CHAPTER 27: Early Quantum Theory and Models of the Atom

Answers to Questions

1. Bluish stars are the hottest, whitish-yellow stars are hot, and reddish stars are the coolest. This follows from Wien's law, which says that stars with the shortest wavelength peak in their spectrum have the highest temperatures.

2. The difficulty with seeing objects in the dark is that although all objects emit radiation, only a small portion of the electromagnetic spectrum can be detected by our eyes. Usually objects are so cool that they only give off very long wavelengths of light (infrared), which are too long for our eyes to detect.

3. No. The bulb, which is at a cooler temperature, has a redder tint to it than that of the hotter Sun. Wien's law says that the peak wavelength in the spectrum of emitted light is much longer for the cooler object, which makes it redder.

4. The red bulb used in black-and-white film dark rooms is a very "cool" filament, thus it does not emit much radiation at all in the range of visible wavelengths (and the small amount that it does emit in the visible region is not very intense), which means it will not develop the black-and-white film while still allowing a person to see what's going on. A red bulb will not work very well in a dark room that is used for color film. It will expose and develop the film during the process, especially at the red end of the spectrum, ruining the film.

5. Since the wavelength and the frequency of light are inversely proportional, and since the threshold wavelength of the light used in the photoelectric effect increased for the second metal, this means the frequency of incident light decreased for the second metal, which means that the work function of the second metal is smaller than the first metal. In other words, it is easier to knock the electrons out of the second metal, thus it has a smaller work function.

6. The wave theory of light predicts that if you use a very low frequency beam of light, but a very intense beam, eventually you would be able to eject electrons from the surface of a metal, as more and more energy is added to the metal. The fact that there is a cutoff frequency favors the particle theory of light, since it predicts that below a certain cutoff frequency of the incident beam of light that the metal will never eject an electron no matter how high the intensity of the beam. Experiments have conclusively shown that a cutoff frequency does exist, which strongly supports the particle theory of light.

7. UV light causes sunburns and visible light does not due to the higher frequency and energy carried by the UV photons. The UV photons can penetrate farther into the skin and once they are at this deeper level they can deposit a large amount of energy that can ionize atoms/molecules and cause damage to cells.

8. Yes, an X-ray photon that scatters from an electron does have its wavelength changed. The photon gives some of its energy to the electron during the collision and the electron recoils slightly. Thus, the photon's energy is less and its wavelength is longer after the collision, since the energy and wavelength are inversely proportional to each other $\left(E = hv = hc/\lambda\right)$.

9. In the photoelectric effect, the photons have only a few eV of energy, whereas in the Compton Effect, the photons have more than 1000 times greater energy and a correspondingly smaller wavelength. Also,

in the photoelectric effect, the incident photons kick electrons completely out of the material and the photons are absorbed in the material while the electrons are detected and studied, whereas in the Compton Effect, the incident photons just knock the electrons out of their atoms (but not necessarily out of the material) and then the photons are detected and studied.

10. (*a*) The energy of the light wave is spreading out spherically from the point source and the surface of this sphere is getting bigger as $4\pi r^2$. Thus, the intensity (energy/area) is decreasing proportionally as $1/r^2$.
    (*b*) As the particles are emitted from the point source in all directions, they spread out over a spherical surface that gets bigger as $4\pi r^2$. Thus, the intensity (number of particles/area) also decreases proportionally as $1/r^2$.
    Based on the above comments, we cannot use intensity of light from a point source to distinguish between the two theories.

11. (*a*) If a light source, such as a laser (especially an invisible one), was focused on a photocell in such a way that as a burglar opened a door or passed through a window that the beam was blocked from reaching the photocell, a burglar alarm could be triggered when the current in the ammeter went to 0 Amps.
    (*b*) If a light source was focused on a photocell in a smoke detector in such a way that as the density of smoke particles in the air became thicker and thicker, more and more of the light attempting to reach the photocell would be scattered and at some set minimum level the alarm would go off.
    (*c*) Hold up the photocell in the light conditions you want to know about and then read the ammeter. As the intensity of the light goes up, the number of photoelectrons goes up and the current increases. All you need to do is calibrate the ammeter to a known intensity of light.

12. We say that light has wave properties since we see it act like a wave when it is diffracted or refracted or exhibits interference with other light. We say that light has particle properties since we see it act like a particle in the photoelectric effect and Compton scattering.

13. We say that electrons have wave properties since we see them act like a wave when they are diffracted. We say that electrons have particle properties since we see them act like particles when they are bent by magnetic fields or accelerated and fired into materials where they scatter other electrons like billiard balls.

14.

Property	Photon	Electron
Mass	None	$9.11\times10^{-31}\,\text{kg}$
Charge	None	$-1.60\times10^{-19}\,\text{C}$
Speed	$3\times10^{8}\,\text{m/s}$	$< 3\times10^{8}\,\text{m/s}$

15. If an electron and a proton travel at the same speed, the proton has a shorter wavelength. Since $\lambda = h/mv$ and the mass of the proton is 1840 times larger than the mass of the electron, when they have the same speed then the wavelength of the proton is 1840 times smaller than that of the electron.

16. In Rutherford's planetary model of the atom, the Coulomb force keeps the electrons from flying off into space. Since the protons in the center are positively charged, the negatively charged electrons are attracted to the center by the Coulomb force and orbit around the center just like the planets orbiting a sun in a solar system due to the attractive gravitational force.

17. To tell if there is oxygen near the surface of the Sun, you need to collect the light that is coming from the Sun and spread it out using a diffraction grating or prism so you can see the spectrum of wavelengths. If there is oxygen near the surface, we should be able to detect the atomic spectra (an absorption spectra) of the lines of oxygen in the spectrum.

18. Since the hydrogen gas is only at room temperature, almost all of the electrons will be in their ground state. As light excites these electrons up to higher energy levels, they all fall back down to the ground state, which is how the Lyman series is created. You need to heat up the gas to a temperature that is high enough where the electrons are in many different energy states and where they are falling down from extremely high energy states down to the mid-level energy states, which would create the other series.

19. The closely spaced energy levels in Figure 27-27 correspond to the different transitions of electrons from one energy state to another. When these transitions occur, they emit radiation that creates the closely spaced spectral lines shown in Figure 27-22.

20. It is possible for the de Broglie wavelength $(\lambda = h/p)$ of a particle to be bigger than the dimension of the particle. If the particle has a very small mass and a slow speed (like a low-energy electron or proton) then the wavelength may be larger than the dimension of the particle.

    It is also possible for the de Broglie wavelength of a particle to be smaller than the dimension of the particle if it has a large momentum and a moderate speed (like a baseball). There is no direct connection between the size of a particle and the size of the de Broglie wavelength of a particle. For example, you could also make the wavelength of a proton much smaller than the size of the proton by making it go very fast.

21. The electrons of a helium atom should be closer to their nucleus than the electrons in a hydrogen atom. This is because each of the electrons in the helium atom "sees" two positive charges at the nucleus, instead of just one positive charge for the hydrogen, and thus they are more strongly attracted.

22. Even though hydrogen only has one electron, it still has an infinite number of energy states for that one electron to occupy and each line in the spectrum represents a transition between two of those possible energy levels.

23. The Balmer series was discovered first, even though the Lyman series is brighter, because the Balmer series lines occur in the visible region of the electromagnetic spectrum. It was only later that the UV (Lyman) and IR (Paschen) regions were explored thoroughly.

24. When a photon is emitted by a hydrogen atom as the electron makes a transition from one energy state to a lower one, not only does the photon carry away energy and momentum, but to conserve momentum, the electron must also take away some momentum. If the electron carries away some momentum, then it must also carry away some of the available energy, which means that the photon takes away less energy than Equation 27-10 predicts.

25. Cesium will give a higher maximum kinetic energy for the ejected electrons. Since the incident photons bring in a given amount of energy, and in cesium less of this energy goes to releasing the electron from the material (the work function), it will give off electrons with a higher kinetic energy.

26. (*a*) No. It is possible that you could have many more IR photons in that beam than you have UV photons in the other beam. In this instance, even though each UV photon has more energy than each IR photon, the IR beam could be carrying more total energy than the UV beam.

(*b*) Yes. A single IR photon will always have less energy than a single UV photon due to the inverse relationship between wavelength and frequency (or energy) of light. The long wavelength IR photon has a lower frequency and less energy than the short wavelength UV photon.

27. No, fewer electrons are emitted, but each one is emitted with higher kinetic energy, when the 400 nm light strikes the metal surface. Since the intensity (energy per unit time) is the same, but the 400 nm photons each have more energy than the 450 nm photons, then there are fewer photons hitting the surface per unit time. This means that fewer electrons will be ejected per unit time from the surface with the 400 nm light. The maximum kinetic energy of the electrons leaving the metal surface will be greater, though, since the incoming photons have shorter wavelengths and more energy per photon and it still takes the same amount of energy (the work function) to remove each electron. This “extra” energy goes into higher kinetic energy of the ejected electrons.

28. The spectral lines of hydrogen found at room temperature will be identical to some of the lines found at high temperature, but there will be many more lines at the higher temperature. These extra lines correspond to the electrons making transitions to the higher energy excited states that are only accessible at higher temperatures.

Solutions to Problems

1. The velocity of the electron in the crossed fields is given by

$$v = \frac{E}{B}.$$

The radius of the path in the magnetic field is

$$r = \frac{mv}{eB} = \frac{mE}{eB^2}, \text{ or}$$

$$\frac{e}{m} = \frac{E}{rB^2} = \frac{(320\,\text{V/m})}{(7.0\times10^{-3}\,\text{m})(0.86\,\text{T})^2} = \boxed{6.2\times10^4\,\text{C/kg.}}$$

2. The velocity of the electron in the crossed fields is given by

$$v = \frac{E}{B} = \frac{(1.88\times10^4\,\text{V/m})}{(2.90\times10^{-3}\,\text{T})} = \boxed{6.48\times10^6\,\text{m/s.}}$$

For the radius of the path in the magnetic field, we have

$$r = \frac{mv}{qB}$$

$$= \frac{(9.11\times10^{-31}\,\text{kg})(6.48\times10^6\,\text{m/s})}{(1.60\times10^{-19}\,\text{C})(2.90\times10^{-3}\,\text{T})} = 1.27\times10^{-2}\,\text{m} = \boxed{1.27\,\text{cm.}}$$

$\boxed{3.}$ The force from the electric field must balance the weight:

$$qE = \frac{neV}{d} = mg;$$

$$\frac{n(1.60\times10^{-19}\,\text{C})(340\,\text{V})}{(1.0\times10^{-2}\,\text{m})} = (2.8\times10^{-15}\,\text{kg})(9.80\,\text{m/s}^2), \text{ which gives } n = \boxed{5.}$$

4. We find the temperature for a peak wavelength of 440 nm:

$$T=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{\lambda_{\text{P}}}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{\left(440\times10^{-9}\,\text{m}\right)}=\boxed{6.59\times10^{3}\,\text{K.}}$$

5. (*a*) We find the peak wavelength from

$$\lambda_{\text{P}}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{T}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{(273\,\text{K})}=1.06\times10^{-5}\,\text{m}=\boxed{10.6\,\mu\text{m.}}$$

This wavelength is in the near infrared.

(*b*) We find the peak wavelength from

$$\lambda_{\text{P}}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{T}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{(3500\,\text{K})}=8.29\times10^{-7}\,\text{m}=\boxed{829\,\text{nm.}}$$

This wavelength is in the infrared.

(*c*) We find the peak wavelength from

$$\lambda_{\text{P}}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{T}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{(4\,\text{K})}=7.25\times10^{-4}\,\text{m}=\boxed{0.73\,\text{mm.}}$$

This wavelength is in the microwave region.

(*d*) We find the peak wavelength from

$$\lambda_{\text{P}}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{T}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{(2.725\,\text{K})}=1.06\times10^{-2}\,\text{m}=\boxed{1.06\text{ cm.}}$$

This wavelength is in the microwave region.

6. (*a*) The temperature for a peak wavelength of 15.0 nm is

$$T=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{\lambda_{\text{P}}}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{\left(18.0\times10^{-9}\,\text{m}\right)}=\boxed{1.61\times10^{5}\,\text{K.}}$$

(*b*) We find the peak wavelength from

$$\lambda_{\text{P}}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{T}=\frac{\left(2.90\times10^{-3}\,\text{m}\bullet\text{K}\right)}{(2000\,\text{K})}=1.45\times10^{-6}\,\text{m}=\boxed{1.45\,\mu\text{m.}}$$

Note that this is not in the visible range.

7. Because the energy is quantized, $E = nhf$, the difference in energy between adjacent levels is

$$\Delta E=hf=\left(6.63\times10^{-34}\,\text{J}\bullet\text{s}\right)\left(8.1\times10^{13}\,\text{Hz}\right)=\boxed{5.4\times10^{-20}\,\text{J}=0.34\,\text{eV.}}$$

8. (*a*) The potential energy on the first step is

$$\text{PE}_1=mgh=(68.0\,\text{kg})\left(9.80\,\text{m/s}^2\right)(0.200\,\text{m})=\boxed{133\,\text{J.}}$$

(*b*) The potential energy on the second step is

$$\text{PE}_2=mg2h=2\text{PE}_1=2(133\,\text{J})=\boxed{267\,\text{J.}}$$

(*c*) The potential energy on the third step is

$$\text{PE}_3 = mg3h = 3\text{PE}_1 = 3(133\,\text{J}) = \boxed{400\,\text{J.}}$$

(*d*) The potential energy on the *n*th step is

$$\text{PE}_\text{n} = mgnh = n\text{PE}_1 = n(133\,\text{J}) = \boxed{133n\,\text{J.}}$$

(*e*) The change in energy is

$$\Delta E = \text{PE}_2 - \text{PE}_6 = (2-6)(133\,\text{J}) = \boxed{-533\,\text{J.}}$$

9. We use a body temperature of $98°\text{F} = 37°\text{C} = 310\,\text{K}$. We find the peak wavelength from

$$\lambda_\text{P} = \frac{(2.90\times10^{-3}\,\text{m}\bullet\text{K})}{T} = \frac{(2.90\times10^{-3}\,\text{m}\bullet\text{K})}{(310\,\text{K})} = 9.4\times10^{-6}\,\text{m} = \boxed{9.4\,\mu\text{m.}}$$

10. The energy of the photon is

$$E = hf = (6.63\times10^{-34}\,\text{J}\bullet\text{s})(88.5\times10^{6}\,\text{Hz}) = 5.87\times10^{-26}\,\text{J} = \boxed{3.67\times10^{-7}\,\text{eV.}}$$

11. The energy of the photons with wavelengths at the ends of the visible spectrum are

$$E_1 = hf_1 = \frac{hc}{\lambda_1} = \frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})(3.00\times10^{8}\,\text{m/s})}{(400\times10^{-9}\,\text{m})} = 5.0\times10^{-19}\,\text{J};$$

$$E_2 = hf_2 = \frac{hc}{\lambda_2} = \frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})(3.00\times10^{8}\,\text{m/s})}{(750\times10^{-9}\,\text{m})} = 2.7\times10^{-19}\,\text{J.}$$

Thus the range of energies is $\boxed{2.7\times10^{-19}\,\text{J} < E < 5.0\times10^{-19}\,\text{J}}$ or $\boxed{1.7\,\text{eV} < E < 3.1\,\text{eV.}}$

12. We find the wavelength from

$$\lambda = \frac{c}{f} = \frac{hc}{E} = \frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})(300\times10^{3}\,\text{eV})} = \boxed{4.14\times10^{-3}\,\text{nm.}}$$

Significant diffraction occurs when the opening is on the order of the wavelength. Thus there would be $\boxed{\text{insignificant diffraction}}$ through the doorway.

13. We find the minimum frequency from

$$E_\text{min} = hf_\text{min};$$

$$(0.1\text{eV})(1.60\times10^{-19}\,\text{J/eV}) = (6.63\times10^{-34}\,\text{J}\bullet\text{s})\,f_\text{min}, \text{ which gives } f_\text{min} = \boxed{2.4\times10^{13}\,\text{Hz.}}$$

The maximum wavelength is

$$\lambda_\text{max} = \frac{c}{f_\text{min}} = \frac{(3.00\times10^{8}\,\text{m/s})}{(2.4\times10^{13}\,\text{Hz})} = \boxed{1.2\times10^{-5}\,\text{m.}}$$

14. The momentum of the photon is

$$p = \frac{h}{\lambda} = \frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})}{(6.00\times10^{-7}\,\text{m})} = \boxed{1.1\times10^{-27}\,\text{kg}\bullet\text{m/s.}}$$

15. The momentum of the photon is

$$p = \frac{h}{\lambda} = \frac{(6.63\times10^{-34}\ \text{J•s})}{(0.010\times10^{-9}\ \text{m})} = \boxed{6.6\times10^{-23}\ \text{kg•m/s.}}$$

16. The energy of a single photon is

$$E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\ \text{J•s})(3.00\times10^{8}\ \text{m/s})}{(550\times10^{-9}\ \text{m})} = 3.62\times10^{-19}\ \text{J.}$$

Therefore, the number of photons required for an observable flash is calculated as

$$\frac{10^{-18}\ \text{J}}{3.62\times10^{-19}\ \text{J}} = 2.8.$$

Rounding up, we find that $\boxed{3}$ photons are required.

17. At the threshold frequency, the kinetic energy of the photoelectrons is zero, so we have

$$\text{KE} = hf - W = 0;$$

$$hf_{\text{min}} = W_0;$$

$$(6.63\times10^{-34}\ \text{J•s})\, f_{\text{min}} = 4.3\times10^{-19}\ \text{J, which gives } f_{\text{min}} = \boxed{6.5\times10^{14}\ \text{Hz.}}$$

18. At the threshold wavelength, the kinetic energy of the photoelectrons is zero, so we have

$$\text{KE} = hf - W_0 = 0;$$

$$\frac{hc}{\lambda_{\text{max}}} = W_0,\ \text{or}$$

$$\lambda_{\text{max}} = \frac{(6.63\times10^{-34}\ \text{J•s})(3.00\times10^{8}\ \text{m/s})}{(1.60\times10^{-19}\ \text{J/eV})(3.10\ \text{eV})} = \boxed{401\text{nm.}}$$

19. The photon of visible light with the maximum energy has the least wavelength:

$$hf_{\text{max}} = \frac{(1.24\times10^{3}\ \text{eV•nm})hc}{\lambda_{\text{min}}} = \frac{(6.63\times10^{-34}\ \text{J•s})(3.00\times10^{8}\ \text{m/s})}{(1.60\times10^{-19}\ \text{J/eV})(400\times10^{-9}\ \text{m})} = 3.11\ \text{eV.}$$

Electrons will not be emitted if this energy is less than the work function.
The metals with work functions greater than 3.11 eV are $\boxed{\text{copper and iron.}}$

20. (*a*) At the threshold wavelength, the kinetic energy of the photoelectrons is zero, so we have

$$\text{KE} = hf - W_0 = 0;$$

$$W_0 = \frac{hc}{\lambda_{\text{max}}} = \frac{(6.63\times10^{-34}\ \text{J•s})(3.00\times10^{8}\ \text{m/s})}{(1.60\times10^{-19}\ \text{J/eV})(570\times10^{-9}\ \text{m})} = \boxed{2.18\ \text{eV.}}$$

(*b*) The stopping voltage is the voltage that gives a potential energy change equal to the maximum kinetic energy:

$$\text{KE}_{\text{max}} = eV_0 = hf - W_0;$$

$$(1\text{e})V_0 = \left[\frac{(6.63\times10^{-34}\ \text{J•s})(3.00\times10^{8}\ \text{m/s})}{(1.60\times10^{-19}\ \text{J/eV})(400\times10^{-9}\ \text{m})}\right] - 2.18\ \text{eV} = 3.11\ \text{eV} - 2.18\ \text{eV} = 0.93\ \text{eV},$$

so the stopping voltage is $\boxed{0.93\ \text{V.}}$

21. The photon of visible light with the maximum energy has the minimum wavelength:

$$hf_{\max} = \frac{hc}{\lambda_{\min}} = \frac{(6.63\times10^{-34}\text{ J•s})(3.00\times10^{8}\text{ m/s})}{(160\times10^{-19}\text{ J/eV})(400\times10^{-9}\text{ m})} = 3.11\text{ eV}.$$

The maximum kinetic energy of the photoelectrons is

$$\text{KE}_{\max} = hf - W_0 = 3.11\text{ eV} - 2.48\text{ eV} = \boxed{0.63\text{ eV}.}$$

22. The energy of the photon is

$$E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\text{ J•s})(3.00\times10^{8}\text{ m/s})}{(1.60\times10^{-19}\text{ J/eV})(365\times10^{-9}\text{ m})} = 3.41\text{ eV}.$$

The maximum kinetic energy of the photoelectrons is

$$\text{KE}_{\max} = hf - W_0 = 3.41\text{ eV} - 2.48\text{ eV} = \boxed{0.93\text{ eV}.}$$

We find the speed from

$$\text{KE}_{\max} = \tfrac{1}{2}mv^2;$$

$$(0.93\text{ eV})(1.60\times10^{-19}\text{ J/eV}) = \tfrac{1}{2}(9.11\times10^{-31}\text{ kg})v^2,\text{ which gives } v = \boxed{5.7\times10^{5}\text{ m/s}.}$$

23. The energy of the photon is

$$hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\text{ J•s})(3.00\times10^{8}\text{ m/s})}{(1.60\times10^{-19}\text{ J/eV})(285\times10^{-9}\text{ m})} = 4.36\text{ eV}.$$

We find the work function from

$$\text{KE}_{\max} = hf - W_0;$$

$$1.40\text{ eV} = 4.36\text{ eV} - W_0,\text{ which gives } W_0 = \boxed{2.96\text{ eV}.}$$

[24.] The threshold wavelength determines the work function:

$$W_0 = \frac{hc}{\lambda_{\max}} = \frac{(6.63\times10^{-34}\text{ J•s})(3.00\times10^{8}\text{ m/s})}{(1.60\times10^{-19}\text{ J/eV})(350\times10^{-9}\text{ m})} = 3.55\text{ eV}.$$

(*a*) The energy of the photon is

$$hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\text{ J•s})(3.00\times10^{8}\text{ m/s})}{(1.60\times10^{-19}\text{ J/eV})(280\times10^{-9}\text{ m})} = 4.44\text{ eV}.$$

The maximum kinetic energy of the photoelectrons is

$$\text{KE}_{\max} = hf - W_0 = 4.44\text{ eV} - 3.54\text{ eV} = \boxed{0.90\text{ eV}.}$$

(*b*) Because the wavelength is greater than the threshold wavelength, the photon energy is less than the work function, so there will be [no ejected electrons.]

25. The energy required for the chemical reaction is provided by the photon:

$$E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\text{ J•s})(3.00\times10^{8}\text{ m/s})}{(1.60\times10^{-19}\text{ J/eV})(660\times10^{-9}\text{ m})} = \boxed{1.9\text{ eV}.}$$

Each reaction takes place in a molecule, so we have

$$E = \frac{(1.9\text{ eV/molecule})(6.02\times10^{23}\text{ molecules/mol})(1.60\times10^{-19}\text{ J/eV})}{(4186\text{ J/kcal})}$$

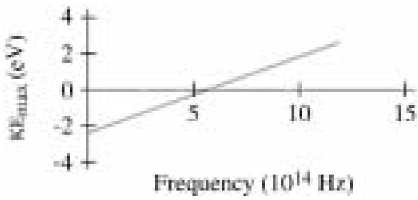
$$= \boxed{43\text{ kcal/mol}.}$$

26. The stopping voltage is the voltage that gives a potential energy change equal to the maximum kinetic energy:

$$\text{KE}_{\max} = eV_0 = hf - W_0;$$

$$(1\text{e})(1.64\,\text{V}) = \left[\frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})(230\times10^{-9}\,\text{m})}\right] - W_0, \text{ which gives } W_0 = \boxed{3.76\text{ eV.}}$$

27.



If we use linear regression to find the slope of the line (using $y = mx + b$ form), we obtain $m = 4.16\times10^{-15}\,\text{eV}\bullet\text{s}$, and for the y-intercept we obtain $b = -2.30$ eV. Comparing this to the equation for the photoelectric effect,

$$\text{KE}_{\max} = hf - W_0,$$

we find that $h = m$ and $W_0 = -b$.

(*a*) With the necessary unit conversion, $h = (4.16\times10^{-15}\,\text{eV}\bullet\text{s})(1.60\times10^{-19}\,\text{J/eV}) = \boxed{6.7\times10^{-34}\,\text{J}\bullet\text{s.}}$

(This is slightly higher than the best known value of $6.6\times10^{-34}\,\text{J}\bullet\text{s}$.)

(*b*) In the equation

$$\text{KE} = hf - W_0,$$

we set $\text{KE} = 0$ and find f:

$$0 = (4.16\times10^{-15}\,\text{eV}\bullet\text{s})\,f - (2.30\text{ eV}), \text{ which gives } f = \boxed{5.5\times10^{14}\,\text{Hz.}}$$

(*c*) $W_0 = \boxed{2.30\text{ eV.}}$

28. For the energy of the photon, we have

$$E = hf = \frac{hc}{\lambda}$$

$$= \frac{(6.626\times10^{-34}\,\text{J}\bullet\text{s})(2.998\times10^{8}\,\text{m/s})}{(1.602\times10^{-19}\,\text{J/eV})\lambda} = \frac{(1.240\times10^{-6}\,\text{eV}\bullet\text{m})}{\lambda} = \frac{1.240\times10^{3}\,\text{eV}\bullet\text{nm}}{\lambda(\text{nm})}$$

29. (*a*) $$\frac{h}{m_0c} = \frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})}{(9.11\times10^{-31}\,\text{kg})(3.00\times10^{8}\,\text{m/s})} = \boxed{2.43\times10^{-12}\,\text{m.}}$$

(*b*) $$\frac{h}{m_0c} = \frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})}{(1.67\times10^{-27}\,\text{kg})(3.00\times10^{8}\,\text{m/s})} = \boxed{1.32\times10^{-15}\,\text{m.}}$$

(*c*) For the energy of the photon we have

$$E = hf = \frac{hc}{\lambda} = \frac{hc}{\left(\frac{h}{m_0c}\right)} = m_0c^2.$$

30. We find the Compton wavelength shift for a photon scattered from an electron:

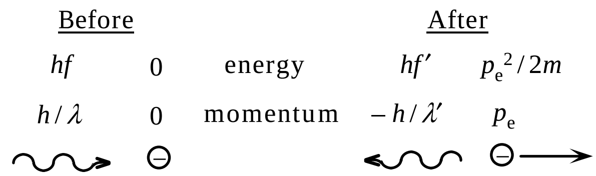
$$\lambda' - \lambda = \left(\frac{h}{m_0 c}\right)(1 - \cos\theta).$$

(*a*) $\lambda'_a - \lambda = \left(2.43 \times 10^{-12}\text{ m}\right)\left(1 - \cos 45°\right) = \boxed{7.12 \times 10^{-13}\text{ m.}}$

(*b*) $\lambda'_b - \lambda = \left(2.43 \times 10^{-12}\text{ m}\right)\left(1 - \cos 90°\right) = \boxed{2.43 \times 10^{-12}\text{ m.}}$

(*c*) $\lambda'_c - \lambda = \left(2.43 \times 10^{-12}\text{ m}\right)\left(1 - \cos 180°\right) = \boxed{4.86 \times 10^{-12}\text{ m.}}$

31. (*a*) For the conservation of momentum for the head-on collision, we have



$$\frac{h}{\lambda} + 0 = -\left(\frac{h}{\lambda'}\right) + p_e, \text{ or } \frac{h}{\lambda'} = p_e - \left(\frac{h}{\lambda}\right).$$

For energy conservation, we have

$$\left(\frac{hc}{\lambda}\right) + m_0c^2 = \left(\frac{hc}{\lambda'}\right) + \left[\left(m_0c^2\right)^2 + p_e^{\,2}c^2\right]^{\frac{1}{2}}$$

$$= \left(\frac{hc}{\lambda'}\right) + m_0c^2 + \left(\frac{p_e^{\,2}}{2m_0}\right),$$

where we have used the approximation $(1 + x)^{\frac{1}{2}} \approx 1 + \frac{x}{2}$, for $x \ll 1$.

When we use the result from momentum conservation, we get

$$\left(\frac{hc}{\lambda}\right) = p_e c - \left(\frac{hc}{\lambda}\right) + \left(\frac{p_e^{\,2}}{2m_0}\right), \text{ or}$$

$$\left[\frac{p_e^{\,2}}{2\left(9.11 \times 10^{-31}\text{ kg}\right)}\right] + p_e\left(3.00 \times 10^8\text{ m/s}\right) - 2\left[\frac{\left(6.63 \times 10^{-34}\text{ J•s}\right)\left(3.00 \times 10^8\text{ m/s}\right)}{\left(0.100 \times 10^{-9}\text{ m}\right)}\right] = 0.$$

When we solve this quadratic for p_e, the positive solution is

$$p_e = 1.295 \times 10^{-23}\text{ kg•m/s}.$$

The kinetic energy of the electron is

$$\text{KE} = \frac{p_e^{\,2}}{2m_0} = \frac{\left(1.295 \times 10^{-23}\text{ kg•m/s}\right)^2}{2\left(9.11 \times 10^{-31}\text{ kg}\right)} = \boxed{9.21 \times 10^{-17}\text{ J}}\left(576\text{ eV}\right).$$

Because this is much less than $m_0c^2 = 0.511\text{MeV}$, we are justified in using the expansion.

(*b*) For the wavelength of the recoiling photon, we have

$$\frac{h}{\lambda'} = p_e - \left(\frac{h}{\lambda}\right);$$

$$\frac{\left(6.63 \times 10^{-34}\text{ J•s}\right)}{\lambda'} = 1.295 \times 10^{-23}\text{ kg•m/s} - \left[\frac{\left(6.63 \times 10^{-34}\text{ J•s}\right)}{\left(0.100 \times 10^{-9}\text{ m}\right)}\right],$$

which gives $\lambda' = 1.05 \times 10^{-10}\text{ m} = \boxed{0.105\text{nm.}}$

$\boxed{32.}$ The kinetic energy of the pair is

$$\text{KE} = hf - 2m_0c^2 = 3.84\text{ MeV} - 2\left(0.511\text{MeV}\right) = \boxed{2.82\text{ MeV.}}$$

33. The photon with the longest wavelength has the minimum energy to create the masses:

$$hf_{\min} = \frac{hc}{\lambda_{\max}} = 2m_0c^2;$$

$$\frac{\left(6.63\times10^{-34}\,\text{J}\bullet\text{s}\right)}{\lambda_{\max}} = 2\left(1.67\times10^{-27}\,\text{kg}\right)\left(3.00\times10^{8}\,\text{m/s}\right),\ \text{which gives }\lambda_{\max} = \boxed{6.62\times10^{-16}\,\text{m.}}$$

34. The photon with minimum energy to create the masses is

$$hf_{\min} = 2m_0c^2 = 2(207)(0.511\,\text{MeV}) = \boxed{212\,\text{MeV.}}$$

The wavelength is

$$\lambda = \frac{\left(6.63\times10^{-34}\,\text{J}\bullet\text{s}\right)\left(3.00\times10^{8}\,\text{m/s}\right)}{\left(1.60\times10^{-19}\,\text{J/eV}\right)\left(212\times10^{6}\,\text{eV}\right)} = \boxed{5.86\times10^{-15}\,\text{m.}}$$

35. Since an electron and a positron have identical masses, the energy of each photon will consist of the total energy from one electron or positron, as given by

$$E = \frac{m_0c^2}{\sqrt{1-\frac{v^2}{c^2}}}.$$

For $v < 0.001c$, this is essentially identical to

$$E = m_0c^2 = \left(\frac{0.51\,\text{MeV}}{c^2}\right)c^2 = \boxed{0.51\,\text{MeV.}}$$

The momentum of each photon is

$$p = \frac{E}{c} = \boxed{\frac{0.51\,\text{MeV}}{c}.}$$

36. The energy of the photon is

$$hf = 2\left(\text{KE} + m_0c^2\right) = 2\left(0.245\,\text{MeV} + 0.511\,\text{MeV}\right) = \boxed{1.51\,\text{MeV.}}$$

The wavelength is

$$\lambda = \frac{\left(6.63\times10^{-34}\,\text{J}\bullet\text{s}\right)\left(3.00\times10^{8}\,\text{m/s}\right)}{\left(1.60\times10^{-19}\,\text{J/eV}\right)\left(1.51\times10^{6}\,\text{eV}\right)} = \boxed{8.23\times10^{-13}\,\text{m.}}$$

37. We find the wavelength from

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{\left(6.63\times10^{-34}\,\text{J}\bullet\text{s}\right)}{(0.23\,\text{kg})(0.10\,\text{m/s})} = \boxed{2.9\times10^{-32}\,\text{m.}}$$

38. We find the wavelength from

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{\left(6.63\times10^{-34}\,\text{J}\bullet\text{s}\right)}{\left(1.67\times10^{-27}\,\text{kg}\right)\left(6.5\times10^{4}\,\text{m/s}\right)} = \boxed{6.1\times10^{-12}\,\text{m.}}$$

39. We find the speed from

$$\lambda = \frac{h}{p} = \frac{h}{mv};$$

$$0.24\times10^{-9}\text{ m}=\frac{\left(6.63\times10^{-34}\text{ J•s}\right)}{\left(9.11\times10^{-31}\text{ kg}\right)v},\text{ which gives }v=3.03\times10^{6}\text{ m/s}.$$

Because this is much less than c, we can use the classical expression for the kinetic energy. The kinetic energy is equal to the potential energy change:

$$eV=\text{KE}=\tfrac{1}{2}mv^2=\tfrac{1}{2}\left(9.11\times10^{-31}\text{ kg}\right)\left(3.03\times10^{6}\text{ m/s}\right)^2=4.19\times10^{-18}\text{ J}=26.2\text{ eV}.$$

Thus the required potential difference is $\boxed{26\text{ V.}}$

40. With $\text{KE}=\dfrac{p^2}{2m_0}$, we have

$$\lambda=\frac{h}{p}=\frac{h}{\left[2m_0\left(\text{KE}\right)\right]^{\frac{1}{2}}}.$$

If we form the ratio for the two particles with equal wavelengths, we get

$$1=\left[\frac{m_{0\text{e}}\left(\text{KE}_\text{e}\right)}{\text{m}_{0\text{p}}\left(\text{KE}_\text{P}\right)}\right]^{\frac{1}{2}},\text{ or }\frac{\text{KE}_\text{e}}{\text{KE}_\text{p}}=\frac{m_{0\text{p}}}{m_{0\text{e}}}=\frac{\left(1.67\times10^{-27}\text{ kg}\right)}{\left(9.11\times10^{-31}\text{ kg}\right)}=\boxed{1.84\times10^{3}.}$$

41. (*a*) We find the momentum from

$$p=\frac{h}{\lambda}=\frac{6.63\times10^{-34}\text{ J•s}}{5.0\times10^{-10}\text{ m}}=\boxed{1.3\times10^{-24}\text{ kg•m/s.}}$$

(*b*) We find the speed from

$$\lambda=\frac{h}{p}=\frac{h}{mv};$$

$$5.0\times10^{-10}\text{ m}=\frac{6.63\times10^{-34}\text{ J•s}}{\left(9.11\times10^{-31}\text{ kg}\right)v},\text{ which gives }v=\boxed{1.5\times10^{6}\text{ m/s.}}$$

(*c*) With $v<0.005c$, we can calculate KE classically:

$$\text{KE}=\tfrac{1}{2}mv^2$$
$$=\tfrac{1}{2}\left(9.11\times10^{-31}\text{ kg}\right)\left(1.5\times10^{6}\text{ m/s}\right)^2=9.7\times10^{-19}\text{ J},\text{ which converted to electron-volts}$$

equals $\dfrac{\left(9.7\times10^{-19}\right)}{\left(1.06\times10^{-19}\text{ J/eV}\right)}=6.0\text{ eV}$. This is the energy gained by an electron as it is accelerated through a potential difference of $\boxed{6.0\text{ V.}}$

42. Because all the energies are much less than m_0c^2, we can use $\text{KE}=\dfrac{p^2}{2m_0}$, so

$$\lambda=\frac{h}{p}=\frac{h}{\left[2m_0\left(\text{KE}\right)\right]^{\frac{1}{2}}}=\frac{hc}{\left[2m_0c^2\left(\text{KE}\right)\right]^{\frac{1}{2}}}.$$

(*a*) $$\lambda=\frac{hc}{\left[2m_0c^2\left(\text{KE}\right)\right]^{\frac{1}{2}}}=\frac{\left(6.63\times10^{-34}\text{ J•s}\right)\left(3.00\times10^{8}\text{ m/s}\right)}{\left(1.60\times10^{-19}\text{ J/eV}\right)\left[2\left(0.511\times10^{6}\text{ eV}\right)\left(10\text{ eV}\right)\right]^{\frac{1}{2}}}=3.9\times10^{-10}\text{ m}=\boxed{0.39\text{ nm.}}$$

(*b*) $$\lambda = \frac{hc}{\left[2m_0c^2(\text{KE})\right]^{\frac{1}{2}}} = \frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})\left[2(0.511\times10^{6}\,\text{eV})(100\ \text{eV})\right]^{\frac{1}{2}}} = 1.2\times10^{-10}\,\text{m} = \boxed{0.12\,\text{nm.}}$$

(*c*) $$\lambda = \frac{hc}{\left[2m_0c^2(\text{KE})\right]^{\frac{1}{2}}} = \frac{(6.63\times10^{-34}\,\text{J}\bullet\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})\left[2(0.511\times10^{6}\,\text{eV})(1.0\times10^{3}\ \text{eV})\right]^{\frac{1}{2}}}$$
$$= 3.9\times10^{-11}\,\text{m} = \boxed{0.039\,\text{nm.}}$$

43. With $\text{KE} = \frac{p^2}{2m_0}$, we have

$$\lambda = \frac{h}{p} = \frac{h}{\left[2m_0(\text{KE})\right]^{\frac{1}{2}}}.$$

If we form the ratio for the two particles with equal kinetic energies, we get

$$\frac{\lambda_\text{p}}{\lambda_\text{e}} = \left(\frac{m_{0\text{e}}}{m_{0\text{p}}}\right)^{\frac{1}{2}}.$$

Because $m_{0\text{p}} > m_{0\text{e}}, \lambda_\text{p} < \lambda_\text{e}$.

44. The kinetic energy is equal to the potential energy change:

$$\text{KE} = eV = (1\text{e})(20.0\times10^{3}\ \text{V}) = 30.0\times10^{3}\ \text{eV} = 0.0300\,\text{MeV}.$$

Because this is 6% of m_0c^2, the electron is relativistic. We find the momentum from

$$E^2 = \left[(\text{KE}) + m_0c^2\right]^2 = p^2c^2 + m_e{}^2c^4, \quad \text{or}$$

$$p^2c^2 = (\text{KE})^2 + 2(\text{KE})m_0c^2;$$

$$p^2c^2 = (0.0300\,\text{MeV})^2 + 2(0.0300\,\text{MeV})(0.511\text{MeV}), \text{ which gives } pc = 0.178\,\text{MeV}, \text{ or}$$

$$p = \frac{(0.178\,\text{MeV})(1.60\times10^{-13}\ \text{J/MeV})}{(3.00\times10^{8}\ \text{m/s})} = 9.47\times10^{-23}\ \text{kg}\bullet\text{m/s}.$$

The wavelength is

$$\lambda = \frac{h}{p} = \frac{(6.63\times10^{-34}\ \text{J}\bullet\text{s})}{(9.47\times10^{-23}\ \text{kg}\bullet\text{m/s})} = \boxed{7.0\times10^{-12}\ \text{m.}}$$

Because $\lambda \ll 5$ cm, $\boxed{\text{diffraction effects are negligible.}}$

45. For diffraction, the wavelength must be on the order of the opening. We find the speed from

$$\lambda = \frac{h}{p} = \frac{h}{mv};$$

$$10\,\text{m} = \frac{(6.63\times10^{-34}\ \text{J}\bullet\text{s})}{(1400\ \text{kg})v}, \text{ which gives } v = \boxed{4.7\times10^{-38}\ \text{m/s.}}$$

Not a good speed if you want to get somewhere.
At a speed of $30\,\text{m/s}$, $\lambda \ll 10\,\text{m}$, so there will be $\boxed{\text{no diffraction.}}$

46. The kinetic energy of the electron is

$$\text{KE} = \frac{p^2}{2m_0} = \frac{h^2}{2m_0\lambda^2} = \frac{\left(6.63\times10^{-34}\ \text{J}\bullet\text{s}\right)^2}{2\left(9.11\times10^{-31}\ \text{kg}\right)\left(0.20\times10^{-9}\ \text{m}\right)^2} = 6.03\times10^{-18}\ \text{J} = 37.7\,\text{eV}.$$

Because this must equal the potential energy change, the required voltage is $\boxed{37.7\ \text{V.}}$

47. The wavelength of the electron is

$$\lambda = \frac{h}{p} = \frac{h}{\left[2m_0(\text{KE})\right]^{\frac{1}{2}}} = \frac{hc}{\left[2m_0c^2(\text{KE})\right]^{\frac{1}{2}}}$$

$$= \frac{\left(6.63\times10^{-34}\ \text{J}\bullet\text{s}\right)\left(3.00\times10^{8}\ \text{m/s}\right)}{\left(1.60\times10^{-19}\ \text{J/eV}\right)\left[2\left(0.511\times10^{6}\ \text{eV}\right)\left(2450\ \text{eV}\right)\right]^{\frac{1}{2}}} = 2.48\times10^{-11}\,\text{m} = \boxed{2.48\times10^{-2}\,\text{nm.}}$$

This is the maximum possible resolution, as discussed in Section 27-9.

48. The energy of a level is $E_n = -\frac{(13.6\ \text{eV})}{n^2}$.

(*a*) The transition from $n = 1$ to $n' = 3$ is an $\boxed{\text{absorption,}}$ because the $\boxed{\text{final state,}}$ $n' = 3$, has a higher energy. The energy of the photon is

$$hf = E_{n'} - E_n = -(13.6\ \text{eV})\left[\left(\frac{1}{3^2}\right) - \left(\frac{1}{1^2}\right)\right] = 12.1\ \text{eV}.$$

(*b*) The transition from $n = 6$ to $n' = 2$ is an $\boxed{\text{emission,}}$ because the $\boxed{\text{initial state,}}$ $n' = 2$, has a higher energy. The energy of the photon is

$$hf = -\left(E_{n'} - E_n\right) = (13.6\ \text{eV})\left[\left(\frac{1}{2^2}\right) - \left(\frac{1}{6^2}\right)\right] = 3.0\ \text{eV}.$$

(*c*) The transition from $n = 4$ to $n' = 5$ is an $\boxed{\text{absorption,}}$ because the $\boxed{\text{final state,}}$ $n' = 5$, has a higher energy. The energy of the photon is

$$hf = E_{n'} - E_n = -(13.6\ \text{eV})\left[\left(\frac{1}{5^2}\right) - \left(\frac{1}{4^2}\right)\right] = 0.31\ \text{eV}.$$

The photon for the transition from $\boxed{n = 1 \text{ to } n' = 3}$ has the largest energy.

49. To ionize the atom means removing the electron, or raising it to zero energy:

$$E_{\text{ion}} = 0 - E_n = \frac{(13.6\ \text{eV})}{n^2} = \frac{(13.6\ \text{eV})}{2^2} = \boxed{3.4\ \text{eV.}}$$

50. From $\Delta E = \frac{hc}{\lambda}$, we see that the third longest wavelength comes from the transition with the third smallest energy: $\boxed{n = 6 \text{ to } n' = 3.}$

51. Doubly ionized lithium is like hydrogen, except that there are three positive charges ($Z = 3$) in the nucleus. The square of the product of the positive and negative charges appears in the energy term for the energy levels. We can use the results for hydrogen, if we replace e^2 by Ze^2:

$$E_n = -\frac{Z^2(13.6\ \text{eV})}{n^2} = -\frac{3^2(13.6\ \text{eV})}{n^2} = -\frac{(122\ \text{eV})}{n^2}.$$

We find the energy needed to remove the remaining electron from

$$E = 0 - E_1 = 0 - \left[-\frac{(122\text{ eV})}{(1)^2} \right] = \boxed{122\text{ eV.}}$$

52. (*a*) For the jump from $n = 4$ to $n = 2$, we have

$$\lambda = \frac{hc}{(E_4 - E_2)} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})[-0.85\text{ eV} - (-3.4\text{ eV})]} = 4.88\times10^{-7}\,\text{m} = \boxed{488\,\text{nm.}}$$

(*b*) For the jump from $n = 3$ to $n = 1$, we have

$$\lambda = \frac{hc}{(E_3 - E_1)} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})[-1.5\text{ eV} - (-13.6\text{ eV})]} = 1.03\times10^{-7}\,\text{m} = \boxed{103\,\text{nm.}}$$

(*c*) The energy of the $n = 5$ level is

$$E_5 = \frac{-(13.6\text{ eV})}{5^2} = -0.54\text{ eV.}$$

For the jump from $n = 5$ to $n = 2$, we have

$$\lambda = \frac{hc}{(E_5 - E_2)} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})[-0.54\text{ eV} - (-3.4\text{ eV})]} = 4.35\times10^{-7}\,\text{m} = \boxed{435\,\text{nm.}}$$

53. For the Rydberg constant we have

$$R = \frac{2\pi^2 e^4 m k^2}{h^3 c}$$

$$= \frac{2\pi(1.602177\times10^{-19}\,\text{C})^4(9.109390\times10^{-31}\,\text{kg})(8.988\times10^{9}\,\text{N}\cdot\text{m}^2/\text{C}^2)^2}{(6.626076\times10^{-34}\,\text{J}\cdot\text{s})^3(2.997925\times10^{8}\,\text{m/s})}$$

$$= 1.0974\times10^{7}\,\text{m}^{-1}.$$

54. The longest wavelength corresponds to the minimum energy, which is the ionization energy:

$$\lambda = \frac{hc}{E_{\text{ion}}} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})(13.6\text{ eV})} = 9.14\times10^{-8}\,\text{m} = \boxed{91.4\,\text{nm.}}$$

55. The energy of the photon is

$$hf = E_{\text{ion}} + \text{KE} = 13.6\text{ eV} + 10.0\text{ eV} = 23.6\,\text{eV.}$$

We find the wavelength from

$$\lambda = \frac{hc}{hf} = \frac{(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})(23.6\text{ eV})} = 5.27\times10^{-8}\,\text{m} = \boxed{52.7\,\text{nm.}}$$

56. Singly ionized helium is like hydrogen, except that there are two positive charges ($Z = 2$) in the nucleus. The square of the product of the positive and negative charges appears in the energy term for the energy levels. We can use the results for hydrogen, if we replace e^2 by Ze^2:

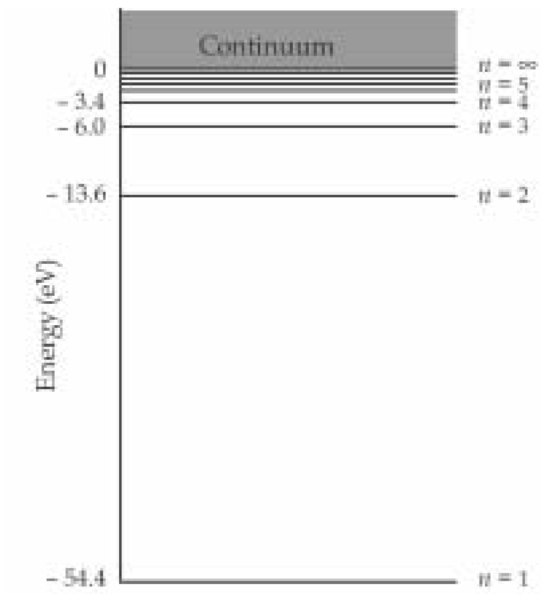
$$E_n = -\frac{Z^2(13.6\text{ eV})}{n^2} = -\frac{2^2(13.6\text{ eV})}{n^2} = -\frac{(54.4\text{ eV})}{n^2}.$$

We find the energy of the photon from the $n = 6$ to $n = 2$ transition:

$$E = E_6 - E_2 = -(54.4\text{ eV})\left[\left(\frac{1}{6^2}\right) - \left(\frac{1}{2^2}\right)\right] = 12.1\text{ eV}.$$

Because this is the energy difference for the $n = 1$ to $n = 3$ transition in hydrogen, the photon can be absorbed by a hydrogen atom which will jump from $\boxed{n = 1 \text{ to } n = 3.}$

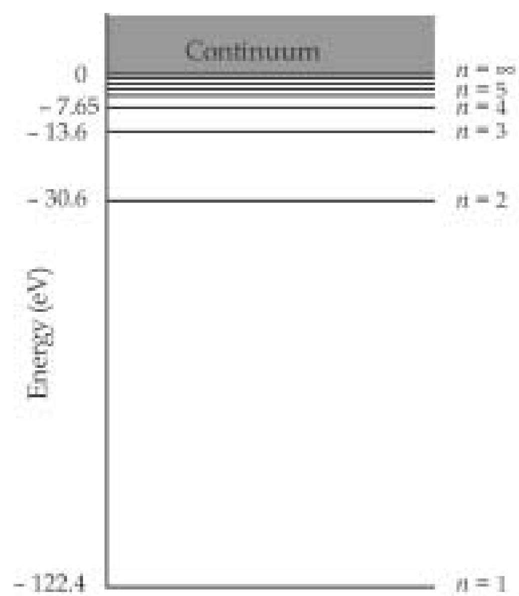
57. Singly ionized helium is like hydrogen, except that there are two positive charges ($Z = 2$) in the nucleus. The square of the product of the positive and negative charges appears in the energy term for the energy levels. We can use the results for hydrogen, if we replace e^2 by Ze^2:



$$E_n = -\frac{Z^2(13.6\text{ eV})}{n^2} = -\frac{2^2(13.6\text{ eV})}{n^2} = -\frac{(54.4\text{ eV})}{n^2}.$$

58. Doubly ionized lithium is like hydrogen, except that there are three positive charges ($Z = 3$) in the nucleus. The square of the product of the positive and negative charges appears in the energy term for the energy levels. We can use the results for hydrogen, if we replace e^2 by Ze^2:

$$E_n = -\frac{Z^2(13.6\text{ eV})}{n^2} = -\frac{3^2(13.6\text{ eV})}{n^2} = -\frac{(122\text{ eV})}{n^2}.$$



59. The potential energy for the ground state is

$$\text{PE} = -\frac{ke^2}{r_1} = \frac{(9.00\times10^9\text{ N}\bullet\text{m}^2/\text{C}^2)(1.60\times10^{-19}\text{ C})^2}{(0.529\times10^{-10}\text{ m})} = -4.35\times10^{-18}\text{ J} = \boxed{-27.2\text{ eV}.}$$

The kinetic energy is

$$\text{KE} = E_1 - \text{PE} = -13.6 \text{ eV} - (-27.2 \text{ eV}) = \boxed{+13.6 \text{ eV.}}$$

60. We find the value of n from

$$r_n = n^2 r_1;$$

$$1.00 \times 10^{-3}\,\text{m} = n^2\left(0.529 \times 10^{-10}\,\text{m}\right), \text{ which gives } n = \boxed{4.35 \times 10^3.}$$

The energy of this orbit is

$$E = -\frac{(13.6 \text{ eV})}{n^2} = -\frac{(13.6 \text{ eV})}{\left(4.35 \times 10^3\right)^2} = \boxed{-7.2 \times 10^{-7}\,\text{eV.}}$$

61. We find the velocity from the quantum condition:

$$mvr_1 = \frac{nh}{2\pi};$$

$$\left(9.11 \times 10^{-31}\,\text{kg}\right)v\left(0.529 \times 10^{-10}\,\text{m}\right) = \frac{(1)\left(6.63 \times 10^{-34}\,\text{J}\bullet\text{s}\right)}{2\pi},$$

which gives $v = 2.18 \times 10^6 \text{ m/s} = 7.3 \times 10^{-3} c.$

The relativistic factor is

$$\left[1 - \left(\frac{v}{c}\right)^2\right]^{\frac{1}{2}} \approx 1 - \tfrac{1}{2}\left(\frac{v}{c}\right)^2 = 1 - 2.7 \times 10^{-5}.$$

Because this is essentially 1, the use of nonrelativistic formulas is $\boxed{\text{justified.}}$

62. If we compare the two forces:

$$F_e = \frac{ke^2}{r^2}, \text{ and } F_g = \frac{Gm_e m_p}{r^2},$$

we see that we can use the hydrogen expressions if we replace ke^2 with $Gm_e m_p$. For the radius we get

$$r_1 = \frac{h^2}{4\pi^2 G m_e^2 m_p}$$

$$= \frac{\left(6.63 \times 10^{-34}\,\text{J}\bullet\text{s}\right)^2}{4\pi^2\left(6.67 \times 10^{-11}\,\text{N}\bullet\text{m}^2/\text{kg}^2\right)\left(9.11 \times 10^{-31}\,\text{kg}\right)^2\left(1.67 \times 10^{-27}\,\text{kg}\right)}$$

$$= \boxed{1.20 \times 10^{29}\,\text{m.}}$$

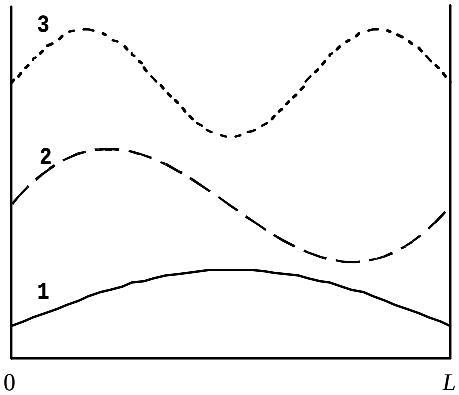
The ground state energy is

$$E_1 = -\frac{2\pi^2 G^2 m_e^3 m_p^2}{h^2}$$

$$= -\frac{2\pi^2\left(6.67 \times 10^{-11}\,\text{N}\bullet\text{m}^2/\text{kg}^2\right)^2\left(9.11 \times 10^{-31}\,\text{kg}\right)^3\left(1.67 \times 10^{-27}\,\text{kg}\right)^2}{\left(6.63 \times 10^{-34}\,\text{J}\bullet\text{s}\right)^2}$$

$$= \boxed{-4.21 \times 10^{-97}\,\text{J.}}$$

63. (*a*)



(*b*) From the diagram we see that the wavelengths are given by

$$\lambda_n = \frac{2L}{n}, \quad n = 1, 2, 3, \ldots .$$

so the momentum is

$$p_n = \frac{h}{\lambda} = \frac{nh}{2L}, \quad n = 1, 2, 3, \ldots .$$

Thus the kinetic energy is

$$\mathrm{KE}_n = \frac{p_n{}^2}{2m} = \frac{n^2h^2}{8mL^2}, \quad n = 1, 2, 3, \ldots .$$

(*c*) Because the potential energy is zero inside the box, the total energy is the kinetic energy. For the ground state energy, we get

$$E_1 = \mathrm{KE}_1 = \frac{n^2h^2}{8mL^2}$$

$$= \frac{(1)^2\left(6.63\times10^{-34}\ \mathrm{J{\bullet}s}\right)^2}{8\left(9.11\times10^{-31}\ \mathrm{kg}\right)\left(0.50\times10^{-10}\ \mathrm{m}\right)^2} = 2.41\times10^{-17}\ \mathrm{J} = \boxed{150\ \mathrm{eV.}}$$

(*d*) For the baseball, we get

$$E_1 = \mathrm{KE}_1 = \frac{n^2h^2}{8mL^2}$$

$$= \frac{(1)^2\left(6.63\times10^{-34}\ \mathrm{J{\bullet}s}\right)^2}{8\left(0.140\,\mathrm{kg}\right)\left(0.50\,\mathrm{m}\right)^2} = \boxed{1.6\times10^{-66}\ \mathrm{J.}}$$

We find the speed from

$$\mathrm{KE}_1 = \tfrac{1}{2}mv^2;$$

$$1.6\times10^{-66}\ \mathrm{J} = \tfrac{1}{2}\left(0.140\,\mathrm{kg}\right)v^2, \text{ which gives } v = \boxed{4.7\times10^{-33}\ \mathrm{m/s.}}$$

(*e*) We find the width of the box from

$$E_1 = \frac{n^2h^2}{8mL^2}$$

$$\left(22\ \mathrm{eV}\right)\left(1.60\times10^{-19}\ \mathrm{J/eV}\right) = \frac{(1)^2\left(6.63\times10^{-34}\ \mathrm{J{\bullet}s}\right)^2}{8\left(9.11\times10^{-31}\ \mathrm{kg}\right)L^2},$$

which gives $L = 1.3\times10^{-10}\ \mathrm{m} = \boxed{0.13\,\mathrm{nm.}}$

64. We find the peak wavelength from

$$\lambda_{\mathrm{p}} = \frac{\left(2.90\times10^{-3}\,\mathrm{m\bullet K}\right)}{T} = \frac{\left(2.90\times10^{-3}\,\mathrm{m\bullet K}\right)}{\left(2.7\,\mathrm{K}\right)} = 1.1\times10^{-3}\,\mathrm{m} = \boxed{1.1\,\mathrm{mm.}}$$

65. To produce a photoelectron, the hydrogen atom must be ionized, so the minimum energy of the photon is 13.6 eV. We find the minimum frequency of the photon from

$$E_{\min} = hf_{\min};$$

$$\left(13.6\ \mathrm{eV}\right)\left(1.60\times10^{-19}\ \mathrm{J/eV}\right) = \left(6.63\times10^{-34}\,\mathrm{J\bullet s}\right) f_{\min}, \text{which gives } f_{\min} = \boxed{3.28\times10^{15}\,\mathrm{Hz.}}$$

66. Because the energy is much less than m_0c^2, we can use $\mathrm{KE} = \dfrac{p^2}{2m_0}$, so the wavelength of the electron is

$$\lambda = \frac{h}{p} = \frac{h}{\left[2m_0\left(\mathrm{KE}\right)\right]^{\frac{1}{2}}} = \frac{hc}{\left[2m_0c^2\left(\mathrm{KE}\right)\right]^{\frac{1}{2}}}$$

$$= \frac{\left(6.63\times10^{-34}\,\mathrm{J\bullet s}\right)\left(3.00\times10^{8}\,\mathrm{m/s}\right)}{\left(1.60\times10^{-19}\,\mathrm{J/eV}\right)\left[2\left(0.511\times10^{6}\,\mathrm{eV}\right)\left(85\ \mathrm{eV}\right)\right]^{\frac{1}{2}}} = 1.33\times10^{-10}\,\mathrm{m} = 0.133\,\mathrm{nm.}$$

We find the spacing of the planes from

$$2d\sin\theta = m\lambda;$$

$$2d\sin38^\circ = \left(1\right)\left(0.133\,\mathrm{nm}\right), \text{ which gives } d = \boxed{0.108\,\mathrm{nm.}}$$

67. The energy of the photon is

$$E = hf = \frac{hc}{\lambda}$$

$$= \frac{\left(6.63\times10^{-34}\,\mathrm{J\bullet s}\right)\left(3.00\times10^{8}\ \mathrm{m/s}\right)}{\left(12.2\times10^{-2}\,\mathrm{m}\right)} = 1.63\times10^{-24}\,\mathrm{J.}$$

Thus the rate at which photons are produced in the oven is

$$N = \frac{P}{E} = \frac{\left(760\,\mathrm{W}\right)}{\left(1.63\times10^{-24}\,\mathrm{J}\right)} = \boxed{4.66\times10^{26}\ \mathrm{photons/s.}}$$

68. The energy of the photon is

$$hf = \frac{hc}{\lambda} = \frac{\left(6.63\times10^{-34}\,\mathrm{J\bullet s}\right)\left(3.00\times10^{8}\,\mathrm{m/s}\right)}{\left(550\times10^{-9}\,\mathrm{m}\right)} = 3.62\times10^{-19}\,\mathrm{J.}$$

We find the intensity of photons from

$$I_{\mathrm{photons}} = \frac{I}{hf} = \frac{\left(1400\,\mathrm{W/m^2}\right)}{\left(3.62\times10^{-19}\,\mathrm{J}\right)} = \boxed{3.87\times10^{21}\ \mathrm{photons/s\bullet m^2.}}$$

69. The impulse on the wall is due to the change in momentum of the photons:

$$F\Delta t = \Delta p = np = \frac{nh}{\lambda}, \text{ or}$$

$$\frac{n}{\Delta t} = \frac{F\lambda}{h} = \frac{(5.5\times10^{-9}\,\text{N})(633\times10^{-9}\,\text{m})}{(6.63\times10^{-34}\,\text{J•s})} = \boxed{5.3\times10^{18}\text{ photons/s.}}$$

70. The energy of the photon is

$$hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\,\text{J•s})(3.00\times10^{8}\,\text{m/s})}{(550\times10^{-9}\,\text{m})} = 3.62\times10^{-19}\,\text{J}.$$

Because the light radiates uniformly, the intensity at a distance L is

$$I = \frac{P}{4\pi L^2}, \text{ so the rate at which energy enters the pupil is}$$

$$\frac{E}{t} = I\pi r^2 = \frac{Pr^2}{4L^2}.$$

Thus the rate at which photons enter the pupil is

$$\frac{n}{t} = \frac{\left(\frac{E}{t}\right)}{hf} = \frac{Pr^2}{4L^2hf}$$

$$= \frac{(0.030)(100\,\text{W})(2.0\times10^{-3}\,\text{m})^2}{4(1.0\times10^{3}\,\text{m})^2(3.62\times10^{-19}\,\text{J})}$$

$$= \boxed{8.3\times10^{6}\text{ photons/s.}}$$

71. Since an electron and a positron have identical masses, the energy of each photon will consist of the total energy from one electron or positron. Of that energy,

$$E = m_0c^2 = \left(\frac{0.51\,\text{MeV}}{c^2}\right)c^2 = 0.51\,\text{MeV}$$

comes from the conversion of mass into energy. The rest of the 0.90 MeV comes from the particle's kinetic energy: $0.90\,\text{MeV} - 0.51\,\text{MeV} = \boxed{0.39\,\text{MeV}}$ for each particle.

72. The required momentum is

$$p = \frac{h}{\lambda}, \text{ or}$$

$$pc = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34}\,\text{J•s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})(5.0\times10^{-12}\,\text{m})} = 2.49\times10^{5}\,\text{eV} = 0.249\,\text{MeV}.$$

(*a*) For the proton, $pc \ll m_0c^2$, so we can find the required kinetic energy from

$$\text{KE} = \frac{p^2}{2m_0} = \frac{(pc)^2}{2m_0c^2} = \frac{(0.249\,\text{MeV})^2}{2(938\,\text{MeV})} = 3.3\times10^{-5}\,\text{MeV} = 33\text{ eV}.$$

The potential difference to produce this kinetic energy is

$$V = \frac{\text{KE}}{e} = \frac{(33\,\text{eV})}{(1\text{e})} = \boxed{33\,\text{V.}}$$

(*b*) For the electron, *pc* is on the order of m_0c^2, so we can find the required kinetic energy from

$$\text{KE} = \left[(pc)^2 + \left(m_0c^2\right)^2\right]^{\frac{1}{2}} - m_0c^2$$

$$= \left[(0.249\,\text{MeV})^2 + (0.511\,\text{MeV})^2\right]^{\frac{1}{2}} - 0.511\,\text{MeV} = 0.057\,\text{MeV} = 57\,\text{keV}.$$

The potential difference to produce this kinetic energy is

$$V = \frac{\text{KE}}{e} = \frac{(57\,\text{KeV})}{(1\text{e})} = \boxed{57\,\text{kV.}}$$

73. If we ignore the recoil motion, at the closest approach the kinetic energy of both particles is zero. The potential energy of the two charges must equal the initial kinetic energy of the α particle:

$$\text{KE} = \frac{kZ_\alpha Z_{\text{Au}}e^2}{r_{\min}};$$

$$(4.8\,\text{MeV})\left(1.60\times10^{-13}\ \text{J/MeV}\right) = \frac{\left(9.00\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)(2)(79)\left(1.60\times10^{-19}\,\text{C}\right)^2}{r_{\min}},$$

which gives $r_{\min} = \boxed{4.7\times10^{-14}\,\text{m.}}$

74. The decrease in mass occurs because a photon has been emitted:

$$\frac{\Delta m}{m_0} = \frac{\left(\dfrac{\Delta E}{c^2}\right)}{m_0} = \frac{\Delta E}{m_0c^2} = \frac{(-13.6\ \text{eV})\left[\left(\dfrac{1}{1^2}\right) - \left(\dfrac{1}{3^2}\right)\right]}{\left(939\times10^{6}\ \text{eV}\right)} = \boxed{-1.29\times10^{-8}.}$$

75. The ratio of the forces is

$$\frac{F_g}{F_e} = \frac{\left(\dfrac{Gm_em_p}{r^2}\right)}{\left(\dfrac{ke^2}{r^2}\right)} = \frac{Gm_em_p}{ke^2}$$

$$= \frac{\left(6.67\times10^{-11}\ \text{N}\bullet\text{m}^2/\text{kg}^2\right)\left(9.11\times10^{-31}\ \text{kg}\right)^2\left(1.67\times10^{-27}\ \text{kg}\right)}{\left(9.00\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(1.60\times10^{-19}\ \text{C}\right)^2} = \boxed{4.4\times10^{-40}.}$$

$\boxed{\text{Yes,}}$ the gravitational force may be safely ignored.

76. The potential difference produces a kinetic energy of 12.3 eV, so it is possible to provide this much energy to the hydrogen atom through collisions. From the ground state, the maximum energy of the atom is $-13.6\ \text{eV} + 12.3\ \text{eV} = -1.3\ \text{eV}$. From the energy level diagram, we see that this means the atom could be excited to the *n* = 3 state, so the possible transitions when the atom returns to the ground state are *n* = 3 to *n* = 2, *n* = 3 to *n* = 1, and *n* = 2 to *n* = 1. For the wavelengths we have

$$\lambda_{3\to2} = \frac{hc}{(E_3 - E_2)} = \frac{\left(6.63\times10^{-34}\ \text{J}\bullet\text{s}\right)\left(3.00\times10^{8}\,\text{m/s}\right)}{\left(1.60\times10^{-19}\,\text{J/eV}\right)\left[-1.5\ \text{eV} - (-3.4\ \text{eV})\right]} = 6.54\times10^{-7}\,\text{m} = \boxed{654\,\text{nm;}}$$

$$\lambda_{3\to1} = \frac{hc}{(E_3 - E_1)} = \frac{\left(6.63\times10^{-34}\ \text{J}\bullet\text{s}\right)\left(3.00\times10^{8}\,\text{m/s}\right)}{\left(1.60\times10^{-19}\,\text{J/eV}\right)\left[-1.5\ \text{eV} - (-13.6\ \text{eV})\right]} = 1.03\times10^{-7}\,\text{m} = \boxed{103\,\text{nm;}}$$

$$\lambda_{2\to1} = \frac{hc}{(E_2 - E_1)} = \frac{(6.63\times10^{-34}\,\text{J•s})(3.00\times10^{8}\,\text{m/s})}{(1.60\times10^{-19}\,\text{J/eV})[-3.4\text{ eV} - (-13.6\text{ eV})]} = 1.22\times10^{-7}\,\text{m} = \boxed{122\,\text{nm;}}$$

77. The stopping potential is the voltage that gives a potential energy change equal to the maximum kinetic energy:

$$\text{KE}_{\text{max}} = eV_0 = \frac{hc}{\lambda} - W_0;$$

$$(1\text{e})(2.10\,\text{V})(1.60\times10^{-19}\text{ J/eV}) = \frac{(6.63\times10^{-34}\,\text{J•s})(3.00\times10^{8}\text{ m/s})}{290\times10^{-9}\,\text{m}} - W_0,$$

which gives $W_0 = 3.50\times10^{-19}\,\text{J}$.
With the 440-nm light, then,

$$eV_0 = \frac{(6.63\times10^{-34}\,\text{J•s})(3.00\times10^{8}\text{ m/s})}{440\times10^{-9}\,\text{m}} - 3.50\times10^{-19}\,\text{J}$$

$$= 1.02\times10^{-19}\,\text{J} = \frac{1.02\times10^{-19}\,\text{J}}{1.60\times10^{-19}\text{ J/eV}} = 0.64\text{ eV}.$$

The potential difference needed to cancel an electron kinetic energy of 0.64 eV is $\boxed{0.64\text{ V.}}$

78. (*a*) The electron has a charge *e*, so the potential difference produces a kinetic energy of *eV*. The shortest wavelength photon is produced when all the kinetic energy is lost and a photon emitted:

$$hf_{\text{max}} = \frac{hc}{\lambda_0} = eV, \text{ which gives } \lambda_0 = \frac{hc}{eV}.$$

(*b*) $$\lambda_0 = \frac{hc}{eV} = \frac{(6.63\times10^{-34}\,\text{J•s})(3.00\times10^{8}\text{ m/s})}{(1.60\times10^{-19}\,\text{J/eV})(30\times10^{3}\,\text{eV})} = 4.1\times10^{-11}\,\text{m} = \boxed{0.041\,\text{nm.}}$$

79. The energy of a photon in terms of the momentum is

$$E = hf = \frac{hc}{\lambda} = pc.$$

The rate at which photons are striking the sail is

$$\frac{N}{\Delta t} = \frac{IA}{E} = \frac{IA}{pc}.$$

Because the photons reflect from the sail, the change in momentum of a photon is

$$\Delta p = 2p.$$

The impulse on the sail is due to the change in momentum of the photons:

$$F\Delta t = N\Delta p, \text{ or}$$

$$F = \left(\frac{N}{\Delta t}\right)\Delta p = \left(\frac{IA}{pc}\right)(2p) = \frac{2IA}{c} = \frac{2(1000\,\text{W/m}^2)(1\times10^{3}\,\text{m})^2}{(3.00\times10^{8}\text{ m/s})} = \boxed{7\text{ N.}}$$

80. The maximum kinetic energy of the photoelectrons is

$$\text{KE}_{\text{max}} = \frac{hc}{\lambda} - W_0 = \frac{(6.63\times10^{-34}\,\text{J•s})(3.00\times10^{8}\text{ m/s})}{300\times10^{-9}\,\text{m}} - (2.2\text{ eV})(1.60\times10^{-19}\text{ J/eV}) = 3.11\times10^{-19}\,\text{J}.$$

Since $p = mv$ and $\text{KE} = \frac{1}{2}mv^2$, $p = \sqrt{2m(\text{KE})}$, and so

$$\lambda_{\min} = \frac{h}{\sqrt{2m(\text{KE}_{\max})}} = \frac{6.63\times10^{-34}\,\text{J}\cdot\text{s}}{\sqrt{2(9.11\times10^{-31}\,\text{kg})(3.11\times10^{-19}\,\text{J})}} = 8.8\times10^{-10}\,\text{m} = \boxed{0.88\,\text{nm.}}$$

81. With photon energy $hf = 6.0$ eV and stopping potential $V_0 = 4.0\,\text{V}$, we write

$$eV_0 = hf - W_0;$$

$$4.0\text{ eV} = 6.0\text{ eV} - W_0, \text{ which gives } W_0 = 2.0\text{ eV}.$$

If the photons' wavelength is doubled, the energy is halved, from 6.0 eV to 3.0 eV. Now, with no stopping potential applied, we write

$$\text{KE}_{\max} = 3.0\text{ eV} - 2.0\text{ eV} = \boxed{1.0\text{ eV.}}$$

If the photons' wavelength is tripled, the energy is reduced from 6.0 eV to 2.0 eV. And we write

$$\text{KE}_{\max} = 2.0\text{ eV} - 2.0\text{ eV} = 0.$$

No electrons are emitted, and $\boxed{\text{no current}}$ flows.

82. We find the wavelength of the light from

$$d\sin\theta = m\lambda;$$

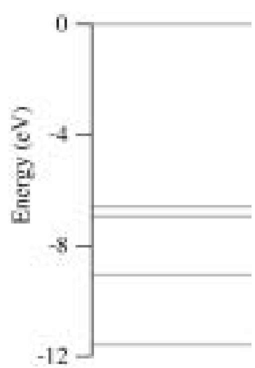
$$(0.010\times10^{-3}\,\text{m})\sin 3.5° = (1)\lambda, \text{ which gives } \lambda = 6.10\times10^{-7}\,\text{m}.$$

Electrons with the same wavelength (and hence the same diffraction pattern) will have a velocity given by the equation

$$p = mv = \frac{h}{\lambda};$$

$$(9.11\times10^{-31}\,\text{kg})v = \frac{6.63\times10^{-34}\,\text{J}\cdot\text{s}}{6.10\times10^{-7}\,\text{m}}, \text{ which gives } v = \boxed{1.2\times10^{3}\,\text{m/s.}}$$

83. (*a*)



(*b*) Absorption of a 5.1 eV photon represents a transition from the $\boxed{\text{ground state}}$ to the state 5.1 eV above that, the third excited state. Possible photon emission energies are found by considering all the possible downward transitions that might occur as the electron makes its way back to the ground state:

$$5.1\text{ eV} - 4.7\text{ eV} = \boxed{0.4\text{ eV}}$$

$$4.7\text{ eV} - 2.5\text{ eV} = \boxed{2.2\text{ eV}}$$

$$2.5\text{ eV} - 0 = \boxed{2.5\text{ eV}}$$

but also

$$5.1\text{ eV} - 2.5\text{ eV} = \boxed{2.6\text{ eV}}$$

$$4.7\text{ eV} - 0 = \boxed{4.7\text{ eV}}$$

and

$$5.1\text{ eV} - 0 = \boxed{5.1\text{ eV.}}$$

84. (*a*) The stopping voltage is found from

$$eV_0 = \frac{hc}{\lambda} - W_0$$

$$= \frac{(6.63\times10^{-34}\text{ J•s})(3.00\times10^{8}\text{ m/s})}{(424\times10^{-9}\text{m})(1.60\times10^{-19}\text{ J/eV})} - 2.28\text{ eV} = 0.65\text{ eV, which gives } V_0 = \boxed{0.65\text{ V.}}$$

(*b*) KE_{max} equals the energy found in part (a), namely 0.65 eV or

$$(0.65\text{ eV})(1.60\times10^{-19}\text{ J/eV}) = 1.04\times10^{-19}\text{ J.}$$

The speed is determined by

$$\text{KE}_{\text{max}} = \tfrac{1}{2}mv_{\text{max}}^2;$$

$$1.04\times10^{-19}\text{ J} = \tfrac{1}{2}(9.11\times10^{-31}\text{kg})v_{\text{max}}^2,\text{ which gives } v_{\text{max}} = \boxed{4.8\times10^{5}\text{ m/s.}}$$

(*c*) The de Broglie wavelength is

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63\times10^{-34}\text{ J•s}}{(9.11\times10^{-31}\text{kg})(4.8\times10^{5}\text{ m/s})} = 1.52\times10^{-9}\text{ m} = \boxed{1.5\text{nm.}}$$

85. The electron acquires a kinetic energy of 96 eV. This is related to the speed by the equation

$$\text{KE} = \tfrac{1}{2}mv^2;$$

$$(96\text{ eV})(1.60\times10^{-19}\text{ J/eV}) = \tfrac{1}{2}(9.11\times10^{-31}\text{kg})v^2,\text{ which gives } v = 5.81\text{m/s.}$$

The ratio $\frac{e}{m}$ is then found using

$$\frac{e}{m} = \frac{v}{Br} = \frac{5.81\text{m/s}}{(3.67\times10^{-4}\text{T})(9.0\times10^{-2}\text{m})} = \boxed{1.8\times10^{11}\text{ C/kg.}}$$

86. First we find the area of a sphere whose radius is the Earth–Sun distance:

$$A = 4\pi r^2 = 4\pi(150\times10^{9}\text{m})^2 = 2.83\times10^{23}\text{m}^2.$$

We multiply this by the given intensity to find the Sun’s total power output:

$$(2.83\times10^{23}\text{m}^2)(1350\text{ W/m}^2) = 3.82\times10^{26}\text{ W.}$$

Multiplying by the number of seconds in a year gives the annual energy output

$$E = (3.82\times10^{26}\text{ W})(3600\text{s/h})(24\text{h/d})(365.25\text{d/y}) = 1.20\times10^{34}\text{ J/y.}$$

Finally we divide by the energy of one photon to find the number of photons per year:

$$\frac{E}{hf} = \frac{E\lambda}{hc} = \frac{(1.20\times10^{34}\text{ J/y})(550\times10^{-9}\text{m})}{(6.63\times10^{-34}\text{ J•s})(3.00\times10^{8}\text{ m/s})} = \boxed{3.33\times10^{52}\text{ photons/y.}}$$

87. We can use Bohr's analysis of the hydrogen atom, where we replace the proton mass with Earth's mass, the electron mass with the Moon's mass, and the electrostatic force $F_e = \frac{ke^2}{r^2}$ with the gravitational force $F_g = \frac{Gm_E m_M}{r^2}$. To account for the change in force, we replace ke^2 with $Gm_E m_M$.

With these replacements, the expression for the Bohr radius changes from

$$r_1 = \frac{h^2}{4\pi^2 mke^2} \text{ to } r_1 = \frac{h^2}{4\pi^2 Gm_E m_M^2},$$

while the expression for the lowest energy level changes from

$$E_1 = -\frac{2\pi^2 e^4 mk^2}{h^2} \text{ to } E_1 = -\frac{2\pi^2 G^2 m_E^2 m_M^3}{h^2}.$$

With $r_n = n^2 r_1$ and $E_n = \frac{E_1}{n^2}$, we find

$$r_n = \frac{n^2 \left(6.63\times10^{-34}\,\text{J}\bullet\text{s}\right)^2}{4\pi^2\left(6.67\times10^{-11}\,\text{N}\bullet\text{m}^2/\text{kg}^2\right)\left(5.98\times10^{24}\,\text{kg}\right)\left(7.35\times10^{22}\,\text{kg}\right)^2} = \boxed{n^2\left(5.17\times10^{-129}\,\text{m}\right)}$$

and

$$E_n = -\frac{2\pi^2\left(6.67\times10^{-11}\,\text{N}\bullet\text{m}^2/\text{kg}^2\right)^2\left(5.98\times10^{24}\,\text{kg}\right)^2\left(7.35\times10^{22}\,\text{kg}\right)^3}{n^2\left(6.63\times10^{-34}\,\text{J}\bullet\text{s}\right)^2}$$

$$= \boxed{-\frac{2.84\times10^{165}\,\text{J}}{n^2}.}$$

With the actual value $r_n = 384\times10^6\,\text{m}$, it follows that

$$n = \sqrt{\frac{384\times10^6\,\text{m}}{5.17\times10^{-129}\,\text{m}}} = 2.73\times10^{68}.$$

The difference between $n = 2.73\times10^{68}$ and $n+1 = 2.73\times10^{68}+1$ certainly makes no detectable difference in the values of r_n and E_n. Hence the quantization of energy and radius is $\boxed{\text{not apparent.}}$