1. A problem with the classical theory for radiation from a blackbody was that the theory predicted too much radiation in the ________________ wavelengths.
   A. ultraviolet
   B. visible
   C. infrared
   D. microwave
   E. radio

2. _______________ theoretical assumptions on quantization overcame the difficulty with a major problem with understanding blackbody radiation.
   A. Hertz's
   B. Planck's
   C. Einstein's
   D. Maxwell's
   E. Bohr's

3. Using the quantum theory of EM waves, ___________ was successful in explaining the photoelectric effect. (He later won a Nobel Prize for this work.)
   A. Hertz
   B. Planck
   C. Einstein
   D. Maxwell
   E. Bohr

4. The energy of a photon of wavelength 400 nm is _______________.
   A. $3.11 \times 10^{-19}$ J
   B. $3.50 \times 10^{-19}$ J
   C. $3.87 \times 10^{-19}$ J
   D. $4.25 \times 10^{-19}$ J
   E. $4.97 \times 10^{-19}$ J
5. An x-ray photon of energy $3.20 \times 10^{-15}$ J has what wavelength?

A. 200 nm  
B. 62.1 pm  
C. 32.7 nm  
D. 5.73 pm  
E. 1.07 nm

6. A photon of frequency $6.40 \times 10^{14}$ Hz has what energy?

A. 1.26 eV  
B. 1.93 eV  
C. 2.11 eV  
D. 2.65 eV  
E. 3.17 eV

7. A 2.00 eV photon has what frequency?

A. $6.40 \times 10^{14}$ Hz  
B. $1.86 \times 10^{14}$ Hz  
C. $3.15 \times 10^{14}$ Hz  
D. $7.21 \times 10^{14}$ Hz  
E. $4.83 \times 10^{14}$ Hz

8. Photons from a source each have energy 3.30 eV. Photons from a second source have double the frequency of those from the first source. What is the energy of a photon from the second source?

A. 6.60 eV  
B. 13.2 eV  
C. 1.65 eV  
D. 0.825 eV  
E. 3.96 eV
9. A 1.00 mW laser produces photons of wavelength 633 nm. How many photons per second does the laser emit?

A. $6.33 \times 10^{10}$
B. $1.27 \times 10^{12}$
C. $3.18 \times 10^{15}$
D. $4.28 \times 10^{16}$
E. $1.60 \times 10^{19}$

11. In a photoelectric effect experiment, the frequency of photons bombarding the surface is increased until photoelectrons just start to leave the surface. If this occurs at a frequency of $6.0 \times 10^{14}$ Hz, what is the work function of the surface?

A. 1.0 eV
B. 1.5 eV
C. 2.0 eV
D. 2.5 eV
E. 3.0 eV

12. Photons of red light cause a surface to emit photoelectrons with maximum kinetic energy $K_{\text{red}}$. If photons of blue light of the same intensity are now used in the experiment, which of the following statements is true about the photoelectrons emitted (if any are emitted)?

A. No photoelectrons are emitted.
B. Maximum $K_{\text{blue}} < K_{\text{red}}$.
C. Maximum $K_{\text{blue}} = K_{\text{red}}$.
D. Maximum $K_{\text{blue}} > K_{\text{red}}$.
E. None of the choices is true.

13. Sodium has a work function of 2.46 eV. Of the following wavelengths, which is the one of the longest wavelength that could cause photoelectrons to be released from the sodium?

A. 300 nm
B. 400 nm
C. 500 nm
D. 600 nm
E. 700 nm
15. The work function of a surface is $6.53 \times 10^{-19}$ J. What is this quantity in eV?

A. 2.46  
B. 3.13  
C. 3.93  
D. 4.08  
E. 4.70

16. What is the threshold frequency for a surface with work function 4.14 eV?

A. $1.00 \times 10^{12}$ Hz  
B. $1.00 \times 10^{13}$ Hz  
C. $1.00 \times 10^{14}$ Hz  
D. $1.00 \times 10^{15}$ Hz  
E. $1.00 \times 10^{16}$ Hz

18. Light of wavelength 400 nm bombards a surface with work function 2.46 eV. What is the maximum kinetic energy of the photoelectrons from this surface?

A. No photoelectrons are emitted.  
B. 2.46 eV  
C. 3.30 eV  
D. 0.640 eV  
E. 0.840 eV

20. Monochromatic light shines on a surface with work function 1.80 eV. The maximum energy of the emitted photoelectrons is 0.620 eV. What is the wavelength of the monochromatic light?

A. 200 nm  
B. 290 nm  
C. 689 nm  
D. 602 nm  
E. 512 nm
21. Electrons are accelerated through a potential difference of 90.0 kV and directed at a tungsten target to produce x-rays. What is the shortest wavelength of the x-rays produced?

A. 669 pm  
B. 508 pm  
C. 72.6 pm  
D. 13.8 pm  
E. 14.3 pm

22. Electrons are accelerated through a potential difference of 90.0 kV and directed at a tungsten target to produce x-rays. What is the cutoff frequency in the x-ray spectrum produced?

A. $2.17 \times 10^{19}$ Hz  
B. $2.10 \times 10^{19}$ Hz  
C. $1.17 \times 10^{21}$ Hz  
D. $9.25 \times 10^{21}$ Hz  
E. $6.20 \times 10^{15}$ Hz

23. An x-ray tube produces photons down to a 0.0827 nm wavelength. What is the accelerating potential for this tube?

A. 123 kV  
B. 9.22 kV  
C. 8.00 kV  
D. 10.0 kV  
E. 15.0 kV

24. The Compton shift equation for the wavelength shift is derived from the law(s) of:

A. conservation of momentum.  
B. conservation of energy.  
C. conservation of charge.  
D. conservation of momentum and charge.  
E. conservation of energy and momentum.

25. The maximum shift in wavelength in Compton scattering is what multiple of the Compton wavelength ($h/m_\text{s}s$)?

A. 0.5  
B. 1  
C. 2  
D. 4  
E. unlimited
26. An x-ray photon with wavelength 15.0 pm is scattered at 84.0° by an electron. What is the wavelength of the scattered photon?

A. 31.0 pm  
B. 14.9 pm  
C. 1.57 pm  
D. 17.2 pm  
E. 12.8 pm

27. An x-ray photon with wavelength 15.0 pm is scattered at 84.0° by an electron. What is the resulting kinetic energy of the electron?

A. 568 keV  
B. 59.5 keV  
C. 30.1 keV  
D. 15.0 keV  
E. 10.5 keV

28. In a Compton scattering experiment, the scattered photon has a wavelength of 6.55 pm. If the scattering angle is 50°, what is the wavelength of the incident photon?

A. 5.68 pm  
B. 7.42 pm  
C. 3.28 pm  
D. 0.868 pm  
E. 2.43 pm

31. In the formula $1/\lambda = R(1/n_f^2 - 1/n_i^2)$, Balmer found that for the visible lines in hydrogen that $n_f =$ _______.

A. 1  
B. 2  
C. 3  
D. 4  
E. 5
34. The orbits of the electron in the Bohr model of the hydrogen atom are those in which the electron's _______________ is quantized in integral multiples of $h/2\pi$.

A. kinetic energy  
B. potential energy  
C. total energy  
D. linear momentum  
E. angular momentum

35. The radius of the Bohr orbit for hydrogen with $n = 3$ is ______ time(s) that for the orbit with $n = 1$.

A. 1/3  
B. 3  
C. 6  
D. 9  
E. 18

39. What is the wavelength of a photon emitted when an electron in hydrogen goes from the $n = 4$ state to the $n = 1$ state?

A. 323 nm  
B. 156 nm  
C. 121 nm  
D. 103 nm  
E. 97.3 nm

40. A photon that is emitted during a transition in hydrogen from the $n = 27$ state to the $n = 2$ state is in which of the following series?

A. Lyman  
B. Balmer  
C. Paschen  
D. Brackett  
E. All of the choices are correct.

41. For the ion He$^+$, what is the energy of the ground state?

A. -13.6 eV  
B. -27.2 eV  
C. -54.4 eV  
D. -6.80 eV  
E. -3.40 eV
42. What is the energy of a photon emitted in a transition from the \( n = 3 \) state to the \( n = 2 \) state in He\(^+\)?

A. 15.1 eV  
B. 7.56 eV  
C. 3.78 eV  
D. 2.12 eV  
E. 1.89 eV

44. What is the ionization energy of the hydrogen atom in the \( n = 2 \) state?

A. 13.6 eV  
B. -13.6 eV  
C. 3.40 eV  
D. -3.40 eV  
E. -1.51 eV

45. The minimum energy that a photon must have to undergo pair production is:

A. 0.511 MeV.  
B. 1.022 MeV.  
C. 2.044 MeV.  
D. 0.256 MeV.  
E. any amount more than zero.