Questions

1. Does a lightbulb at a temperature of 2500 K produce as white a light as the Sun at 6000 K? Explain.

2. If energy is radiated by all objects, why can we not see them in the dark? (See also Section 14-8.)

3. What can be said about the relative temperatures of whitish-yellow, reddish, and bluish stars? Explain.

4. Darkrooms for developing black-and-white film were sometimes lit by a red bulb. Why red? Explain if such a bulb would work in a darkroom for developing color film.

5. If the threshold wavelength in the photoelectric effect increases when the emitting metal is changed to a different metal, what can you say about the work functions of the two metals?

6. Explain why the existence of a cutoff frequency in the photoelectric effect more strongly favors a particle theory rather than a wave theory of light.

7. UV light causes sunburn, whereas visible light does not. Suggest a reason.

8. The work functions for sodium and cesium are 2.28 eV and 2.14 eV, respectively. For incident photons of a given frequency, which metal will give a higher maximum kinetic energy for the electrons? Explain.

9. Explain how the photoelectric circuit of Fig. 27-6 could be used in (a) a burglar alarm, (b) a smoke detector, (c) a photographic light meter.

10. (a) Does a beam of infrared photons always have less energy than a beam of ultraviolet photons? Explain. (b) Does a single photon of infrared light always have less energy than a single photon of ultraviolet light? Why?

11. Light of 450-nm wavelength strikes a metal surface, and a stream of electrons emerges from the metal. If light of the same intensity but of wavelength 400 nm strikes the surface, are more electrons emitted? Does the energy of the emitted electrons change? Explain.

12. If an X-ray photon is scattered by an electron, does the photon's wavelength change? If so, does it increase or decrease? Explain.

13. In both the photoelectric effect and in the Compton effect, a photon collides with an electron causing the electron to fly off. What is the difference between the two processes?

14. Why do we say that light has wave properties? Why do we say that light has particle properties?

15. Why do we say that electrons have wave properties? Why do we say that electrons have particle properties?

16. What are the differences between a photon and an electron? Be specific; make a list.

17. If an electron and a proton travel at the same speed, which has the shorter wavelength? Explain.

18. An electron and a proton are accelerated through the same voltage. Which has the longer wavelength? Explain why.

19. In Rutherford's planetary model of the atom, what keeps the electrons from flying off into space?

20. When a wide spectrum of light passes through hydrogen gas at room temperature, absorption lines are observed that correspond only to the Lyman series. Why don't we observe the other series?

21. How can you tell if there is oxygen near the surface of the Sun?

22. (a) List at least three successes of the Bohr model of the atom, according to Section 27-12. (b) List at least two observations that the Bohr model could not explain, according to Section 27-13.

23. According to Section 27-11, what were the two main difficulties of the Rutherford model of the atom?

24. Is it possible for the de Broglie wavelength of a "particle" to be greater than the dimensions of the particle? To be smaller? Is there any direct connection? Explain.

25. How can the spectrum of hydrogen contain so many lines when hydrogen contains only one electron?

26. Explain how the closely spaced energy levels for hydrogen near the top of Fig. 27-29 correspond to the closely spaced spectral lines at the top of Fig. 27-24.

27. In a helium atom, which contains two electrons, do you think that on average the electrons are closer to the nucleus or farther away than in a hydrogen atom? Why?

28. The Lyman series is brighter than the Balmer series, because this series of transitions ends up in the most common state for hydrogen, the ground state. Why then was the Balmer series discovered first?

29. Use conservation of momentum to explain why photons emitted by hydrogen atoms have slightly less energy than that predicted by Eq. 27-10.

30. State if a continuous or a line spectrum is produced by each of the following: (a) a hot solid object; (b) an excited, rarefied gas; (c) a hot liquid; (d) light from a hot solid that passes through a cooler rarefied gas; (e) a hot dense gas. For each, if a line spectrum is produced, is it an emission or an absorption spectrum?

31. Suppose we obtain an emission spectrum for hydrogen at very high temperature (when some of the atoms are in excited states), and an absorption spectrum at room temperature, when all atoms are in the ground state. Will the two spectra contain identical lines?
1. Which of the following statements is true regarding how blackbody radiation changes as the temperature of the radiating object increases?  
   (a) Both the maximum intensity and the peak wavelength increase.  
   (b) The maximum intensity increases, and the peak wavelength decreases.  
   (c) Both the maximum intensity and the peak wavelength decrease.  
   (d) The maximum intensity decreases, and the peak wavelength increases.

2. As red light shines on a piece of metal, no electrons are released. When the red light is slowly changed to shorter-wavelength light (basically progressing through the rainbow), nothing happens until yellow light shines on the metal, at which point electrons are released from the metal. If this metal is replaced with a metal having a higher work function, which light would have the best chance of releasing electrons from the metal?  
   (a) Blue.  
   (b) Red.  
   (c) Yellow would still work fine.  
   (d) We need to know more about the metals involved.

3. A beam of red light and a beam of blue light have equal intensities. Which statement is true?  
   (a) There are more photons in the blue beam.  
   (b) There are more photons in the red beam.  
   (c) Both beams contain the same number of photons.  
   (d) The number of photons is not related to intensity.

4. Which of the following is necessarily true?  
   (a) Red light has more energy than violet light.  
   (b) Violet light has more energy than red light.  
   (c) A single photon of red light has more energy than a single photon of violet light.  
   (d) A single photon of violet light has more energy than a single photon of red light.  
   (e) None of the above.  
   (f) A combination of the above (specify).

5. If a photon of energy $E$ ejects electrons from a metal with kinetic energy $KE$, then a photon with energy $E/2$  
   (a) will eject electrons with kinetic energy $KE/2$.  
   (b) will eject electrons with an energy greater than $KE/2$.  
   (c) will eject electrons with an energy less than $KE/2$.  
   (d) might not eject any electrons.

6. If the momentum of an electron were doubled, how would its wavelength change?  
   (a) No change.  
   (b) It would be halved.  
   (c) It would double.  
   (d) It would be quadrupled.  
   (e) It would be reduced to one-fourth.

7. Which of the following can be thought of as either a wave or a particle?  
   (a) Light.  
   (b) An electron.  
   (c) A proton.  
   (d) All of the above.

8. When you throw a baseball, its de Broglie wavelength is  
   (a) the same size as the ball.  
   (b) about the same size as an atom.  
   (c) about the same size as an atom's nucleus.  
   (d) much smaller than the size of an atom's nucleus.

9. Electrons and photons of light are similar in that  
   (a) both have momentum given by $h/\lambda$.  
   (b) both exhibit wave–particle duality.  
   (c) both are used in diffraction experiments to explore structure.  
   (d) All of the above.  
   (e) None of the above.

10. In Rutherford's famous set of experiments described in Section 27–10, the fact that some alpha particles were deflected at large angles indicated that (choose all that apply)  
    (a) the nucleus was positive.  
    (b) charge was quantized.  
    (c) the nucleus was concentrated in a small region of space.  
    (d) most of the atom is empty space.  
    (e) None of the above.

11. Which of the following electron transitions between two energy states $(n)$ in the hydrogen atom corresponds to the emission of a photon with the longest wavelength?  
    (a) $2 \rightarrow 5$.  
    (b) $5 \rightarrow 2$.  
    (c) $5 \rightarrow 8$.  
    (d) $8 \rightarrow 5$.

12. If we set the potential energy of an electron and a proton to be zero when they are an infinite distance apart, then the lowest energy a bound electron in a hydrogen atom can have is  
    (a) 0.  
    (b) $-13.6 \text{ eV}$.  
    (c) any possible value.  
    (d) any value between $-13.6 \text{ eV}$ and 0.

13. Which of the following is the currently accepted model of the atom?  
    (a) The plum-pudding model.  
    (b) The Rutherford atom.  
    (c) The Bohr atom.  
    (d) None of the above.

14. Light has all of the following except:  
    (a) mass.  
    (b) momentum.  
    (c) kinetic energy.  
    (d) frequency.  
    (e) wavelength.
Problems

27-1 Discovery of the Electron

1. (I) What is the value of $e/m$ for a particle that moves in a circle of radius 14 mm in a 0.86-T magnetic field if a perpendicular 640-V/m electric field will make the path straight?

2. (II) (a) What is the velocity of a beam of electrons that go undeflected when passing through crossed (perpendicular) electric and magnetic fields of magnitude $1.88 \times 10^4$ V/m and $2.60 \times 10^{-3}$ T, respectively? (b) What is the radius of the electron orbit if the electric field is turned off?

3. (II) An oil drop whose mass is $2.8 \times 10^{-15}$ kg is held at rest between two large plates separated by 1.0 cm (Fig. 27-3), when the potential difference between the plates is 340 V. How many excess electrons does this drop have?

27-2 Blackbodies: Planck’s Quantum Hypothesis

4. (I) How hot is a metal being welded if it radiates most strongly at 520 nm?

5. (I) Estimate the peak wavelength for radiation emitted from (a) ice at 0°C, (b) a floodlamp at 3100 K, and (c) helium at 4 K, assuming blackbody emission. In what region of the EM spectrum is each?

6. (I) (a) What is the temperature if the peak of a blackbody spectrum is at 18.0 nm? (b) What is the wavelength at the peak of a blackbody spectrum if the body is at a temperature of 2200 K?

7. (I) An HCl molecule vibrates with a natural frequency of $8.1 \times 10^{12}$ Hz. What is the difference in energy (in joules and electron volts) between successive values of the oscillation energy?

8. (II) The steps of a flight of stairs are 20.0 cm high (vertically). If a 62.0-kg person stands on both feet on the same step, what is the gravitational potential energy of this person, relative to the ground, on (a) the first step, (b) the second step, (c) the third step, (d) the nth step? (e) What is the change in energy as the person descends from step 6 to step 2?

9. (II) Estimate the peak wavelength of light emitted from the pupil of the human eye (which approximates a blackbody) assuming normal body temperature.

27-3 and 27-4 Photons and the Photoelectric Effect

10. (I) What is the energy of photons (joules) emitted by a 91.7-MHz FM radio station?

11. (I) What is the energy range (in joules and eV) of photons in the visible spectrum, of wavelength 400 nm to 750 nm?

12. (I) A typical gamma ray emitted from a nucleus during radioactive decay may have an energy of 320 keV. What is its wavelength? Would we expect significant diffraction of this type of light when it passes through an everyday opening, such as a door?

13. (I) Calculate the momentum of a photon of yellow light of wavelength 5.80 $\times 10^{-7}$ m.

14. (I) What is the momentum of a $\lambda = 0.014$ nm X-ray photon?

15. (I) For the photoelectric effect, make a table that shows expected observations for a particle theory of light and for a wave theory of light. Circle the actual observed effects.

(See Section 27-3.)

16. (II) About 0.1 eV is required to break a “hydrogen bond” in a protein molecule. Calculate the minimum frequency and maximum wavelength of a photon that can accomplish this.

17. (II) What minimum frequency of light is needed to eject electrons from a metal whose work function is $4.8 \times 10^{-19}$ J?

18. (II) The human eye can respond to as little as $10^{-18}$ J of light energy. For a wavelength of the peak of visual sensitivity, 550 nm, how many photons lead to an observable flash?

19. (II) What is the longest wavelength of light that will emit electrons from a metal whose work function is 2.90 eV?

20. (I) The work functions for sodium, cesium, copper, and iron are 2.5, 2.1, 4.7, and 4.5 eV, respectively. Which of these metals will not emit electrons when visible light shines on it?

21. (II) In a photoelectric-effect experiment it is observed that no current flows unless the wavelength is less than 550 nm. (a) What is the work function of this material? (b) What stopping voltage is required if light of wavelength 400 nm is used?

22. (II) What is the maximum kinetic energy of electrons ejected from barium ($\theta = 2.48$ eV) when illuminated by white light, $\lambda = 400$ to 750 nm?

23. (II) Barium has a work function of 2.48 eV. What is the maximum kinetic energy of electrons if the metal is illuminated by UV light of wavelength 365 nm? What is their speed?

24. (II) When UV light of wavelength 235 nm falls on a metal surface, the maximum kinetic energy of emitted electrons is 1.40 eV. What is the work function of the metal?

25. (II) The threshold wavelength for emission of electrons from a given surface is 340 nm. What will be the maximum kinetic energy of ejected electrons when the wavelength is changed to (a) 280 nm, (b) 360 nm?

26. (II) A certain type of film is sensitive only to light whose wavelength is less than 630 nm. What is the energy (eV and kcal/mol) needed for the chemical reaction to occur which causes the film to change?

27. (II) When 250-nm light falls on a metal, the current through a photoelectric circuit (Fig. 27-6) is brought to zero at a stopping voltage of 1.64 V. What is the work function of the metal?

28. (II) In a photoelectric experiment using a clean sodium surface, the maximum energy of the emitted electrons was measured for a number of different incident frequencies, with the following results.

<table>
<thead>
<tr>
<th>Frequency ($\times 10^{14}$ Hz)</th>
<th>Energy (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.8</td>
<td>2.60</td>
</tr>
<tr>
<td>10.6</td>
<td>2.11</td>
</tr>
<tr>
<td>10.9</td>
<td>1.81</td>
</tr>
<tr>
<td>9.1</td>
<td>1.47</td>
</tr>
<tr>
<td>8.2</td>
<td>1.10</td>
</tr>
<tr>
<td>6.9</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Plot the graph of these results and find: (a) Planck's constant; (b) the cutoff frequency of sodium; (c) the work function.

29. (II) Show that the energy $E$ (in electron volts) of a photon whose wavelength is $\lambda$ (nm) is given by

$$E = \frac{1.24 \times 10^3 \text{ eV} \cdot \text{nm}}{\lambda \text{ (nm)}}$$

Use at least 4 significant figures for values of $h$, $c$, $e$ (see inside front cover).

*27-5 Compton Effect

*30. (I) A high-frequency photon is scattered off of an electron and experiences a change of wavelength of $1.7 \times 10^{-4}$ nm. At what angle must a detector be placed to detect the scattered photon (relative to the direction of the incoming photon)?
27-9 Electron Microscope

47. What voltage is needed to produce electron wavelengths of 0.26 nm? (Assume that the electrons are nonrelativistic.)

48. Electrons are accelerated by 2850 V in an electron microscope. Estimate the maximum possible resolution of the microscope.

27-11 and 27-12 Spectra and the Bohr Model

49. (I) For the three hydrogen transitions indicated below, with n being the initial state and n' being the final state, is the transition an absorption or an emission? Which is higher, the initial state energy or the final state energy of the atom? Finally, which of these transitions involves the largest energy photon? (a) n = 1, n' = 3; (b) n = 6, n' = 2; (c) n = 4, n' = 5.

50. (I) How much energy is needed to ionize a hydrogen atom in the n = 3 state?

51. (I) The second longest wavelength in the Paschen series in hydrogen (Fig. 27-29) corresponds to what transition?

52. (I) Calculate the ionization energy of doubly ionized lithium, LiIII, which has Z = 3 (and is in the ground state).

53. (I) Determine the wavelength of the second Balmer line (n = 4 to n = 2 transition) using Fig. 27-29. Determine likewise the wavelength of the second Lyman line and the wavelength of the third Balmer line.

54. (I) Evaluate the Rydberg constant R using the Bohr model (compare Eqs. 27-9 and 27-16) and show that its value is

55. (I) What is the longest wavelength light capable of ionizing a hydrogen atom in the ground state?

56. (I) What wavelength photon would be required to ionize a hydrogen atom in the ground state and give the ejected electron a kinetic energy of 11.5 eV?

57. (II) In the Sun, an ionized helium (HeI) atom makes a transition from the n = 6 state to the n = 2 state, emitting a photon. Can that photon be absorbed by hydrogen atoms present in the Sun? If so, between what energy states will the hydrogen atom transition occur?

58. (II) Construct the energy-level diagram for the HeI ion (like Fig. 27-29).

59. (II) Construct the energy-level diagram for doubly ionized lithium, LiIII.

60. (II) Determine the electrostatic potential energy and the kinetic energy of an electron in the ground state of the hydrogen atom.

61. (II) A hydrogen atom has an angular momentum of 5.273 × 10⁻³⁴ kg·m²/s. According to the Bohr model, what is the energy (eV) associated with this state?

62. (II) An excited hydrogen atom could, in principle, have a radius of 1.00 cm. What would be the value of n for a Bohr orbit of this size? What would its energy be?

63. (II) Is the use of nonrelativistic formulas justified in the Bohr atom? To check, calculate the electron's velocity, v, in terms of a, for the ground state of hydrogen, and then calculate

64. (II) Show that the magnitude of the electrostatic potential energy of an electron in any Bohr orbit of a hydrogen atom is twice the magnitude of its kinetic energy in that orbit.

65. (II) Suppose an electron was bound to a proton, as in the hydrogen atom, but by the gravitational force rather than by the electric force. What would be the radius, and energy, of the first Bohr orbit?