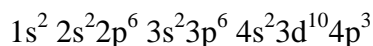


1980

a) 2 points



b) 2 points

for the two electrons in the 4s: 4, 0, 0, +1/2 and 4, 0, 0, - 1/2

for the three electrons in the 4p: 4, 1, -1, +1/2; 4, 1, 0, +1/2 and 4, 1, +1, +1/2

c) 2 points

Paramagnetic. It has three unpaired electrons.

d) 2 points

Na₃As - each Na gives up one electron to the As, the As has a complete octet and the sodium atoms are ionically bonded to the arsenic

AsCl₃ - the three chlorines each have one half-filled orbital and the arsenic has three. So three covalent bonds are created and the As has one non-bonding pair to make a pyramidal structure.

AsF₅ - fluorine is so electronegative that it draws the two electrons of the non-bonding pair of AsCl₃ into bonding. A 4d orbital is involved in the sp³d hybridization, yielding a trigonal bipyramidal shape.

1981

a) 1 point

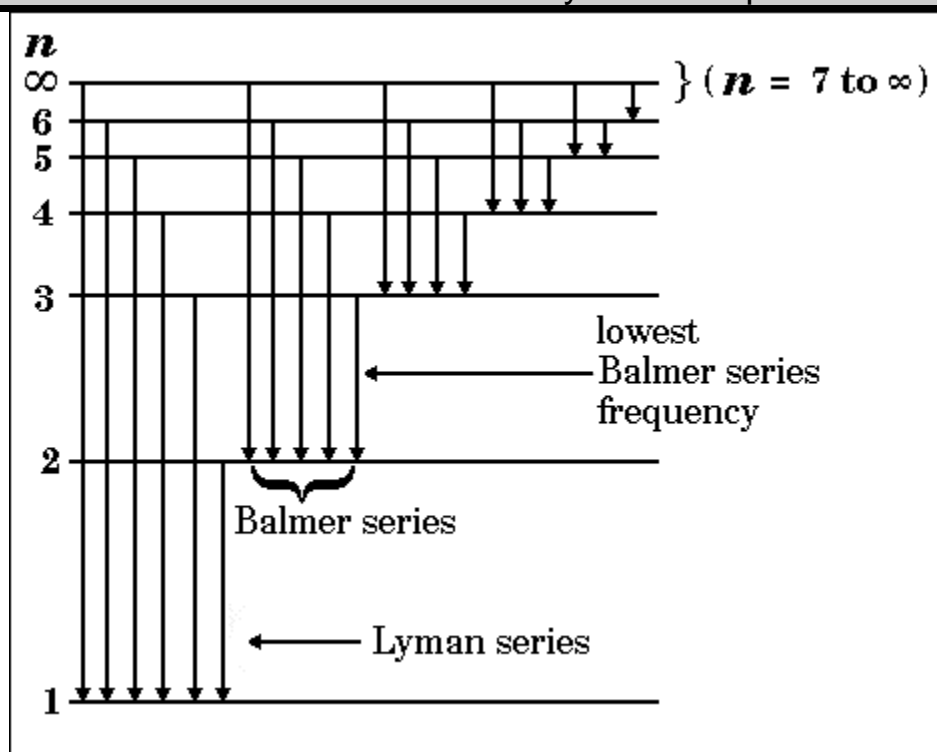
Quantized energy levels or discrete energies or wave properties of electron produce discrete energy states in a gas.

b) 2 points

The excited state atoms can relax to several lower energy states (see diagram in c).

Each final state energy level produces a separate series.

c) 2 points



d) 3 points

Emission spectra are photons emitted from excited state systems as they drop to lower energy states.

Absorption spectra result from the absorption of electromagnetic radiation. Electrons are excited to a higher energy state.

Hydrogen atoms are in the lowest electronic energy state at 25 °C ($n = 1$) so absorptions will be $n = 1$ to $n = 2, 3, 4$, etc.

1987

Special rules for this question:

An ambiguous 2 pt. response receives only 1 pt

An incorrect statement in an otherwise correct 2 pt response will result in a score of 1 pt

The answers labeled (i) below received two points; (ii) received one point.

a) two points

The radii of the alkali metal ions increase with increasing atomic number because:

(i) the principle quantum number (or shell or energy level) increases

(ii) there is an increase in shielding (or the number of orbitals increases)

b) two points

The chloride ion is larger than the chlorine atom because:

- (i) electron- electron repulsion increases (or shielding increases or the electron-proton ratio increases or the effective nuclear charge decreases)
- (ii) an extra electron generally increases the size

c) two points

The ionization energy of Mg is greater than that for Al because:

- (i) the 3p orbital is at a higher energy than the 3s orbital (or the electron in Al is shielded from the nucleus more completely by the 3s electron than the 3s electrons shield one another from the nucleus)
- (ii) a 3p electron is easier to remove than a 3s electron

d) two points

The much greater difference between the 2nd and 3rd ionization energies in Mg (relative to the difference between the 1st and 2nd) is due to the 3rd electron being removed from the 2p subshell after the first 2 were removed from the 3s subshell.

1987

a) three points

It is impossible to determine (or measure) both the position and momentum of any particle (or object, or body) simultaneously.

OR

The more exactly the position of a particle is known, the less exactly the position or velocity of the particle is known.

OR

$(\Delta x)(\Delta p) \geq h\text{-bar}$ (or $h / 4\pi$)

h = Planck's constant

Δx = uncertainty in position

Δp = uncertainty in momentum

Notes:

1 point is given for the notion of simultaneous determination. (A number of students give the first sentence but omit the word simultaneously. (They got 2 out of 3.) If the second or third versions of the answer are given, simultaneity is understood.

If they give the equation, they must have a $>$ sign, not just an $=$ sign, or they lose 1 pt.

A student who gives a correct answer but adds erroneous material gets one point deducted.

b) five points

Bohr postulated that the electron in a H atom travels about the nucleus in a circular orbit and has a fixed angular momentum. With a fixed radius of orbit and a fixed momentum (or energy), $(\Delta x)(\Delta p) < h/4\pi$

and violates the uncertainty principle.

Students receive 2 pts total for the above. If they say only "the electron travels in circular orbits", they get 1 point. They also get credit for saying elliptical orbits. To receive full credit, they must describe an aspect of the Bohr theory.

The following portion of the answer is worth three points.

The wavelength of a particle is given by the deBroglie relation:

$$\lambda = h/mv$$

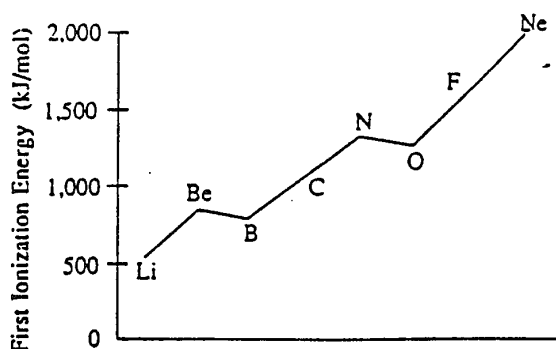
For masses of macroscopic objects, h/m is so small for any v that λ is so small as to be undetectable. For an electron, m is so small that h/mv yields a detectable λ .

OR

They may say the product of the uncertainties in position and velocity depends on h/m and since h is so small ($h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s}$) unless m is very small, as for an electron, the product of the uncertainties is too small to be detected.

Students may discuss the fact that measuring the position and momentum requires having a photon strike the particle. The photon has an energy comparable to that of an electron but small compared to that of a macroscopic object. They must stress mass rather than size as the important distinction to get full credit.

A student who says λ or $(\Delta x)(\Delta p)$ depends on "size" and not mass gets 2 points if discussion is otherwise okay.



The diagram shows the first ionization energies for the elements from Li to Ne. Briefly (in one to three sentences) explain each of the following in terms of atomic structure.

- In general, there is an increase in the first ionization energy from Li to Ne.
- The first ionization energy of B is lower than that of Be.
- The first ionization energy of O is lower than that of N.
- Predict how the first ionization energy of Na compares to those of Li and of Ne. Explain.

- Across the period from Li to Ne the number of protons is increasing (1)
in the nucleus hence the nuclear charge is increasing with a consequently
stronger attraction for electrons and an increase in I.E. (1)
- The electron ionized in the case of Be is a 2s electron (1)
whereas in the case of B it is a 2p electron.
2p electrons are higher in energy than 2s electrons because of (1)
lesser penetration of the core.
- The electron ionized in O is paired with another electron in (1)
the same orbital, whereas in N the electron comes from a
singly-occupied orbital. The ionization energy of the O (1)
electron is less because of the repulsion between two electrons
in the same orbital.
- The ionization energy of Na will be less than that of both (1)
Li and Ne because the electron removed comes from an
orbital which is farther from the nucleus, therefore less (1)
tightly held.

(3) (A) Electron configuration of Na & Mg (1 point)

{ Octet/Noble gas stability comparison of Na & Mg }
 { Energy difference explanation between Na & Mg } any
 { Size difference explanation between Na & Mg } one = 1 point

Note:

If only Na or Mg is used 1 point can be earned by showing the respective electron configuration and using one of the other explanations.

Shielding / effective nuclear charge discussion (1 point)

(1) (B) Correct direction and explanation of any one of the following:

shielding differences

energy differences

proton / # electron differences

(2) (C) (i) Ni unpaired electrons / paramagnetic

(ii) Zn paired electrons / diamagnetic

(iii) Ni unpaired electrons / Zn paired electrons

(iiii) Ni paramagnetic / Zn diamagnetic

ORBITAL DISCUSSION / HUND'S RULE / DIAGRAMS (1 point)

any one set earns 1 point

(2) (D) Expanded octet or sp³d hybrid of phosphorus (1 point)

LACK OF d orbitals in nitrogen (1 point)

Nitrogen is too or small to accommodate (bond) 5 fluorines (2 or 5 bonding sites).

CHEMISTRY

STANDARDS

Question 9

- (a) Ca^{2+} has fewer electrons, thus it is smaller than Ca (1 pt.)

The outermost electron in Ca is in a 4s orbital, whereas the outermost electron in Ca^{2+} is in a 3p orbital (1 pt.)

Note: The first point is earned for indicating the loss of electrons, the second point for indicating the outermost electrons are in different shells -- must account for the magnitude of the size difference between Ca and Ca^{2+} .

- (b) U for CaO is more negative than U for K_2O , so it is more difficult to break up the CaO lattice (stronger bonds in CaO). (1 pt.)

Ca^{2+} is smaller than K^+ , so internuclear separations (between cations and O^{2-}) are less,

OR, (1 pt.)

Ca^{2+} is more highly charged than K^+ , thus cation- O^{2-} bonds are stronger

Note: understanding what "lattice energy" is earns 1 point; size or charge explanation needed for the second point. Responses that use Lewis structures or otherwise indicate *molecules* rather than ionic lattice earn no points.

- (c) (i) Ca has more protons and is smaller. The outermost electrons are more strongly held by the nuclear charge of Ca. (1 pt.)

(ii) The outermost electrons in Ca are in the 4s, which is a higher energy orbital (more shielded) than the 3p electron in K. (1 pt.)

Note: for (i), the idea of attraction between nucleus and electrons must be present; for (ii), a "noble-gas configuration" argument must be tied to an energy argument in order to earn credit.

- (d) The highest energy (outermost) electron in Al is in a 3p orbital, whereas that electron in Mg is in a 3s orbital. (1 pt.)

The 3p electron in Al is of higher energy (is more shielded) than is the 3s electron in Mg. (1 pt.)

Note: noting that different orbitals are involved earns the first point; a correct energy argument earns the second point.

Responses that attribute the greater stability of Ca over K (or K^+ over Ca^+ , or Mg over Al) to the stability of a completely filled (vs. half or partially filled) orbital earn NO credit.

Question 6

(8 points)

1997

- (a) Response must contain a cogent discussion of the forces between the nucleus and the outermost (or “ionized”) electron. For example, a discussion of “the outermost electron on K ...” should include one of the following:

- i. it is farther from nucleus than the outermost electron on Li
- ii. it is more shielded from the nucleus (or “experiences a lower effective nuclear charge”) than the outermost electron on Li
- iii. it is in a higher energy orbital (4s) than the outermost electron on Li (2s).”

*2 points
for any one*

Notes: “K is larger than Li” earns 1 point.

No points earned for “K electron is easier to remove” (or some other restatement).

- (b) Nitrogen has one less proton than oxygen
Nitride and oxide ions are isoelectronic

1 point

1 point

or,

In nitride ion the electron/proton ratio is greater, causing more repulsion; thus, nitride is the larger ion.

2 points

- (c) A Zn atom has more protons (10 more) than an atom of Ca

1 point

Electrons in *d* orbitals of Zn have a lower principal quantum number; thus, they are not in orbitals that are farther from the nucleus.

1 point

- (d) Correct identification of the orbitals involved (2s versus 2p)

1 point

Clear statement that the two orbitals have different energies

1 point

Note: Arguments that “the 2p orbital is farther out than the 2s orbital”, or that “the Be atom has a filled subshell, which is a more stable configuration” earn no explanation point.

General note: For all parts (a) through (d), discussions of position in the periodic table earn no points.

AP[®] CHEMISTRY
1999 SCORING GUIDELINES

Question 2

9 points

One point deduction for mathematical error (maximum once per question)

One point deduction for error in significant figures* (maximum once per question)

*number of significant figures must be correct within +/- one digit.

(a) (i) $\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^{17} \text{ nm/sec}}{495 \text{ nm}}$ (or, $= \frac{3.00 \times 10^8 \text{ m/sec}}{495 \times 10^{-9} \text{ m}}$) = $6.06 \times 10^{14} \text{ sec}^{-1}$ *1 pt*

(ii) $E = h\nu = (6.626 \times 10^{-34} \text{ J sec})(6.06 \times 10^{14} \text{ sec}^{-1}) = 4.02 \times 10^{-19} \text{ J}$ *1 pt*

(iii) $(4.02 \times 10^{-19} \text{ J})(6.022 \times 10^{23} \text{ mol}^{-1})(0.00100 \text{ kJ/J}) = 242 \text{ kJ/mol}$ *1 pt*

Note: No units required if answers are numerically same as above. No penalty if answers are correct with different units and units are explicitly indicated (e.g., for part (ii), $4.02 \times 10^{-22} \text{ kJ}$ is acceptable)

(b) (i) Energy is emitted. *1 pt*

The $n = 6$ state is at a higher energy than the $n = 2$ state. Going from a high energy state to a low energy state means that energy must be emitted. *1 pt*

Note: The key idea is that the energy of the $n = 6$ state is higher (more excited) than the lower (less excited) $n = 2$ state. The argument that “ e^- is farther away” at the $n = 6$ level is not accepted.

(ii) $E_2 = \frac{-2.178 \times 10^{-18} \text{ J}}{2^2} = -5.45 \times 10^{-19} \text{ J}$, $E_6 = \frac{-2.178 \times 10^{-18} \text{ J}}{6^2} = -6.05 \times 10^{-20} \text{ J}$
 $\Delta E = E_6 - E_2 = -6.05 \times 10^{-20} \text{ J} - (-5.45 \times 10^{-19} \text{ J}) = 4.84 \times 10^{-19} \text{ J}$

OR, *1 pt*

$$\Delta E = 2.178 \times 10^{-18} \left(\frac{1}{2^2} - \frac{1}{6^2} \right) \text{ J} = 2.178 \times 10^{-18} (0.2222) \text{ J} = 4.84 \times 10^{-19} \text{ J}$$

Note: Point earned for determining the energy of transition.
Negative energies acceptable.

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Question 2 (cont.)

$$E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E}$$

OR,

1 pt

$$\nu = \frac{E}{h} = \frac{4.84 \times 10^{-19} \text{ J}}{6.626 \times 10^{-34} \text{ J sec}} = 7.30 \times 10^{14} \text{ sec}^{-1}$$

Note: Point earned for writing or using $E = \frac{hc}{\lambda}$, or for calculating the frequency, ν

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 \text{ m sec}^{-1}}{7.30 \times 10^{14} \text{ sec}^{-1}} \times \frac{1 \text{ nm}}{10^{-9} \text{ m}} = 411 \text{ nm}$$

OR,

1 pt

$$\lambda = \frac{(6.626 \times 10^{-34} \text{ J sec})(3.00 \times 10^{17} \text{ nm sec}^{-1})}{4.84 \times 10^{-19} \text{ J}} = 411 \text{ nm}$$

Note: Point earned for correct wavelength; $\lambda = 4.11 \times 10^{-7} \text{ m}$ accepted.
Negative wavelength not accepted.

- (iii) The positive charge holding the electron is greater for He^+ , which has a 2+ nucleus, than for H with its 1+ nucleus. The stronger attraction means that it requires more energy **1 pt** for the electron to move to higher energy levels. Therefore, transitions from high energy states to lower states will be more energetic for He^+ than for H.

Note: Other arguments accepted, such as, “ E is proportional to Z^2 . Since $Z = 2$ for He^+ and $Z = 1$ for H, all energy levels in He^+ are raised (by a factor of 4).” Other accepted answers must refer to the increased charge on the He^+ nucleus, and NOT the mass.

One point deduction for mathematical error (maximum once per question)

One point deduction for error in significant figures* (maximum once per question)

*number of significant figures must be correct within +/- one digit

AP[®] Chemistry 2000 — Scoring Standards

Question 7
(8 points)

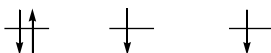
- (a) The isotopes have the same number (34) of protons, *1 pt.*
but a different number of neutrons. *1 pt.*

- No comment about the number of electrons is necessary

- (b) $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^4$ *1 pt.*
or
 $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^4$

- No point is earned for $[\text{Ar}] 4s^2 3d^{10} 4p^4$, because the question specifically asks for a complete electron configuration.

Since there are three different $4p$ orbitals, there must be two unpaired electrons. *1 pt.*



Notes: The second part should have some explanation of Hund's rule, and may include a diagram. The second point can still be earned even if the first point is not IF the electron configuration is incorrect, but the answer for the second part is consistent with the electron configuration given in the first part.

- (c) (i) The ionized electrons in both Se and Br are in the same energy level, *1 pt.*
but Br has more protons than Se, so the attraction to the nucleus is greater.

Note: There should be two arguments in an acceptable answer -- the electrons removed are from the same ($4p$) orbital **and** Br has more protons (a greater nuclear charge) than Se.

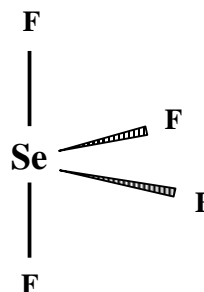
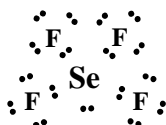
- (ii) The electron removed from a Te atom is in a $5p$ orbital, while the electron removed from an Se atom is in a $4p$ orbital. The $5p$ orbital is at a higher energy than the $4p$ orbital, thus the removal of an electron in a $5p$ orbital requires less energy. *1 pt.*

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Question 7
(continued)

(d)

1 pt.



Notes: One point earned for a correct Lewis diagram and a sketch. The Lewis diagram and the molecular structure may be combined into one sketch if both aspects (electron pairs and structure) are correct. Dots, lines, or a mixture of both can be used in the Lewis diagram. The lone pair of electrons need not be shown in the sketch -- just the atomic positions. No credit earned for just a verbal description of molecular geometry (“see-saw”, “saw-horse”, or something “distorted”), because the question clearly asks the student to “sketch the molecular structure”.

The SeF₄ molecule is polar, because the polarities induced by the bonds and the lone pair of electrons do not cancel.

1 pt.