Chapter 28

Atomic Physics

Answers to Even Numbered Conceptual

6. Classically, the electron can occupy any energy state. That is, all energies would be allowed. Therefore, if the electron obeyed classical mechanics, its spectrum, which originates from transitions between states, would be continuous rather than discrete.

8. The de Broglie wavelength of macroscopic objects such as a baseball moving with a typical speed such as 30 m/s is very small and impossible to measure. That is, $\lambda = h/mv$, is a very small number for macroscopic objects. We are not able to observe diffraction effects because the wavelength is much smaller than any aperture through which the object could pass.

10. In both cases the answer is yes. Recall that the ionization energy of hydrogen is 13.6 eV. The electron can absorb a photon of energy less than 13.6 eV by making a transition to some intermediate state such as one with $n = 2$. It can also absorb a photon of energy greater than 13.6 eV, but in doing so, the electron would be separated from the proton and have some residual kinetic energy.

Problem Solutions

28.1 The Balmer equation is $\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$, or $\lambda = \frac{4}{R_H}\left(\frac{n^2}{n^2-4}\right)$

When $n = 3$,

$$\lambda = \frac{4}{1.097\,37\times 10^{7}\text{ m}^{-1}}\left(\frac{9}{9-4}\right) = 6.56\times 10^{-7}\text{ m} = \boxed{656\text{ nm}}$$

When $n = 4$,

$$\lambda = \frac{4}{1.097\,37\times 10^{7}\text{ m}^{-1}}\left(\frac{16}{16-4}\right) = 4.86\times 10^{-7}\text{ m} = \boxed{486\text{ nm}}$$

When $n = 5$,

$$\lambda = \frac{4}{1.097\,37\times 10^{7}\text{ m}^{-1}}\left(\frac{25}{25-4}\right) = 4.34\times 10^{-7}\text{ m} = \boxed{434\text{ nm}}$$

28.3 (a) From Coulomb's law,

$$|F| = \frac{k_e|q_1q_2|}{r^2} = \frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(1.60\times10^{-19}\ \mathrm{C}\right)^2}{\left(1.0\times10^{-10}\ \mathrm{m}\right)^2} = \boxed{2.3\times10^{-8}\ \mathrm{N}}$$

(b) The electrical potential energy is

$$PE = \frac{k_eq_1q_2}{r} = \frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(-1.60\times10^{-19}\ \mathrm{C}\right)\left(1.60\times10^{-19}\ \mathrm{C}\right)}{1.0\times10^{-10}\ \mathrm{m}}$$

$$= -2.3\times10^{-18}\ \mathrm{J}\left(\frac{1\ \mathrm{eV}}{1.60\times10^{-19}\ \mathrm{J}}\right) = \boxed{-14\ \mathrm{eV}}$$

28.7 (a) $r_n = n^2a_0$ yields $r_2 = 4\left(0.0529\ \mathrm{nm}\right) = \boxed{0.212\ \mathrm{nm}}$

(b) With the electrical force supplying the centripetal acceleration,

$$\frac{m_ev_n^2}{r_n} = \frac{k_ee^2}{r_n^2}, \text{ giving } v_n = \sqrt{\frac{k_ee^2}{m_er_n}} \text{ and } p_n = m_ev_n = \sqrt{\frac{m_ek_ee^2}{r_n}}$$

Thus,

$$p_2 = \sqrt{\frac{m_ek_ee^2}{r_2}} = \sqrt{\frac{\left(9.11\times10^{-31}\ \mathrm{kg}\right)\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(1.6\times10^{-19}\ \mathrm{C}\right)^2}{0.212\times10^{-9}\ \mathrm{m}}}$$

$$= \boxed{9.95\times10^{-25}\ \mathrm{kg\cdot m/s}}$$

(c) $L_n = n\left(\frac{h}{2\pi}\right) \rightarrow L_2 = 2\left(\frac{6.63\times10^{-34}\ \mathrm{J\cdot s}}{2\pi}\right) = \boxed{2.11\times10^{-34}\ \mathrm{J\cdot s}}$

(d) $KE_2 = \frac{1}{2}m_ev_2^2 = \frac{p_2^2}{2m_e} = \frac{\left(9.95\times10^{-25}\ \mathrm{kg\cdot m/s}\right)^2}{2\left(9.11\times10^{-31}\ \mathrm{kg}\right)} = 5.44\times10^{-19}\ \mathrm{J} = \boxed{3.40\ \mathrm{eV}}$

(e) $PE_2 = \frac{k_e(-e)e}{r_2} = -\frac{\left(8.99\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\left(1.60\times10^{-19}\ \mathrm{C}\right)^2}{\left(0.212\times10^{-9}\ \mathrm{m}\right)}$

$$= -1.09\times10^{-18}\ \mathrm{J} = \boxed{-6.80\ \mathrm{eV}}$$

(f) $E_2 = KE_2 + PE_2 = 3.40 \text{ eV} - 6.80 \text{ eV} = \boxed{-3.40 \text{ eV}}$

28.10 (b) From $\dfrac{1}{\lambda} = R_H\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right)$

or $\lambda = \dfrac{1}{R_H}\left(\dfrac{n_i^2 n_f^2}{n_i^2 - n_f^2}\right)$ with $n_i = 6$ and $n_f = 2$

$$\lambda = \frac{1}{1.097\,37\times10^7 \text{ m}^{-1}}\left[\frac{(36)(4)}{36-4}\right] = 4.10\times10^{-7} \text{ m} = \boxed{410 \text{ nm}}$$

(a) $E = \dfrac{hc}{\lambda} = \dfrac{(6.63\times10^{-34} \text{ J}\cdot\text{s})(3.00\times10^8 \text{ m/s})}{410\times10^{-9} \text{ m}} = 4.85\times10^{-19} \text{ J} = \boxed{3.03 \text{ eV}}$

(c) $f = \dfrac{c}{\lambda} = \dfrac{3.00\times10^8 \text{ m/s}}{410\times10^{-9} \text{ m}} = \boxed{7.32\times10^{14} \text{ Hz}}$

28.15 From $\dfrac{1}{\lambda} = R_H\left(\dfrac{1}{n_f^2} - \dfrac{1}{n_i^2}\right)$, it is seen that (for a fixed value of n_f) λ_{max} occurs when $n_i = n_f + 1$ and λ_{min} occurs when $n_i \to \infty$.

(a) For the Lyman series $(n_f = 1)$,

$$\frac{1}{\lambda_{max}} = (1.097\,37\times10^7 \text{ m}^{-1})\left(\frac{1}{1^2} - \frac{1}{2^2}\right) \to \lambda_{max} = 1.22\times10^{-7} \text{ m} = \boxed{122 \text{ nm}}$$

and

$$\frac{1}{\lambda_{min}} = (1.097\,37\times10^7 \text{ m}^{-1})\left(\frac{1}{1^2} - \frac{1}{\infty}\right) \to \lambda_{min} = 9.11\times10^{-8} \text{ m} = \boxed{91.1 \text{ nm}}$$

(b) For the Paschen series $(n_f = 3)$,

$$\frac{1}{\lambda_{max}} = (1.097\,37\times10^7 \text{ m}^{-1})\left(\frac{1}{3^2} - \frac{1}{4^2}\right) \to \lambda_{max} = 1.87\times10^{-6} \text{ m} = \boxed{1.87\times10^3 \text{ nm}}$$

and

28.17 The batch of excited atoms must make these six transitions to get back to the ground state: $n_i = 2 \rightarrow n_f = 1$, also $n_i = 3 \rightarrow n_f = 2$ and $n_i = 3 \rightarrow n_f = 1$, and also $n_i = 4 \rightarrow n_f = 3$ and $n_i = 4 \rightarrow n_f = 2$ and $n_i = 4 \rightarrow n_f = 1$. Thus, the incoming light must have just enough energy to produce the $n_i = 1 \rightarrow n_f = 4$ transition. It must be the third line of the Lyman series in the absorption spectrum of hydrogen. The incoming photons must have wavelength given by

$$\frac{1}{\lambda} = R_H\left(\frac{1}{1^2} - \frac{1}{4^2}\right) = \frac{15R_H}{16} \text{ or } \lambda = \frac{16}{15R_H} = \frac{16}{15\left(1.097\,37\times 10^{7}\text{ m}^{-1}\right)} = \boxed{97.2\text{ nm}}$$

28.27 (a) From $E_n = -\frac{Z^2(13.6\text{ eV})}{n^2}$, $E_1 = -\frac{(3)^2(13.6\text{ eV})}{(1)^2} = \boxed{-122\text{ eV}}$

(b) Using $r_n = \frac{n^2 a_0}{Z}$ gives $r_1 = \frac{(1)^2 a_0}{3} = \frac{0.0529\times 10^{-9}\text{ m}}{3} = \boxed{1.76\times 10^{-11}\text{ m}}$

28.33 In the 3*p* subshell, $n = 3$ and $\ell = 1$. The 6 possible quantum states are

$n = 3$	$\ell = 1$	$m_\ell = +1$	$m_s = \pm\frac{1}{2}$
$n = 3$	$\ell = 1$	$m_\ell = 0$	$m_s = \pm\frac{1}{2}$
$n = 3$	$\ell = 1$	$m_\ell = -1$	$m_s = \pm\frac{1}{2}$

28.34 (a) For a given value of the principle quantum number *n*, the orbital quantum number l varies from 0 to $n-1$ in integer steps. Thus, if $n = 4$, there are $\boxed{4}$ possible values of l : $l = 0, 1, 2, \text{ and } 3$

(b) For each possible value of the orbital quantum number l, the orbital magnetic quantum number m_l ranges from $-l$ to $+l$ in integer steps. When the principle quantum number is $n = 4$ and the largest allowed value of the orbital quantum number is $l = 3$, there are $\boxed{7}$ distinct possible values for m_l. These values are:

$$m_l = -3, -2, -1, 0, +1, +2, \text{ and } +3$$

28.36 (a) The electronic configuration for oxygen $(Z = 8)$ is $\boxed{1s^2\,2s^2\,2p^4}$

(b) The quantum numbers for the 8 electrons can be:

1*s* states	$n = 1$	$\ell = 0$	$m_\ell = 0$	$m_s = \pm\frac{1}{2}$
2*s* states	$n = 2$	$\ell = 0$	$m_\ell = 0$	$m_s = \pm\frac{1}{2}$
2*p* states	$n = 2$	$\ell = 1$	$m_\ell = 0$ $m_\ell = 1$	$m_s = \pm\frac{1}{2}$ $m_s = \pm\frac{1}{2}$

28.37 (a) For Electron #1 and also for Electron #2, $n = 3$ and $\ell = 1$. The other quantum numbers for each of the 30 allowed states are listed in the tables below.

	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s
Electron #1	+1	$+\frac{1}{2}$	+1	$+\frac{1}{2}$	+1	$+\frac{1}{2}$	+1	$-\frac{1}{2}$	+1	$-\frac{1}{2}$	+1	$-\frac{1}{2}$
Electron #2	+1	$-\frac{1}{2}$	0	$\pm\frac{1}{2}$	-1	$\pm\frac{1}{2}$	+1	$+\frac{1}{2}$	0	$\pm\frac{1}{2}$	-1	$\pm\frac{1}{2}$

	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s
Electron #1	0	$+\frac{1}{2}$	0	$+\frac{1}{2}$	0	$+\frac{1}{2}$	0	$-\frac{1}{2}$	0	$-\frac{1}{2}$	0	$-\frac{1}{2}$
Electron #2	+1	$\pm\frac{1}{2}$	0	$-\frac{1}{2}$	-1	$\pm\frac{1}{2}$	+1	$\pm\frac{1}{2}$	0	$+\frac{1}{2}$	-1	$\pm\frac{1}{2}$

	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s	m_ℓ	m_s
Electron #1	-1	$+\frac{1}{2}$	-1	$+\frac{1}{2}$	-1	$+\frac{1}{2}$	-1	$-\frac{1}{2}$	-1	$-\frac{1}{2}$	-1	$-\frac{1}{2}$
Electron #2	+1	$\pm\frac{1}{2}$	0	$\pm\frac{1}{2}$	-1	$-\frac{1}{2}$	+1	$\pm\frac{1}{2}$	0	$\pm\frac{1}{2}$	-1	$+\frac{1}{2}$

There are $\boxed{30 \text{ allowed states}}$, since Electron #1 can have any of three possible values of m_ℓ for both spin up and spin down, totaling six possible states. For each of these states, Electron #2 can be in either of the remaining five states.

(b) Were it not for the exclusion principle, there would be $\boxed{36}$ possible states, six for each electron independently.

28.41 For nickel, $Z = 28$ and

$$E_K \approx -(Z-1)^2 \frac{13.6 \text{ eV}}{(1)^2} = -(27)^2(13.6 \text{ eV}) = -9.91\times 10^3 \text{ eV}$$

$$E_L \approx -(Z-3)^2 \frac{13.6 \text{ eV}}{(2)^2} = -(25)^2 \frac{(13.6 \text{ eV})}{4} = -2.13\times 10^3 \text{ eV}$$

Thus, $E_\gamma = E_L - E_K = -2.13 \text{ keV} - (-9.91 \text{ keV}) = 7.78 \text{ keV}$

and

$$\lambda = \frac{hc}{E_\gamma} = \frac{(6.63\times 10^{-34} \text{ J}\cdot\text{s})(3.00\times 10^{8} \text{ m/s})}{7.78 \text{ keV}\left(1.60\times 10^{-16} \text{ J/keV}\right)} = 1.60\times 10^{-10} \text{ m} = \boxed{0.160 \text{ nm}}$$