The Light Thief: Why Transition-Metal Ions Are Coloured

Ligands split the five d orbitals of a transition-metal ion into a lower and an upper level. A d electron absorbs the one band of visible light whose energy equals the gap and jumps up (a d–d transition); the rest of the light reaches the eye, so we see the complementary colour: Ti^{3+}(aq) eats green-yellow and looks purple, Cu^{2+}(aq) eats red-orange and looks blue. The ligand sets the gap (ruby and emerald are both Cr^{3+}), and d^0 / d^{10} ions such as Sc^{3+} and Zn^{2+} are colourless.

Name: Date: Score: ____ / 25

A. Fill in the blanks

1. The colour of transition-metal ions arises from ____ transitions.

2. The colour we see is the ____ colour of the light absorbed.

3. The frequency of light absorbed is determined by the nature of the ____.

4. Sc^{3+} (Z of Sc = 21) has ____ d electrons, so it is colourless.

5. Zn^{2+} (Z of Zn = 30) has ____ d electrons, so it is colourless.

6. In a free ion the five d orbitals have ____ energy.

B. True or False

7. Cu^{2+}(aq) is blue because it absorbs blue light. True / False

8. Ligands split the d orbitals into two sets of different energy. True / False

9. Ti^{4+} salts are coloured. True / False

10. The energy absorbed in a d–d transition usually lies in the visible region. True / False

11. The same metal ion always has the same colour, whatever its ligands. True / False

C. Assertion and reason

12. Assertion (A): Zn^{2+} salts are colourless.
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: _____

13. Assertion (A): Cu^{2+}(aq) appears blue.
Reason (R): Cu^{2+} absorbs blue light.

(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

14. Which aquated ion is purple?

(a) Ti^{3+} (b) Ni^{2+}

(c) Cu^{2+} (d) Zn^{2+}

Answer: _____

15. Which ion is colourless in water?

(a) V^{3+} (b) Mn^{2+}

(c) Sc^{3+} (d) Co^{2+}

Answer: _____

16. A solution absorbs green-yellow light. Its colour is:

(a) green (b) yellow

(c) purple (d) orange

Answer: _____

17. $Ni^{2+}(aq)$ is:

(a) blue (b) green

(c) pink (d) colourless

Answer: _____

18. Which configuration cannot show a d–d transition?

(a) $3d^1$ (b) $3d^5$

(c) $3d^9$ (d) $3d^{10}$

Answer: _____

19. In a d–d transition the electron moves:

(a) from s to d (b) between two d levels

(c) out of the ion (d) into the nucleus

Answer: _____

E. Numerical problems

20. $[Ti(H_2O)_6]^{3+}$ absorbs most strongly near 500 nm. Use E = 1240/λ(nm) eV to find the energy gap.

21. Ruby's gap is about 2.23 eV and emerald's about 2.05 eV. Find the wavelength each absorbs most (λ = 1240/E).

F. Short answer questions

22. Explain why $Ti^{3+}(aq)$ is coloured but $Ti^{4+}(aq)$ is colourless.

23. What is meant by complementary colour? Give one example from transition-metal ions.

24. Ruby and emerald both contain Cr^{3+}. Why do they have different colours?

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) pink	1 → ____
2. Ti^{3+} ($3d^1$)	(b) purple	2 → ____
3. Mn^{2+} ($3d^5$)	(c) colourless	3 → ____
4. Ni^{2+} ($3d^8$)	(d) blue	4 → ____
5. Cu^{2+} ($3d^9$)	(e) green	5 → ____

Detailed solutions

1. d–d

2. complementary

3. ligand

4. 0

5. 10

6. equal

7. False. It absorbs red-orange light; blue is the complementary colour that is transmitted.

8. True. With six ligands: three lower, two upper.

9. False. Ti^{4+} is $3d^0$: no d electron, so no d–d transition.

10. True. NCERT 4.3.10.

11. False. Cr^{3+} is red in ruby and green in emerald; the ligand sets the gap.

12. (a) No empty d orbital above, so no d–d transition.

13. (c) The reason is false: it absorbs red-orange; blue is what remains.

14. (a) Ti^{3+}. Ti^{3+} ($3d^1$) absorbs green-yellow; NCERT Table 4.8.

15. (c) Sc^{3+}. Sc^{3+} is $3d^0$.

16. (c) purple. Red + blue are left: purple.

17. (b) green. NCERT Table 4.8: Ni^{2+} ($3d^8$) green.

18. (d) $3d^{10}$. No vacancy in the d orbitals.

19. (b) between two d levels. Lower d set → upper d set.

20. E = 1240 / 500. **Answer: ≈ 2.5 eV**

21. 1240/2.23 ≈ 556 nm; 1240/2.05 ≈ 605 nm. **Answer: ruby ≈ 556 nm (yellow-green), emerald ≈ 605 nm (orange-red)**

22. Ti^{3+} is $3d^1$: its one d electron can absorb visible light and jump from the lower to the upper d level (d–d transition); the complementary colour (purple) is seen. Ti^{4+} is $3d^0$: no d electron, no d–d transition, no visible absorption.

23. The colour that remains when one band is removed from white light (opposite on the colour wheel). $Cu^{2+}(aq)$ absorbs red-orange and looks blue.

24. The surroundings (ligand field) of Cr^{3+} differ: ruby's d-orbital gap is larger, so it absorbs yellow-green and looks red; emerald's gap is smaller, so it absorbs red-orange and looks green.

25. 1 → (c), 2 → (b), 3 → (a), 4 → (e), 5 → (d). Match each aquated ion with its colour (NCERT Table 4.8).