

Solid State Double Displacement Reaction at Room Temperature

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‘Double displacement reactions’ are commonly observed in solutions and aqueous phase. They are less common in solid phase and generally requires high temperature to take place. However, in this article, we report double displacement reactions taking place in solid phase at room temperature. We also highlight the criteria required for the occurrence of displacement reactions in solid state at room temperature. The driving force for all the double displacement reactions is explained using Pearson’s hard and soft acid and base (HSAB) concept, and in few cases involvement or aid of water of hydration is observed.

Introduction

Displacement reactions are chemical reactions in which more reactive elements displace the less reactive elements from their compounds. Displacement reactions are more common in solutions or in the liquid phase but rare in the solid phase due to lack of mobility of atoms or ions [1]. Displacement reactions are classified into two types – ‘single displacement’ reactions and ‘double displacement’ reactions.

During a single displacement reaction, an element displaces another less reactive element from its compound. Displacement of silver from silver nitrate solution by copper is an example of single displacement reaction in aqueous phase. This displacement occurs due to the position of the metals in the activity series [2]. On the other hand, thermite reaction between iron rust and aluminum, ignited by magnesium ribbon is an example of single displacement reaction in solid phase. A single displacement re-



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Keywords

Displacement reaction, double replacement reaction, solid state reaction.



Double displacement reactions in solid phase are rare and sluggish, observed mostly at high temperatures. The experiments demonstrated in this article follows double displacement reaction in solid phase at room temperature.

action in solid phase is driven by the position of the element in the Ellingham diagram [3], but high temperature is required to increase the mobility of ions or atoms [1].

Double displacement reaction is a type of chemical reaction in which a cation from one compound displaces the cation from another compound and vice versa. Mostly, double displacement reactions are observed in the solution phase, during which one of the formed product escapes from the solution phase either as a precipitate or in the form of a gas. The reaction between silver nitrate with sodium chloride to give sodium nitrate and silver chloride precipitate [4] is an example of double displacement reaction in solution phase. It is aided by the affinity of cations towards the anions of their interest which is explained by Pearson's HSAB concept [5]. The reaction between zinc oxide and copper (II) sulfate to give zinc sulfate and copper (II) oxide is an example for solid phase double displacement reaction taking place at high temperature [1]. It is interesting to note that displacement reactions in the solid phase requires high temperature for better mobility of atoms or ions, but even at these high temperatures the reaction between solids are slow and incomplete.

In this context, we report simple double displacement reactions taking place in solid phase at room temperature, and explain the conditions for these displacement reactions to occur. The demonstration can be used to explain the concept of double displacement reaction at school level and moving a step further to explain the concept of Pearson's HSAB concept for undergraduates. The latter serves as the driving force for the exchange of ions during double displacement reaction.

Experimental Methods

All the chemicals used in this work, such as $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$, $\text{BaBr}_2 \cdot 2\text{H}_2\text{O}$, CdBr_2 , CuCO_3 , anhydrous $\text{Cu}_3(\text{PO}_4)_2$, $\text{Pb}_3(\text{PO}_4)_2$, and CdCO_3 are A. R. grade purchased from Loba Chemie, and used without further purification. In order to study the solid phase double displacement reaction, 0.01 mol of follow-



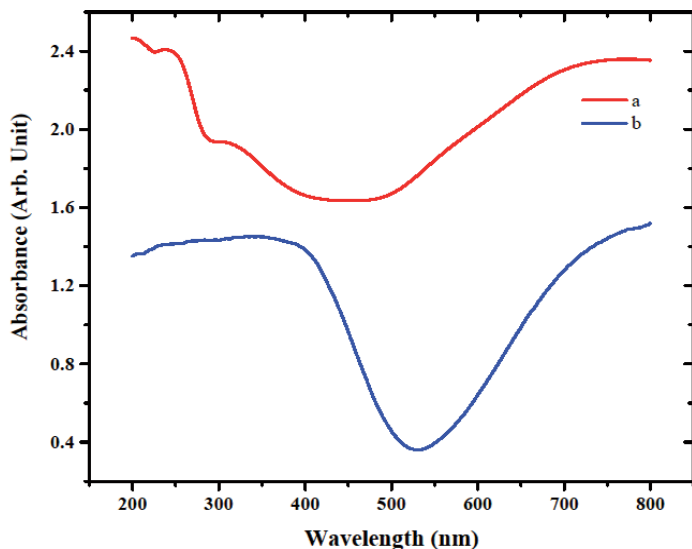


Figure 1. Diffused reflectance spectrum of (a) copper sulfate pentahydrate. (b) Reaction mixture of copper sulfate pentahydrate and barium chloride dihydrate.

ing combination of chemicals were taken (i) $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$, (ii) $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and $\text{BaBr}_2 \cdot 2\text{H}_2\text{O}$, (iii) $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and CdBr_2 , (iv) CuCO_3 and $\text{BaBr}_2 \cdot 2\text{H}_2\text{O}$ and (v) anhydrous $\text{Cu}_3(\text{PO}_4)_2$ and $\text{BaBr}_2 \cdot 2\text{H}_2\text{O}$ into a clean mortar and grounded. All the obtained samples were characterized on UV-Vis diffuse reflectance spectra using a Varian Cary 5000 spectrophotometer. To the grounded mixture of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and $\text{BaBr}_2 \cdot 2\text{H}_2\text{O}$, add 0.01 mol of (vi) $\text{Pb}_3(\text{PO}_4)_2$ and (vii) CdCO_3 , and grounded. The obtained mixtures were characterized by change in color.

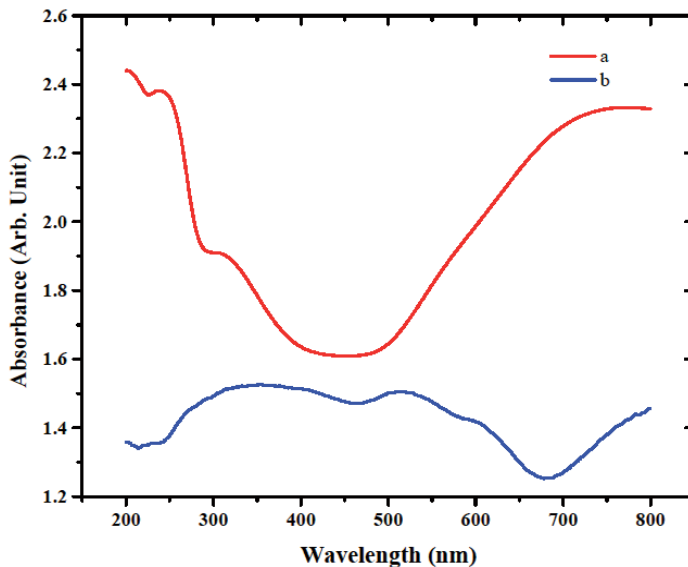
Results and Discussion

(i) Reaction between copper (II) sulfate and barium chloride gives copper (II) chloride and barium sulfate, which is characterized by the change of color from blue to green. A change in absorbance maximum from 450 nm to 520 nm is observed in the UV-DRS as shown in *Figure 1*.

(ii) Reaction between copper (II) sulfate and barium bromide gives copper (II) bromide and barium sulfate, which is characterized by the change of color from blue to brown. A change in absorbance maximum from 450 nm to 670 nm is observed in the DRS as



Figure 2. Diffused reflectance spectrum of (a) copper sulfate pentahydrate (b) reaction mixture of copper sulfate pentahydrate and barium bromide dihydrate.



shown in *Figure 2*.

(iii) No characteristic change in color or absorbance maximum was observed in DRS as shown in *Figure 3* for the reaction between copper (II) sulfate and cadmium (II) bromide. This indicates that there is no double displacement reaction taking place.

(iv) No reaction between copper (II) carbonate and barium bromide is observed, which is characterized by no change in color and no change in absorbance maximum in the DRS as shown in *Figure 4*.

(v) No reaction between copper (II) phosphate and barium bromide is observed, which is characterized by no change in color and no change in absorbance maximum as observed in the DRS shown in *Figure 5*.

(vi) Reaction (ii) between copper (II) sulfate and barium bromide gives copper (II) bromide and barium sulfate. Added lead (II) phosphate, reacts with formed copper (II) bromide to form lead (II) bromide and copper (II) phosphate, which characterized by the change of color from brown to blue.

(vii) Reaction (ii) between copper (II) sulfate and barium bromide



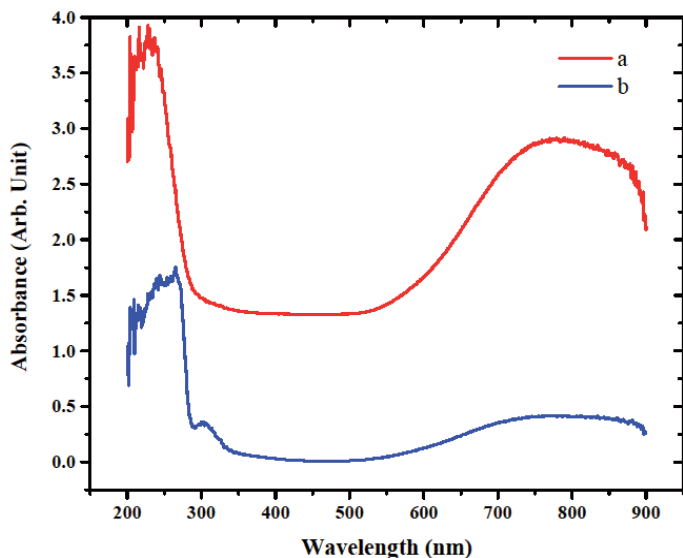


Figure 3. Diffused reflectance spectrum of (a) copper sulfate pentahydrate (b) reaction mixture of copper sulfate pentahydrate and cadmium bromide

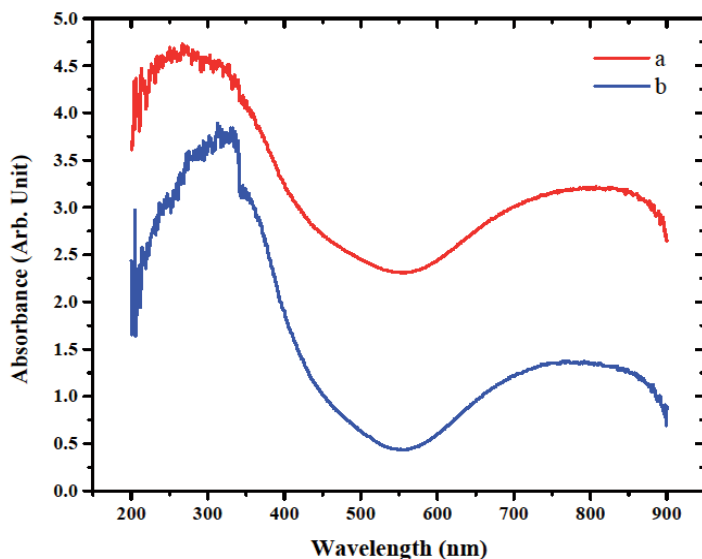
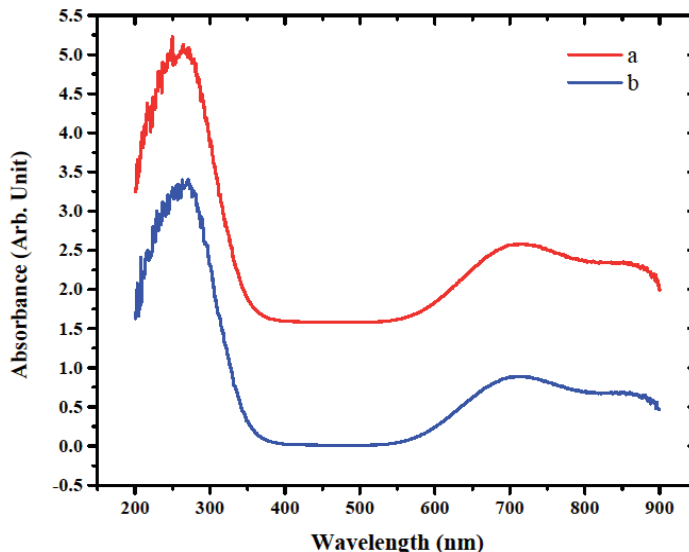


Figure 4. Diffused reflectance spectrum of (a) copper carbonate (b) reaction mixture of copper carbonate and barium bromide

gives copper (II) bromide and barium sulfate. Added cadmium carbonate, reacts with the formed copper (II) bromide to form cadmium bromide and copper (II) carbonate, which characterized by the change of color from brown to bluish green.



Figure 5. Diffused reflectance spectrum of (a) copper phosphate (b) reaction mixture of copper phosphate and barium bromide



Double displacement reaction between copper (II) sulfate and barium chloride is due to affinity of barium ion (hard acid) towards sulfate ion (hard base).

Double displacement reaction between copper (II) sulfate and barium chloride is due to affinity of barium ion (hard acid) towards sulfate ion (hard base) which can be explained using Pearson's HSAB concept [5]. Similarly, reaction between copper (II) sulfate and barium bromide can be understood by the affinity of barium ion towards sulfate ion.

No reaction is observed between copper (II) sulfate and cadmium (II) bromide. Though copper (II) ion (borderline acid) shows affinity towards bromide ion (borderline base), the reaction is forbidden by Pearson's HSAB concept [5] which says that "hard acid prefers hard base and not soft base, like wise soft acid prefers soft base and not hard acid." Cadmium (II) ion (soft acid) does not prefer sulfate ion (hard base).

No reaction is observed between copper (II) carbonate and barium bromide. Though the reaction is allowed by Pearson's HSAB concept [5], the copper (II) carbonate is insoluble in water, so fails to interact with water of hydration of barium bromide. Hence, no double displacement is observed. Similarly, no reaction is observed between copper (II) phosphate and barium bromide is due to the insoluble nature of copper (II) phosphate in water.



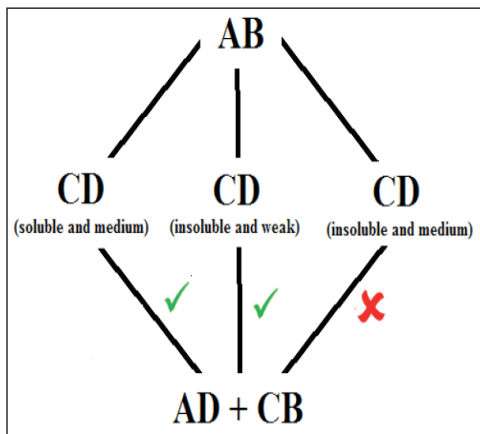


Figure 6. Solid state double displacement reaction.

With the aid of water of hydration and driving force of Pearson's HSAB concept, copper (II) bromide was obtained from reaction mixture (ii), added lead (II) phosphate reacts with the copper (II) bromide and characteristic color change from brown to blue is observed, indicating the formation of lead bromide and copper (II) phosphate. Lead (II) phosphate is insoluble in water, but still undergoes reaction with copper bromide due to weak interaction between lead (II) ion (soft acid) and phosphate ion (hard base). Likewise, reaction between mixture (ii) and cadmium carbonate to form cadmium bromide and copper (II) carbonate indicated by the change in color from brown to bluish green can be explained by the weak interaction between cadmium ion (soft acid) and carbonate ion (hard base). Hence, it is clear that solubility in water has no significance if the interaction between any one of the reactant is weak.

It is evident that the driving force for the double displacement reaction is due to the nature of interaction between ions in the solid, classified based on the Pearson's HSAB concept and in some cases, the water of hydration aids the displacement reaction.

Conclusion

Double displacement reaction taking place in solid state at room temperature were reported. Based on the interactions between the cations and the anions, the reactions are classified as following:

1) Interaction between hard acid–hard base, soft acid–soft base, and borderline acid–borderline base is strong.



2) Interaction between borderline acid–hard base, hard acid–borderline base, borderline acid–soft base, and soft acid–borderline base is medium.

3) Interaction between soft acid–hard base and hard acid–soft base is weak.

Criteria for the double displacement reaction taking place in solid state at room temperature are (*Figure 6*):

a) Double displacement reaction in solid phase is observed only when the interaction is favored by Pearson's HSAB concept.

b) Solubility in water has no significance if the interaction between the ions present in any one of the reactants is weak.

c) Solubility in water helps to interact with water of hydration if the interaction between the ions present in any one of the reactants is medium.

A new role of water of hydration is reported in this article and future studies will uncover the mechanism of aid of water of hydration in solid phase double displacement reactions.

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Suggested Reading

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