CHAPTER 3 SELF-QUIZ

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1. False: The region in space where an electron is most likely to be found is called an orbital.
2. False: Electron configurations are often condensed by writing them using the previous noble-gas core as a starting point. In this system, [Ar] $3d^3 4s^2$ would represent vanadium.
3. False: The *f* sublevel is thought to have seven orbitals.
4. True
5. True
6. False: Rutherford knew the nucleus had to be very small because very few alpha particles were deflected when fired through a layer of gold atoms.
7. False: Electrons shifting to lower levels, according to Bohr, would account for emission spectra.
8. True
9. True
10. True
11. False: The Pauli exclusion principle states that no more than two electrons may occupy the same orbital, and that they must have opposite spins.
12. (b)
13. (d)
14. (a)
15. (c)
16. (c)
17. (b)
18. (b)
19. (d)

CHAPTER 3 REVIEW

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Understanding Concepts

1. (a) Rutherford interpreted the deflection of alpha particles travelling through a thin foil to mean that atoms had tiny, massive nuclei.
   (b) Bohr interpreted the bright-line spectrum of hydrogen to mean that electrons exist only at specific energy levels.
2. The Rutherford model explained nothing about the nature of electrons. The Bohr model did not make acceptable predictions for atoms larger than hydrogen.
3. Orbit and orbital are terms that both refer to electrons within atoms. An orbit is a simplistic representation of a small particle in a circular path, used in the Bohr–Rutherford model. An orbital is a probability density for a wave function that "occupies" a volume of space, used in the visualizing of the quantum mechanical model.
4. The main kind of experimental work used to develop the concepts of quantum mechanics was spectroscopy, specifically the analysis of bright-line spectra.
5. (a) Quantum is a term referring to a smallest unit or part of something.
   (b) Orbital is a term describing a volume of space that is "occupied" by an electron.
   (c) Electron probability density describes the calculated likelihood of locating an electron at any point within a given volume of space.
   (d) Photon is a quantum of electromagnetic energy— a smallest "piece" or "package" of light.
6.

$2p$ ↑↓ ↑ ↑

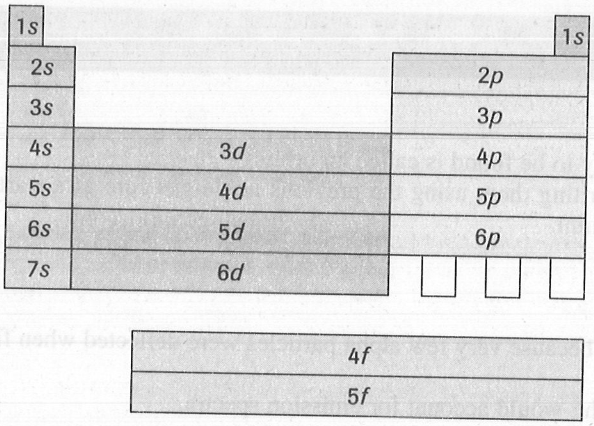
$2s$ ↑↓

$1s$ ↑↓

oxygen atom, O

(a) the main/principal energy level is the first number: 1,2, ...
(b) the energy sublevel (subshell) is the letter following: *s*, *p*, ...
(c) the orbital orientation (*x*, *y*, or *z* axis) is the respective __ line
(d) the spin of the electron (up or down) is the arrow: ↑ or ↓

7. The idea of electron spin comes from observations of line spectra influenced by a magnetic field as well as evidence from different kinds of magnetism.

8. 

9. According to quantum mechanics, an element's properties relate to its position in the periodic table because its position is directly related to the orbital configuration of its atoms.

10.

potassium ion, K^+	sulfide ion, S^{2-}
3p ↑↓ ↑↓ ↑↓	3p ↑↓ ↑↓ ↑↓
3s ↑↓	3s ↑↓
2p ↑↓ ↑↓ ↑↓	2p ↑↓ ↑↓ ↑↓
2s ↑↓	2s ↑↓
1s ↑↓	1s ↑↓

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

11. (a) All of the alkali metals are soft, metallic solids with low melting and boiling points. They have high chemical reactivity, readily forming +1 ions.
    (b) We explain properties, using their electron configurations. All have a single *s* electron in the highest energy orbital, which is easily removed by the attraction of other atoms. The nearly empty valence shell creates the metallic properties—conductivity, shininess, and so on.

12. (a) $1s^2\ 2s^2\ 2p^6\ 3s^2$
    (b) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$
    (c) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$
    (d) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^1$
    (e) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6\ 6s^1\ 4f^{14}\ 5d^{10}$

13. (a) [Kr] $5s^2\ 4d^1$
    (b) [Kr] $5s^2\ 4d^{10}\ 5p^3$
    (c) [Xe] Ba^{2+}

14. Aluminum and titanium should be paramagnetic because these two atoms have unpaired electrons. Beryllium and mercury have atoms with filled orbitals.

15. (a) arsenic atom, As
    (b) rubidium ion, Rb^+
    (c) iodide ion, I^-
    (d) holmium atom, Ho

16. (a) $2e^-$
    (b) $8e^-$
    (c) $18e^-$
    (d) $32e^-$

17. A $2p_x$ orbital is identical to the $2p_y$ and $2p_z$ orbitals, except for orientation. It lies at 90° to the other two.

18. (a) Max Planck explained that electromagnetic energy could be released only in smallest given amounts, which he called "quanta," with the amount determined by the frequency of the radiation.
    (b) Louis de Broglie suggested that particles could have properties and characteristics of waves, and that this effect would be significant for tiny, fast-moving particles like electrons.

(c) Albert Einstein proposed that light (electromagnetic energy) actually travels as quanta, which he called "photons," and he used this concept to explain the evidence of the phenomenon called the photoelectric effect.

(d) Werner Heisenberg hypothesized that electron behaviour cannot ever be exactly described, but only discussed as a probability system, within limits imposed by his "uncertainty principle."

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

19. (a) Both sodium and chlorine atoms have unfilled electron energy levels. When an electron transfers from a sodium atom to a chlorine atom, both attain the same electron configuration as a noble-gas atom. The noble gases are quite unreactive, which is thought to be due to their completely filled electron energy levels.

(b) The occupied and empty energy levels for lithium and sodium are quite different. Therefore, electron transitions would be different, producing different colours. (It is not possible to explain or predict the specific colours in this course.)

(c) Both sodium and silver atoms can obtain a more stable electron arrangement of filled electron orbitals if one electron is removed from an atom and it forms a 1+ ion. A sodium ion becomes [Ne] and a silver ion becomes [Kr] $4d^{10}$. Combined with a chloride ion (1–), the formulas are therefore similar.

(d) A tin atom has the electron configuration [Kr] $5s^2\ 4d^{10}\ 5p^2$. This atom could lose its $5p^2$ electrons to form a 2+ ion or lose both the $5s^2$ electrons and the $5p^2$ electrons to form a 4+ ion.

Applying Inquiry Skills

20. Evidence is the basis of the scientific process. Careful evaluation of evidence is crucial, since poor evidence may lead to incorrect support of a theory, law, or generalization. Good-quality evidence can also show an existing concept to be false.

21. Useful techniques would likely include spectroscopy—possibly visible, ultraviolet, and/or infrared.

22. (a) The design is basically good but you cannot visually observe the infrared spectrum using a hand-held spectroscope. It is also questionable whether the quality of a hand-held spectroscope will be adequate. The spectrum should be photographed with a good-quality spectroscope and suitable photographic film.

(b) This design is inadequate to identify the components of a mixture. A flame test could suggest some components, particularly certain metal ions. A qualitative analysis scheme would be necessary to identify other components.

(c) A better design would be to crush the cereal and insert the magnet directly into the cereal. This would be more likely to attract any small bits of iron present.

(d) The calcium in calcium sulfate is in the form of calcium ions, not calcium metal. The test with a strong magnet should be done on calcium metal.

23. (a) The analogy is good in the sense that there are certain, fixed steps like quantized energy levels. However, the analogy fails in two ways. Electron energy levels are not evenly spaced and quantum mechanics has no picture of a particle such as an electron physically moving from one location to another.

(b) The computer simulation can be useful to illustrate some characteristics suggested by the quantum mechanics if using a probability interpretation, not a wave model. Nevertheless, the computer program that is based on some simplified view of quantum mechanics cannot be used to test the theory. Only experimental evidence can provide this kind of a test.

Making Connections

24. (a) Some examples of benefits to medical diagnosis might include light spectroscopy, which is used to identify substances present in the body; MRI scanning, which allows examination of the interior of the body; and lasers, which allow illumination and examination of the body interior through fibre-optic devices.

(b) Some possible answers and perspectives might include:
Economically, government funding of "pure" research is expensive; and the area does not include a profit or "payback" component.
Socially, the benefits to society from increased knowledge inevitably advance our standard of living in our understanding of the atom.
Scientifically, the entire scientific community constantly lobbies for funding for research to satisfy the *desire to know*.

25. (a) Rutherford won the Nobel Prize for Chemistry in 1908, for the concept of the nuclear atom, for the theory of radioactive disintegration, and for determining the nature of the alpha particle. Soddy won the Nobel Prize for Chemistry in 1921, for the discovery of (explaining the nature of) isotopes of elements.

(b) Every aspect of modern technological society that has to do with radioactivity or nuclear energy in any form is to some extent directly dependent on work done by Rutherford and Soddy. This includes nuclear power generators, radioisotope uses in industry, research, analysis, and medicine, and our understanding of geologic processes, among many others.

CHAPTER 4 CHEMICAL BONDING

Reflect on Your Learning

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1. *[likely initial answer]* When elements react, the product will be a molecular compound if the reactants are both nonmetals, like chlorine and phosphorus; and the product will be an ionic compound if the reactants are a nonmetal and a metal, like chlorine and potassium.
   [a more complete answer] When two nonmetals such as chlorine and phosphorus react, the relatively small difference in electronegativities results in a sharing of valence electrons to produce a covalently bonded molecule. Molecular substances may be solids, liquids, or gases, depending on the intermolecular forces present, and are nonconductors of electricity in any state, including aqueous. When a nonmetal and a metal such as chlorine and potassium react, the relatively large difference in electronegativities results in a transfer of one or more valence electrons from the metal to the nonmetal, producing positive and negative ions. Ionic substances are always solids at ambient temperatures, generally hard with high melting points, and conduct electricity in their molten and aqueous states.
2. *[likely initial answer]* We can explain and predict the bonding of some small, simple molecules with Lewis diagrams, using the octet rule.
   [a more complete answer] We can explain and predict the bonding of some small, simple molecules by considering the valence orbitals in an electron configuration. A half-filled valence orbital on one atom can overlap with another half-filled valence orbital on a second atom to form a combined orbital with a pair of electrons of opposite spin. Considering either the shape of these valence orbitals or simply the number of groups of bonded electrons around a central atom, we can explain or predict the shape of a small molecule.
3. *[likely initial answer]* A structural diagram can be drawn for the molecular compounds: $C_5H_{12(l)}$, $CH_3OH_{(l)}$, and $CO_{2(s)}$. These substances will all be nonconductors of electricity in any state. Sodium, $Na_{(s)}$, is made up of sodium atoms and is a shiny, silvery solid that conducts electricity very well. Sodium chloride, $NaCl_{(s)}$, is an ionic compound made up of sodium and chloride ions. Sodium chloride is soluble in water and the solution conducts electricity. Diamond, $C_{(s)}$, is made up of carbon atoms and is a clear, colourless, very hard solid.
   [a more complete answer]
   $C_5H_{12(l)}$ is a molecular compound whose molecules contain five carbon atoms each with a tetrahedral arrangement of four single covalent bonds. This substance is nonpolar with a low melting and boiling point due to weak intermolecular attractive forces; and is probably not soluble in water.
   $CH_3OH_{(l)}$ is a molecular compound whose molecules contain a carbon atom with a tetrahedral arrangement of four single covalent bonds and an oxygen atom with a V-shaped arrangement of two single covalent bonds. This polar compound has a somewhat higher melting and boiling point, compared to similar-sized nonpolar molecules, due to hydrogen bonding intermolecular attractive forces; and is probably soluble in water.
   $Na_{(s)}$ is a metallic element with sodium cations in a sea of mobile valence electrons which produces a non-directional bonding. This explains its mechanical properties and electrical conductivity. The low electronegativity of a sodium atom partly explains its reactivity and tendency to form ionic compounds.
   $NaCl_{(s)}$ is an ionic compound, with strong ionic bonding between its cations and anions. The ions are arranged in a lattice structure with a regular repeating pattern of alternating positive and negative ions. The structure explains its crystalline nature, hardness, and relatively high melting and boiling point.
   $CO_{2(s)}$ is a molecular compound with linear molecules containing double covalent bonds between the carbon and the oxygen atoms. The bond dipoles cancel to produce a nonpolar molecule. Because the molecules are relatively small and only London forces exist between them, the melting and boiling point should be relatively low.
   $C_{(s)}$ (diamond) is a nonmetallic element with a continuous network of carbon atoms connected to each other in a tetrahedral bonding arrangement. A diamond is like a single macromolecule. The 3-D arrangement of relatively strong covalent bonds explains its great hardness and very high melting and boiling point.

Try This Activity: Properties and Forces

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(a) The glass and the plate do not slide over each other easily when pressed together.
(b) Dishwashing liquid does not make the surface between the glass and plate slippery when they are pressed together.
(c) The gear oil does make the contact surface between the glass and plate slippery, even when they are pressed together.
(d) Dishwashing liquid seems to be a more effective adhesive.

trons of an argon atom could not be promoted to the 3*d* level to perhaps form some covalently bonded compounds. These compounds are obviously unstable since no one has found any but maybe some could be formed at very low temperatures.

Technological Applications

Most of the technological uses of argon in society are based on three factors. It is readily available since it makes up nearly 1% of the atmosphere of the Earth. It is inexpensive because it is easily extracted in high purity from air. And finally, it is chemically inert. There are many situations where technology requires that chemical reaction not take place, and in these situations argon finds its primary uses. Some common examples include the following:

- Argon is placed in incandescent and fluorescent light bulbs at about 400 Pa pressure, which inhibits the tendency of metal atoms to boil off the surface of very hot filaments, thus prolonging filament life. Other gases would react with the hot metals themselves, but argon does not.
- Argon is widely used in welding and torch-cutting systems to create an inert blanketing atmosphere around the high-temperature area. This gaseous blanket prevents the metal from oxidizing while it is very hot.
- Argon is used as the atmosphere in metallurgy vessels where reactive elements, such as titanium, are produced. An argon atmosphere keeps them from reacting the instant they are formed.
- Silicon and germanium crystals—which are critical for production of semiconductors and microchip circuits—may be grown in an argon atmosphere to ensure high purity and evenness of atomic arrangement in such crystals.

Argon produces a bluish light when present at low pressure in a glass tube connected to a high potential difference (voltage). This has been used for decades as a way to produce a blue colour in commercial display signs, just as neon is used to produce a red-orange colour. Modern technology has developed many new uses for the light emitted by argon.

The emission of light by excited argon atoms is presumed to be due to electron energy-level shifts—consistent with atomic structure theory from Bohr through to quantum mechanics. The argon atoms' electrons are raised to various excited states, and then emit several characteristic frequencies (wavelengths) of monochromatic light as they drop back to a ground state. An examination of argon's spectrum for light emitted by a low-pressure, high-voltage tube shows it to be a typical "bright-line" spectrum. An application of quantum mechanical technology allows lasers to be created that operate using argon as one of the gases producing the desired monochromatic light. Following are two special examples of this technology:

- Laser eye surgery commonly uses argon-fluorine "excimer" lasers to produce a coherent beam at 193 nm wavelength to vaporize corneal tissue, allowing reshaping of the eye surface to improve vision acuity.
- Laser "light show" systems are becoming common in the world of entertainment. Argon lasers produce bright blue and green colour wavelengths, and krypton lasers produce vivid red colour, so a laser using a mixture of these two gases can be constructed to produce all three primary colours. This means that, just as on a television screen, these three colours can be combined to produce all apparent colours of the visible spectrum. The very bright laser beams can be projected separately onto a screen, and moved at high speed to produce stunning visual effects.

Careers Involving Argon

Some careers directly involving argon include:

- Gas Plant (Liquid Air) Operator/Technician

  Individuals working in plant operations involving the extraction of argon from the atmosphere; usually operating compression and fractionation equipment and control systems.
- Inert Gas Welder

  Individuals using modern technology and equipment to perform inert gas welding and cutting operations on metals.
- Light Bulb Manufacturing Plant Operator/Technician

  Individuals working in plant operations involving the placement of argon into light sources using specialized equipment and control systems.
- Semiconductor Production Plant Operator/Technician

  Individuals working in plant operations involving the growing and doping of crystals in special argon atmospheres, and associated technology and quality control.
- Laser Eye Surgeon

  Medical doctors specially trained to use excimer lasers to perform corrective eye-surface restructuring.
- Surgical Optical Laser Technician

  Individuals specially trained to service and adjust precise tolerance lasers for eye surgeries.

- Light Show Operators/Technicians

  Individuals specially trained to operate, program, service, and adjust light show lasers.

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Web Sites

http://lasereye.net/laser_eye_surgery_hawaii_kw.htm#Laser%20Types
http://www.laserist.org/Laserist/showbasics_laser.html

UNIT 2 SELF-QUIZ

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1. False: The term orbital refers to the volume of space an electron occupies near a nucleus.
2. True
3. True
4. True
5. False: The ground state electron configuration for all alkali metals shows that the highest energy electrons are in an *s* sublevel.
6. False: There are thought to be five *d* energy sublevels.
7. True
8. False: Schrödinger became famous by developing wave equation mathematics to describe electrons as wave functions.
9. True
10. True
11. False: VSEPR theory predicts that a central atom with three bonded atoms and one lone pair of electrons should have a pyramidal shape.
12. True
13. True
14. False: VSEPR and Lewis theories are complete enough to explain the structure and shape of the molecules in gaseous silane, $SiH_{4(g)}$, which is used as a doping agent in the manufacture of semiconductors for solid-state devices.
15. True
16. True
17. True
18. False: Ionic bonding involves three-dimensional structures with positive and negative ions attracting each other.
19. True
20. (a)
21. (b)
22. (c)
23. (a)
24. (a)
25. (a)
26. (c)
27. (d)
28. (b)
29. (d)
30. (b)

31. (b)
32. (a)
33. (b)
34. (c)
35. (a)
36. (c)
37. (b)
38. (c)
39. (a)
40. (d)

UNIT 2 REVIEW

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Understanding Concepts

1. When most alpha particles pass through the thin foil essentially unaffected, it indicates that somehow they are meeting negligible resistance; so most of the structure of the atoms they are hitting seems to be essentially empty space. When a very few alpha particles are very significantly deflected, it indicates that a tiny part of the structure of the target atoms must be relatively massive and positively charged.
2. (a) The electron was discovered as a result of the qualitative studies of cathode rays by Crookes and, in particular, by the quantitative studies of cathode rays by Thomson.
   (b) The proton was discovered as a result of the alpha particle scattering experiments by Rutherford and, in particular, by the studies of positive rays (hydrogen ions) in a cathode ray tube by Rutherford and Thomson.
   (c) The neutron was discovered as a result of radioactive decay studies by Soddy, mass spectrometer work by Aston, and, in particular, by bombarding elements with alpha particles by Chadwick.
3. (a) Atoms of an element may have different numbers of neutrons in their nuclei. These different nuclei therefore differ in mass; and, if a nucleus containing a given number of neutrons is unstable, that nucleus will be radioactive.
   (b) The term applied to such atoms is *isotope*.
4. Max Planck suggested that energy radiated from heat sources was quantized, meaning that it could not be any frequency at all, but must be a multiple of some smallest value. He could not form an equation to correctly predict the frequencies radiated without this supposition, even though it seemed completely illogical at the time.
5. Rutherford knew that a stationary electron would be attracted by, and pulled into, the positive nucleus of an atom. He thought the electrons would be orbiting just like the planets around the Sun.
6. Bohr knew that if electrons were travelling in orbits, they would be accelerating and therefore radiating electromagnetic energy constantly. This would mean that all atoms would collapse and this is not observed.
7. Bohr's First Postulate states (assumes) that electrons do not radiate energy as they orbit the nucleus because each orbit corresponds to a state of constant energy, called a stationary state.
8. Bohr's Second Postulate assumes that electrons may increase or decrease in energy only by undergoing a transition (jump) from one stationary state to another.
9. (a)

   2*p* ↑ ↑ ↑
   2*s* ↑↓
   1*s* ↑↓
   nitrogen atom, N

   (b)

   3*p* ↑↓ ↑↓ ↑↓
   3*s* ↑↓
   2*p* ↑↓ ↑↓ ↑↓
   2*s* ↑↓
   1*s* ↑↓
   sulfide ion, S^{2-}

(c)

3p ↑↓ ↑↓ ↑↓

3s ↑↓

2p ↑↓ ↑↓ ↑↓

2s ↑↓

1s ↑↓

potassium ion, K^+

(d)

2s ↑↓

1s ↑↓

beryllium atom, Be

(e)

4d ↑ ↑ _ _ _

5s ↑↓

4p ↑↓ ↑↓ ↑↓

3d ↑↓ ↑↓ ↑↓ ↑↓ ↑↓

4s ↑↓

3p ↑↓ ↑↓ ↑↓

3s ↑↓

2p ↑↓ ↑↓ ↑↓

2s ↑↓

1s ↑↓

zirconium atom, Zr

10. Technetium metal has an electron configuration of [Kr] $5s^2\ 4d^5$. This means that it has five unpaired electrons in *d* orbitals. Unpaired electrons usually indicates that the substance will be at least paramagnetic and attracted by a magnet.
11. The bottom of the glass filling first is similar to the aufbau principle; lower energy levels are filled first. The level surface is similar to Hund's Rule. There should be an electron in each orbital of a level before any orbital is assigned a second electron.
12. Once you get to the fourth period in the table, the energies of the *s* and *d* orbitals of different principal quantum numbers start to cross. This means that transition metal atoms are filling the *s* orbital of a higher level while filling the *d* orbital of a lower level. In addition, some rearrangement of the distribution of electons in *s* and *d* orbitals occurs to utilize the extra stability of a half-filled or filled *d* orbital.
13. (a) Ti $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^2$
    (b) Tc $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^5$
    (c) Fe^{3+} $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$
    (d) Br^- $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6$
    (e) Se^{2-} $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6$
14. (a) Zr [Kr] $5s^2\ 4d^2$
    (b) Hg [Xe] $6s^2\ 4f^{14}\ 5d^{10}$
    (c) Ra [Rn] $7s^2$
    (d) I^- [Kr] $5s^2\ 4d^{10}\ 5p^6$ or [Xe]
    (e) U^{6+} [Rn]
15. An *f* sublevel consists of 7 possible orbitals which can be occupied by a maximum of 14 electrons.
16. (a) Br atom
    (b) Ag^+ silver ion
    (c) Hf^{4+} hafnium(IV) ion
    (d) In indium atom
    (e) S^{2-} sulfide ion