

## Supporting Information

### Appendix S1. Reliability and Internal Consistency of the Chemistry Knowledge Assessment

#### **S1.1 Overview of the Assessment Instrument**

Academic performance was assessed using a 60-item multiple-choice chemistry knowledge test developed for *Introductory Chemistry I* and aligned with course learning objectives. The assessment sampled six core content areas relevant to the intervention: molecular orbital theory, periodic table, atomic properties, isomerism, gas laws, and electrostatics, with ten items allocated to each topic to ensure balanced representation across the curriculum. All items were dichotomously scored (1 = correct; 0 = incorrect). Content validity was supported through test blueprinting and alignment of items with instructional outcomes, with items designed to span a range of conceptual and reasoning demands appropriate for introductory chemistry.

#### **S1.2 Internal Consistency Reliability**

Internal consistency reliability of the assessment was evaluated using the Kuder–Richardson Formula 20 (KR-20), which is appropriate for dichotomously scored instruments (Kuder and Richardson, 1937):

$$KR - 20 = \frac{k}{k - 1} \left( 1 - \frac{\sum pq}{\sigma^2} \right)$$

where  $k$  is the number of items,  $p$  is the proportion of students answering an item correctly,  $q = 1 - p$ , and  $\sigma^2$  is the variance of total test scores.

Table S1.1. KR-20 Reliability Calculation Summary

COMPONENT	VALUE
Number of items ( $k$ )	60
Number of Students	116
Mean test score	46.66
SD	5.12
Variance of total scores ( $\sigma^2$ )	26.21
$\sum pq$	9.50
KR-20	0.65

### S1.3 TOPIC SUMMARY STATISTICS

Table S1.3.1 Molecular Orbital Theory

<b>Item</b>	<b>Difficulty (p)</b>	<b>Discrimination (rpb)</b>
Q1	0.853	-0.054
Q2	0.759	-0.011
Q3	0.853	-0.039
Q4	0.621	0.251
Q5	0.862	0.009
Q6	0.543	0.257
Q7	0.828	0.098
Q8	0.638	0.540
Q9	0.871	0.127
Q10	0.828	0.149

Table S1.3.2 Periodic Table

<b>Item</b>	<b>Difficulty (p)</b>	<b>Discrimination (rpb)</b>
Q11	0.716	0.672
Q12	0.776	-0.036
Q13	0.879	-0.073
Q14	0.819	0.070
Q15	0.836	-0.047
Q16	0.836	-0.101
Q17	0.974	-0.021
Q18	0.690	0.671
Q19	0.672	0.551
Q20	0.621	0.488

Table S1.3.3 Atomic Properties

<b>Item</b>	<b>Difficulty (p)</b>	<b>Discrimination (rpb)</b>
Q21	0.871	0.074
Q22	0.767	0.250
Q23	0.879	-0.094
Q24	0.724	0.337
Q25	0.724	0.345
Q26	0.698	0.457
Q27	0.759	0.255
Q28	0.664	0.432
Q29	0.672	0.336
Q30	0.698	0.311

Table S1.3.4 Gas Laws

<b>Item</b>	<b>Difficulty (p)</b>	<b>Discrimination (rpb)</b>
Q31	0.776	0.053

<b>Item</b>	<b>Difficulty (p)</b>	<b>Discrimination (rpb)</b>
Q32	0.733	0.170
Q33	0.716	0.296
Q34	0.724	0.301
Q35	0.793	0.124
Q36	0.836	0.065
Q37	0.698	0.373
Q38	0.733	0.221
Q39	0.638	0.500
Q40	0.741	0.238

Table S1.3.5 Electrostatics

<b>Item</b>	<b>Difficulty (p)</b>	<b>Discrimination (rpb)</b>
Q41	0.767	0.133
Q42	0.759	0.192
Q43	0.767	0.168
Q44	0.733	0.279
Q45	0.741	0.142
Q46	0.724	0.337
Q47	0.759	0.185
Q48	0.707	0.321
Q49	0.724	0.333
Q50	0.733	0.239

Table S1.3.6 Isomerism

<b>Item</b>	<b>Difficulty (p)</b>	<b>Discrimination (rpb)</b>
Q51	0.802	0.247
Q52	0.776	0.348
Q53	0.931	-0.173
Q54	0.595	0.568
Q55	0.862	0.143
Q56	0.940	0.030
Q57	0.940	-0.042
Q58	0.940	-0.077
Q59	0.793	0.135
Q60	0.914	-0.153

Table S1.3.7 Difficulty and Discrimination – Topic Summary

<b>TOPIC</b>	<b>MEAN DIFFICULTY</b>	<b>MEAN DISCRIMINATION</b>
Molecular Orbital Theory	0.766	0.133
Periodic Table	0.782	0.217
Atomic Properties	0.761	0.076

Gas Laws	0.733	0.044
Electrostatics	0.776	0.105
Isomerism	0.849	0.102

## OVERALL

Statistic	Value
KR-20	0.65
Mean item difficulty	0.78
Mean discrimination	0.11

## S1.4 CHEMISTRY PERFORMANCE QUIZ

### CHEMISTRY PERFORMANCE QUIZ - MOLECULAR ORBITAL THEORY

#### 1. Which of the following statements about molecular orbitals (MOs) is true?

- a) Bonding MOs have higher energy than their corresponding atomic orbitals.
- b) Antibonding MOs are formed by the constructive interference of atomic orbitals.
- c) A  $\sigma^*$  (sigma-star) orbital has a node between the nuclei.
- d)  $\pi$ -bonding orbitals result from the end-to-end overlap of atomic orbitals.
- e) Only s orbitals contribute to molecular orbital formation.

**Answer:** c) A  $\sigma^*$  (sigma-star) orbital has a node between the nuclei.

#### 2. In a homonuclear diatomic molecule, how does the energy ordering of $\pi$ and $\sigma$ molecular orbitals change as the atomic number increases ( $Z > 8$ )?

- a)  $\pi$  orbitals are always lower in energy than  $\sigma$  orbitals.
- b) The  $\sigma_{2p}$  orbital becomes lower in energy than the  $\pi_{2p}$  orbitals for  $Z > 8$ .
- c) The  $\sigma_{2p}$  orbital remains higher in energy than the  $\pi_{2p}$  orbitals for all diatomic molecules.
- d) The energy order of  $\pi$  and  $\sigma$  orbitals remains unchanged with increasing atomic number.
- e) The  $\pi_{2p}$  and  $\sigma_{2p}$  orbitals merge in energy for heavier diatomic molecules.

**Answer:** b) The  $\sigma_{2p}$  orbital becomes lower in energy than the  $\pi_{2p}$  orbitals for  $Z > 8$ .

#### 3. According to Molecular Orbital Theory, what is the bond order of the $O_2^+$ (oxygen cation) species?

- a) 1.5
- b) 2.0
- c) 2.5
- d) 3.0
- e) 3.5

**Answer:** c) 2.5

#### 4. Which of the following diatomic species is diamagnetic?

- a)  $B_2$
- b)  $O_2$
- c)  $C_2$

- d)  $\text{N}_2^+$
- e)  $\text{O}_2^+$

**Answer:** c)  $\text{C}_2$

**5. Which of the following best describes the bonding in carbon monoxide (CO) using Molecular Orbital Theory?**

- a) CO has a bond order of 2.
- b) The highest occupied molecular orbital (HOMO) is primarily localized on oxygen.
- c) The lowest unoccupied molecular orbital (LUMO) is primarily localized on carbon.
- d) The molecule has significant  $\pi$  back-donation from oxygen to carbon.
- e) The bonding MOs have contributions from only carbon because of electronegativity differences.

**Answer:** c) The lowest unoccupied molecular orbital (LUMO) is primarily localized on carbon.

**6. In Molecular Orbital Theory, which of the following statements about bond order is correct?**

- a) Bond order is always an integer.
- b) A bond order of zero indicates a stable molecule.
- c) Higher bond order generally corresponds to greater bond strength.
- d) Bond order is defined as the sum of bonding and antibonding electrons divided by two.
- e) Bond order is independent of electron configuration.

**Answer:** c) Higher bond order generally corresponds to greater bond strength.

**7. What happens to the bond order of  $\text{O}_2$  when it is ionized to  $\text{O}_2^-$ ?**

- a) Increases
- b) Decreases
- c) Remains the same
- d) Cannot be determined
- e) Becomes zero

**Answer:** b) Decreases

**8. Which molecular orbital of  $\text{CO}_2$  is the highest in energy and typically unoccupied?**

- a)  $\pi^*$  (antibonding)
- b)  $\sigma^*$  (antibonding)
- c)  $\pi$  (bonding)
- d)  $\sigma$  (bonding)
- e) Nonbonding orbital

**Answer:** a)  $\pi^*$  (antibonding)

**9. Which statement about heteronuclear diatomic molecules (e.g., NO, HF) is correct?**

- a) Molecular orbitals are equally shared between both atoms.
- b) More electronegative atoms contribute more to bonding orbitals.

- c) Antibonding orbitals are always localized on the less electronegative atom.
- d) The bond order must always be an integer.
- e) The bond order is always the same as in the homonuclear case.

**Answer:** b) More electronegative atoms contribute more to bonding orbitals.

**10. In the MO diagram of benzene, what is the total number of  $\pi$  molecular orbitals?**

- a) 3
- b) 4
- c) 5
- d) 6
- e) 12

**Answer:** d) 6

#### CHEMISTRY PERFORMANCE QUIZ – THE PERIODIC TABLE

**11. Which of the following statements about the periodic table is correct?**

- a) Elements in the same period exhibit similar chemical properties.
- b) The atomic radius increases across a period due to increased nuclear charge.
- c) Ionization energy generally increases across a period from left to right.
- d) Alkali metals are found in Group 2 of the periodic table.
- e) Noble gases have the highest electronegativity values in their respective periods.

**Answer:** c) Ionization energy generally increases across a period from left to right.

**12. Which of the following trends is NOT correctly described?**

- a) Atomic radius decreases across a period due to increased effective nuclear charge.
- b) Ionization energy decreases down a group due to increased shielding.
- c) Electronegativity generally increases across a period.
- d) Electron affinity is always negative for all elements.
- e) Transition metals often exhibit variable oxidation states due to d-orbital involvement.

**Answer:** d) Electron affinity is always negative for all elements.

*(Some elements, such as noble gases and alkaline earth metals, have positive or near-zero electron affinities.)*

**13. The most electronegative element in the periodic table is:**

- a) Oxygen
- b) Nitrogen
- c) Fluorine
- d) Chlorine
- e) Sulfur

**Answer:** c) Fluorine

**14. Which of the following correctly describes the lanthanide contraction?**

- a) It results from increasing shielding effect in the 4f orbitals.
- b) It is responsible for the similar sizes of the 4d and 5d transition metals.
- c) It causes a dramatic increase in atomic radii among the lanthanides.
- d) It leads to the expansion of d-orbitals in transition metals.
- e) It has no significant effect on periodic trends.

**Answer: b) It is responsible for the similar sizes of the 4d and 5d transition metals.**

**15. Which of the following groups contains only metalloids?**

- a) B, Al, Si, Ge
- b) B, Si, Ge, As, Sb, Te
- c) Al, Si, P, S
- d) C, Si, Sn, Pb
- e) Be, Mg, Ca, Sr

**Answer: b) B, Si, Ge, As, Sb, Te**

**16. Which of the following statements about noble gases is FALSE?**

- a) They have full valence shells.
- b) Their ionization energies are among the highest in the periodic table.
- c) They are chemically inert under standard conditions.
- d) They readily form ionic compounds with alkali metals.
- e) Xenon can form compounds with fluorine and oxygen under specific conditions.

**Answer: d) They readily form ionic compounds with alkali metals.**

**17. Which of the following best explains why transition metals exhibit multiple oxidation states?**

- a) Their s-orbital electrons are held very weakly.
- b) The presence of partially filled d-orbitals allows different numbers of electrons to be lost.
- c) Their nuclear charge is significantly higher than that of main-group elements.
- d) They have the highest electron affinities of any element.
- e) They always form a +2 oxidation state.

**Answer: b) The presence of partially filled d-orbitals allows different numbers of electrons to be lost.**

**18. The first-row transition metal with the highest number of unpaired d-electrons in its ground state is:**

- a) Scandium (Sc)
- b) Vanadium (V)
- c) Chromium (Cr)
- d) Iron (Fe)
- e) Zinc (Zn)

**Answer: c) Chromium (Cr) (It has six unpaired d-electrons in the  $3d^5 4s^1$  configuration.)**

**19. Which of the following elements has the highest second ionization energy?**

- a) Sodium (Na)
- b) Magnesium (Mg)
- c) Aluminum (Al)
- d) Potassium (K)
- e) Calcium (Ca)

**Answer: d) Potassium (K)**

**20. The diagonal relationship in the periodic table explains similarities between which pairs of elements?**

- a) Lithium and Sodium
- b) Carbon and Silicon
- c) Boron and Aluminum
- d) Lithium and Magnesium
- e) Calcium and Strontium

**Answer: d) Lithium and Magnesium** (*Elements in the same diagonal position in the periodic table often exhibit similar properties due to comparable charge densities.*)

#### CHEMISTRY PERFORMANCE QUIZ – ATOMIC PROPERTIES

**21. Which of the following best explains why atomic radii decrease across a period in the periodic table?**

- a) The number of protons increases, pulling electrons closer to the nucleus.
- b) Electron-electron repulsion significantly increases, causing the atom to contract.
- c) The number of core electrons increases, leading to stronger shielding.
- d) The number of valence electrons remains constant, leading to a size decrease.
- e) Ionization energy decreases across a period, causing atomic size to shrink.

**Answer: a) The number of protons increases, pulling electrons closer to the nucleus.**

**22. Which of the following factors primarily determines atomic radius?**

- a) The number of valence electrons
- b) The number of core electrons only
- c) The balance between nuclear charge and electron shielding
- d) The total number of protons only
- e) The ionization energy of the atom

**Answer: c) The balance between nuclear charge and electron shielding**

**23. Which of the following atoms has the largest atomic radius?**

- a) Na
- b) Mg
- c) Al
- d) Si
- e) Cl

**Answer: a) Na**

*(Atomic radius decreases across a period due to increasing  $Z_{eff}$ ).*

**24. Why does ionization energy generally increase across a period?**

- a) Electron shielding increases.
- b) The number of valence electrons decreases.
- c) Atomic size increases.
- d) Effective nuclear charge increases.
- e) The number of protons remains constant.

**Answer: d) Effective nuclear charge increases.**

**25. Which of the following elements has the highest first ionization energy?**

- a) Na
- b) Mg
- c) Al
- d) P
- e) Ar

**Answer: e) Ar**

*(Noble gases have the highest ionization energies in their periods due to their full valence shells.)*

**26. Which element has the most negative electron affinity, meaning it releases the most energy upon gaining an electron?**

- a) Li
- b) O
- c) N
- d) Cl
- e) Ne

**Answer: d) Cl**

**27. Which of the following correctly explains why noble gases have positive or near-zero electron affinities?**

- a) They have high ionization energies.
- b) Their electron clouds repel additional electrons due to a full valence shell.
- c) They have a very small atomic radius.
- d) Their d-orbitals are involved in bonding.
- e) They readily form negative ions.

**Answer: b) Their electron clouds repel additional electrons due to a full valence shell.**

**28. What is the correct trend for electronegativity across the periodic table?**

- a) It increases down a group and increases across a period.
- b) It decreases across a period and increases down a group.
- c) It increases across a period and decreases down a group.
- d) It remains constant across a period but decreases down a group.
- e) It depends only on atomic mass.

**Answer: c) It increases across a period and decreases down a group.**

**29. Which of the following statements correctly describes the trend in ionic radius compared to atomic radius?**

- a) Cations are larger than their parent atoms because they gain protons.
- b) Cations are smaller than their parent atoms because they lose valence electrons.
- c) Anions are smaller than their parent atoms due to increased  $Z_{\text{eff}}$ .
- d) Anions and cations are always the same size as their parent atoms.
- e) Ionic radius is independent of electron configuration.

**Answer: b) Cations are smaller than their parent atoms because they lose valence electrons.**

**30. Which of the following elements would have the smallest second ionization energy?**

- a) Na
- b) Mg
- c) Al
- d) Si
- e) Cl

**Answer: b) Mg**

#### CHEMISTRY PERFORMANCE QUIZ – ISOMERISM

**31. Which of the following statements correctly describes structural (constitutional) isomers?**

- a) They have the same molecular formula but different connectivity of atoms.
- b) They have identical physical and chemical properties.
- c) They always exist in equilibrium with each other.
- d) They differ in the arrangement of atoms in space but have the same connectivity.
- e) They have different molecular formulas but belong to the same homologous series.

**Answer: a) They have the same molecular formula but different connectivity of atoms.**

**32. Which of the following is NOT an example of structural isomerism?**

- a) Chain isomerism
- b) Position isomerism
- c) Functional group isomerism
- d) Geometric (cis-trans) isomerism
- e) Tautomerism

**Answer: d) Geometric (cis-trans) isomerism** (*This is an example of stereoisomerism, not structural isomerism.*)

**33. Which type of isomerism arises due to restricted rotation around a double bond or a cyclic system?**

- a) Optical isomerism
- b) Chain isomerism
- c) Geometrical (cis-trans) isomerism
- d) Functional group isomerism
- e) Metamerism

**Answer: c) Geometrical (cis-trans) isomerism**

**34. Which of the following compounds can exhibit cis-trans isomerism?**

- a) 1-chloropropane
- b) 2-butene
- c) Methanol
- d) Benzene
- e) Ethane

**Answer: b) 2-butene** (*It has a C=C bond with different groups attached to each carbon.*)

**35. Which of the following statements about enantiomers is TRUE?**

- a) Enantiomers have different molecular formulas.
- b) Enantiomers rotate plane-polarized light in opposite directions.
- c) Enantiomers can be interconverted by simple rotation around a single bond.
- d) Enantiomers have different boiling points.
- e) Enantiomers cannot be separated by physical methods.

**Answer: b) Enantiomers rotate plane-polarized light in opposite directions.**

**36. What is the minimum number of chiral centers required for a molecule to exhibit optical isomerism?**

- a) 0
- b) 1
- c) 2
- d) 3
- e) 4

**Answer: b) 1** (*A molecule with one chiral center is usually chiral and can exhibit optical isomerism.*)

**37. Which type of isomerism is exhibited by C<sub>3</sub>H<sub>6</sub>O where one isomer is propanal and another is acetone?**

- a) Chain isomerism
- b) Functional group isomerism
- c) Geometrical isomerism
- d) Optical isomerism
- e) Tautomerism

**Answer: b) Functional group isomerism** (*Propanal is an aldehyde, while acetone is a ketone.*)

**38. Which of the following molecules exhibits meso isomerism?**

- a) 2-butanol
- b) 2-chloropropane
- c) 2,3-dichlorobutane
- d) 3-methylpentane
- e) Benzene

**Answer: c) 2,3-dichlorobutane** (*It has a plane of symmetry, making it a meso compound.*)

**39. Which of the following is NOT a characteristic of diastereomers?**

- a) They have different physical properties.
- b) They are non-superimposable mirror images.
- c) They have different boiling and melting points.
- d) They may exhibit cis-trans isomerism.
- e) They do not rotate plane-polarized light in equal and opposite directions.

**Answer: b) They are non-superimposable mirror images**

**40. Which type of isomerism is observed in ethers where the alkyl groups attached to the oxygen differ in size?**

- a) Chain isomerism
- b) Functional group isomerism
- c) Geometrical isomerism
- d) Metamerism
- e) Optical isomerism

**Answer: d) Metamerism** (*Metamerism occurs in compounds like ethers, ketones, and amines when different alkyl groups are attached to the same functional group.*)

#### CHEMISTRY PERFORMANCE QUIZ – GAS LAWS

**41. Which of the following statements correctly describes Boyle's Law?**

- a) The volume of a gas is directly proportional to its pressure at constant temperature.
- b) The volume of a gas is inversely proportional to its pressure at constant temperature.
- c) The pressure of a gas is directly proportional to its temperature at constant volume.
- d) The volume of a gas is directly proportional to its temperature at constant pressure.
- e) The number of moles of gas does not affect the volume at constant temperature and pressure.

**Answer: b) The volume of a gas is inversely proportional to its pressure at constant temperature.**

**42. The ideal gas equation  $PV=nRT$  implies which of the following relationships?**

- a) If pressure increases while the number of moles and temperature remain constant, volume increases.

- b) If the number of moles of gas increases while pressure and temperature remain constant, volume decreases.
- c) If temperature increases at constant volume, pressure increases.
- d) If volume is held constant, decreasing the number of gas molecules increases pressure.
- e) If pressure decreases and temperature remains constant, volume decreases.

**Answer: c) If temperature increases at constant volume, pressure increases.**

**43. The partial pressure of a gas in a mixture is determined using:**

- a) Boyle's Law
- b) Charles' Law
- c) Dalton's Law
- d) Avogadro's Law
- e) Graham's Law

**Answer: c) Dalton's Law**

**44. According to Avogadro's Law, which of the following is true?**

- a) Equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.
- b) The total pressure of a gas mixture is the sum of the individual gas pressures.
- c) The rate of diffusion of a gas is inversely proportional to its molar mass.
- d) The volume of a gas is directly proportional to its pressure at constant temperature.
- e) The energy of gas molecules is proportional to the inverse of their velocity.

**Answer: a) Equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.**

**45. Which of the following statements correctly describes Graham's Law of Effusion?**

- a) The rate of effusion of a gas is directly proportional to its molar mass.
- b) The rate of effusion of a gas is inversely proportional to the square root of its molar mass.
- c) The rate of diffusion of a gas is independent of molar mass.
- d) The rate of effusion is dependent only on the temperature of the gas.
- e) All gases diffuse at the same rate under identical conditions.

**Answer: b) The rate of effusion of a gas is inversely proportional to the square root of its molar mass.**

**46. A sample of oxygen gas occupies 10.0 L at 25°C and 1.00 atm. What will be the volume if the pressure is doubled while temperature remains constant?**

- a) 5.0 L
- b) 10.0 L
- c) 20.0 L
- d) 40.0 L
- e) 0.5 L

**Answer: a) 5.0 L**

*(According to Boyle's Law:  $P_1V_1=P_2V_2$ , so doubling the pressure halves the volume.)*

**47. The van der Waals equation accounts for deviations of real gases from ideal behavior by including terms that correct for:**

- a) Molecular size and intermolecular forces.
- b) Molecular polarity and atmospheric pressure.
- c) Gas compressibility and temperature.
- d) Isothermal expansion and heat capacity.
- e) The kinetic energy of gas molecules.

**Answer: a) Molecular size and intermolecular forces.**

**48. Which of the following correctly explains why real gases deviate from ideal behavior at high pressures?**

- a) The kinetic energy of gas molecules increases significantly.
- b) The volume of gas molecules becomes significant compared to the total volume.
- c) The temperature of the gas decreases due to compression.
- d) The gas molecules completely stop moving.
- e) The molar mass of the gas increases at high pressures.

**Answer: b) The volume of gas molecules becomes significant compared to the total volume.**

*(At high pressures, the assumption that gas molecules occupy negligible volume breaks down, causing deviation from ideal gas behavior.)*

**49. According to the kinetic molecular theory of gases, which of the following is NOT an assumption?**

- a) Gas particles are in constant, random motion.
- b) The volume of gas particles is negligible compared to the total volume.
- c) There are strong intermolecular forces between gas particles.
- d) The average kinetic energy of gas particles is proportional to temperature in kelvin.
- e) Gas particles undergo perfectly elastic collisions.

**Answer: c) There are strong intermolecular forces between gas particles.**

*(Ideal gases are assumed to have negligible intermolecular forces.)*

**50. If a gas expands against a vacuum, which of the following correctly describes the process?**

- a) The gas does work on the surroundings.
- b) The surroundings do work on the gas.
- c) The process is isothermal and reversible.
- d) The expansion is spontaneous and does no work.
- e) The expansion results in an increase in temperature.

**Answer:**

**d) The expansion is spontaneous and does no work.**

*(Expansion against a vacuum is called free expansion, where no work is done as there is no external pressure.)*

## CHEMISTRY PERFORMANCE QUIZ – ELECTROSTATICS

**51. Which of the following statements about Coulomb's law is correct?**

- a) The force between two point charges is directly proportional to the square of the distance between them.
- b) The force between two point charges is inversely proportional to the product of the charges.
- c) The force between two point charges is inversely proportional to the square of the distance between them.
- d) The force between two point charges depends only on the magnitude of the charges, not their separation.
- e) Coulomb's law applies only to charges in a vacuum.

**Answer: c) The force between two point charges is inversely proportional to the square of the distance between them.**

**52. What happens to the electric field inside a conductor in electrostatic equilibrium?**

- a) It is zero.
- b) It is uniform and nonzero.
- c) It points outward from the surface.
- d) It depends on the type of material of the conductor.
- e) It varies with the charge distribution inside the conductor.

**Answer: a) It is zero.**

**53. Which of the following correctly describes the behavior of electric field lines?**

- a) They originate from negative charges and terminate at positive charges.
- b) They always form closed loops.
- c) They are always perpendicular to the surface of a conductor in electrostatic equilibrium.
- d) They represent paths along which a charge must move.
- e) They never intersect unless in a non-uniform field.

**Answer: c) They are always perpendicular to the surface of a conductor in electrostatic equilibrium.**

**54. The electric potential at a point is defined as:**

- a) The force per unit charge at that point.
- b) The work done per unit charge in bringing a charge from infinity to that point.
- c) The energy stored in an electric field.
- d) The rate at which charge flows past a point.
- e) The amount of charge stored per unit voltage.

**Answer: b) The work done per unit charge in bringing a charge from infinity to that point.**

**55. According to the principle of charge conservation, which of the following statements is true?**

- a) Charge can be created but not destroyed.
- b) The total charge in an isolated system remains constant.
- c) Electrons and protons can be created in different amounts during a reaction.
- d) Charge can be transferred from one object to another, but its total amount in the universe is constantly increasing.
- e) A neutral object cannot gain or lose charge.

**Answer: b) The total charge in an isolated system remains constant.**

**56. Which of the following best describes an equipotential surface?**

- a) It is a surface on which the electric potential is the same at all points.
- b) It is a surface on which the electric field strength is uniform.
- c) It is a surface where the charge density is maximum.
- d) It is a surface along which the electric field is parallel.
- e) It is a surface that always intersects electric field lines.

**Answer: a) It is a surface on which the electric potential is the same at all points.**

**57. A parallel plate capacitor is charged and then disconnected from the battery. If the plate separation is doubled, what happens to the voltage between the plates?**

- a) It is halved.
- b) It remains the same.
- c) It doubles.
- d) It becomes zero.
- e) It increases exponentially.

**Answer: c) It doubles**

**58. Why is capacitance important in electrochemical cells such as batteries and supercapacitors?**

- a) It determines the voltage at which a battery operates.
- b) It helps store charge, which can be quickly released to provide power.
- c) It is responsible for the movement of ions in the electrolyte.
- d) It prevents the loss of charge due to electron leakage.
- e) It ensures that only oxidation reactions occur at the anode.

**Answer: b) It helps store charge, which can be quickly released to provide power.**

**59. A charge of  $+3\mu\text{C}$  is placed at the origin. What is the direction of the electric field at the point (0, 5) cm?**

- a) Towards the charge
- b) Away from the charge
- c) Parallel to the y-axis, pointing downward
- d) Perpendicular to the y-axis
- e) Zero

**Answer: b) Away from the charge**

**60. A conducting sphere of radius  $R$  carries a charge  $Q$ . Where is the electric field maximum?**

- a) Inside the sphere
- b) On the surface of the sphere
- c) Just outside the sphere
- d) At infinity
- e) It is uniform everywhere.

**Answer: c) Just outside the sphere**