

# Chemical Hyperalgebra: Dismutation Reactions

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(Received September 15, 2010)

## Abstract

The main purpose of this paper is to provide examples of hyperstructures and weak hyperstructures associated with dismutation reactions.

## 1 Introduction

Algebraic hyperstructures represent a natural extension of classical algebraic structures and they were introduced in 1934 by the French mathematician F. Marty [8]. In a classical algebraic structure, the composition of two elements is an element, while in an algebraic hyperstructure, the composition of two elements is a set. Hundreds of papers and several books have been written till now on hyperstructures. Many of them are concerned with the applications of hyperstructures in other topics. There exists a rich bibliography: publications appeared within 1992 can be found in “*Prolegomena of Hypergroup Theory*” by P. Corsini [1]. This book contains the principal definitions endowed with examples and the basic results of the theory.

A recent book on these topics is “*Applications of Hyperstructure Theory*” by P. Corsini and V. Leoreanu [2]. Another monograph is devoted especially to the study of Hyperring Theory, written by Davvaz and Leoreanu-Fotea [6].

One of the topics of great interest, in the last years, is the study of weak hyperstructures, so-called  $H_v$ -structures. The class of  $H_v$ -structures is the largest class of algebraic hyperstructures. These structures satisfy weak axioms, where the non-empty intersection replaces the equality. This topic was introduced in 1990 by Vougiouklis [11], also see [3, 13]. Another book on “Hyperstructures and Their Representations” by T. Vougiouklis, was published one year later [12].

In [5, 4], B. Davvaz, A. Dehghan Nezaad, and A. Benvidi provided examples of hyperstructures associated with chain reactions.

The main purpose of this paper is to present examples of hyperstructures and weak hyperstructures associated with dismutation reactions.

## 2 Hypergroups and $H_v$ -groups

An *algebraic hyperstructure* is a non-empty set  $H$  together with a function  $\cdot : H \times H \longrightarrow \wp^*(H)$  called *hyperoperation*, where  $\wp^*(H)$  denotes the set of all non-empty subsets of  $H$ . If  $A, B$  are non-empty subsets of  $H$  and  $x \in H$ , then we define

$$A \cdot B = \bigcup_{a \in A, b \in B} a \cdot b, \quad x \cdot B = \{x\} \cdot B, \quad \text{and} \quad A \cdot x = A \cdot \{x\}.$$

The hyperoperation  $(\cdot)$  is called *associative* in  $H$  if

$$(x \cdot y) \cdot z = x \cdot (y \cdot z) \text{ for all } x, y, z \text{ in } H$$

which means that

$$\bigcup_{u \in x \cdot y} u \cdot z = \bigcup_{v \in y \cdot z} x \cdot v.$$

We say that a semihypergroup  $(H, \cdot)$  is a *hypergroup* if for all  $x \in H$ , we have  $x \cdot H = H \cdot x = H$ . A hypergroupoid  $(H, \cdot)$  is an  $H_v$ -group, if for all  $x, y, z \in H$ , the following conditions hold:

- (1)  $x \cdot (y \cdot z) \cap (x \cdot y) \cdot z \neq \emptyset$
- (2)  $x \cdot H = H \cdot x = H$ .

A non-empty subset  $K$  of a hypergroup (respectively,  $H_v$ -group)  $H$  is called a *subhypergroup* (respectively,  $H_v$ -subgroup) of  $H$  if  $a \cdot K = K \cdot a = K$  for all  $a \in K$ .

Let  $(H_1, \cdot)$  and  $(H_2, *)$  be two  $H_v$ -groups. A map  $f : H_1 \longrightarrow H_2$  is called an  $H_v$ -homomorphism or a *weak homomorphism* if

$$f(x \cdot y) \cap f(x) * f(y) \neq \emptyset, \text{ for all } x, y \in H_1.$$

$f$  is called an *inclusion homomorphism* if

$$f(x \cdot y) \subseteq f(x) * f(y), \text{ for all } x, y \in H_1 .$$

Finally,  $f$  is called a *strong homomorphism* if

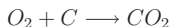
$$f(x \cdot y) = f(x) * f(y), \text{ for all } x, y \in H_1 .$$

If  $f$  is onto, one to one and strong homomorphism, then it is called an *isomorphism*. In this case we write  $H_1 \cong H_2$ .

### 3 Oxidation–Reduction Reactions

In a redox reactions or oxidation–reduction reaction, electrons are transferred from one reactant to another. Oxidation refers to the loss of electrons, while reduction refers to the gain of electrons. A substance that has strong affinity for electrons and tends to extract them from other species is called an oxidizing agent or an oxidant. A reducing agent, or reductant, is a reagent that readily donates electrons to another species [10]. A half–reaction is a reduction or an oxidation reaction. Two half–reactions are needed to form a whole reaction. Redox reactions have a number of similarities to acid–base reactions. Like acid–base reactions, redox reactions are a matched set; you do not have an oxidation reaction without a reduction reaction happening at the same time. When the change in free energy ( $\Delta G$ ) is negative, a process or chemical reaction proceeds spontaneously in the forward direction. When  $\Delta G$  is positive, the process proceeds spontaneously in reverse. In electrochemical reactions  $\Delta G = -nFE$ , where  $n$ ,  $F$ , and  $E$  are number of electrons transferred in the reaction, Faraday constant and cell potential, respectively [10].

The change in the oxidation state of a species lets you know if it has undergone oxidation or reduction. Oxidation is the process in which an atom undergoes an algebraic increase in oxidation number, and reduction is the process in which an atom undergoes an algebraic decrease in oxidation number. On this basis, oxidation–reduction is involved in the reaction



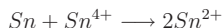
In this reaction, oxidation number of the  $C$  atom increases from zero to +4 whereas, the oxidation number of  $O$  atom decreases from zero to  $-2$ . Furthermore, the total increase in the oxidation number equals to the total decrease in oxidation number [9].

## 4 Dismutation reactions

Disproportionation or dismutation is used to describe two particular types of chemical reactions:

(1) A chemical reaction of the type  $2A \longrightarrow A' + A''$ , where  $A, A'$  and  $A''$  are different chemical species [14]. Most but not all are redox reactions. For example  $2H_2O \longrightarrow H_3O^+ + OH^-$  is a *disproportionation*, but is not a redox reaction.

(2) A chemical reaction in which two or more atoms of the same element originally having the same oxidation state react with other chemical(s) or themselves to give different oxidation numbers. In another word, disproportionation is a reaction in which a species is simultaneously reduced and oxidized to form two different oxidation numbers. The reverse of disproportionation is called comproportionation. *Comproportionation* is a chemical reaction where two reactants, each containing the same element but with a different oxidation number, will form a product with an oxidation number intermediate of the two reactants. For example, an element tin in the oxidation states 0 and +4 can comproportionate to the state +2. The standard reduction potentials of all half reactions are:  $E^\circ_{Sn^{4+}/Sn^{2+}} = 0.154 \text{ V}$ ,  $E^\circ_{Sn^{2+}/Sn} = -0.136 \text{ V}$ ,  $E^\circ_{Sn^{4+}/Sn} = 0.009 \text{ V}$ . Therefore, the comproportionation reaction



is spontaneous.

All possible combinations for the set  $S = \{Sn, Sn^{2+}, Sn^{4+}\}$  to do without energy can be displayed as follows. The major products are written in the following table:

$\oplus$	$Sn$	$Sn^{2+}$	$Sn^{4+}$
$Sn$	$Sn$	$Sn, Sn^{2+}$	$Sn^{2+}$
$Sn^{2+}$	$Sn, Sn^{2+}$	$Sn^{2+}$	$Sn^{2+}, Sn^{4+}$
$Sn^{4+}$	$Sn^{2+}$	$Sn^{2+}, Sn^{4+}$	$Sn^{4+}$

We rename  $Sn$ ,  $Sn^{2+}$ , and  $Sn^{4+}$  as follows:

$$Sn := a, \quad Sn^{2+} := b \quad \text{and} \quad Sn^{4+} := c.$$

Then we obtain the following table:

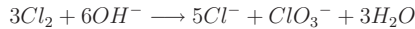
$\oplus$	$a$	$b$	$c$
$a$	$a$	$\{a, b\}$	$b$
$b$	$\{a, b\}$	$b$	$\{b, c\}$
$c$	$b$	$\{b, c\}$	$c$

Now, we have:

$a \oplus (a \oplus a) = a \oplus a = a$	$(a \oplus a) \oplus a = a \oplus a = a$
$b \oplus (a \oplus a) = b \oplus a = \{a, b\}$	$(b \oplus a) \oplus a = \{a, b\} \oplus a = \{a, b\}$
$c \oplus (a \oplus a) = c \oplus a = b$	$(c \oplus a) \oplus a = b \oplus a = \{a, b\}$
$a \oplus (b \oplus a) = a \oplus \{a, b\} = \{a, b\}$	$(a \oplus b) \oplus a = \{a, b\} \oplus a = \{a, b\}$
$a \oplus (c \oplus a) = a \oplus b = \{a, b\}$	$(a \oplus c) \oplus a = b \oplus a = \{a, b\}$
$a \oplus (a \oplus b) = a \oplus \{a, b\} = \{a, b\}$	$(a \oplus a) \oplus b = a \oplus b = \{a, b\}$
$a \oplus (a \oplus c) = a \oplus b = \{a, b\}$	$(a \oplus a) \oplus c = a \oplus c = b$
$b \oplus (b \oplus b) = b \oplus b = b$	$(b \oplus b) \oplus b = b \oplus b = b$
$a \oplus (b \oplus b) = a \oplus b = \{a, b\}$	$(a \oplus b) \oplus b = \{a, b\}$
$c \oplus (b \oplus b) = c \oplus b = \{b, c\}$	$(c \oplus b) \oplus b = \{b, c\} \oplus b = \{b, c\}$
$b \oplus (a \oplus b) = b \oplus \{a, b\} = \{a, b\}$	$(b \oplus a) \oplus b = \{a, b\} \oplus b = \{a, b\}$
$b \oplus (c \oplus b) = b \oplus \{b, c\} = \{b, c\}$	$(b \oplus c) \oplus b = \{b, c\} \oplus b = \{b, c\}$
$b \oplus (b \oplus a) = b \oplus \{a, b\} = \{a, b\}$	$(b \oplus b) \oplus a = b \oplus a = \{a, b\}$
$b \oplus (b \oplus c) = b \oplus \{b, c\} = \{b, c\}$	$(b \oplus b) \oplus c = b \oplus c = \{b, c\}$
$c \oplus (c \oplus c) = c \oplus c = c$	$(c \oplus c) \oplus c = c \oplus c = c$
$a \oplus (c \oplus c) = a \oplus c = b$	$(a \oplus c) \oplus c = b \oplus c = \{b, c\}$
$b \oplus (c \oplus c) = b \oplus c = \{b, c\}$	$(b \oplus c) \oplus c = \{b, c\} \oplus c = \{b, c\}$
$c \oplus (a \oplus c) = c \oplus b = \{b, c\}$	$(c \oplus a) \oplus c = b \oplus c = \{b, c\}$
$c \oplus (b \oplus c) = c \oplus \{b, c\} = \{b, c\}$	$(c \oplus b) \oplus c = \{b, c\} \oplus c = \{b, c\}$
$c \oplus (c \oplus a) = c \oplus b = \{b, c\}$	$(c \oplus c) \oplus a = c \oplus a = b$
$c \oplus (c \oplus b) = c \oplus \{b, c\} = \{b, c\}$	$(c \oplus c) \oplus b = c \oplus b = \{b, c\}$
$a \oplus (b \oplus c) = a \oplus \{b, c\} = \{a, b\}$	$(a \oplus b) \oplus c = \{a, b\} \oplus c = \{b, c\}$
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$b \oplus (a \oplus c) = b \oplus b = b$	$(b \oplus a) \oplus c = \{a, b\} \oplus c = \{b, c\}$
$b \oplus (c \oplus a) = b \oplus b = b$	$(b \oplus c) \oplus a = \{b, c\} \oplus a = \{a, b\}$
$c \oplus (a \oplus b) = c \oplus \{a, b\} = \{b, c\}$	$(c \oplus a) \oplus b = b \oplus b = c$
$c \oplus (b \oplus a) = c \oplus \{a, b\} = \{b, c\}$	$(c \oplus b) \oplus a = \{b, c\} \oplus a = \{a, b\}$

Therefore,  $(S, \oplus)$  is weak associative. Also, we can conclude that  $(\{a, b\}, \oplus)$  is a hypergroup and  $(\{b, c\}, \oplus)$  is an  $H_v$ -semigroup.

Chlorine gas reacts with dilute hydroxide to form chloride, chlorate and water. The ionic equation for this reaction is as follows [7]:



As a reactant, the oxidation number of the elemental chlorine, chloride and chlorate are 0, -1, and +5, respectively. Therefore, chlorine has been oxidized to chlorate whereas it has been reduced to chloride [7].

Indium has three oxidation states 0, +1, and +3. The standard reduction potentials of all half reactions are:  $E^\circ_{In^{3+}/In^+} = -0.434 \text{ V}$ ,  $E^\circ_{In^+/In} = -0.147 \text{ V}$ ,  $E^\circ_{In^{3+}/In} = -0.338 \text{ V}$ . According to the standard reduction potentials, disproportionation reaction

of  $In^+$  is spontaneous. All possible combinations for the set  $S = \{In, In^+, In^{3+}\}$  to do without energy can be displayed as following table.

$\diamond$	$In$	$In^+$	$In^{3+}$
$In$	$In$	$In, In^+$	$In, In^{3+}$
$In^+$	$In, In^+$	$In, In^{3+}$	$In^+, In^{3+}$
$In^{3+}$	$In, In^{3+}$	$In^+, In^{3+}$	$In^{3+}$

We rename  $I_n$ ,  $I_n^+$ , and  $I_n^{3+}$  as follows:

$$I_n := a, \quad I_n^+ := b \quad \text{and} \quad I_n^{3+} := c.$$

Then we obtain the following table:

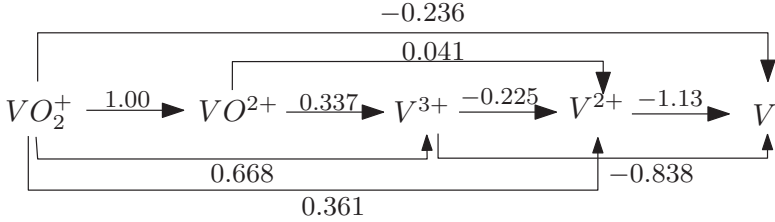
$\oplus$	$a$	$b$	$c$
$a$	$a$	$\{a, b\}$	$\{a, c\}$
$b$	$\{a, b\}$	$\{a, c\}$	$\{b, c\}$
$c$	$\{a, c\}$	$\{b, c\}$	$c$

Now, we have:

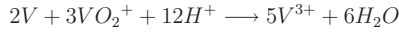
$a \oplus (a \oplus a) = a \oplus a = a$	$(a \oplus a) \oplus a = a \oplus a = a$
$b \oplus (a \oplus a) = b \oplus a = \{a, b\}$	$(b \oplus a) \oplus a = \{a, b\} \oplus a = \{a, b\}$
$c \oplus (a \oplus a) = c \oplus a = \{a, c\}$	$(c \oplus a) \oplus a = \{a, c\} \oplus a = \{a, c\}$
$a \oplus (b \oplus a) = a \oplus \{a, b\} = \{a, b\}$	$(a \oplus b) \oplus a = \{a, b\} \oplus a = \{a, b\}$
$a \oplus (c \oplus a) = a \oplus \{a, c\} = \{a, c\}$	$(a \oplus c) \oplus a = \{a, c\} \oplus a = \{a, c\}$
$a \oplus (a \oplus b) = a \oplus \{a, b\} = \{a, b\}$	$(a \oplus a) \oplus b = a \oplus b = \{a, b\}$
$a \oplus (a \oplus c) = a \oplus \{a, c\} = \{a, c\}$	$(a \oplus a) \oplus c = a \oplus c = \{a, c\}$
$b \oplus (b \oplus b) = b \oplus \{a, c\} = \{a, b, c\}$	$(b \oplus b) \oplus b = b \oplus \{a, c\} \oplus b = \{a, b, c\}$
$a \oplus (b \oplus b) = a \oplus \{a, c\} = \{a, c\}$	$(a \oplus b) \oplus b = \{a, b, c\}$
$c \oplus (b \oplus b) = c \oplus \{a, c\} = \{a, c\}$	$(c \oplus b) \oplus b = \{b, c\} \oplus b = \{a, b, c\}$
$b \oplus (a \oplus b) = b \oplus \{a, b\} = \{a, b, c\}$	$(b \oplus a) \oplus b = \{a, b\} \oplus b = \{a, b, c\}$
$b \oplus (c \oplus b) = b \oplus \{b, c\} = \{a, b, c\}$	$(b \oplus c) \oplus b = \{b, c\} \oplus b = \{a, b, c\}$
$b \oplus (b \oplus a) = b \oplus \{a, b\} = \{a, b, c\}$	$(b \oplus b) \oplus a = \{a, c\} \oplus a = \{a, c\}$
$b \oplus (b \oplus c) = b \oplus \{b, c\} = \{a, b, c\}$	$(b \oplus b) \oplus c = \{a, c\} \oplus c = \{a, c\}$
$c \oplus (c \oplus c) = c \oplus c = c$	$(c \oplus c) \oplus c = c \oplus c = c$
$a \oplus (c \oplus c) = a \oplus c = \{a, c\}$	$(a \oplus c) \oplus c = \{a, c\} \oplus c = \{a, c\}$
$b \oplus (c \oplus c) = b \oplus c = \{b, c\}$	$(b \oplus c) \oplus c = \{b, c\} \oplus c = \{b, c\}$
$c \oplus (a \oplus c) = c \oplus \{a, c\} = \{a, c\}$	$(c \oplus a) \oplus c = \{a, c\} \oplus c = \{a, c\}$
$c \oplus (b \oplus c) = c \oplus \{b, c\} = \{a, c\}$	$(c \oplus b) \oplus c = \{b, c\} \oplus c = \{b, c\}$
$c \oplus (c \oplus a) = c \oplus \{a, c\} = \{a, c\}$	$(c \oplus c) \oplus a = c \oplus a = \{a, c\}$
$c \oplus (c \oplus b) = c \oplus \{b, c\} = \{b, c\}$	$(c \oplus c) \oplus b = c \oplus b = \{b, c\}$
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$a \oplus (c \oplus b) = a \oplus \{b, c\} = \{a, b, c\}$	$(a \oplus c) \oplus b = \{a, c\} \oplus b = \{a, b, c\}$
$b \oplus (a \oplus c) = b \oplus \{a, c\} = \{a, b, c\}$	$(b \oplus a) \oplus c = \{a, b\} \oplus c = \{a, b, c\}$
$b \oplus (c \oplus a) = b \oplus \{a, c\} = \{a, b, c\}$	$(b \oplus c) \oplus a = \{b, c\} \oplus a = \{a, b, c\}$
$c \oplus (a \oplus b) = c \oplus \{a, b\} = \{a, b, c\}$	$(c \oplus a) \oplus b = \{a, c\} \oplus b = \{a, b, c\}$
$c \oplus (b \oplus a) = c \oplus \{a, b\} = \{a, b, c\}$	$(c \oplus b) \oplus a = \{b, c\} \oplus a = \{a, b, c\}$

Therefore,  $(S, \oplus)$  is weak associative. Clearly,  $\oplus$  is commutative. Also, the reproduction axiom holds. Therefore,  $(S, \oplus)$  is a commutative  $H_v$ -group. Moreover,  $(\{a, c\}, \oplus)$  is an  $H_v$ -subgroup of  $(S, \oplus)$ .

Vanadium forms a number of different ions including  $V$ ,  $V^{2+}$ ,  $V^{3+}$ ,  $VO^{2+}$ , and  $VO_2^+$ . The oxidation states of these species are 0, +2, +3, +4, and +5, respectively. The standard reduction potentials of all corresponding half reactions are:



All possible combinations for the set  $S = \{V, V^{2+}, V^{3+}, VO^{2+}, VO_2^+\}$  to do without energy in acidic media can be displayed as following table. When the reactants are added in appropriate stoichiometric ratios. For example vanadium ( $V$ ) reacts with  $VO_2^+$  as follows:



$\oplus$	$V$	$V^{2+}$	$V^{3+}$	$VO^{2+}$	$VO_2^+$
$V$	$V$	$V, V^{2+}$	$V^{2+}, V^{3+}$	$V^{2+}, V^{3+}$	$V^{3+}$
$V^{2+}$	$V, V^{2+}$	$V^{2+}$	$V^{2+}, V^{3+}$	$V^{3+}$	$V^{3+}, VO^{2+}$
$V^{3+}$	$V^{2+}$	$V^{2+}, V^{3+}$	$V^{3+}$	$V^{3+}, VO^{2+}$	$VO^{2+}$
$VO^{2+}$	$V^{2+}, V^{3+}$	$V^{3+}$	$V^{3+}, VO^{2+}$	$VO^{2+}$	$VO^{2+}, VO_2^+$
$VO_2^+$	$V^{3+}$	$V^{3+}, VO^{2+}$	$VO^{2+}$	$VO^{2+}, VO_2^+$	$VO_2^+$

We rename  $V$ ,  $V^{2+}$ ,  $V^{3+}$ ,  $VO^{2+}$ , and  $VO_2^+$  as follows:

$$V := a, \quad V^{2+} := b, \quad V^{3+} := c, \quad VO^{2+} := d \quad \text{and} \quad VO_2^+ := e.$$

Then we obtain the following table:

$\oplus$	$a$	$b$	$c$	$d$	$e$
$a$	$a$	$\{a, b\}$	$b$	$\{b, c\}$	$c$
$b$	$\{a, b\}$	$b$	$\{b, c\}$	$c$	$\{c, d\}$
$c$	$b$	$\{b, c\}$	$c$	$\{c, d\}$	$d$
$d$	$\{b, c\}$	$c$	$\{c, d\}$	$d$	$\{d, e\}$
$e$	$c$	$\{c, d\}$	$d$	$\{d, e\}$	$e$

Now,  $(S, \oplus)$  is a hyperstructure. The hyperstructures  $(\{a, b\}, \oplus)$ ,  $(\{b, c\}, \oplus)$ ,  $(\{c, d\}, \oplus)$ , and  $(\{d, e\}, \oplus)$  are hypergroups. Moreover,

$$(\{a, b\}, \oplus) \cong (\{b, c\}, \oplus) \cong (\{c, d\}, \oplus) \cong (\{d, e\}, \oplus) .$$

The major products between all forms of vanadium are showed in the following table. It is assumed the reactants are added together in 1 : 1 mole ratios.

$\oplus$	$V$	$V^{2+}$	$V^{3+}$	$VO^{2+}$	$VO_2^+$
$V$	$V$	$V, V^{2+}$	$V, V^{2+}$	$V^{2+}$	$V^{2+}, V^{3+}$
$V^{2+}$	$V, V^{2+}$	$V^{2+}$	$V^{2+}, V^{3+}$	$V^{3+}$	$V^{3+}, VO^{2+}$
$V^{3+}$	$V, V^{2+}$	$V^{2+}, V^{3+}$	$V^{3+}$	$V^{3+}, VO^{2+}$	$VO^{2+}$
$VO^{2+}$	$V^{2+}$	$V^{3+}$	$V^{3+}, VO^{2+}$	$VO^{2+}$	$VO^{2+}, VO_2^+$
$VO_2^+$	$V^{2+}, V^{3+}$	$V^{3+}, VO^{2+}$	$VO^{2+}$	$VO^{2+}, VO_2^+$	$VO_2^+$

We rename  $V$ ,  $V^{2+}$ ,  $V^{3+}$ ,  $VO^{2+}$  and  $VO_2^+$  as follows:

$$V := a, \quad V^{2+} := b, \quad V^{3+} := c, \quad VO^{2+} := d \quad \text{and} \quad VO_2^+ := e .$$

Then we obtain the following table:

$\oplus$	$a$	$b$	$c$	$d$	$e$
$a$	$a$	$\{a, b\}$	$\{a, b\}$	$b$	$\{b, c\}$
$b$	$\{a, b\}$	$b$	$\{b, c\}$	$c$	$\{c, d\}$
$c$	$\{a, b\}$	$\{b, c\}$	$c$	$\{c, d\}$	$d$
$d$	$b$	$c$	$\{c, d\}$	$d$	$\{d, e\}$
$e$	$\{b, c\}$	$\{c, d\}$	$d$	$\{d, e\}$	$e$

Now,  $(S, \oplus)$  is a hyperstructure. The hyperstructures  $(\{a, b\}, \oplus)$ ,  $(\{b, c\}, \oplus)$ ,  $(\{c, d\}, \oplus)$ , and  $(\{d, e\}, \oplus)$  are hypergroups. Moreover,

$$(\{a, b\}, \oplus) \cong (\{b, c\}, \oplus) \cong (\{c, d\}, \oplus) \cong (\{d, e\}, \oplus) .$$

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