A Balance That Counts Electrons: Paramagnetism and the Spin-only Magnetic Moment

Every electron is a tiny magnet; in a pair the spins cancel, so only unpaired electrons make an ion paramagnetic. Count them from the ion's d configuration (singly up to d^5, then pairing) and the spin-only formula gives the magnetic moment: $\mu = \sqrt{n(n+2)}$ BM, from 1.73 for one unpaired electron to 5.92 for Mn^{2+} (d^5). A measured μ (Gouy balance) counts the unpaired electrons.

Name: Date: Score: ____ / 25

A. Fill in the blanks

1. Substances attracted by a magnetic field are called ____.

2. Substances weakly repelled by a magnetic field are called ____.

3. Paramagnetism arises from the presence of ____ electrons.

4. The spin-only formula is $\mu = \sqrt{n(n + \text{____})}$ BM.

5. The magnetic moment of one unpaired electron is ____ BM.

6. The unit of magnetic moment is the ____ magneton.

7. The number of unpaired electrons in Mn^{2+} is ____.

B. True or False

8. Zn^{2+} is paramagnetic. True / False

9. Fe^{2+} has the configuration $3d^4$. True / False

10. For 3d ions the orbital contribution to μ is effectively quenched. True / False

11. Two unpaired electrons give a moment of 3.46 BM. True / False

12. Ferromagnetism is an extreme form of paramagnetism. True / False

C. Assertion and reason

13. Assertion (A): Zn^{2+} salts are diamagnetic.
Reason (R): Zn^{2+} has a completely filled $3d^{10}$ configuration.

(a) Both A and R are true, and R explains A
(b) Both A and R are true, but R does not explain A
(c) A is true, R is false
(d) A is false, R is true

Answer: _____

14. Assertion (A): Mn^{2+} has a higher magnetic moment than Cu^{2+}.
Reason (R): Mn^{2+} has more d electrons than Cu^{2+}.

(a) Both A and R are true, and R explains A
(b) Both A and R are true, but R does not explain A
(c) A is true, R is false
(d) A is false, R is true

Answer: _____

D. Choose the correct option

15. The spin-only magnetic moment of Cu^{2+} (Z = 29) is:

(a) 0 BM
(b) 1.73 BM
(c) 2.84 BM
(d) 3.87 BM

Answer: _____

16. The number of unpaired electrons in Ni^{2+} (Z = 28):

(a) 0
(b) 2
(c) 3
(d) 8

Answer: _____

17. Which ion has the highest magnetic moment?

(a) Ti^{3+}
(b) V^{2+}
(c) Fe^{3+}
(d) Ni^{2+}

Answer: _____

18. Which ion is diamagnetic?

(a) Sc^{3+}
(b) Ti^{3+}
(c) Cr^{3+}
(d) Co^{2+}

Answer: _____

19. An ion has μ = 4.90 BM. Its number of unpaired electrons is:

(a) 2
(b) 3
(c) 4
(d) 5

Answer: _____

E. Numerical problems

20. Calculate the spin-only magnetic moment of Cr^{3+} (Z of Cr = 24).

21. Calculate the spin-only magnetic moment of Fe^{2+} (Z of Fe = 26).

22. An ion of the 3d series has μ = 2.84 BM. Find n.

F. Short answer questions

23. Why are most transition-metal ions paramagnetic?

24. How does a Gouy balance show that $CuSO_4$ is paramagnetic?

G. Match the columns

25. Match each item in Column A with the correct item in Column B.

Column A	Column B	Your answer
1. Sc^{3+} ($3d^0$)	(a) 3.87 BM	1 → ____
2. Ti^{3+} ($3d^1$)	(b) 2.84 BM	2 → ____
3. Ni^{2+} ($3d^8$)	(c) 0 BM	3 → ____
4. V^{2+} ($3d^3$)	(d) 5.92 BM	4 → ____
5. Mn^{2+} ($3d^5$)	(e) 1.73 BM	5 → ____

Detailed solutions

1. paramagnetic

2. diamagnetic

3. unpaired

4. 2

5. 1.73

6. Bohr

7. 5

8. False. Zn^{2+} is $3d^{10}$: all electrons are paired, so it is diamagnetic.

9. False. The 4s electrons leave first: Fe^{2+} is $3d^6$ (4 unpaired).

10. True. So μ depends only on the number of unpaired electrons.

11. False. $\mu = \sqrt{8} = 2.84$ BM; μ is not proportional to n.

12. True. NCERT 4.3.9.

13. (a) All paired, so there is no net moment.

14. (c) Mn^{2+} (d^5) has fewer d electrons than Cu^{2+} (d^9); it has more UNPAIRED electrons (5 vs 1).

15. (b) 1.73 BM. Cu^{2+} is $3d^9$: one unpaired electron.

16. (b) 2. Ni^{2+} is $3d^8$: three pairs and two single electrons.

17. (c) Fe^{3+}. Fe^{3+} is $3d^5$: five unpaired, 5.92 BM.

18. (a) Sc^{3+}. Sc^{3+} is $3d^0$.

19. (c) 4. $n(n+2) = 24$, so $n = 4$.

20. Cr = [Ar] $3d^5 4s^1$, $Cr^{3+} = 3d^3$; $n = 3$; $\mu = \sqrt{(3 \times 5)} = \sqrt{15}$. **Answer: 3.87 BM**

21. $Fe^{2+} = 3d^6$; $n = 4$; $\mu = \sqrt{(4 \times 6)} = \sqrt{24}$. **Answer: 4.90 BM**

22. $n(n + 2) = 2.84^2 \approx 8$; $n^2 + 2n - 8 = 0$; $n = 2$. **Answer: 2**

23. Their 3d orbitals are partly filled, so they hold unpaired electrons; each unpaired electron has a magnetic moment that is not cancelled by a partner of opposite spin.

24. The sample hangs between the poles of an electromagnet; when the field is switched on it is drawn into the field and appears heavier on the balance. The change gives the susceptibility, from which μ is found.

25. 1 → (c), 2 → (e), 3 → (b), 4 → (a), 5 → (d). Count n from the configuration, then $\mu = \sqrt{(n(n+2))}$.