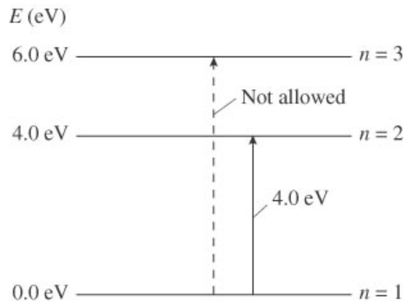
HMWK 7

Ch 29: **P 11, 17, 20, 23, 29, 32, 36, 49, 57, 59**

Problems Chapter 29

P29.11. Prepare: The electron must have $K \geq \Delta E_{atom}$ to cause collisional excitation. The atom is initially in the $n = 1$ ground state: 1 eV = 1.6×10^{-19} J.



Solve: The kinetic energy of the incoming electron is

$$K = \frac{1}{2}mv^2 = \frac{1}{2}(9.11\times10^{-31}\text{ kg})(1.3\times10^6\text{ m/s})^2 = 7.698\times10^{-19}\text{ J} = 4.8\text{ eV}$$

The electron has enough energy to excite the atom to the $n = 2$ stationary state ($E_2 - E_1 = 4.0$ eV). However, it does not have enough energy to excite the atom into the $n = 3$ state, which requires a total energy of 6.0 eV.

Assess: Note that photons are absorbed in a quantum jump from a lower energy level to a higher energy level.

P29.17. Prepare: We will use Table 29.2 for the radii, speeds, and energies for the three states of the Bohr hydrogen atom.

Solve: **(a)** Using the data in Table 29.2, the wavelength of the electron in the $n = 1$ state is

$$\lambda_1 = \frac{h}{mv} = \frac{(6.63\times10^{-34}\text{ J s})}{(9.11\times10^{-31}\text{ kg})(2.19\times10^6\text{ m/s})} = 0.332\text{ nm}$$

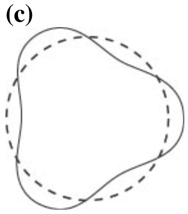
Likewise, $\lambda_2 =$ 0.665 nm, and $\lambda_3 = 0.997$ nm.

(b) For $n = 1$, the circumference of the orbit is $0.0529\text{ nm} \times 2\pi = 0.332\text{ nm}$, which is exactly equal to λ_1. For $n = 2$, the circumference of the orbit is

$$0.212\text{ nm} \times 2\pi = 1.332\text{ nm} = 2\lambda_2 = 2(0.665\text{ nm})$$

Likewise, the data from part **(a)** and Table 29.2 show $3\lambda_3 = 2\pi r_3$.

(c)



P29.20. Prepare: A state is described by four quantum numbers: n, l, m, and m_s.

Solve: (a) $3p$ states correspond to $n = 3$ and $l = 1$. The quantum number m takes values from $-l$ to l. For each of these, the spin quantum number could be $m_s = +1/2$ or $m_s = -1/2$. The quantum numbers of the various $3p$ states are displayed in the table below.

n	3	3	3	3	3	3
l	1	1	1	1	1	1
m	−1	−1	0	0	+1	+1
m_s	+1/2	−1/2	+1/2	−1/2	+1/2	−1/2

(b) A $3d$ state is described by $n = 3$ and $l = 2$. Including the quantum number m, the quantum numbers of the various $3d$ states are displayed in the table below.

n	3	3	3	3	3	3	3	3	3	3
l	2	2	2	2	2	2	2	2	2	2
m	−2	−2	−1	−1	0	0	+1	+1	+2	+2
m_s	+1/2	−1/2	+1/2	−1/2	+1/2	−1/2	+1/2	−1/2	+1/2	−1/2

Assess: Learn well the properties of the four quantum numbers.

P29.23. Prepare: The magnitude of the orbital angular momentum, which is given, is related to the orbital quantum number l through Equation 29.20.

Solve: (a) Equation 29.20 is $L = \sqrt{l(l+1)}\hbar$. Thus,

$$l(l+1) = \left(\frac{L}{\hbar}\right)^2 = \left(\frac{3.65\times 10^{-34}\text{ J s}}{1.05\times 10^{-34}\text{ J s}}\right)^2 = 12 \Rightarrow l = 3$$

This is an f electron.

(b) The l quantum number is required to be less than n. Thus, the minimum possible value of n for an electron in the f state is $n_{\text{min}} = 4$. The corresponding minimum possible energy, using Equation 29.19, is

$$E_{\text{min}} = E_4 = -\frac{13.60\ \text{eV}}{4^2} = -0.85\text{ eV}$$

Assess: The energy of the stationary state depends only on the principal quantum number n.

P29.29. Solve: (a) Nine electrons ($Z = 9$) make the element fluorine (F). These are *not* the nine lowest energy states because $1s^2 2s^2 2p^5$ would be lower in energy than $1s^2 2s^2 2p^4 3d$. This is an excited state of F.

(b) Twenty-eight electrons ($Z = 28$) make the element nickel (Ni). These *are* the 28 lowest energy states because $4s$ fills before $3d$. This is the ground state of Ni.

Assess: The electron configuration for an element provides useful information about the atom.

P29.32. Prepare: Figure 29.18 shows an energy-level diagram for the hydrogen atom. The energy and wavelength of a photon are related by $E = hc/\lambda$.

Solve: The energy associated with light of wavelength 103 nm is

$$E = hc/\lambda = [(6.63\times 10^{-34}\text{ J}\cdot\text{s})(3.00\times 10^{8}\text{ m/s})/(1.03\times 10^{-7}\text{ m})](\text{eV}/1.60\times 10^{-19}\text{ J} = 12.1\text{ eV}$$

If a photon of 12.1 eV is absorbed by a hydrogen atom in the ground state, the energy of the atom is

$$E_f = E_i + \Delta E = -13.6\text{ eV} + 12.1\text{ eV} = -1.5\text{ eV}$$

As a result the atoms are now in the $n = 3$ state. As these atoms undergo transitions to the ground state, possible transitions are:

$$n = 3 \text{ to } n = 2 \qquad E = E_f - E_i = -3.40\text{ eV} - (-1.51\text{ eV}) = 1.89\text{ eV} \qquad \lambda = hc/E = 660\text{ nm}$$

$$n = 3 \text{ to } n = 1 \qquad E = E_f - E_i = -13.6\text{ eV} - (-1.51\text{eV}) = 12.1\text{ eV} \qquad \lambda = hc/E = 103\text{nm}$$

$$n = 2 \text{ to } n = 1 \qquad E = E_f - E_i = -13.6\text{ eV} - (-3.40\text{ eV}) = 10.2\text{ eV} \qquad \lambda = hc/E = 122\text{ nm}$$

Assess: The emission spectra will include light of these three wavelengths.

P29.36. Prepare: Figure P29.36 shows the ground state (with a large number of allowed states) and an excited state (with a large number of allowed states) for a molecule. Even though the ground state has a large number of allowed energy levels, nearly all molecules spend nearly all their time in the very lowest energy levels. They can absorb light (absorption spectrum), which will excite them to any level in the excited state. When molecules are in the excited states, they transform some of the excitation energy into molecular vibrations, causing the molecules to fall to the bottom edge of the excited state. Molecules can then get back to the ground state by radiating energy (emission spectrum). Depending on the amount of energy emitted in the transition they may end up in the top of, bottom of, or someplace in between the ground state. The relationship between energy and wavelength is $E = hc/\lambda$. Note that the larger the wavelength, the smaller the energy.

Solve: The absorption spectrum is the result of transitions from the bottom of the ground state to any allowed energy level in the excited state. The absorption spectrum is the result of wavelengths determined as follows:

$$E_{\text{smallest}} = 2.5\text{ ev} - 0\text{ ev} = 2.5\text{ eV}$$

With the associated wavelength

$$\lambda_{\text{largest}} = hc/E = (6.63\times 10^{-34}\text{ J}\cdot\text{s})(3.0\times 10^{8}\text{ m/s})(\text{eV}/1.6\times 10^{-19}\text{ J})/(2.5\text{ eV}) = 500\text{ nm}$$

$$E_{\text{largest}} = 3.0\text{ eV} - 0\text{ eV} = 3.0\text{ eV}$$

With the associated wavelength

$$\lambda_{\text{smallest}} = hc/E = (6.63\times 10^{-34}\text{ J}\cdot\text{s})(3.0\times 10^{8}\text{ m/s})(\text{eV}/1.6\times 10^{-19}\text{ J})/(3.0\text{ eV}) = 410\text{ nm}$$

The emission spectrum is the result of transitions from the bottom edge of the excited state to any allowed energy level in the ground state. The emission spectrum is the result of wavelengths determined as follows:

$$E_{\text{smallest}} = 0.7\text{ ev} - 2.5\text{ ev} = -1.8\text{ eV}$$

The minus sign just reminds us that the energy of the molecule decreases.
The wavelength associated with this energy is determined by:

$$\lambda_{\text{largest}} = hc/E = (6.63\times 10^{-34}\text{ J}\cdot\text{s})(3.0\times 10^{8}\text{ m/s})(\text{eV}/1.6\times 10^{-19}\text{ J})/(1.8\text{ eV}) = 690\text{ nm}$$

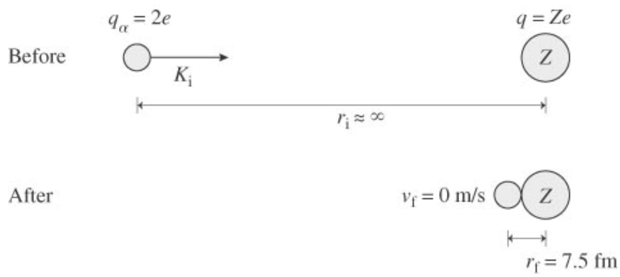
$$E_{\text{largest}} = 0\text{ eV} - 2.5\text{ eV} = -2.5\text{ eV}$$

The minus sign just reminds us that the energy of the molecule decreases.
The wavelength associated with this energy is determined by:

$$\lambda_{\text{smallest}} = hc/E = (6.63\times 10^{-34}\text{ J}\cdot\text{s})(3.0\times 10^{8}\text{ m/s})(\text{eV}/1.6\times 10^{-19}\text{ J})/(2.5\text{ eV}) = 500\text{ nm}$$

Assess: Notice that the largest wavelength of light associated with the absorption spectrum is equal to the smallest wavelength of light associated with the emission spectrum.

P29.49. Prepare: Assume the ^{238}U nucleus is at rest. We will use the energy conservation equation and find the alpha particle's kinetic energy K. This kinetic energy can be obtained if we accelerated the alpha particle through a potential difference of ΔV. The potential energy from the electric field is transformed into the kinetic energy of the alpha particle. That is, $K = q\Delta V = 2e\Delta V$. Thus $\Delta V = K/2e = K$ (in volts)/2.



Solve: The energy conservation equation $K_f + U_f = K_i + U_i$ is

$$0\ \text{J} + \frac{1}{4\pi\varepsilon_0}\frac{(2e)(92e)}{7.5\times 10^{-15}\ \text{m}} = K_i + 0$$

$$\Rightarrow K_i = \frac{(9.0\times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)184(1.60\times 10^{-19}\ \text{C})^2}{7.5\times 10^{-15}\ \text{m}} = 5.65\times 10^{-12}\ \text{J}\times\frac{1\ \text{eV}}{1.60\times 10^{-19}\ \text{J}}$$

$$= 35.33\ \text{MeV}$$

That is, the alpha particle must be fired with 35.33 MeV of kinetic energy. An alpha particle with charge $q = 2e$ gains kinetic energy K eV by accelerating through a potential difference $\Delta V = (1/2\ K)V$. Thus the alpha particle will just reach the ^{238}U nucleus after being accelerated through a potential difference

$$\Delta V = \frac{35.33}{2}\ \text{MV} = 1.77\times 10^7\ \text{V} \approx 1.8\times 10^7\ \text{V} = 18\ \text{MV}$$

P29.57. Prepare: Photons are absorbed in a quantum jump from a lower energy level to a higher energy level. The energy of the emitted photon is exactly equal to the energy between the starting and the ending levels. The energy levels of the stationary states of the hydrogen atom are $E_n = -13.60\ \text{eV}/n^2$ and $n = 1, 2, 3, \ldots$ In the ground state ($n = 1$), $E_1 = -13.60$ eV.

Solve: The change in energy when the hydrogen atom absorbs a 12.75 eV photon is

$$E_n - E_1 = 12.75\ \text{eV} \Rightarrow (-13.60\ \text{eV})\left(\frac{1}{n^2} - 1\right) = 12.75\ \text{eV} \Rightarrow \frac{1}{n^2} = 1 - \frac{12.75}{13.60} = 0.0625 \Rightarrow n = 4$$

When the atom, having been excited to $n = 4$, undergoes a quantum jump to the next lowest energy level (corresponding to $n = 3$), the emitted wavelength is given by Equation 29.2:

$$\lambda_{4\rightarrow 3} = \frac{91.18\ \text{nm}}{1/3^2 - 1/4^2} = 1876\ \text{nm}$$

Assess: This wavelength is in the infrared region.

P29.59. Solve: Because the atoms end at rest, $\Delta K = K_i = \frac{1}{2}mv^2$. Thus

$$\frac{1}{2}m_{\text{atom}}v^2 = E_2 - E_1 = \frac{hc}{\lambda} = \frac{(6.63\times 10^{-34}\ \text{Js})(3.0\times 10^8\ \text{m/s})}{121.6\times 10^9\ \text{m}} = 1.636\times 10^{-18}\ \text{J}$$

$$\Rightarrow v = \sqrt{\frac{2(E_2 - E_1)}{m_{\text{atom}}}} = \sqrt{\frac{2(1.636\times 10^{-18}\ \text{J})}{1.67\times 10^{-27}\ \text{kg}}} = 4.4\times 10^4\ \text{m/s}$$