SUMMARY

The goal of Chapter 29 has been to use quantum physics to understand the properties of atoms, molecules, and their spectra.

IMPORTANT CONCEPTS

The Structure of an Atom

An atom consists of a very small, positively charged nucleus, surrounded by orbiting electrons.
- The number of protons is the atom’s atomic number $Z$.
- The atomic mass number $A$ is the number of protons + the number of neutrons.

The Hydrogen Atom

In Bohr’s model of the hydrogen atom the stationary states are found by requiring that an integer number of de Broglie wavelengths fit around the circumference of the electron’s orbit: $2\pi r = n\lambda$. The integer $n$ is the principal quantum number.

This leads to energy quantization with

$$E_n = -\frac{13.60 \text{ eV}}{n^2}$$

and orbit radii $r_n = n^2 \alpha_B$, where $\alpha_B = 0.053 \text{ nm}$ is the Bohr radius.

The wavelengths of light in the hydrogen atom spectrum are given by the Balmer formula:

$$\lambda_{n-m} = \frac{91.1 \text{ nm}}{\left(\frac{1}{m^2} - \frac{1}{n^2}\right)}$$

for $m = 1, 2, 3, \ldots$ and $n = m + 1, m + 2, \ldots$

The Bohr Atom

In Bohr’s model:
- The atom can exist in only certain stationary states. These states correspond to different electron orbits. Each state is numbered by quantum number $n = 1, 2, 3, \ldots$.
- Each state has a discrete, well-defined energy $E_n$.
- The atom can change its energy by undergoing a quantum jump between two states by emitting or absorbing a photon of energy $E_{\text{photon}} = \Delta E_{\text{atom}} = |E_j - E_i|$.

Beyond the Bohr model, quantum mechanics adds several quantized parameters, each with its own quantum number:
- The orbital angular momentum, quantum number $l$:
  $$L = \sqrt{l(l+1)}h, \quad l = 0, 1, 2, 3, \ldots, n - 1$$
- The angle of the electron orbit, quantum number $m$:
  $$m = -l, -l+1, \ldots, 0, \ldots, l-1, l$$
- The direction of the electron spin, quantum number $m_s$:
  $$m_s = -\frac{1}{2} \text{ or } +\frac{1}{2}$$

The energy of a hydrogen atom depends only on $n$:

$$E_n = -\frac{13.60 \text{ eV}}{n^2}$$

where all states with the same $n$ have the same energy.

Multielectron atoms

Each electron is described by the same quantum numbers $(n, l, m, m_s)$ used for the hydrogen atom, but the energy now depends on $l$ as well as $n$.

The Pauli exclusion principle states that no more than one electron can occupy each quantum state.

Applications

Atomic emission spectra are generated by excitation followed by a photon-emitting quantum jump.
- Excitation occurs by absorption of a photon or by collision.
- A quantized jump can occur only if $\Delta l = \pm 1$.
- Quantized energies give rise to a discrete spectrum.

Molecules

In molecules, the states are spaced very closely into bands of states. Because electrons can be excited to and from many states, the spectra of molecules are broad, not discrete.

Lasers

A photon with energy $E_{\text{photon}} = E_j - E_i$ can induce stimulated emission of a second photon identical to the first. These photons can then induce more atoms to emit photons. If more atoms are in state 2 than in state 1, this process can rapidly build up an intense beam of identical photons. This is the principle behind the laser.
Conceptual Questions

1. A neon discharge emits a bright reddish-orange spectrum. But a glass tube filled with neon is completely transparent. Why doesn’t the neon in the tube absorb orange and red wavelengths?

2. The two spectra shown in Figure Q29.2 belong to the same element, a fictional Element X. Explain why they are different.

3. Is a spectral line with wavelength 656.5 nm seen in the absorption spectrum of hydrogen atoms? Why or why not?

4. J. J. Thomson studied the ionization of atoms in collisions with electrons. He accelerated electrons through a potential difference, shot them into a gas of atoms, then used a mass spectrometer to detect any ions produced in the collisions. By using different gases, he found that he could produce singly ionized atoms of all the elements that he tried. When he used higher accelerating voltages, he was able to produce doubly ionized atoms of all elements except hydrogen.
   a. Why did Thomson have to use higher accelerating voltages to detect doubly ionized atoms than to detect singly ionized atoms?
   b. What conclusion or conclusions about hydrogen atoms can you draw from these observations? Be specific as to how your conclusions are related to the observations.

5. Bohr did not include the gravitational force in his analysis of the hydrogen atom. Is this one of the reasons that his model of the hydrogen atom had only limited success? Explain.

6. If an electron is in a stationary state of an atom, is the electron at rest? If not, what does the term mean?

7. The \( n = 3 \) state of hydrogen has \( E_3 = -1.51 \text{ eV} \).
   a. Why is the energy negative?
   b. What is the physical significance of the specific number \( -1.51 \text{ eV} \)?

8. For a hydrogen atom, list all possible states \((n, l, m)\) that have \( E = -1.51 \text{ eV} \).

9. What are the \( n \) and \( l \) values of the following states of a hydrogen atom: (a) \( 4d \), (b) \( 5f \), (c) \( 6s \)?

10. How would you label the hydrogen-atom states with the following \((n, l, m)\) quantum numbers: (a) \((4, 3, 0)\), (b) \((3, 2, 1)\), (c) \((3, 2, -1)\)?

11. Consider the two hydrogen-atom states \(5d\) and \(4f\). Which has the higher energy? Explain.

12. Does each diagram in Figure Q29.12 represent a possible electron configuration of a neutral element? If so, (i) identify the element and (ii) determine if this is the ground state or an excited state. If not, why not?

![Figure Q29.12](image)

13. Do the following electron configurations represent a possible state of an element? If so, (i) identify the element and (ii) determine if this is the ground state or an excited state. If not, why not?
   a. \( 1s^2 2s^2 2p^3 3s^2 \)
   b. \( 1s^2 2s^2 2p^3 3s \)
   c. \( 1s^2 2s^2 2p^3 3s^2 3p^2 \)

14. Why is the section of the periodic table labeled as “transition elements” exactly 10 elements wide in all rows?

15. An electron is in an \( s \) state. Can it undergo a quantum jump to an \( s \) state? A \( p \) state? A \( d \) state? Explain.

16. Figure Q29.16 shows the energy-level diagram of Element X.
   a. What is the ionization energy of Element X?
   b. An atom in the ground state absorbs a photon, then emits a photon with a wavelength of 1240 nm. What conclusion can you draw about the energy of the photon that was absorbed?
   c. An atom in the ground state has a collision with an electron, then emits a photon with a wavelength of 1240 nm. What conclusion can you draw about the initial kinetic energy of the electron?

17. a. Which states of a hydrogen atom can be excited by a collision with an electron with kinetic energy \( K = 12.5 \text{ eV} \)? Explain.
   b. After the collision the atom is not in its ground state. What happens to the electron? (i) It bounces off with \( K > 12.5 \text{ eV} \), (ii) It bounces off with \( K = 12.5 \text{ eV} \), (iii) It bounces off with \( K < 12.5 \text{ eV} \), (iv) It is absorbed by the atom. Explain your choice.
   c. After the collision, the atom emits a photon. List all the possible \( n \rightarrow m \) transitions that might occur as a result of this collision.

18. What is an atom’s ionization energy? In other words, if you know the ionization energy of an atom, what is it that you know about the atom?
19. Figure Q29.19 shows the energy levels of a hypothetical atom.
   a. What minimum kinetic energy (in eV) must an electron have to collisionally excite this atom and cause the emission of a 620 nm photon? Explain.
   b. Can an electron with \( K = 6 \text{ eV} \) cause the emission of 620 nm light? If so, what is the final kinetic energy of the electron? If not, why not?
   c. Can a 6 eV photon cause the emission of 620 nm light from this atom? Why or why not?
   d. Can a 7 eV photon cause the emission of 620 nm light from this atom? Why or why not?

20. Seven possible transitions are identified on the energy-level diagram in Figure Q29.20. For each, is this an allowed transition? If allowed, is it an emission or an absorption transition, and is the photon infrared, visible, or ultraviolet? If not allowed, why not?

21. A 2.0 eV photon is incident on an atom in the \( p \) state, as shown in the energy-level diagram in Figure Q29.21. Does the atom undergo an absorption transition, a stimulated emission transition, or neither? Explain.

22. A glass tube contains \( 2 \times 10^{11} \) atoms, some of which are in the ground state and some of which are excited. Figure Q29.22 shows the populations for the atoms' three energy levels. Is it possible for these atoms to be a laser? If so, on which transition would laser action occur? If not, why not?

23. An electron collides with an atom in its ground state. The atom then emits a photon of energy \( E_{\text{photon}} \). In this process the change \( \Delta E_{\text{el}} \) in the electron's energy is
   A. Greater than \( E_{\text{photon}} \).
   B. Greater than or equal to \( E_{\text{photon}} \).
   C. Equal to \( E_{\text{photon}} \).
   D. Less than or equal to \( E_{\text{photon}} \).
   E. Less than \( E_{\text{photon}} \).

24. How many states are in the \( l = 4 \) subshell?
   A. 8
   B. 9
   C. 16
   D. 18
   E. 22

25. What is the ground-state electron configuration of calcium \((Z = 20)\)?
   A. \( 1s^22s^22p^63s^23p^64s^24p^6 \)
   B. \( 1s^22s^22p^63s^23p^64s^44p^2 \)
   C. \( 1s^22s^22p^63s^23p^44s^24p^2 \)
   D. \( 1s^22s^22p^63s^23p^44p^2 \)

26. An atom emits a photon with a wavelength of 275 nm. By how much does the atom's energy change?
   A. 0.72 eV
   B. 1.06 eV
   C. 2.29 eV
   D. 3.06 eV
   E. 4.51 eV

27. The energy of a hydrogen atom is \(-3.40 \text{ eV}\). What is the electron's kinetic energy?
   A. 1.70 eV
   B. 2.62 eV
   C. 3.40 eV
   D. 5.73 eV
   E. 6.80 eV

28. The angular momentum of an electron in a Bohr hydrogen atom is \( 3.18 \times 10^{-34} \text{ kg \cdot m}^2/\text{s} \). What is the atom's energy?
   A. \(-13.60 \text{ eV}\)
   B. \(-6.73 \text{ eV}\)
   C. \(-3.40 \text{ eV}\)
   D. \(-1.51 \text{ eV}\)
   E. \(-0.47 \text{ eV}\)

29. A “soft x-ray” photon with an energy of 41.8 eV is absorbed by a hydrogen atom in its ground state, knocking the atom's electron out. What is the speed of the electron as it leaves the atom?
   A. \(1.84 \times 10^3 \text{ m/s}\)
   B. \(3.08 \times 10^3 \text{ m/s}\)
   C. \(8.16 \times 10^3 \text{ m/s}\)
   D. \(3.15 \times 10^6 \text{ m/s}\)
   E. \(3.83 \times 10^6 \text{ m/s}\)

Section 29.1 Spectroscopy

1. Figure 29.2b and Table 29.1 showed the wavelengths of the first four lines in the visible spectrum of hydrogen.
   a. Determine the Balmer formula \( n \) and \( m \) values for these wavelengths.
   b. Predict the wavelength of the fifth line in the spectrum.

2. The wavelengths in the hydrogen spectrum with \( m = 1 \) form a series of spectral lines called the Lyman series. Calculate the wavelengths of the first four members of the series.

3. The Paschen series is analogous to the Balmer series, but with \( m = 3 \). Calculate the wavelengths of the first three members in the Paschen series. What part(s) of the electromagnetic spectrum are these in?
Section 29.2 Atoms
4. How many electrons, protons, and neutrons are contained in the following atoms or ions: (a) $^4\text{Li}$, (b) $^{12}\text{C}$, and (c) $^{18}\text{O}^+$?
5. How many electrons, protons, and neutrons are contained in the following atoms or ions: (a) $^{6}\text{Be}$, (b) $^{14}\text{C}$, and (c) $^{15}\text{N}^{++}$?
6. Write the symbol for an atom or ion with:
   a. four electrons, four protons, and five neutrons.
   b. six electrons, seven protons, and eight neutrons.
7. Write the symbol for an atom or ion with:
   a. three electrons, three protons, and five neutrons.
   b. five electrons, six protons, and eight neutrons.

Section 29.3 Bohr’s Model of Atomic Quantization
8. Figure P29.8 is an energy-level diagram for a simple atom. What wavelengths appear in the atom’s (a) emission spectrum and (b) absorption spectrum?
9. An electron with 2.0 eV of kinetic energy collides with the atom whose energy-level diagram is shown in Figure P29.8. Is the electron able to kick the atom to an excited state? Why or why not?
   a. If your answer to part a was yes, what is the electron’s kinetic energy after the collision?
10. The allowed energies of a simple atom are 0.0 eV, 4.0 eV, and 6.0 eV.
   a. Draw the atom’s energy-level diagram. Label each level with the energy and the principal quantum number.
   b. What wavelengths appear in the atom’s emission spectrum?
   c. What wavelengths appear in the atom’s absorption spectrum?
11. The allowed energies of a simple atom are 0.0 eV, 4.0 eV, and 6.0 eV. An electron traveling at a speed of $1.6 \times 10^6 \text{ m/s}$ collisionally excites the atom. What are the minimum and maximum speeds the electron could have after the collision?

Section 29.4 The Bohr Hydrogen Atom
12. A researcher observes hydrogen emitting photons of energy 1.89 eV. What are the quantum numbers of the two states involved in the transition that emits these photons?
13. A hydrogen atom is in the $n = 3$ state. In the Bohr model, how many electron wavelengths fit around this orbit?
14. A hydrogen atom is in its $n = 1$ state. In the Bohr model, what is the ratio of its kinetic energy to its potential energy?
15. Show, by actual calculation, that the Bohr radius is 0.0529 nm and that the ground-state energy of hydrogen is $-13.60 \text{ eV}$.
16. a. What quantum number of the hydrogen atom comes closest to giving a 500-nm-diameter electron orbit?
   b. What are the electron’s speed and energy in this state?
17. a. Calculate the de Broglie wavelength of the electron in the $n = 1$, 2, and 3 states of the hydrogen atom. Use the information in Table 29.2.
   b. Show numerically that the circumference of the orbit for each of these stationary states is exactly equal to $n$ de Broglie wavelengths.
   c. Sketch the de Broglie standing wave for the $n = 3$ orbit.
18. Show, by calculation, that the first three states of the hydrogen atom have angular momenta $h$, $2h$, and $3h$, respectively.
19. Determine all possible wavelengths of photons that can be emitted from the $n = 4$ state of a hydrogen atom.

Section 29.5 The Quantum-Mechanical Hydrogen Atom
20. List the quantum numbers of (a) all possible 3$p$ states and (b) all possible 3$d$ states.
21. When all quantum numbers are considered, how many different quantum states are there for a hydrogen atom with $n = 1$? With $n = 2$? With $n = 3$? List the quantum numbers of each state.
22. What is the angular momentum of a hydrogen atom in (a) a 4$p$ state and (b) a 5$f$ state? Give your answers as a multiple of $h$.
23. A hydrogen atom has orbital angular momentum $3.65 \times 10^{-34} \text{ J} \cdot \text{s}$. What is the minimum energy, in eV, that this atom could have?

Section 29.6 Multielectron Atoms
24. A hydrogen atom is in the 3$s$ state. Determine (a) its energy, (b) its angular momentum, (c) its quantum number $l$, and (d) the possible values of its magnetic quantum number $m$.
25. The angular momentum of a hydrogen atom is $4.70 \times 10^{-34} \text{ J} \cdot \text{s}$. What is the minimum energy, in eV, that this atom could have?

Section 29.7 Excited States and Spectra
33. An electron with a speed of $5.00 \times 10^6 \text{ m/s}$ collides with an atom. The collision excites the atom from its ground state (0 eV) to a state with an energy of 3.80 eV. What is the speed of the electron after the collision?
34. Hydrogen gas absorbs light of wavelength 103 nm. What wavelengths are seen in the emission spectrum?
35. What is the minimum wavelength of light that can excite the 4$s$ state of sodium?
36. An electron with a kinetic energy of 3.90 eV collides with a sodium atom. What possible wavelengths of light are subsequently emitted?
Section 29.8 Molecules

37. a. Is a $4p \rightarrow 4s$ transition allowed in sodium? If so, what is its wavelength? If not, why not?
   b. Is a $3d \rightarrow 4s$ transition allowed in sodium? If so, what is its wavelength? If not, why not?

38. II Figure P29.38 shows a molecular energy-level diagram. What are the longest and shortest wavelengths in (a) the molecule’s absorption spectrum and (b) the molecule’s fluorescence spectrum?

39. I The molecule whose energy-level diagram is shown in Figure P29.38 is illuminated by 2.7 eV photons. What is the longest wavelength of light that the molecule can emit?

Section 29.9 Stimulated Emission and Lasers

40. I A 1000 W carbon dioxide laser emits an infrared laser beam with a wavelength of 10.6 $\mu$m. How many photons are emitted per second?

41. II A 1.00 mW helium neon-laser emits a visible laser beam with a wavelength of 633 nm. How many photons are emitted per second?

42. II In LASIK surgery, a laser is used to reshape the cornea of the eye to improve vision. The laser produces extremely short pulses of light, each containing 1.0 mJ of energy.
   a. In each pulse there are $9.7 \times 10^{14}$ photons. What is the wavelength of the laser?
   b. Each pulse lasts only 20 ns. What is the average power delivered to the eye during a pulse?

43. II A ruby laser emits an intense pulse of light that lasts a mere 10 ns. The light has a wavelength of 690 nm, and each pulse has an energy of 300 mJ.
   a. How many photons are emitted in each pulse?
   b. What is the rate of photon emission, in photons per second, during the 10 ns that the laser is “on”?

44. II A 2.55 eV photon is emitted from a hydrogen atom. What are the Balmer formula $n$ and $m$ values corresponding to this emission?

45. I Two of the wavelengths emitted by a hydrogen atom are 102.6 nm and 1876 nm.
   a. What are the Balmer formula $n$ and $m$ values for each of these wavelengths?
   b. For each of these wavelengths, is the light infrared, visible, or ultraviolet?

46. II In Example 29.2 it was assumed that the initially stationary gold nucleus would remain motionless during a head-on collision with an 8.3 MeV alpha particle. What is the actual recoil speed of the gold nucleus after that elastic collision? Assume that the mass of a gold nucleus is exactly 50 times the mass of an alpha particle.
   Hint: Review the discussion of perfectly elastic collisions in Chapter 10.

47. I Consider the gold isotope $^{197}$Au.
   a. How many electrons, protons, and neutrons are in a neutral $^{197}$Au atom?
   b. The gold nucleus has a diameter of 14.0 fm. What is the density of matter in a gold nucleus?
   c. The density of lead is 11,400 kg/m$^3$. How many times the density of lead is your answer to part b?

48. II Consider the lead isotope $^{207}$Pb.
   a. How many electrons, protons, and neutrons are in a neutral $^{207}$Pb atom?
   b. The lead nucleus has a diameter of 14.2 fm. What are the electric potential and the electric field strength at the surface of a lead nucleus?

49. II The diameter of an atom is $1.2 \times 10^{-10}$ m and the diameter of its nucleus is $1.0 \times 10^{-13}$ m. What percent of the atom’s volume is occupied by mass and what percent is empty space?

50. I The charge-to-mass ratio of a nucleus, in units of e/µ, is $q/m = Z/A$. For example, a hydrogen nucleus has $q/m = 1/1 = 1$.
   a. Make a graph of charge-to-mass ratio versus proton number $Z$ for nuclei with $Z = 5, 10, 15, 20, \ldots, 90$. For A, use the average atomic mass shown on the periodic table of elements in Appendix B. Show each of these 18 nuclei as a dot, but don’t connect the dots together as a curve.
   b. Describe any trend that you notice in your graph.
   c. What’s happening in the nuclei that is responsible for this trend?

51. I If the nucleus is a few fm in diameter, the distance between the centers of two protons must be $\leq 2$ fm.
   a. Calculate the repulsive electric force between two protons that are 2.0 fm apart.
   b. Calculate the attractive gravitational force between two protons that are 2.0 fm apart. Could gravity be the force that holds the nucleus together?

52. II In a head-on collision, the closest approach of a 6.24 MeV alpha particle to the center of a nucleus is 6.00 fm. The nucleus is in an atom of what element? Assume that the nucleus is heavy enough to remain stationary during the collision.

53. II An 20 MeV alpha particle is fired toward a $^{238}$U nucleus. It follows the path shown in Figure P29.53. What is the alpha particle’s speed when it is closest to the nucleus, 20 fm from its center? Assume that the nucleus doesn’t move.

54. II The oxygen nucleus $^{16}$O has a radius of 3.0 fm.
   a. With what speed must a proton be fired toward an oxygen nucleus to have a turning point 1.0 fm from the surface? Assume that the nucleus is heavy enough to remain stationary during the collision.
   b. What is the proton’s kinetic energy in MeV?
55. The absorption spectrum of an atom consists of the wavelengths 200 nm, 300 nm, and 500 nm.
   a. Draw the atom’s energy-level diagram.
   b. What wavelengths are seen in the atom’s emission spectrum?

56. The first three energy levels of the fictitious element X are shown in Figure P29.56.
   a. What wavelengths are observed in the absorption spectrum of element X?
      Give your answers in nm.
   b. State whether each of your wavelengths in part a corresponds to ultraviolet, visible, or infrared light.
   c. An electron with a speed of $1.4 \times 10^8$ m/s collides with an atom of element X. Shortly afterward, the atom emits a 1240 nm photon. What was the electron’s speed after the collision? Assume that, because the atom is so much more massive than the electron, the recoil of the atom is negligible.

57. A simple atom has four lines in its absorption spectrum. Ignoring any selection rules, how many lines will it have in its emission spectrum?

58. A simple atom has only two absorption lines, at 250 nm and 600 nm. What is the wavelength of the one line in the emission spectrum that does not appear in the absorption spectrum?

59. What is the wavelength of the series limit (i.e., the shortest possible wavelength) of the Lyman series in hydrogen?

60. What is the energy of a Bohr hydrogen atom with a 5.18 nm diameter?

61. A hydrogen atom in the ground state absorbs a 12.75 eV photon. Immediately after the absorption, the atom undergoes a quantum jump to the next-lowest energy level. What is the wavelength of the photon emitted in this quantum jump?

62. a. Calculate the orbital radius and the speed of an electron in both the $n = 99$ and the $n = 100$ states of hydrogen.
   b. Determine the orbital frequency of the electron in each of these states.
   c. Calculate the frequency of a photon emitted in a $100 \rightarrow 99$ transition.
   d. Compare the photon frequency of part c to the average of your two orbital frequencies from part b. By what percent do they differ?

63. Two hydrogen atoms collide head-on. The collision brings both atoms to a halt. Immediately after the collision, both atoms emit a 121.6 nm photon. What was the speed of each atom just before the collision?

64. A beam of electrons is incident on a gas of hydrogen atoms.
   a. What minimum speed must the electrons have to cause the emission of 656 nm light from the $3 \rightarrow 2$ transition of hydrogen?
   b. Through what potential difference must the electrons be accelerated to have this speed?

65. A hydrogen atom in its fourth excited state emits a photon with a wavelength of 1282 nm. What is the atom’s maximum possible orbital angular momentum after the emission? Give your answer as a multiple of $\hbar$.

66. A particular emission line in the hydrogen spectrum has a wavelength of 656.5 nm. What are all possible transitions (e.g., $6d \rightarrow 2s$) that could give rise to this emission?
laser beam to a small spot and by concentrating the power of the laser into very short \((10^{-15} \text{ s})\) pulses that are fired \(10^4\) times each second. Suppose a biologist wants to use two-photon excitation to excite a molecular species that would be excited by 500 nm light in normal one-photon fluorescence microscopy. What minimum intensity \((\text{W/m}^2)\) must the laser beam have during each pulse?

Passage Problems

Light-Emitting Diodes

Light-emitting diodes, known by the acronym LED, produce the familiar green and red indicator lights used in a wide variety of consumer electronics. LEDs are semiconductor devices in which the electrons can exist only in certain energy levels. Much like molecules, the energy levels are packed together close enough to form what appears to be a continuous band of possible energies. Energy supplied to an LED in a circuit excites electrons from a valence band into a conduction band. An electron can emit a photon by undergoing a quantum jump from a state in the conduction band into an empty state in the valence band, as shown in Figure P29.74.

The size of the band gap \(\Delta E_{\text{band}}\) determines the possible energies—and thus the wavelengths—of the emitted photons. Most LEDs emit a narrow range of wavelengths and thus have a distinct color. This makes them well-suited for traffic lights and other applications where a certain color is desired, but it makes them less desirable for general illumination. One way to make a “white” LED is to combine a blue LED with a substance that fluoresces yellow when illuminated with the blue light. The combination of the two colors makes light that appears reasonably white.

Stop to Think 29.1: A is emission, B is absorption. All wavelengths in the absorption spectrum are seen in the emission spectrum, but not all wavelengths in the emission spectrum are seen in the absorption spectrum.

Stop to Think 29.2: 6 protons and 8 neutrons. The number of protons is the atomic number, which is 6. That leaves \(14 - 6 = 8\) neutrons.

Stop to Think 29.3: In emission from the \(n = 3\) to \(n = 2\) transition, but not in absorption. The photon energy has to match the energy difference between two energy levels. Absorption is from the ground state, at \(E_i = 0\) eV. There’s no energy level at 3 eV to which the atom could jump.

Stop to Think 29.4: \(n = 3\). Each antinode is half a wavelength, so this standing wave has three full wavelengths in one circumference.

Stop to Think 29.5: \(n = 3, l = 1\), or a \(3p\) state.

Stop to Think 29.6: B. The atom would have less energy if the 3s electron were in a 2p state.

Stop to Think 29.7: C. Emission is a quantum jump to a lower-energy state. The \(5p \to 4p\) transition is not allowed because \(\Lambda l = 0\) violates the selection rule. The lowest-energy allowed transition is \(5p \to 3d\), with \(E_{\text{photon}} = \Delta E_{\text{atom}} = 3.0\) eV.