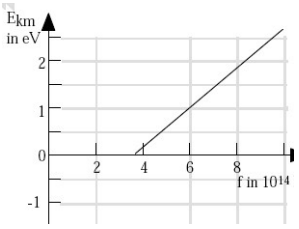
SECTION A – Quantum Physics and Atom Models

1. An atomic particle of mass m moving at speed v is found to have wavelength λ. What is the wavelength of a second particle with three times the speed and twice the mass?
   A) 3λ/2 B) 2λ/3 C) 6λ D) λ/6

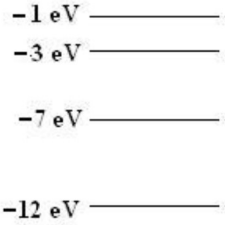
2. A student performs the photoelectric effect experiment and obtains the data depicted in the accompanying graph of $E_{km}$ (maximum kinetic energy) of photoelectrons v. the frequency of the photons. What is the approximate work function of this material?
   A) 1.5 eV B) 2.0 eV C) 2.7 eV D) 3.5 eV




3. According to the Bohr theory of the hydrogen atom, electrons starting in the 4th energy level and eventually ending up in the ground state, could produce a total of how many lines in the hydrogen spectra?
   A) 3 B) 4 C) 5 D) 6

4. In the photoelectric effect experiment, a stopping potential of $V_{stop}$ is needed when light of frequency $f_o$ shines on the electron-emitting metal surface. If the metal surface on which the light shines is replaced with a new material that has half the work function, what is the new stopping potential, $V_{new}$, for light of frequency shining on it?
   A) $V_{new} > 2V_{stop}$ B) $V_{new} = 2\ V_{stop}$ C) $V_{stop} < V_{new} < 2V_{stop}$ D) It is indeterminate from the given information

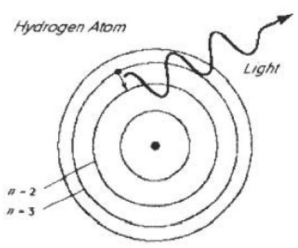
5. The diagram to the right shows the lowest four energy levels for an electron in a hypothetical atom. The electron is excited to the −1 *eV* level of the atom and transitions to the lowest energy state by emitting only two photons. Which of the following energies could not belong to either of the photons?
   (A) 2 *eV* (B) 4 *eV* (C) 5 *eV* (D) 6 *eV*

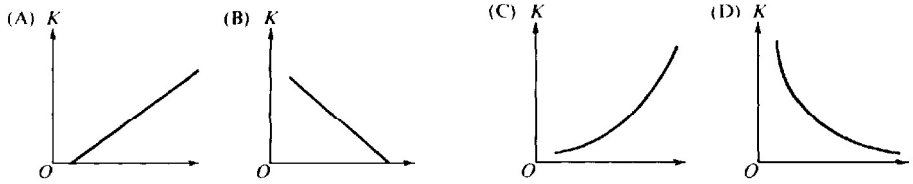



6. Monochromatic light falling on the surface of an active metal causes electrons to be ejected from the metallic surface with a maximum kinetic energy of E. What would happen to the maximum energy of the ejected electrons if the frequency of the light were doubled?
   A) the maximum energy of the electrons would be ½ E
   B) the maximum energy of the electrons would be (√2) E
   C) the maximum energy of the electrons would be 2E
   D) the maximum energy of the electrons would be greater than 2E

7. A very slow proton has its kinetic energy doubled. What happens to the protons corresponding de Broglie wavelength
   A) the wavelength is decreased by a factor of √2
   B) the wavelength is halved
   C) the wavelength is increased by a factor of √2
   D) the wavelength is doubled.

8. The diagram shows light being emitted due to a transition from the n=3 to the n=2 level of a hydrogen atom in the Bohr model. If the transition were from the n=3 to the n=1 level instead, the light emitted would have
   A) lower frequency B) longer wavelength C) greater speed
   D) greater momentum

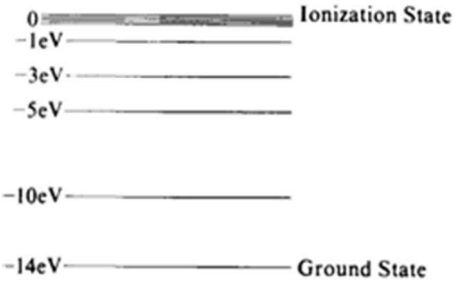




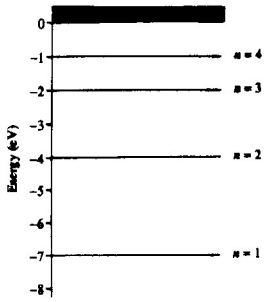

9. Which graph above best shows the maximum kinetic energy K of the photoelectrons as a function of the frequency of incident light?
(A) A (B) B (C) C (D) D

10. Electrons that have been accelerated from rest through a potential difference of 150 volts have a de Broglie wavelength of approximately 1 Angstrom ($10^{-10}$ meter). In order to obtain electrons whose de Broglie wavelength is 0.5 Angstrom ($5 \times 10^{-11}$ meter), what accelerating potential is required?
(A) 37.5 V (B) 75 V (C) 300 V (D) 600 V

11. The energy level diagram is for a hypothetical atom. A gas of these atoms initially in the ground state is irradiated with photons having a continuous range of energies between 7 and 10 electron volts. One would expect photons of which of the following energies to be emitted from the gas?
(A) 1, 2, and 3 eV only
(B) 4, 5, and 9 eV only
(C) 1, 3, 5, and 10 eV only
(D) 1, 5, 7, and 10 eV only



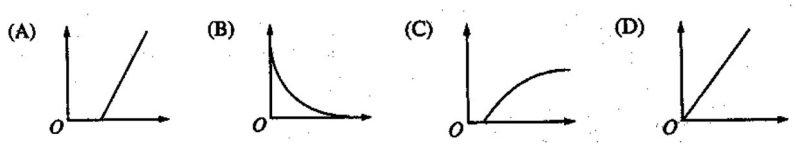

12. A hypothetical atom has four energy states as shown. Which of the following transitions will produce the photon with the longest wavelength?
(A) n = 2 to n = 1
(B) n = 3 to n = 1
(C) n = 4 to n = 1
(D) n = 4 to n = 3




13. In the Bohr model of the atom, the postulate stating that the orbital angular momentum of the electron is quantized can be interpreted in which of the following ways?
(A) An integral number of electron wavelengths must fit into the electron's circular orbit.
(B) Only one electron can exist in each possible electron state.
(C) The atom is composed of a small, positively charged nucleus orbited by electrons.
(D) An incident photon is completely absorbed when it causes an electron to move to a higher energy state.

14. If photons of light of frequency *f* have momentum *p*, photons of light of frequency *2f* will have a momentum of
(A) *2p* (B) $\sqrt{2}p$ (C) $\frac{p}{\sqrt{2}}$ (D) ½ *p*

15. **Multiple Correct.** In an experiment, light of a particular wavelength is incident on a metal surface, and electrons are emitted from the surface as a result. To produce more electrons per unit time but with less kinetic energy per electron, the experimenter should do which of the following? Select two answers:
(A) Increase the intensity of the light.
(B) Decrease the intensity of the light.
(C) Increase the wavelength of the light.
(D) Decrease the wavelength of the light.




16. Which graph above shows the total photoelectric current versus the intensity of the light for a fixed frequency above the cutoff frequency?
(A) A (B) B (C) C (D) D

17. A 50,000 W radio station transmits waves of wavelength 4 m. Which of the following is the best estimate of the number of photons it emits per second?
(A) $10^{22}$ (B) $10^{30}$ (C) $10^{40}$ (D) $10^{56}$

18. Two monochromatic light beams, one red and one green, have the same intensity and the same cross sectional area. How does the energy of each photon and the number of photons crossing a unit area per second in the red beam compare with those of the green beam?

| Energy of Photon | Number of Photons Crossing Unit Area per Second |
|---|---|
| (A) Greater for red | Less for red |
| (B) Greater for red | Greater for red |
| (C) Less for red | Less for red |
| (D) Less for red | Greater for red |

19. In an x-ray tube, electrons striking a target are brought to rest, causing x-rays to be emitted. In a particular x-ray tube, the maximum frequency of the emitted continuum x-ray spectrum is $f_o$. If the voltage across the tube is doubled, the maximum frequency is
(A) $f_o/2$ (B) $f_o/\sqrt{2}$ (C) $\sqrt{2}\, f_o$ (D) $2f_o$

## SECTION B – Nuclear Physics

1. A radioactive oxygen $^{15}O_8$ nucleus emits a positron and becomes
A) $^{15}N_7$ B) $^{15}O_8$ C) $^{14}F_9$ D) $^{15}F_9$

2. A radon $^{220}Rn_{86}$ nucleus emits an alpha particle becomes a
A) $^{216}Po_{84}$ B) $^{220}At_{85}$ C) $^{220}Rn_{86}$ D) $^{220}Fr_{87}$

3. A potassium $^{40}K_{19}$ nucleus emits a $B^-$ and becomes:
A) $^{36}Cl_{17}$ B) $^{40}Ar_{18}$ C) $^{40}K_{19}$ D) $^{40}Ca_{20}$

4. A photon with frequency f behaves as if it had a mass equal to
A) $hf / c^2$ B) $c^2 / hf$ C) $fc^2 / h$ D) $h / fc^2$

5. What does the ? represent in the nuclear reaction $^2H_1 + ^2H_1 \rightarrow ^3He_2 + ?$
A) a beta B) a gamma C) a neutron D) a proton

6. What does the ? represent in the nuclear reaction $^6Li_3 + ? \rightarrow ^7Li_3$
A) an alpha particle B) an electron C) a neutron D) a proton

7. The following equation is an example of what kind of nuclear reaction

$$^{235}U_{92} + ^1n_0 \rightarrow ^{133}Sb_{51} + ^{99}Nb_{41} + 4\ (^1n_0)$$

A) fission B) fusion C) alpha decay D) beta decay

8. The following equation is an example of what kind of nuclear reaction

$$^{12}C_6 + {}^{4}He_2 \rightarrow {}^{16}O_8 + \text{energy}$$

A) fission B) fusion C) alpha decay D) beta decay

9. A nucleus of $^{235}U_{92}$ disintegrates to $^{207}Pb_{82}$ in about a billion years by emitting 7 alpha particles and x beta particles, where x is
A) 3 B) 4 C) 5 D) 6

10. The following nuclear reaction occurs:
$^{4}_{2}He + {}^{9}_{4}Be \rightarrow {}^{12}_{6}C + {}^{A}_{Z}X$. What is $^{A}_{Z}X$ ?

A) a proton B) an electron C) a positron D) a neutron

11. A scientist claims to have perfected a technique in which he can spontaneously convert an electron completely into energy in the laboratory without any other material required. What is the conclusion about this claim from our current understanding of physics?
A) This is possible because Einstein's equation says that mass and energy are equivalent… it is just very difficult to achieve with electrons
B) This is possible and it is done all the time in the high-energy physics labs.
C) The scientist is almost correct… except that in converting the electron to energy, an electron's anti-particle is produced in the process as well.
D) This is not possible because charge conservation would be violated.

12. The most common isotope of Uranium, $^{238}U_{92}$, radioactively decays into lead, $^{206}Pb_{82}$, by a means of a series of alpha and beta particle emissions. How many of each particle must be emitted.
A) 16 alphas, 16 betas B) 16 alphas, 8 betas C) 8 alphas, 6 betas D) 4 alphas, 18 betas

13. Rutherford was the first person to artificially transmute one element into another (nitrogen to oxygen). A nuclear equation for his reaction could be written as follows:

$$\frac{4}{2}He + \frac{14}{7}N \rightarrow \frac{17}{8}O + ?$$

The unknown particle in the above equation is
A) a proton B) a neutron C) an electron D) an alpha particle

14. A nucleus of polonium–218 ($\frac{218}{84}Po$) emits an alpha particle ($\frac{4}{2}\alpha$). The next two elements in radioactive decay chain each emit a beta particle ($\frac{0}{-1}B^{-}$). What would be the resulting nucleus after these three decays have occurred?

A) $\frac{214}{82}Pb$ B) $\frac{214}{84}Po$ C) $\frac{214}{85}At$ D) $\frac{222}{86}Rn$

15. $^{235}_{92}U + {}^{1}_{0}n \rightarrow 3{}^{1}_{0}n + {}^{142}_{56}Ba + \_\_\_\_\_$

The additional product of the nuclear fission reaction shown above is
A) $^{91}_{36}Kr$ B) $^{92}_{35}Br$ C) $^{93}_{36}Kr$ D) $^{93}_{37}Rb$

16. The nuclide $^{214}Pb_{82}$ emits an electron and becomes nuclide X. Which of the following gives the mass number and atomic number of nuclide X?

| | Mass Number | Atomic Number |
|---|---|---|
| A) | 210 | 80 |
| B) | 213 | 83 |
| C) | 214 | 81 |
| D) | 214 | 83 |

17. The nuclear reaction X → Y + Z occurs spontaneously. If $M_x$, $M_Y$, and $M_Z$ are the masses of the three particles. which of the following relationships is true'?
A) $M_x < M_y + M_z$ B) $M_x > M_y + M_z$ C) $M_x - M_y < M_z$ D) $M_x - M_z < M_y$

$$^2_1H + ^2_1H \rightarrow ^3_1H + ^1_1H + 4MeV$$

18. The equation above is an illustration of
A) artificially produced radioactive decay B) naturally occurring radioactive decay
C) nuclear fission D) nuclear fusion

19. A proton collides with a nucleus of $^{14}_7N$. If this collision produces a nucleus of $^{11}_6C$ and one other particle, that particle is _____ .
A) a proton B) a neutron C) an alpha particle D) a beta particle

20. A nucleus of tritium contains 2 neutrons and 1 proton. If the nucleus undergoes beta decay, emitting an electron, the nucleus is transmuted into
A) the nucleus of an isotope of helium B) the nucleus of an isotope of lithium
C) an alpha particle D) a triton

21. Which of the following statements is true of a beta particle?
A) Its speed in a vacuum is 3 x $10^8$ m/s.
B) It is more penetrating than a gamma ray of the same energy.
C) It has a mass of about 1,840 times that of a proton.
D) It can exhibit wave properties.

Questions 22-23
An electron and a positron, each of mass 9.1 x $10^{-31}$ kilogram, are in the same general vicinity and have very small initial speeds. They then annihilate each other, producing two photons.

22. What is the approximate energy of each emerging photon?
A) 0.51 MeV B) 2.0 MeV C) 4.0 MeV
DE) It cannot be determined unless the frequency of the photon is known.

23. What is the angle between the paths of the emerging photons?
(A) 0° B) 45° C) 90° D) 180°

Questions 24-25 Refer to the following reaction:

$$^{235}_{92}U + ^1_0n \rightarrow ^{138}_{56}Ba + ^{95}_{36}Kr + neutrons + released\ energy$$

24. The total number of free neutrons in the products of this reaction is
A) 2 B) 3 C) 4 D) 5

25. Which of the following statements is always true for neutron-induced fission reactions involving $^{235}_{92}U$ ?
I. The end products always include Ba and Kr.
II. The rest mass of the end products is less than that of $^{235}_{92}U + ^1_0n$ .
III. The total number of nucleons (protons plus neutrons) in the end products is less than that in $^{235}_{92}U + ^1_0n$ .
A) II only B) III only C) I and II only D) I and III only

26. Force magnitudes between two objects which are inversely proportional to the square of the distance between the objects include which of the following?

I. Gravitational force between two celestial bodies
II. Electrostatic force between two electrons
III. Nuclear force between two neutrons

A) I only B) III only C) I and II only D) II and III only

27. Quantities that are conserved in all nuclear reactions include which of the following?

I. Electric charge
II. Number of nuclei
III. Number of protons

A) I only B) II only C) I and III only D) II and III only

28. A negative beta particle and a gamma ray are emitted during the radioactive decay of a nucleus of ${}^{214}_{82}Pb$. Which of the following is the resulting nucleus?

A) ${}^{210}_{80}Hg$ B) ${}^{214}_{81}Tl$ C) ${}^{213}_{83}Bi$ D) ${}^{214}_{83}Bi$

29. When ${}^{10}$B is bombarded by neutrons, a neutron can be absorbed and an alpha particle (${}^{4}$He) emitted. If the ${}^{10}$B target is stationary, the kinetic energy of the reaction products is equal to the.

A) kinetic energy of the incident neutron
B) total energy of the incident neutron
C) energy equivalent of the mass decrease in the reaction
D) energy equivalent of the mass decrease in the reaction plus the kinetic energy of the incident neutron

30. ${}^{226}_{88}\mathrm{Ra}$ decays into ${}^{222}_{86}\mathrm{Rn}$ plus

A) a proton B) a neutron C) an electron D) a helium nucleus $\left({}^{4}_{2}\mathrm{He}\right)$

31. Correct statements about the binding energy of a nucleus include which of the following?

I. It is the energy needed to separate the nucleus into its individual protons and neutrons.
II. It is the energy liberated when the nucleus is formed from the original nucleons.
III. It is the energy equivalent of the apparent loss of mass of its nucleon constituents.

A) I only
B) III only
C) I and II only
D) I, II, and III