

3.

**Table 3** Sommerfeld's Electron Energy Sublevels

Primary energy level	Principal quantum number, $n$	Possible secondary quantum numbers, $l$	Number of sublevels per primary level
1	1	0	1
2	2	0, 1	4
3	3	0, 1, 2	9
4	4	0, 1, 2, 3	16

4. For any principal quantum number,  $n$ , the highest possible value of  $l$  is  $n-1$ .

5. For any principal quantum number,  $n$ , the possible values of  $l$  include all of the integers from 0 to  $n-1$ .

## SECTION 3.5 QUESTIONS

(Page 184)

### Understanding Concepts

- The main kind of evidence used comes from atomic line spectra, particularly the splitting of lines.
- The first quantum number describes the main energy level; the second quantum number describes small energy level steps within the main energy level corresponding to different shapes of "orbits"; the third quantum number describes the orientation in space of the electron "orbits"; and the fourth quantum number describes the "spin" of electrons.
- (a) For  $l = 0, 1, 2$ , and  $3$ , there are 0, 3, 5, and 7 possible values of  $m_l$ , respectively.  
(b) Each number is the next greater odd integer (or  $2l + 1$  for all  $l$ s except  $l = 0$ ).  
(c) From the answer to (b), the number of possible values for  $m_l$  for  $l = 4$  must be 9 (the next odd integer).
- The fourth quantum number is  $m_s$ , and it is necessary to explain magnetic properties of atoms.

**Table 4** Summary of Quantum Numbers

$(n)$	$(0 \text{ to } n - 1)$	$(-l \text{ to } +l)$	$(+1/2 \text{ or } -1/2)$
4	0	0	$+1/2, -1/2$
	1	-1, 0, +1	$+1/2, -1/2$
	2	-2, -1, 0, +1, +2	$+1/2, -1/2$
	3	-3, -2, -1, 0, +1, +2, +3	$+1/2, -1/2$

- It takes four quantum numbers to describe fully an electron in an atom. An example listing labels and values of each quantum number might be  $n = 2$ ,  $l = 1$ ,  $m_l = -1$ , and  $m_s = +1/2$ . This might describe an electron in a hydrogen atom in an "excited" state.
- For each principal quantum number from  $n = 1$  to  $n = 3$  (see Table 4), there can be 2, 8, and 18 different electron descriptions.
- In the development of scientific knowledge, empirical knowledge usually comes first. Examples from this section are the investigation of bright line spectra and of magnetic effects upon these spectra—both of which preceded the theory that attempts to explain them in terms of atomic structure.

## 3.6 ATOMIC STRUCTURE AND THE PERIODIC TABLE

### PRACTICE

(Page 191)

### Understanding Concepts

- The aufbau principle states that electrons occupy lowest energy orbitals first. The Pauli exclusion principle states that no more than two electrons (of opposite spin) may occupy the same orbital, and Hund's rule states that electrons are not paired within sublevel orbitals until each sublevel orbital has at least one electron.

2. A periodic table can be used to help complete energy level diagrams because it is arranged according to electron energy levels, sublevels, and orbitals.

3. (a)  $3p \uparrow \uparrow \uparrow$   
 $3s \uparrow\downarrow$

$2p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $2s \uparrow\downarrow$

$1s \uparrow\downarrow$   
 phosphorus atom, P

(b)  $4s \uparrow$

$3p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $3s \uparrow\downarrow$

$2p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $2s \uparrow\downarrow$

$1s \uparrow\downarrow$   
 potassium atom, K

(c)  $3d \uparrow \uparrow \uparrow \uparrow \uparrow$   
 $4s \uparrow\downarrow$

$3p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $3s \uparrow\downarrow$

$2p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $2s \uparrow\downarrow$

$1s \uparrow\downarrow$   
 manganese atom, Mn

(d)  $2p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $2s \uparrow\downarrow$

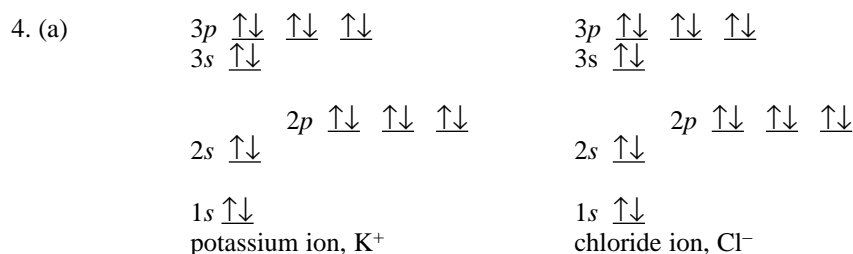
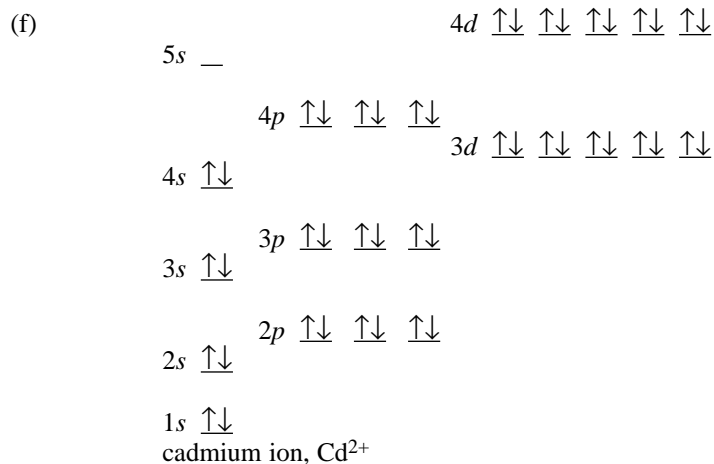
$1s \uparrow\downarrow$   
 nitride ion,  $N^{3-}$

(e)  $4p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $3d \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $4s \uparrow\downarrow$

$3p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $3s \uparrow\downarrow$

$2p \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$   
 $2s \uparrow\downarrow$

$1s \uparrow\downarrow$   
 bromide ion,  $Br^-$



(b) An atom of the noble gas argon, Ar, has the same electron orbital energy level diagram as do these two ions.

### Extension

5.  $1s$  would be  $n = 1, l = 0$   
 $2s$  would be  $n = 2, l = 0$   
 $2p$  would be  $n = 2, l = 1$   
 $3d$  would be  $n = 3, l = 2$

### PRACTICE

(Page 194)

### Understanding Concepts

6. (a) beryllium  
 (b) fluorine  
 (c) sodium  
 (d) sulfur
7. sodium  $1s^2 2s^2 2p^6 3s^1$   
 magnesium  $1s^2 2s^2 2p^6 3s^2$   
 aluminum  $1s^2 2s^2 2p^6 3s^2 3p^1$   
 silicon  $1s^2 2s^2 2p^6 3s^2 3p^2$   
 phosphorus  $1s^2 2s^2 2p^6 3s^2 3p^3$   
 sulfur  $1s^2 2s^2 2p^6 3s^2 3p^4$   
 chlorine  $1s^2 2s^2 2p^6 3s^2 3p^5$   
 argon  $1s^2 2s^2 2p^6 3s^2 3p^6$
8. fluorine  $[\text{He}] 2s^2 2p^5$   
 chlorine  $[\text{Ne}] 3s^2 3p^5$   
 bromine  $[\text{Ar}] 4s^2 4p^5$   
 iodine  $[\text{Kr}] 5s^2 5p^5$   
 astatine  $[\text{Xe}] 6s 6p^5$

Each halogen configuration ends with two  $s$  and three  $p$  orbitals.

Other chemical families, such as the alkali metals, also have similar valence orbital configurations.

9. fluoride ion  $1s^2 2s^2 2p^6$   
 sodium ion  $1s^2 2s^2 2p^6$
10. Isoelectronic means having the same number of electrons.
11. zinc ion  $[\text{Ar}] 3d^{10}$   
 cadmium ion  $[\text{Kr}] 4d^{10}$   
 mercury(II) ion  $[\text{Xe}] 4f^{14} 5d^8$

## SECTION 3.6 QUESTIONS

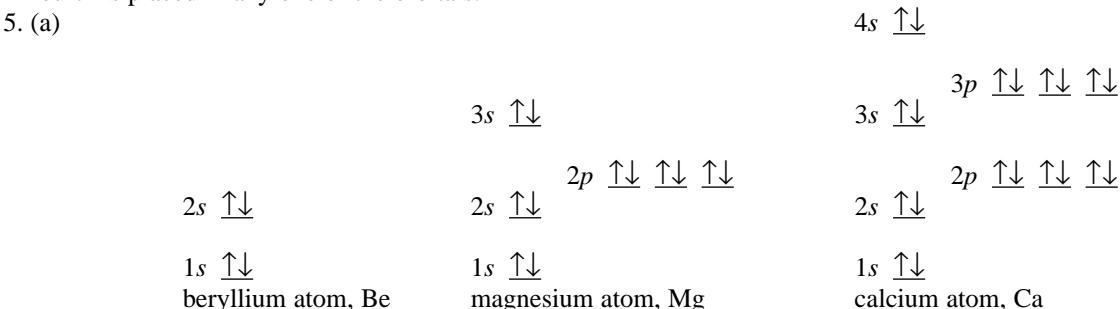
(Page 197)

### Understanding Concepts

1. Maximum number of electrons: (a)  $2e^-$  (b)  $8e^-$  (c)  $18e^-$  (d)  $32e^-$
- 2.

Orbitals and Electrons in <i>s</i> , <i>p</i> , <i>d</i> , and <i>f</i> Sublevels				
Sublevel	Symbol	Value of <i>l</i>	Number of orbitals	Max # of electrons
(a)	<i>s</i>	0	1	2
(b)	<i>p</i>	1	4	8
(c)	<i>d</i>	2	9	18
(d)	<i>f</i>	3	16	32

3. The aufbau principle states that electrons occupy lower energy orbitals first. Either a diagonal orbital diagram or the periodic table can be used to determine this order of occupancy.
4. If four electrons are to be placed into a *p* subshell, the aufbau principle states that all lower energy levels must already be full, and Hund's rule states that each of the three *p* orbitals must already have one occupying electron before the fourth is placed in any one of the orbitals.



- (b) These diagrams all show two *s* electrons in the highest energy orbital.
6. (a) *s*  
 (b) *d*  
 (c) *p*  
 (d) *f*
7. (a) The halide ions have a charge of negative one,  $-1$ .  
 (b) The electron configuration of each halogen shows one less electron than a full *p* orbital energy level; for example, fluorine is  $1s^2 2s^2 2p^5$ , chlorine is  $1s^2 2s^2 2p^6 3s^2 3p^5$ , bromine is  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$ , and so on. We explain the ion charge by assuming that halogens strongly attract one extra electron to occupy the unfilled *p* orbital in the highest orbital energy level.
8. (a) A sodium ion,  $\text{Na}^+$ , has a configuration of  $1s^2 2s^2 2p^6$ , the same as that of a neon atom, Ne.  
 (b) These two chemical entities are both chemically very stable, and have the same electron configuration; but sodium ions are positively charged and strongly attract negative ions to form ionic solid compounds, while neutral neon atoms have extremely weak attractive forces, and form a noble gas at room conditions.
9. The electron configuration for  $\text{Sb}^{3+}$  is  $[\text{Kr}] 5s^2 4d^{10}$ . The electron configuration for  $\text{Sb}^{5+}$  is  $[\text{Kr}] 4d^{10}$ .
10. The electron configuration for a gallium atom, Ga, is  $[\text{Ar}] 4s^2 3d^{10} 4p^1$ . The  $\text{Ga}^{3+}$  ion has most probably lost three electrons from the fourth shell, and so should have a configuration of  $[\text{Ar}] 3d^{10}$ .
11. Copper has an electron configuration of  $[\text{Ar}] 4s^1 3d^{10}$  and therefore has an unpaired electron ( $4s^1$ ). Zinc has an electron configuration of  $[\text{Ar}] 4s^2 3d^{10}$  and has no unpaired electrons.

12. A gold atom should have an electron configuration of  $[\text{Xe}] 6s^2 4f^{14} 5d^9$ , if we use the aufbau principle. However, a filled  $d$  suborbital creates extra stability, especially in large atoms, so  $[\text{Xe}] 6s^1 4f^{14} 5d^{10}$  is the normal configuration.
13. (a)  $\text{Sc}^{3+}$  has a probable configuration of  $1s^2 2s^2 2p^6 3s^2 3p^6$ , or  $[\text{Ar}]$ .  
 (b)  $\text{Ag}^+$  has a probable configuration of  $[\text{Kr}] 4d^{10}$ .  
 (c)  $\text{Fe}^{3+}$  has a probable configuration of  $[\text{Ar}] 3d^5$ .  
 $\text{Fe}^{2+}$  has a probable configuration of  $[\text{Ar}] 4s^1 3d^5$ .  
 (d)  $\text{Th}^+$  has a probable configuration of  $[\text{Rn}] 7s^2 5f^1$ .  
 $\text{Th}^{3+}$  has a probable configuration of  $[\text{Rn}] 5f^1$ .
14. Carbon, silicon, and germanium atoms have (respectively) electron configurations of  $1s^2 2s^2 2p^2$ ,  $1s^2 2s^2 2p^6 3s^2 3p^2$ , and  $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^2$ . Each of these atoms has four electrons in the highest numbered shell of orbitals, and likely use these four electrons for bonding.

### Applying Inquiry Skills

15. (a) The result predicted by classical theory is that the atoms should hit a target to form a solid pattern because the atoms should hit the photographic plate randomly within the beam. The result predicted by quantum theory is that the pattern should be two distinct lines.  
 (b) Silver has an electron configuration of  $[\text{Kr}] 5s^1 4d^{10}$ , with a single unpaired  $s$  valence electron. If all silver atoms were identical, any magnetic moment caused by the external field should move the atoms in random directions, since it could be oriented in any direction as the atoms enter the field. The two distinct lines indicate that a silver atom must have one of two distinct and opposite magnetic moments. This was later interpreted to be due to the valence (unpaired) electron having one of only two possible (and opposite) “spins.”

### Making Connections

16. (a) Dimes were shipped out of the country because it is illegal to deface or alter Canadian currency in Canada.  
 (b) These metals have very different magnetic properties, which could be used to separate them.  
 (c) A magnet should separate these coins easily, because nickel is ferromagnetic (strongly magnetic) and silver is not.
17. ESR spectroscopy places samples of paramagnetic material in a high uniform magnetic field to split the energy levels of the ground state. The results can be used to help determine molecular structures and properties, such as the degree of movement (rotation) of side groups on structures. Another area deals with finding probable redox activation sites on protein molecules. The dynamics (movements) of molecules in liquid and solid phases can be examined to determine properties of new materials.
18. MRI uses alterations to the spin of a proton—which has two quantum states like that of an electron—to cause signals to be emitted from materials such as human tissue that can be used to scan the interior of the material in great detail, without harmful invasion of the material by physical objects or high-energy electromagnetic radiation. Like ESR, MRI uses a very powerful magnetic field to align subatomic particles.

MRI has its major use in medicine, where it provides excellent detailed scans of soft tissue, allowing doctors to diagnose illness and abnormalities much more effectively than with X rays.

The political issue associated with MRI use is the cost of health care. MRI machines are very valuable to doctors, but the machines (and the technicians to run them) are in short supply, highly technical, and very expensive.

## 3.7 WAVE MECHANICS AND ORBITALS

### SECTION 3.7 QUESTIONS

(Page 202)

#### Understanding Concepts

- (a) Louis Victor, 7<sup>th</sup> Duc de Broglie, believed that particles could have properties and characteristics of waves, and that this effect would be significant for tiny, fast-moving particles like electrons.

(b) Erwin Schrödinger imagined electron behaviour within the atom structure as a wave phenomenon, described by a wave mechanical equation.

(c) Werner Heisenberg thought that electron behaviour cannot ever be exactly described, but only discussed as a probability system, within limits imposed by his “uncertainty principle.”
- An electron orbital describes the three-dimensional region of space occupied by an electron, that is, in which we calculate a high probability (usually > 90%) of detecting an electron of a specific energy.

An orbit is a simplified (incorrect, but useful) idea describing electrons as orbiting nuclei in circular or elliptical paths.