Chapter 30: Quantum Physics

9. The tungsten filament in a standard light bulb can be considered a blackbody radiator.

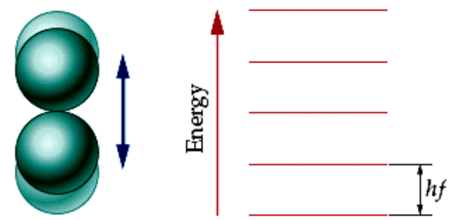
Use Wien's Displacement Law (equation 30-1) to find the peak frequency of the radiation from the tungsten filament.

1. (a) Solve Eq. 30-1 for the peak frequency:

$$f_{\text{peak}} = \left(5.88\times10^{10}\ \text{s}^{-1}\cdot\text{K}^{-1}\right)T$$
$$= \left(5.88\times10^{10}\ \text{s}^{-1}\cdot\text{K}^{-1}\right)\left(2850\ \text{K}\right) = \boxed{1.68\times10^{14}\ \text{Hz}}$$

2. (b) Because the peak frequency is that of infrared electromagnetic radiation, the light bulb radiates more energy in the infrared than the visible part of the spectrum.

10. The image shows two oxygen atoms oscillating back and forth, similar to a mass on a spring. The image also shows the evenly spaced energy levels of the oscillation.



Use equation 13-11 to calculate the period of oscillation for the two atoms. Calculate the frequency, using equation 13-1, from the inverse of the period. Multiply the period by Planck's constant to calculate the spacing of the energy levels.

1. (a) Set the frequency equal to the inverse of the period:

$$T = 2\pi\sqrt{\frac{m}{k}}$$
$$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{1215\ \text{N/m}}{1.340\times10^{-26}\ \text{kg}}} = \boxed{4.792\times10^{13}\ \text{Hz}}$$

2. (b) Multiply the frequency by Planck's constant:

$$E = hf = (6.63\times10^{-34}\ \text{J}\cdot\text{s})(4.792\times10^{13}\ \text{Hz}) = \boxed{3.18\times10^{-20}\ \text{J}}$$

19. The light from a flashlight can be considered as the emission of many photons of the same frequency. The power output is equal to the number of photons emitted per second multiplied by the energy of each photon.

Divide the emitted power by the energy of each photon, given by equation 30-4, to calculate the rate of photon emission.

Calculate the rate of photon emission:

$$\frac{P}{E} = \frac{P}{hf} = \frac{2.5\ \text{W}}{\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(5.2\times10^{14}\ \text{Hz}\right)} = \boxed{7.3\times10^{18}\ \text{photons/s}}$$

22. Each photon contains a quantized amount of energy, determined by the photon wavelength. The total energy of 2.5 J is obtained by the addition of many photons.

Calculate the energy of a single photon from its wavelength using equations 30-4 and 14-1. Divide the total energy by the energy of the single photon to calculate the number of photons.

1. (a) Use equations 30-4 and 14-1 to write the energy of a single photon:

$$E = hf = h\frac{c}{\lambda}$$

2. Divide the total energy by the energy of a single 350-nm photon:

$$n = \frac{E_{\text{total}}}{E_{\text{photon}}} = \frac{\lambda E_{\text{total}}}{hc} = \frac{\left(350\times10^{-9}\ \text{m}\right)\left(2.5\ \text{J}\right)}{\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00\times10^{8}\ \text{m/s}\right)} = \boxed{4.4\times10^{18}\ \text{photons}}$$

3. (b) Divide the total energy by the energy of a 750-nm photon:

$$n = \frac{(750\times10^{-9}\ \text{m})(2.5\ \text{J})}{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(3.00\times10^{8}\ \text{m/s})} = \boxed{9.4\times10^{18}\ \text{photons}}$$

29. Photons with energies greater than the work function of a metal can eject electrons from that metal.

Use equation 30-6 to calculate the cut-off frequencies for the two metals.

1. (a) Because higher-frequency photons have higher energies, and since $W_{\text{Al}} > W_{\text{Ca}}$, $\boxed{\text{aluminum}}$ requires higher-frequency light to produce photoelectrons.

2. (b) Calculate the cutoff frequency for aluminum:

$$f_{\text{Al}} = \frac{W_{\text{Al}}}{h} = \frac{(4.28\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}{6.63\times10^{-34}\ \text{J}\cdot\text{s}} = \boxed{1.03\times10^{15}\ \text{Hz}}$$

3. Calculate the cutoff frequency for calcium:

$$f_{\text{Ca}} = \frac{W_{\text{Ca}}}{h} = \frac{(2.87\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}{6.63\times10^{-34}\ \text{J}\cdot\text{s}} = \boxed{6.93\times10^{14}\ \text{Hz}}$$

32. When white light is incident upon the potassium, the photons with energies greater than the work function of potassium will eject electrons. The greater the photon energy, the greater the kinetic energy of the ejected electron.

Because the photon energy is proportional to the frequency, the photons with the greatest frequency will eject electrons with the maximum kinetic energy. Insert the maximum frequency into equation 30-7 to calculate the maximum kinetic energy of the photoelectrons. Then use equation 30-6 to calculate the cutoff frequency. All photons with smaller frequencies will not eject electrons.

1. (a) Use equation 30-7 to find K_{max}:

$$K_{\text{max}} = hf - W_0 = \frac{(6.63\times10^{-34}\ \text{J}\cdot\text{s})(7.90\times10^{14}\ \text{Hz})}{1.60\times10^{-19}\ \text{J/eV}} - 2.24\ \text{eV}$$

$$= \boxed{1.03\ \text{eV}}$$

2. (b) Calculate the cutoff frequency:

$$f = \frac{W_0}{h} = \frac{(2.24\ \text{eV})(1.60\times10^{-19}\ \text{J/eV})}{6.63\times10^{-34}\ \text{J}\cdot\text{s}} = 5.41\times10^{14}\ \text{Hz}$$

3. Write the frequency range for which no electrons are emitted:

$$\boxed{4.00\times10^{14}\ \text{Hz} \le f < 5.41\times10^{14}\ \text{Hz}}$$

66. Because the proton is significantly more massive than an electron, it will have a greater momentum when the proton and electron have the same speed. The de Broglie wavelength is inversely proportional to the particle momentum.

Calculate the ratio of the de Broglie wavelengths using equation 30-16, where the momentum is the mass times velocity.

1. (a) Because $\lambda = h/mv$ and $m_{\text{e}} < m_{\text{p}}$, for identical speeds, an $\boxed{\text{electron}}$ has a longer de Broglie wavelength than a proton.

2. (b) Calculate the ratio of wavelengths:

$$\frac{\lambda_{\text{e}}}{\lambda_{\text{p}}} = \frac{h/m_{\text{e}}v}{h/m_{\text{p}}v} = \frac{m_{\text{p}}}{m_{\text{e}}} = \frac{1.673\times10^{-27}\ \text{kg}}{9.109\times10^{-31}\ \text{kg}} = \boxed{1836}$$

$\boxed{67.}$ An electron and proton have the same de Broglie wavelength, which means that they must also have the same momentum. However, their kinetic energies will differ because they have different masses.

Use equation 30-16 to write the kinetic energy in terms of the de Broglie wavelength. Then divide the kinetic energy of the proton by the kinetic energy of the electron to calculate their ratio.

1. (a) The proton and electron have the same momentum because they have the same de Broglie wavelength. The kinetic energy, $K = p^2/2m$, is inversely proportional to the mass, and $m_{\text{e}} < m_{\text{p}}$. For identical momenta, an $\boxed{\text{electron}}$ has a greater kinetic energy than a proton.

2. (b) Write the kinetic energy in terms of the wavelength: $K = p^2/2m = h^2/2m\lambda^2$

3. Calculate the ratio of the kinetic energies:

$$\frac{K_e}{K_p} = \frac{h^2/2m_e\lambda^2}{h^2/2m_p\lambda^2} = \frac{m_p}{m_e} = \frac{1.673\times10^{-27}\ \text{kg}}{9.109\times10^{-31}\ \text{kg}} = \boxed{1836}$$