28.3 (a) From Coulomb's law,

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

(b) The electrical potential energy is

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

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

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

(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,

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

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

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

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

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

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

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

28.8 (a) With the electrical force supplying the centripetal acceleration,

$$\frac{m_e v_n^2}{r_n} = \frac{k_e e^2}{r_n^2}, \text{ giving } v_n = \sqrt{\frac{k_e e^2}{m_e r_n}}$$

where $r_n = n^2 a_0 = n^2 (0.052\,9 \text{ nm})$

Thus,

$$v_1 = \sqrt{\frac{k_e e^2}{m_e r_1}} = \sqrt{\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.60 \times 10^{-19} \text{ C})^2}{(9.11 \times 10^{-31} \text{ kg})(0.052\,9 \times 10^{-9} \text{ m})}} = \boxed{2.19 \times 10^6 \text{ m/s}}$$

(b) $$KE_1 = \frac{1}{2} m_e v_1^2 = \frac{k_e e^2}{2r_1} = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.60 \times 10^{-19} \text{ C})^2}{2(0.052\,9 \times 10^{-9} \text{ m})}$$

$$= 2.18 \times 10^{-18} \text{ J} = \boxed{13.6 \text{ eV}}$$

(c) $$PE_1 = \frac{k_e(-e)e}{r_1} = -\frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.60 \times 10^{-19} \text{ C})^2}{(0.052\,9 \times 10^{-9} \text{ m})}$$

$$= -4.35 \times 10^{-18} \text{ J} = \boxed{-27.2 \text{ eV}}$$

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

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

$$\lambda = \frac{1}{1.097\,37 \times 10^7 \text{ m}^{-1}} \left[\frac{(36)(4)}{36-4} \right] = 4.10 \times 10^{-7} \text{ m} = \boxed{410 \text{ nm}}$$

(a) $$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{410 \times 10^{-9} \text{ m}} = 4.85 \times 10^{-19} \text{ J} = \boxed{3.03 \text{ eV}}$$

(c) $$f = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{410 \times 10^{-9} \text{ m}} = \boxed{7.32 \times 10^{14} \text{ Hz}}$$

28.13 The energy absorbed by the atom is

$$E_\gamma = E_f - E_i = 13.6\text{ eV}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$

(a) $E_\gamma = 13.6\text{ eV}\left(\frac{1}{9} - \frac{1}{25}\right) = \boxed{0.967\text{ eV}}$

(b) $E_\gamma = 13.6\text{ eV}\left(\frac{1}{25} - \frac{1}{49}\right) = \boxed{0.266\text{ eV}}$

28.14 (a) The energy absorbed is

$$\Delta E = E_f - E_i = 13.6\text{ eV}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right) = 13.6\text{ eV}\left(\frac{1}{1} - \frac{1}{9}\right) = \boxed{12.1\text{ eV}}$$

28.20 (a) Starting from the $n = 4$ state, there are 6 possible transitions as the electron returns to the ground $(n = 1)$ state. These transitions are: $n = 4 \to n = 1$, $n = 4 \to n = 2$, $n = 4 \to n = 3$, $n = 3 \to n = 1$, $n = 3 \to n = 2$, and $n = 2 \to n = 1$. Since there is a different change in energy associated with each of these transitions there will be $\boxed{\text{6 different wavelengths}}$ observed in the emission spectrum of these atoms.

(b) The longest observed wavelength is produced by the transition involving the smallest change in energy. This is the $n = 4 \to n = 3$ transition, and the wavelength is

$$\lambda_{\max} = \frac{hc}{E_4 - E_3} = \frac{\left(6.626\times10^{-34}\text{ J}\cdot\text{s}\right)\left(2.998\times10^{8}\text{ m/s}\right)}{-13.6\text{ eV}\left(\frac{1}{4^2} - \frac{1}{3^2}\right)}\left(\frac{1\text{ eV}}{1.602\times10^{-19}\text{ J}}\right)\left(\frac{1\text{ nm}}{10^{-9}\text{ m}}\right)$$

or $\lambda_{\max} = \boxed{1.88\times10^{3}\text{ nm}}$

Since this transition terminates on the $n = 3$ level, this is part of the $\boxed{\text{Paschen series}}$

28.25 For minimum initial kinetic energy, $KE_{total} = 0$ after collision. Hence, the two atoms must have equal and opposite momenta before impact. The atoms then have the same initial kinetic energy, and that energy is converted into excitation energy of the atom during the collision. Therefore,

$$KE_{atom} = \frac{1}{2}m_{atom}v^2 = E_2 - E_1 = 10.2\text{ eV}$$

or $$v=\sqrt{\frac{2(10.2\text{ eV})}{m_{atom}}}=\sqrt{\frac{2(10.2\text{ eV})\left(1.60\times10^{-19}\text{ J/eV}\right)}{1.67\times10^{-27}\text{ kg}}}=\boxed{4.42\times10^{4}\text{ m/s}}$$

27.34 The de Broglie wavelength of a particle of mass m is $\lambda=h/p$ where the momentum is given by $p=\gamma mv=mv\Big/\sqrt{1-(v/c)^2}$. Note that when the particle is not relativistic, then $\gamma\approx1$, and this relativistic expression for momentum reverts back to the classical expression.

(a) For a proton moving at speed $v=2.00\times10^{4}\text{ m/s}$, $v<<c$ and $\gamma\approx1$ so

$$\lambda=\frac{h}{m_p v}=\frac{6.63\times10^{-34}\text{ J}\cdot\text{s}}{\left(1.67\times10^{-27}\text{ kg}\right)\left(2.00\times10^{4}\text{ m/s}\right)}=\boxed{1.98\times10^{-11}\text{ m}}$$

(b) For a proton moving at speed $v=2.00\times10^{7}\text{ m/s}$

$$\lambda=\frac{h}{\gamma m_p v}=\frac{h}{m_p v}\sqrt{1-(v/c)^2}$$

$$=\frac{\left(6.63\times10^{-34}\text{ J}\cdot\text{s}\right)}{\left(1.67\times10^{-27}\text{ kg}\right)\left(2.00\times10^{7}\text{ m/s}\right)}\sqrt{1-\left(\frac{2.00\times10^{7}\text{ m/s}}{3.00\times10^{8}\text{ m/s}}\right)^2}=\boxed{1.98\times10^{-14}\text{ m}}$$

27.35 (a) From $\lambda=h/p=h/mv$, the speed is

$$v=\frac{h}{m_e\lambda}=\frac{6.63\times10^{-34}\text{ J}\cdot\text{s}}{\left(9.11\times10^{-31}\text{ kg}\right)\left(5.00\times10^{-7}\text{ m}\right)}=1.46\times10^{3}\text{ m/s}=\boxed{1.46\text{ km/s}}$$

(b) $$\lambda=\frac{h}{m_e v}=\frac{6.63\times10^{-34}\text{ J}\cdot\text{s}}{\left(9.11\times10^{-31}\text{ kg}\right)\left(1.00\times10^{7}\text{ m/s}\right)}=\boxed{7.28\times10^{-11}\text{ m}}$$

27.40 From Chapter 24, the minima (or dark fringes) in a single slit diffraction pattern occur where $\sin\theta=m\lambda/a$ for $m=\pm1,\pm2,\pm3,\ldots$ Here, λ is the wavelength of the wave passing through the slit of width a. When the fringes are observed on a screen at distance L from the slit, the distance from the central maximum to the minima of order m is given by $y_m=L\tan\theta_m\approx L\sin\theta_m=m\lambda(L/a)$. The spacing between successive minima is then

$$\Delta y=y_{m+1}-y_m=\lambda\left(\frac{L}{a}\right)$$

Hence, if $\Delta y = 2.10$ cm when $L = 20.0$ cm and $a = 0.500$ nm, the de Broglie wavelength of the electrons passing through the slit must be

$$\lambda = \Delta y\left(\frac{a}{L}\right) = \left(2.10\times10^{-2}\ \text{m}\right)\left(\frac{0.500\times10^{-9}\ \text{m}}{20.0\times10^{-2}\ \text{m}}\right) = 5.25\times10^{-11}\ \text{m}$$

The momentum of one of these electrons is then

$$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{5.25\times10^{-11}\ \text{m}} = 1.263\times10^{-23}\ \text{kg}\cdot\text{m/s}$$

and, assuming the electron is non-relativistic, its kinetic energy is

$$KE = \frac{p^2}{2m_e} = \frac{\left(1.263\times10^{-23}\ \text{kg}\cdot\text{m/s}\right)^2}{2\left(9.11\times10^{-31}\ \text{kg}\right)}\left(\frac{1\ \text{eV}}{1.60\times10^{-19}\ \text{J}}\right) = \boxed{547\ \text{eV}}$$

Note that if the particle had been relativistic, its kinetic energy would have been computed from $KE = E - E_R = \sqrt{p^2c^2 + E_R^2} - E_R$

27.41 (a) The required electron momentum is

$$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{1.0\times10^{-11}\ \text{m}}\left(\frac{1\ \text{keV}}{1.60\times10^{-16}\ \text{J}}\right) = 4.1\times10^{-7}\ \frac{\text{keV}\cdot\text{s}}{\text{m}}$$

and the total energy is

$$E = \sqrt{p^2c^2 + E_R^2}$$

$$= \sqrt{\left(4.1\times10^{-7}\ \frac{\text{keV}\cdot\text{s}}{\text{m}}\right)^2\left(3.00\times10^{8}\ \text{m/s}\right)^2 + \left(511\ \text{keV}\right)^2} = 526\ \text{keV}$$

The kinetic energy is then,

$$KE = E - E_R = 526\ \text{keV} - 511\ \text{keV} = \boxed{15\ \text{keV}}$$

(b) $E_\gamma = \dfrac{hc}{\lambda}$

$$= \frac{\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3.00\times10^{8}\ \text{m/s}\right)}{1.0\times10^{-11}\ \text{m}}\left(\frac{1\ \text{keV}}{1.60\times10^{-16}\ \text{J}}\right) = \boxed{1.2\times10^{2}\ \text{keV}}$$

28.33 In the $3p$ 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: $\ell = 0, 1, 2,$ and 3

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

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

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:

$1s$ states	$n = 1$	$\ell = 0$	$m_\ell = 0$	$m_s = \pm\frac{1}{2}$
$2s$ states	$n = 2$	$\ell = 0$	$m_\ell = 0$	$m_s = \pm\frac{1}{2}$
$2p$ 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 $\boxed{\text{30 allowed states}}$, 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.

28.38 (a) For $n=1$, $\ell=0$ and there are $2(2\ell+1)$ states $=2(1)=\boxed{2}$ sets of quantum numbers

(b) For $n=2$, $\ell=0$ for $2(2\ell+1)$ states $=2(0+1)=2$ sets
and $\ell=1$ for $2(2\ell+1)$ states $=2(2+1)=6$ sets
total number of sets = $\boxed{8}$

(c) For $n=3$, $\ell=0$ for $2(2\ell+1)$ states $=2(0+1)=2$ sets
and $\ell=1$ for $2(2\ell+1)$ states $=2(2+1)=6$ sets
and $\ell=2$ for $2(2\ell+1)$ states $=2(4+1)=10$ sets
total number of sets = $\boxed{18}$

(d) For $n=4$, $\ell=0$ for $2(2\ell+1)$ states $=2(0+1)=2$ sets
and $\ell=1$ for $2(2\ell+1)$ states $=2(2+1)=6$ sets
and $\ell=2$ for $2(2\ell+1)$ states $=2(4+1)=10$ sets
and $\ell=3$ for $2(2\ell+1)$ states $=2(6+1)=14$ sets
total number of sets = $\boxed{32}$

(e) For $n=5$, $\ell=0$ for $2(2\ell+1)$ states $=2(0+1)=2$ sets
and $\ell=1$ for $2(2\ell+1)$ states $=2(2+1)=6$ sets
and $\ell=2$ for $2(2\ell+1)$ states $=2(4+1)=10$ sets
and $\ell=3$ for $2(2\ell+1)$ states $=2(6+1)=14$ sets
and $\ell=4$ for $2(2\ell+1)$ states $=2(8+1)=18$ sets
total number of sets = $\boxed{50}$

For $n=1$: $2n^2=2$ For $n=2$: $2n^2=8$
For $n=3$: $2n^2=18$ For $n=4$: $2n^2=32$
For $n=5$: $2n^2=50$