electron in the atom changes from energy level *d* to energy level *e*.

100. Based on your calculated value of the frequency of the absorbed photon, determine its classification in the electromagnetic spectrum.

101. Calculate the frequency of the absorbed photon. [Show all work, including the equation and substitution with units.]

102. Express the energy of the absorbed photon in joules.

103. Determine the energy of the absorbed photon in electronvolts.

Base your answers to questions **104** through **106** on the information below.

A photon with a frequency of 5.48×10^{14} hertz is emitted when an electron in a mercury atom falls to a lower energy level.

104. Determine the energy of this photon in electronvolts.

105. Calculate the energy of this photon in joules. [Show all work, including the equation and substitution with units.]

106. Identify the color of light associated with this photon.

Base your answers to questions **107** through **109** 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.

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

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

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

110. Calculate the wavelength of a photon having 3.26×10^{-19} joule of energy. [Show all work, including the equation and substitution with units.]

Base your answers to questions **111** and **112** on the information and data table below.

In the first nuclear reaction using a particle accelerator, accelerated protons bombarded lithium atoms, producing alpha particles and energy. The energy resulted from the conversion of mass into energy. The reaction can be written as shown below.

$${}^{1}_{1}H + {}^{7}_{3}Li \rightarrow {}^{4}_{2}He + {}^{4}_{2}He + \text{energy}$$

Data Table

Particle	Symbol	Mass (u)
proton	${}^{1}_{1}H$	1.007 83
lithium atom	${}^{7}_{3}Li$	7.016 00
alpha particle	${}^{4}_{2}He$	4.002 60

111. Determine the energy in megaelectronvolts produced in the reaction of a proton with a lithium atom.

112. Determine the difference between the total mass of the reactants (the proton and lithium atom), and the total mass of the products (the two alpha particles), in universal mass units.

113. Base your answer to the following question on the information below.

In a mercury atom, as an electron moves from energy level *i* to energy level *a,* a single photon is emitted.

Determine the energy, in electron volts, of this emitted photon.

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

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

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

________e → ________e + ________e + ________e

Base your answers to questions **115** through **117** on the information below.

A photon with a frequency of 5.02×10^{14} hertz is absorbed by an excited hydrogen atom. This causes the electron to be ejected from the atom, forming an ion.

115. What is the number of the *lowest* energy level (closest to the ground state) of a hydrogen atom that contains an electron that would be ejected by the absorption of this photon?

116. Determine the energy of this photon in electronvolts.

117. Calculate the energy of this photon in joules. [Show all work, including the equation and substitution with units.]

Base your answers to questions **118** through **121** 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 natures 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 protons 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-antiparticlepairs. 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

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

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

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

121. 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?

122. Base your answer to the following question 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.

What characteristic of light determines the amount of energy carried by a photon of that light?

A) amplitude
B) frequency
C) phase
D) velocity

123. If a proton were to combine with an antiproton, they would annihilate each other and become energy. Calculate the amount of energy that would be released by this annihilation. [Show all work, including the equation and substitution with units.]

124. Determine the frequency of a photon whose energy is 3.00×10^{-19} joule.

Base your answers to questions **125** through **129** on the Energy Level Diagram for Hydrogen in the *Reference Tables for Physical Settings/Physics*.

125. Determine the energy, in electronvolts, of a photon emitted by an electron as it moves from the $n = 6$ to the $n = 2$ energy level in a hydrogen atom.

126. Is this the only energy and/or frequency that an electron in the $n = 6$ energy level of a hydrogen atom could emit? Explain your answer.

127. Calculate the frequency of the emitted photon. [Show all work, including the equation and substitution with units.]

128. Convert the energy of the photon to joules.

129. Determine the energy, in electronvolts, of a photon emitted by an electron as it moves from the $n = 6$ to the $n = 2$ energy level in a hydrogen atom.

---

130. After a uranium nucleus emits an alpha particle, the total mass of the new nucleus and the alpha particle is less than the mass of the original uranium nucleus. Explain what happens to the missing mass.

Base your answers to questions **131** and **132** on the information below.

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

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

132. A lambda particle can be classified as a

A) baryon B) lepton
C) meson D) photon

---

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

134. How much energy, in megaelectronvolts, is produced when 0.250 universal mass unit of matter is completely converted into energy?

135. A photon has a wavelength of 9.00×10^{-10} meter. Calculate the energy of this photon in joules.

136. The alpha line in the Balmer series of the hydrogen spectrum consists of light having a wavelength of 6.56×10^{-7} meter.
a Calculate the frequency of this light.
b Determine the energy in joules of a photon of this light.
c Determine the energy in electronvolts of a photon of this light.

Base your answers to questions **137** through **139** on the information below.

The light of the "alpha line" in the Balmer series of the hydrogen spectrum has a wavelength of 6.58×10^{-7} meter.

137. Using your answer to the previous question explain whether or not this result verifies that the “alpha line” corresponds to a transition from energy level $n = 3$ to energy level $n = 2$ in a hydrogen atom.

138. What is the energy of an “alpha line” photon in electronvolts?

139. Calculate the energy of an "alpha line" photon in joules. [Show all work, including the equation and substitution with units.]

Base your answers to questions **140** and **141** on the information and equation below.

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

neutron $\rightarrow$ proton + electron + electron antineutrino + energy

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

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

Base your answers to questions **142** and **143** on the information below.

Louis de Broglie extended the idea of waveparticle duality to all of nature with his matterwave equation, $\lambda = \frac{h}{mv}$, where λ is the particle's wavelength, m is its mass, v is its velocity, and h is Planck's constant.

142. The wavelength of this particle is of the same order of magnitude as which type of electromagnetic radiation?

143. Using this equation, calculate the de Broglie wavelength of a hydrogen nucleus (mass = 6.7×10^{-27} kg) moving with a speed of 2.0×10^{6} meters per second.[Show all work, including the equation and substitution with units.]

---

144. Explain why a hydrogen atom in the ground state can absorb a 10.2-electronvolt photon, but can *not* absorb an 11.0-electronvolt photon.

145. Base your answer to the following question on the information below.

An electron in a hydrogen atom drops from the *n* = 3 energy level to the *n* = 2 energy level.

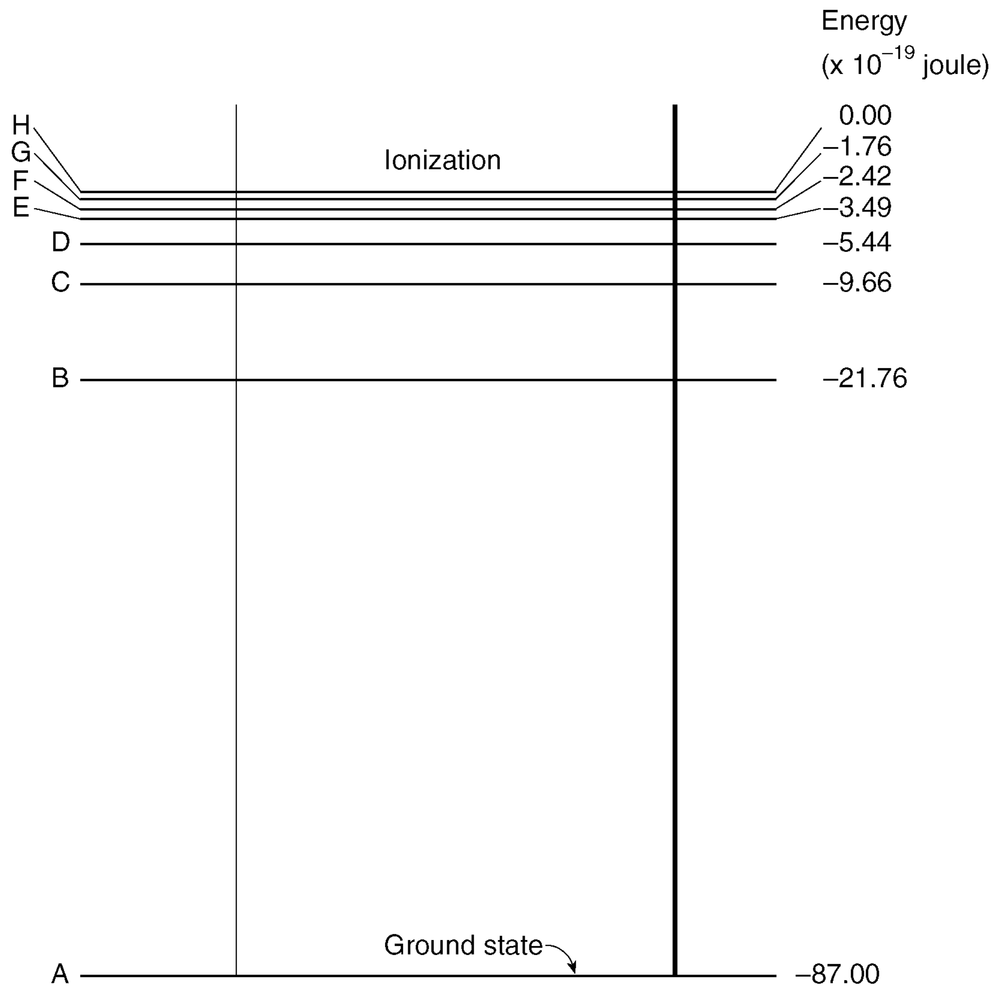
a What is the energy, in electronvolts, of the emitted photon?
b What is the energy, in joules, of the emitted photon?
c Calculate the frequency of the emitted radiation.
d Calculate the wavelength of the emitted radiation.

Base your answers to questions **146** and **147** on the information and diagram below. The diagram shows the collision of an incident photon having a frequency of 2.00×10^{19} hertz with an electron initially at rest.

146. What is the total energy of the two-particle system after the collision?

147. Calculate the initial energy of the photon. [Show all calculations, including the equation and substitution with units.]

Base your answers to questions **148** and **149** on the diagram below, which shows some energy levels for an atom of an unknown substance.



148. Calculate the frequency of the photon emitted when an electron in this atom changes from the *F* energy level to the *B* energy level. [Show all work, including the equation and substitution with units.]

149. Determine the minimum energy in Joueles necessary for an electron to change from the *B* energy level to the *F* energy level.

Base your answers to questions **150** and **151** on the information below.

When an electron and its antiparticle (positron) combine, they annihilate each other and become energy in the form of gamma rays.

150. What conservation law prevents this from happening with two electrons?

151. The positron has the same mass as the electron. Calculate how many joules of energy are released when they annihilate. [Show all work, including the equation and substitution with units.]

Base your answers to questions **152** through **155** on the information below.

When an electron in an excited hydrogen atom falls from a higher to a lower energy level, a photon having a wavelength of 6.58×10^{-7}meter is emitted.

152. Is this photon an x-ray photon? Justify your answer.

153. Determine which *two* energy levels the electron has fallen between to emit this photon.

154. Convert the energy of the photon to electronvolts.

155. Calculate the energy of a photon of this light wave in joules. [Show all calculations, including the equation and substitution with units.]

Base your answers to questions **156** through **159** on the information below.

A mercury atom makes a direct transition from energy level e to energy level b.

156. Explain what would happen if a 4.50-electronvolt photon were incident on a mercury atom in the ground state.

157. Determine the frequency of the radiation corresponding to the emitted photon. [Show all calculations, including the equation and substitution with units.]

158. What is the energy of the emitted photon in joules?

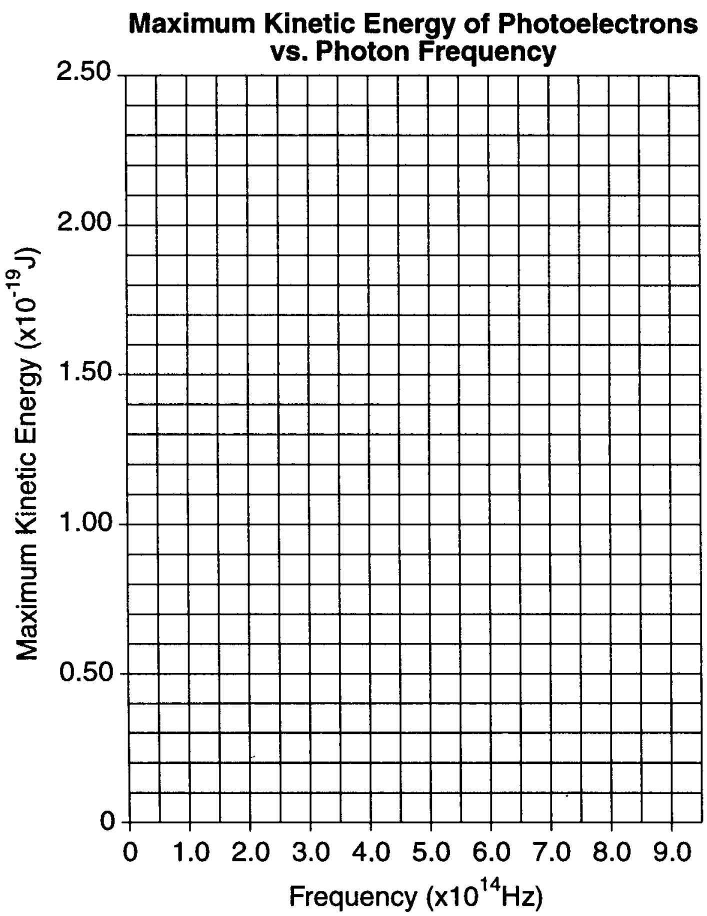
159. Determine the energy, in electron-volts, given off in the transition. [Show all calculations including the equation and substitution with units.]

Base your answers to questions **160** through **164** on the information and table below.

A photoemissive metal was illuminated successively by photons of various frequencies. The maximum kinetic energies of the emitted photoelectrons were measured and recorded in the table below.

Using the information in the data table, construct a graph on the grid provided, following the directions below.

FREQUENCY ($\times 10^{14}$ Hz)	MAXIMUM KINETIC ENERGY ($\times 10^{-19}$ J)
5.3	0.58
6.0	1.08
6.9	1.73
7.6	2.07



160. Name the physical constant represented by the slope of a graph of maximum kinetic energy of photoelectrons versus photon frequency.

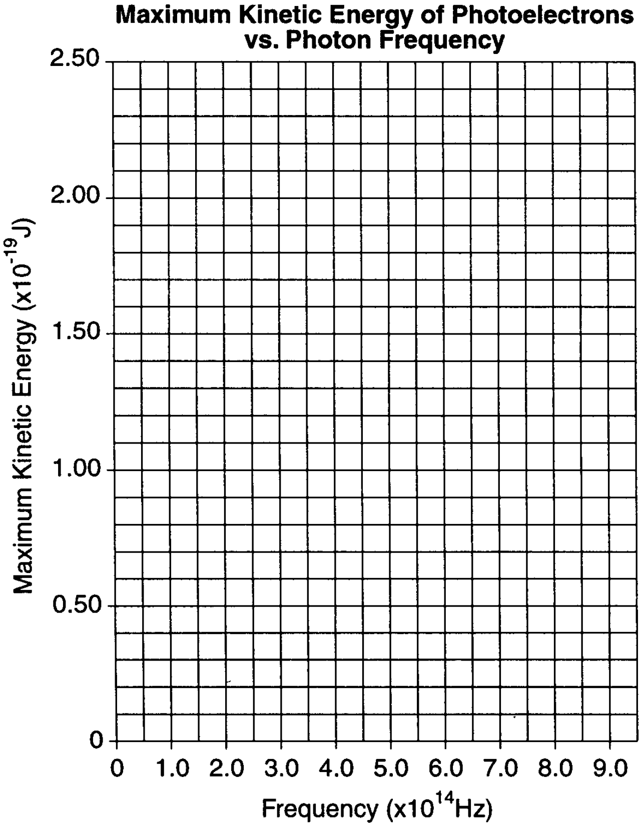
161. Determine the slope of the graph. [Show all calculations, including the equation and substitution with units.]

162. Using the graph, determine the threshold frequency of the metal.

163. Draw the best-fit line.

164. Plot the data points for maximum kinetic energy versus frequency.

FREQUENCY ($\times 10^{14}$ Hz)	MAXIMUM KINETIC ENERGY ($\times 10^{-19}$ J)
5.3	0.58
6.0	1.08
6.9	1.73
7.6	2.07



165. *a* Using the information and the data table, construct a graph on your answer paper, following the directions below.

(1) Mark an appropriate scale on the axis labeled "Maximum Kinetic Energy (eV)."
(2) Plot the data on the grid and draw the best-fit line.

b Based on the graph, what is the threshold frequency of the metal used in this experiment?

c If data from a different photoemissive metal were graphed, which characteristic of the graph would remain the same?

Base your answers to questions **166** through **168** on the information below.

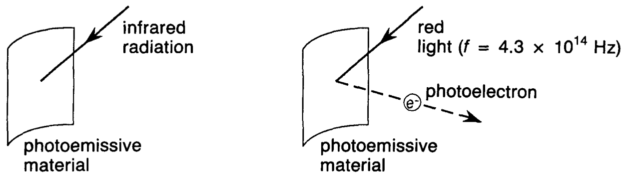
A hydrogen atom emits a 2.55-electronvolt photon as its electron changes from one energy level to another.

166. Determine the frequency of the emitted photon.
[Show all calculations, including the equation and the substitution with units.]

167. Express the energy of the emitted photon in joules.
[Show all calculations including equations and substitutions with appropriate units.]

168. Using the Reference Tables for Physics, determine the energy level change for the electron.

169. Infrared electromagnetic radiation incident on a material produces no photoelectrons. When red light of equal intensity is shone on the same material, photoelectrons are emitted from the surface.



Using one or more complete sentences, explain why the visible red light causes photo-electric emission, but the infrared radiation does not.

Base your answers to questions **170** through **172** on the information below and on your knowledge of physics.

An electron in a mercury atom changes from energy level *b* to a higher energy level when the atom absorbs a single photon with an energy of 3.06 electronvolts.

170. Calculate the frequency of the photon. [Show all work, including the equation and substitution with units.]

171. Determine the energy of the photon, in joules.

172. Determine the letter that identifies the energy level to which the electron jumped when the mercury atom absorbed the photon.

Answer Key
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1. **D**
2. **B**
3. **C**
4. **D**
5. **C**
6. **B**
7. **A**
8. **D**
9. **B**
10. **C**
11. **A**
12. **D**
13. **B**
14. **B**
15. **B**
16. **A**
17. **A**
18. **B**
19. **C**
20. **C**
21. **B**
22. **C**
23. **D**
24. **A**
25. **D**
26. **D**
27. **C**
28. **A**
29. **B**
30. **A**
31. **B**
32. **A**
33. **A**
34. **B**
35. **C**
36. **A**
37. **B**
38. **A**
39. **C**
40. **B**
41. **B**
42. **B**
43. **A**
44. **D**
45. **C**
46. **C**
47. **B**
48. **B**
49. **D**
50. **B**
51. **A**
52. **C**
53. **A**
54. **B**
55. **A**
56. **C**
57. **C**
58. **C**
59. **A**
60. **D**
61. **C**
62. **C**
63. **B**
64. **B**
65. **B**
66. **A**
67. **D**
68. **D**
69. **B**
70. **D**
71. **B**
72. **A**
73. **C**
74. **A**
75. **D**
76. **D**
77. **A**
78. **A**
79. **D**
80. **B**
81. **B**
82. **C**
83. **A**
84. Strong force, strong, strong nuclear force or strong interaction.
85. 0
86. 9
87. — mass — charge — momentum — energy
88. 6.63×10^{-18} J
89. The ground state is the lowest available energy level that an atom can have *or* that the ground state is the most stable energy state.
90. $E = 3.16 \times 10^{-19}$ J
91. –8 *or* 10^{-8}
92. $m = 3.56 \times 10^{-24}$ kg *or* $m_{total} = 3.56 \times 10^{-24}$ kg
93. 1.60×10^{-7} J
94. $-1e$
95. udd *or* up, down, down
96. photon can be absorbed and that the energy of the photon is exactly equal to the energy-level difference between the ground state and level *d*.
97. 5.43 eV
98. $E_{photon} = \dfrac{hc}{\lambda}$

    $E_{photon} = \dfrac{(6.63 \times 10^{-34}\ \text{J}\bullet\text{s})(3.00 \times 10^{8}\text{m/s})}{2.29 \times 10^{-7}\text{m}}$
99. 4.22×10^{-2} u
100. infrared
101. $E_{photon} = hf$

     $f = \dfrac{E_{photon}}{h}$

     $f = \dfrac{1.98 \times 10^{-19}\ \text{J}}{6.63 \times 10^{-34}\ \text{J}\bullet\text{s}}$

     $f = 2.99 \times 10^{14}$ Hz
102. 1.98×10^{-19}J
103. 1.24 ev.
104. 2.27 eV
105. $E_{photon} = hf \rightarrow E_{photon} = (6.63 \times 10^{-34}\ J\bullet s)(5.48 \times 10^{14}\ Hz) \rightarrow E_{photon} = 3.63 \times 10^{-19}\ J$
106. green
107. –The particles have enough (kinetic) energy to be converted to that much mass.
     –Energy is converted to mass.
108. +1e *or* 1e
109. meson *or* hadron

Answer Key
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110.

$$E_{photon} = \frac{hc}{\lambda}$$
$$\lambda = \frac{hc}{E_{photon}}$$
$$\lambda = \frac{(6.63 \times 10^{-34}\ \text{J•s})(3.00 \times 10^{8}\ \text{m/s})}{3.26 \times 10^{-19}\ \text{J}}$$
$$\lambda = 6.10 \times 10^{-7}\ \text{m}$$

111. 17.3 MeV

112. 0.01863 u

113. 8.82 eV

114.

$$\underline{\quad -1 \quad}\ \text{e} \rightarrow \underline{\quad -1 \quad}\ \text{e} + \underline{\quad 0 \quad}\ \text{e} + \underline{\quad 0 \quad}\ \text{e}$$

115. $n = 3$.

116. 2.08 eV.

117.

$$E_{photon} = hf$$
$$E_{photon} = (6.63 \times 10^{-34}\ \text{J•s})\ (5.02 \times 10^{14}\ \text{Hz})$$
$$E_{photon} = 3.33 \times 10^{-19}\ \text{J}$$

118. — Although matter is only created in matter&ndash-;antimatter pairs, most matter is normal. — matter, not $\frac{1}{2}$ antimatter — It should be balanced by antimatter. — Matter can only be created in particle&ndash-;antiparticle pairs.

119. Identify charge as one characteristic that antimatter particles must possess.

120. — identical — the same

121. antiproton

122. **__B__**

123.

$$E = mc^2$$
$$E = 2(1.67 \times 10^{-27}\text{kg})(3.00 \times 10^{8}\text{m/s})^2$$
$$E = 3.01 \times 10^{-10}$$
or
$$\frac{1\text{u}}{931\ \text{MeV}} = \frac{2\text{u}}{\text{x MeV}}$$
$$x = 1860\ \text{MeV}$$

124. 4.52×10^{14} Hz

125. 3.02 eV

126. Examples: – No, the n = 6 can return to any of the 5 lower levels. – No, the electron can drop to many different energy levels. – The electron can fall from n = 6 to any other level between n = 5 and n = 1. – $6 \rightarrow 5$ $6 \rightarrow 4$ $6 \rightarrow 3$ $6 \rightarrow 1$

127.

$$E = \frac{hc}{\lambda}$$
$$f = \frac{E}{h}$$
$$f = \frac{4.83 \times 10^{19}\text{J}}{6.63 \times 10^{34}\text{J} \cdot \text{s}}$$
$$f = 7.29 \times 10^{14}\text{Hz}$$

128. 4.83×10^{-19} J

129. 3.02 eV

130. Indicate that mass is converted into energy.

131. 0e

132. **__A__**

133. -1.6×10^{-19} C

134. 233 MeV

135. $E = 2.21 \times 10^{-16}$

136. *a* $f = 4.57 \times 10^{14}\text{Hz}$ or $f = 4.6 \times 10^{14}\text{Hz}$
b $f = 3.03 \times 10^{-19}\text{J}$
c 1.89 eV

137. Allow credit for indicating that the n_3 to n_2 transition is also **1.89** eV.

138. Allow credit for **1.89** eV.

139.

$$E = \frac{hc}{\lambda}$$
$$E = \frac{(6.63 \times 10^{-34}\text{Js})(3.00 \times 10^{8}\text{m/s})}{6.58 \times 10^{-7}\text{m})}$$
$$E = 3.02 \times 10^{-19}\text{J}$$

140. zero *or* neutral

141. The neutron is more massive.

142. The wavelength of this particle is of the same order of magnitude as gamma rays.

143.

$$\lambda = \frac{h}{mv}$$
$$\lambda = \frac{(6.63 \times 10^{-34}\text{J} \cdot \text{s})}{(6.7 \times 10^{-27}\text{kg})(2.0 \times 10^{6}\text{m/s})}$$
$$\lambda = 4.9 \times 10^{-14}\text{m}$$

144. The photon's energy must match exactly an energy level transition for the photon to be absorbed.

145. *a* 1.89 eV.
b 3.02×10^{-19} J.
c $f = 4.56 \times 10^{14}$ Hz
d $\lambda = 6.59 \times 10^{-7}$ m

146. examples:
– It is the same as the energy of the system before the collision.
– Energy is conserved.
– The energy is the same as before the collision.
– 1.33×10^{-14} J

147. $E_{photon} = hf$
$E = (6.63 \times 10^{-34}\ \text{J•s})(2.00 \times 10^{19}\ \text{Hz})$
$E = 1.33 \times 10^{-14}$ J *or* $E = 13.3 \times 10^{-15}$ J•s•Hz

148. $E = hf$
$f = 2.92 \times 10^{15}$ 1/s or Hz

149. 19.34×10^{-19} J

150. conservation of charge.

151. $E = mc^2$
$E = 1.64 \times 10^{-13}$ J

152. it cannot be an x-ray because the wavelength is too long

153. 3 and 2

154. 1.89 eV

155.

$$E = \frac{hc}{\lambda}$$
$$E = \frac{6.63 \times 10^{-34}\ \text{J} \cdot \text{s}(3.00 \times 10^{8}\ \text{m/s})}{6.58 \times 10^{-7}\ \text{m}}$$
$$E = 3.02 \times 10^{-19}\text{J}$$

156. Nothing will happen. *or* The photon will not be absorbed. *or* The mercury atom will remain in the ground state.

157.

$$E = hf$$
$$f = \frac{E}{h}$$
$$f = \frac{3.2 \times 10^{-19}\ \text{J}}{6.6 \times 10^{-34}\ \text{J} \cdot \text{s}}$$
$$f = 4.8 \times 10^{14}\ \text{Hz}$$
$$f = 4.848 \times 10^{14}\,\frac{1}{s}$$

158. 3.2×10^{-19} J *or* $(2.03\ \text{eV})(1.6 \times 10^{-19}\ \text{J/eV}) = 3.248 \times 10^{-19}$ J

159. 2.03 eV

160. Planck's constant

161. slope = 6.7×10^{-24} J•s *or* 0.67×10^{-33} J/Hz

162. 4.4×10^{14} HZ $\pm$ 0.2×10^{14} Hz

163. Graph

Answer Key
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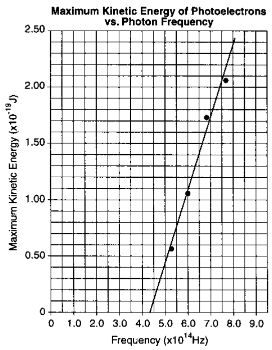
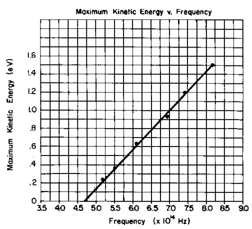
164. 

165.
a. 

166. 6.2×10^{14} Hz

167. 4.1×10^{-19} J *or*
4.08×10^{-19} J

168. $n = 4$ to $n = 2$

169. The energy of red light equals or exceeds the threshold frequency of the material. The energy of infrared light is less than the threshold frequency.

170. $-E_{photon} = hf \quad - f = \frac{E_{photon}}{h} \quad - f = \frac{4.90 \times 10^{-19}\text{ J}}{6.63 \times 10^{-34}\text{ J}\bullet\text{s}}$
$f = 7.39 \times 10^{14}\text{ Hz } oe\ 7.38 \times 10^{14}\text{ Hz}$

171. $4.90 \times 10^{-19}\text{ J } or\ 4.89 \times 10^{-19}\text{ J}$

172. f *or* energy level f