

Supplementary Materials

Appendix S1

Table showing examples of written feedback in the 3TMCQ given by test-makers classified according to the four levels in Hattie and Timperley (2007).

Type of feedback levels	Examples of written feedback
Task only	Close enough. The bridge between copper and zinc occurs in SOD not in haemoglobin
Self only	Good reasoning for answer!
Task + self	Good job, H explains your answer in (1) best, especially for species X. Y is indeed the metal centre and not the complex ion, good job for spotting that.
Self-regulation only	But yes, I get what you mean. What causes the swapping then? (Psst, see how the ligands/orbitals are spaced for sq planar) Refer to the diagrams showing the position of ligands and orbitals for sq planar. What effect do you think that has on energy levels? The reason's kinda in the notes too. Look at where the ligands and orbitals are spaced and what effect that has on energy. I think you can take it from there.
Process only	By picking reason 3, you are saying that the t _{2g} and e _g subshells do not have to belong to the d-orbitals. In this case, option 2 can also be the correct answer.
Self + self-regulation	Good deduction of final answer! Elimination is useful but definitely not all the time!
Self + tasks + self-regulation	Good job! Perhaps you could list out specifically which molecule belongs to which diagram? You could also talk about the plane of symmetry within the molecule i.e. meso compound Good job with identifying the species correctly. Just take note that H helps explain your answer in (1) better by justifying why X is a Lewis Base
Self + process	Good elimination method with clear explanation provided. There are many other ways to eliminate too but this will suffice! But why 4/5 confidence level? What are your doubts?
Task + process	Ni ²⁺ is 3d ⁸ . Max multiplicity is obtained when the d orbitals are singly occupied. However, singly occupied d orbitals will only give us 5 electrons. There are 3 more electrons to be considered and they will be paired up according to the Aufbau principle where orbitals of a lower energy will be occupied first. According to Hund's rule, for the same multiplicity, the term with the greatest L lies lowest in energy. To achieve the greatest L, the occupancy of electrons is as shown above. L = ...→F term. Since (2S+1)=3, the ground state term is 3F.
Task + process & self-regulation	The electron configuration stated for Cu and Zn are correct. However, it may not directly link to reason why Zn is not TM. Rather, linking how Zn ²⁺ has fully filled d orbitals and hence does not fit definition of TM would be good. Copper is actually a TM as it commonly forms Cu ²⁺ which has a configuration of [Ar]3d ⁹ , making it have partially filled d orbitals.

Appendix S2 – Sample of six 3TMCQ coded with revised Bloom’s Taxonomy (cognitive dimension). [NB. Confidence levels and explanations questions are not shown.]

I) Remember Level

EG1. Which metal is used as substitution to investigate metal binding sites in metalloenzymes e.g. Carbonic Anhydrase IL Carboxypeptidase A?

- A. Zn^{2+}
- B. Mn^{2+}
- C. Ca^{2+}
- D. Co^{2+}

II) Understand level

EG1. The following statements describe Zn^{2+}

- (i) Zn^{2+} has a redox active centre
- (ii) Zn^{2+} has a structural role which assists the catalytic function
- (iii) Zn^{2+} enhances the acidity of a coordinated ligand
- (iv) Zn^{2+} can act as an assembly point for the reactants

Which of the following statements correctly states why it can be used in metalloenzymes?

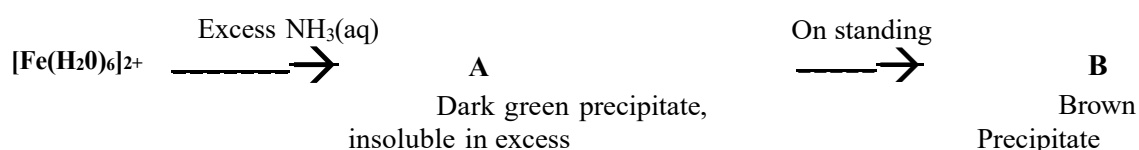
- A. (i), (ii), (iii)
- B. (i), (ii), (iv)
- C. (ii), (iii), (iv)
- D. All of the above

EG2. A compound has a chemical formula of $[Cu(NH_3)_4]^+$ (Volz, 2013). Given that the element copper has a proton number of **29**, what is the colour of the complex and electronic configuration of the copper ion in this compound?

([Ar] = $1s^2 2s^2 2p^6 3s^2 3p^6$)

- A. blue, [Ar] $3d^{10} 4s^0$
- B. blue, [Ar] $3d^9 4s^1$
- C. colourless, [Ar] $3d^{10} 4s^0$
- D. colourless, [Ar] $3d^9 4s^1$

EG3. During qualitative analysis, $NaOH(aq)$ or $NH_3(aq)$ can be added to solutions containing metal cations in order to discern their identity. The colour of the precipitate formed by the reaction can be used to determine the metal identity. The reaction usually involves an acid-base reaction or a ligand exchange. In some cases, the precipitate dissolves in excess $NaOH(aq)$ or $NH_3(aq)$ due to the formation of a soluble complex. One such example is shown below:



What is the identity of the unknown complexes?

	A	B
A.	$[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$	$[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]^+$
B.	$[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$	$[\text{Fe}(\text{H}_2\text{O})_3(\text{OH})_3]$
C.	$[\text{Fe}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$	$[\text{Fe}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{3+}$
D.	$[\text{Fe}(\text{NH}_3)_4(\text{OH})_2]$	$[\text{Fe}(\text{NH}_3)_3(\text{OH})_3]$
E.	$[\text{Fe}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$	$[\text{Fe}(\text{NH}_3)_3(\text{OH})_3]$

III) Apply level

EG1. Vanadium can be obtained readily in 3 oxidation states. As vanadium complexes provide good examples that illustrate the use of Orgel diagrams for the interpretation of electron transition-metal spectra, VO^{2+} ion was synthesized and examined. Diagram 1 illustrates the crystal field splitting of the VO^{2+} ion. Subsequently, from this VO^{2+} ion, $[\text{VO}(\text{H}_2\text{O})_5]^{2+}$ was synthesized by simple synthetic techniques. It is noted that the multiple $\text{V}=\text{O}$ bond in VO^{2+} causes a tetragonal compression type distortion from a true octahedral geometry. Hence, the supposed octahedron experienced compression along the Z-axis, resulting in further splitting of the previously equivalent d-orbitals. This is also illustrated in the same diagram.

Figure of Ligand Field Diagram for $[\text{VO}(\text{H}_2\text{O})_5]^{2+}$ complex from Ophardt (1984) (not shown due to copyright restrictions)

With reference to the Orgel diagrams (see Figure 1), predict the number of absorption bands that will be observed in the electronic spectra of $[\text{VO}(\text{H}_2\text{O})_5]^{2+}$.

- A. One
- B. Three
- C. Zero (Negligible)

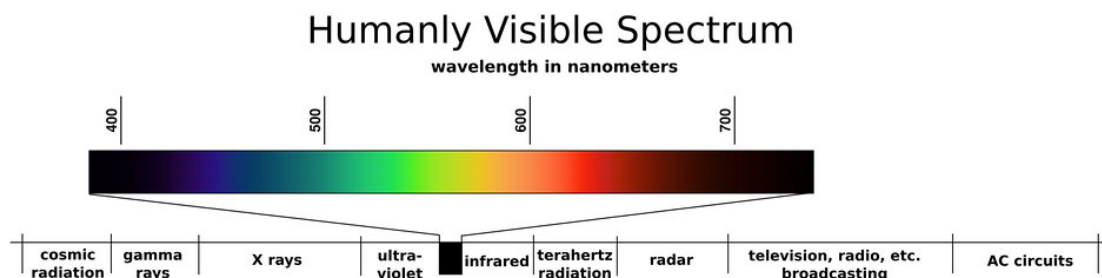
References: Ophardt, C. (1984). Synthesis and spectra of vanadium complexes. *Journal of Chemical Education*, 61(12), 1102-. <https://doi-org.libproxy.nie.edu.sg/10.1021/ed061p1102>

EG2. Phthalocyanines (**Pc**) were discovered by accident in the early 20th century. A Scottish dye company used to produce the pigment phthalimide, a fine white solid. The reaction was usually carried out in a glass-lined, mild steel vessel. A peculiar incident occurred where a particular reactor was yielding a coloured product instead. Upon investigation, the chemists found a crack on the inner glass lining of the reactor, which exposed the inside of the vessel to the outer mild-steel lining. They concluded that the impurity was formed from a reaction with iron. Subsequently, this led them to successfully synthesising the "unwanted" impurity, iron phthalocyanine in the laboratory.

Today, many other metal phthalocyanines are used commercially as dyes. Examples include copper (II) phthalocyanine [**Cu(Pc)**] and nickel phthalocyanine [**Ni(Pc)**]. The structure and electronic absorption spectra of [**Cu(Pc)**] and [**Ni(Pc)**] are shown below. (not shown due to copyright restrictions)

The visible light spectrum is given below for reference

Lim, N. T-L., Lee, Y-J., & Lee, P. P. F. (2023). What types of feedback do undergraduate chemistry students give each other? A case study from Singapore. *International Journal of Innovation in Science and Mathematics Education*, 31(2), 34-46.
<https://doi.org/10.30722/IJISME.31.02.003>



"[Humanly Visible Spectrum](#)" by [entirelysubjective](#) from [CC BY 2.0](#).

Using the information above, deduce the colours of **[Cu(Pc)]** and **(Ni(Pc))**.

- | | [Cu(Pc)] | [Ni(Pc)] |
|----|-----------------|-----------------|
| A. | green | blue |
| B. | blue | green |
| C. | red | brown |
| D. | brown | yellow |