International Journal of Mathematics Trends and Technology
ISSN: 2231-5373/ https://doi.org/10.14445/22315373/IJMTT-V72I5P106
Volume 72 Issue 5, 74-80, May 2026

Original Article

Commutativity of Hyperrings with Generalized Reverse Derivations

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Received: 28 March 2026 Revised: 30 April 2026 Accepted: 16 May 2026 Published: 29 May 2026

Abstract - *In this paper, the notion of generalized reverse derivations on Krasner hyperrings is introduced, and investigated the commutativity of prime hyperrings. In particular, it establishes several results showing that under suitable conditions on generalized reverse derivations and their associated reverse derivations, a prime hyperring becomes commutative in some cases, reverse derivation* $\delta = 0$*. The obtained results contribute to the development of derivation theory in algebraic hyperstructures and provide new insights into the structural properties of hyperrings.*

Keywords - *16Y20, 16W25, 20N20, Hyperrings, Hyperstructure.*

1. Introduction

The theory of hyperstructures was introduced by F. Marty [6] in 1934 through his pioneering work on hypergroups by presenting his ideas at the 8th Congress of Scandinavian Mathematicians through his paper *"Sur une généralisation de la notion de groupe"*. Later, J. Mittas [11] developed the theory of canonical hypergroups and hyperlattices. The concept of a hyperring was introduced by M. Krasner [15], where addition is defined as a hyperoperation while multiplication remains a binary operation. Since then, hyperring theory has attracted considerable attention due to its rich algebraic structure and applications in several branches of mathematics. A detailed study of hyperrings and their applications can be found in the work of B. Davvaz and V. Leoreanu-Fotea [3].

Derivations play an important role in understanding the structural properties of algebraic systems. In classical ring theory, derivations were introduced by E. C. Posner [5], and later several researchers investigated their applications to prime and semiprime rings. Reverse derivations were initiated by I. N. Herstein [10] and subsequently studied by Bresar and Vukman [14]. The concept of generalized derivations was introduced by M. Bresar [15], and Aboubakr and Gonalaz [1] investigated generalized reverse derivations on semiprime rings. The interaction between derivations and commutativity has also been widely studied. Bell and Martindale III [9] obtained significant commutativity results for prime rings admitting derivations and related mappings.

In the context of hyperrings, recent developments have focused on extending derivation theory from classical rings to hyperstructures. Asokkumar [2] studied derivations on hyperrings and prime hyperrings, while Sonone and Pawar [16] investigated semi-derivations on prime hyperrings. Yilmaz and Yazrali [4] also studied semi-derivations on hyperrings. Basavaraju et al. [7] recently studied commutativity conditions on hyperrings under reverse derivations. Although derivations and reverse derivations have been extensively studied in classical rings, comparatively little attention has been devoted to generalized reverse derivations in hyperring structures. However, generalized reverse derivations on Krasner hyperrings have not yet been systematically investigated.

The present work extends the theory of reverse derivations on hyperrings to the broader framework of generalized reverse derivations on Krasner hyperrings. Unlike classical ring structures, Krasner hyperrings involve multivalued hyperaddition, which introduces additional algebraic difficulties in establishing commutativity conditions and structural identities. By combining techniques from derivation theory and hyperstructure theory, several new commutativity results for prime hyperrings are obtained. In particular, sufficient conditions are established under which a prime hyperring becomes commutative, in some cases, reverse derivation $\delta = 0$.

Compared with earlier studies on reverse derivations and generalized derivations in classical rings and hyperrings, the present work investigates the broader framework of generalized reverse derivations on Krasner hyperrings. Existing works mainly focus on reverse derivations and generalized derivations, whereas generalized reverse derivations in the hyperring setting have not been systematically studied. The multivalued nature of hyperaddition in Krasner hyperrings introduces additional algebraic difficulties that do not arise in ordinary ring theory. By carefully combining techniques from derivation theory and hyperstructure theory, several new commutativity conditions for prime hyperrings are established. In particular, the obtained results generalize and extend the commutativity results reported in [7] to the setting of generalized reverse derivations on Krasner hyperrings.

The paper is organized as follows. Section 2 contains preliminary definitions and basic results related to hyperrings and reverse derivations. In Section 3, we present several lemmas required for the main results. Section 4 is devoted to various theorems involving generalized reverse derivations on prime hyperrings.

2. Preliminaries

In this section, we recall some basic definitions and concepts of hyperstructures, which will be used in the sequel. For more details, we refer to L. Kamali and B. Davvaz, [12] and Asokkumar [2]. For a set H, let P(H) denote the power set of H, and $P^*(H) = P(H) - \{\emptyset\}$.

Definition 2.1 [6]: A mapping $\circ: H \times H \to P^*(H)$ It is called a hyperoperation. An algebraic system (H, ∘) is called a hypergroupoid. Let $(H,\circ)$ be a hypergroupoid. For any subsets M and N of H, and $h \in H$, we define $M \circ N = \bigcup_{m\in M, n\in N} m \circ n$ and $M \circ h = M \circ \{h\}, h \circ N = \{h\} \circ N$
A hypergroupoid (H, ∘) is said to be commutative if $m \circ n = n \circ m$, for all $m, n \in H$.

Definition 2.2 [6]: A hypergroupoid $(H,\circ)$ is called a semihypergroup if, for all $a, b, c \in H$, we have $(a \circ b) \circ c = a \circ (b \circ c)$, which means that $\bigcup_{u\in a\circ b}(u \circ c) = \bigcup_{v\in b\circ c}(a \circ v)$.
A hypergroupoid (H, ∘) is called a quasihypergroup if for all a of H we have $a \circ H = H \circ a = H$. This condition is also called the reproduction axiom.

Definition 2.3 [**15**]**:** A Krasner hyperring is an algebraic structure $(R, +,\cdot)$which satisfies the following axioms:
(1) $(R, +)$ is a canonical hypergroup:
(i) $(R, +)$ is a semihypergroup, that is, $p + (q + r) = (p + q) + r$, for all $p, q, r \in R$,
(ii) $p + q = q + p,$ for all$p, q \in R$,
(iii) There exists $0 \in R$ such that $0 + p = \{p\}$, for all $p \in R$,
(iv) For all $p \in R$ there exists a unique element, denoted by $-p \in R$ such that $0 \in p + (-p)$,
(v) $r \in p + q$ implies that $q \in -p + r$ and $p \in r - q$, for all $p, q, r \in R$.
(2) $(R,\cdot)$ is a semigroup having zero as a bilaterally absorbing element, i.e.
(a) $(x \cdot y) \cdot z = x \cdot (y \cdot z)$, for all $x, y, z \in R$;
(b) $x \cdot 0 = 0 \cdot x = 0$, for all $x \in R$.
(3) The multiplication · is distributive with respect to the hyperoperation +, i.e.
$x \cdot (y + z) = x \cdot y + x \cdot z$ and $(x + y) \cdot z = x \cdot z + y \cdot z$, for all $x, y, z \in R$.
$p \cdot 0 = 0 \cdot p = 0$ for all $p \in R$.

Example 1[2]**:** The set $R = \{0, p\}$ with the following hyperoperations is a hyperring.

Table-1

$\oplus$	0	p
0	$\{0\}$	$\{p\}$
p	$\{p\}$	R

$\otimes$	0	p
0	$\{0\}$	$\{0\}$
p	$\{0\}$	$\{p\}$

Definition 2.4 [12]: A hyperring R is said to be a commutative hyperring if $ab = ba$ for every $a, b \in R$.
Definition 2.5 [12]: The center of R is $Z(R) = \{\forall a \in R/ab = ba, \forall a \in R\}$, where R is a hyperring.
Definition 2.6 [2]: A nonempty subset I of R is said to be hyperideal if (i) $p, q \in I$ implies that $p - q \subseteq I$, (ii) $p \in I$ and $r \in R$ imply that $rp \in I$ or $pr \in I$.

Definition 2.7 [2]: For any $a, b \in R$. A hyperring R is known as a prime hyperring if $aRb = 0$ either $a = 0$ or $b = 0$. The hyperring R is called Semiprime, if for any $a \in R$, the condition $aRa = 0$ holds only when $a = 0$.

Example 2[12]: Let R = {0, 1, 2}, consider the hyperoperations as a prime hyperring.

Table-2

⊕	0	1	2
0	0	1	2
1	**1**	**1**	R
2	**2**	R	**2**

⊗	0	1	2
0	0	0	0
1	0	1	2
2	0	**2**	**1**

Definition 2.8 [12]: A hyperring R is said to be n-torsion free if $0 \in na = \underbrace{a + a + \ldots + a}_{n\ times}$, where $n \in N$ and $a \in R$ implies that $a = 0$.
Note: Example 1 is a non-trivial example for n-torsion free.

Definition 2.9 [8]: Let R be a hyperring. The function $\delta: R \to R$ is said to be a derivation of R if for every $a, b \in R$,
(i) $\delta(a + b) \subseteq \delta(a) + \delta(b)$;
(ii) $\delta(ab) \in \delta(a)b + a\delta(b)$.
If, in addition, $\delta(a + b) = \delta(a) + \delta(b)$ $a, b \in R$ then δ is called a strong derivation of R.

Definition 2.9 [12]: Let R be a hyperring. The function $\delta: R \to R$ is said to be a reverse derivation of R if for every $a, b \in R$,
(i) $\delta(a + b) \subseteq \delta(a) + \delta(b)$;
(ii) $\delta(ab) \in \delta(b)a + b\delta(a)$.
If, in addition, $\delta(a + b) = \delta(a) + \delta(b)$ $a, b \in R$ then δ is called a strong reverse derivation of R.

Definition 2.11: Let R be a hyperring. A map $G: R \to R$ is said to be a generalized reverse derivation of R associated with a reverse derivation δ of R. Then for all $a, b \in R$,
(i) $G(a + b) \subseteq G(a) + G(b)$;
(ii) $G(ab) \in G(b)a + b\delta(a) = \delta(b)a + bG(a)$.
This definition generalizes the notion of reverse derivations and provides a broader framework for studying structural properties in hyperrings.

Example 3: Consider a hyperring $R = \{0, p, q, r\}$ with the hyperaddition ⊕ and multiplication ⊗ defined as follows

Table-3

⊕	0	p	q	r
0	$\{0\}$	$\{p\}$	$\{q\}$	$\{r\}$
p	$\{p\}$	R	$\{p, q, r\}$	$\{p, q, r\}$
q	$\{q\}$	$\{p, q, r\}$	R	$\{p, q, r\}$
r	$\{r\}$	$\{p, q, r\}$	$\{p, q, r\}$	R

⊗	0	p	q	r
0	$\{0\}$	$\{0\}$	$\{0\}$	$\{0\}$
p	$\{0\}$	$\{p\}$	$\{q\}$	$\{r\}$
q	$\{0\}$	$\{q\}$	$\{r\}$	$\{p\}$
r	$\{0\}$	$\{r\}$	$\{p\}$	$\{r\}$

The map $G: R \to R$ defined by $G(0) = 0, G(p) = p, G(q) = p$, $G(r) = r$ and δ maps R onto R is the reverse derivation associated with G and defined as $\delta(0) = 0$, $\delta(p) = p$, $\delta(q) = q$, $\delta(r) = r$ then, it is clear that G is the generalized reverse derivation of R.

For instance, for $a = p$ and $b = q$, we have $pq = q$, so $G(pq) = p$. Also,

$$G(q)p \oplus q\delta(p) = p \otimes p \oplus q \otimes p = p \oplus q = \{p, q, r\},$$

Which shows that $G(pq) \in G(q)p \oplus q\delta(p)$.

Example 4: Let R be a hyperring and $M(R) = \left\{\begin{pmatrix} 0 & p \\ 0 & q \end{pmatrix} : p, q \in R\right\}$ be a collection of 2×2 matrices over R.

A hyperaddition $\oplus$ is defined on $M(R)$ and $A = \begin{pmatrix} 0 & p \\ 0 & q \end{pmatrix}, B = \begin{pmatrix} 0 & r \\ 0 & s \end{pmatrix}$ be two Matrices in $M(R)$ then $A \oplus B = \left\{\begin{pmatrix} 0 & l \\ 0 & m \end{pmatrix} : l \in p + r, m \in q + s\right\}$, for all $A, B \in M(R)$.

A multiplication $\otimes$ defined on $M(R)$ by $A \otimes B = \begin{pmatrix} 0 & ps \\ 0 & qs \end{pmatrix}$

For all $A, B \in M(R)$. Clearly, hyperaddition and multiplication are well defined. $(M(R), \oplus, \otimes)$ forms a Krasner Hyperring. Now define a function δ on $M(R)$ by $\delta \begin{pmatrix} 0 & p \\ 0 & q \end{pmatrix} = \begin{pmatrix} 0 & -q \\ 0 & 0 \end{pmatrix}$. Here δ is well-defined. Now we prove that δ is a strong reverse derivation, for $A, B \in M(R)$, that is $\delta\{A \oplus B\}$ and the set $\delta(A) \oplus \delta(B)$ are equal and equal to the set $\left\{\begin{pmatrix} 0 & t \\ 0 & 0 \end{pmatrix} : t \in -q - s\right\}$ and also $\delta\{A \otimes B\} = \delta \begin{pmatrix} 0 & ps \\ 0 & qs \end{pmatrix} = \begin{pmatrix} 0 & -qs \\ 0 & 0 \end{pmatrix} = \delta(B) \otimes A \oplus B \otimes \delta(A)$. Thus δ is a strong reverse derivation on $M(R)$. Now define a function G on $M(R)$ by $G\left(\begin{pmatrix} 0 & p \\ 0 & q \end{pmatrix}\right) = \begin{pmatrix} 0 & 0 \\ 0 & q \end{pmatrix}$. Clearly, this map is well defined.

Now we prove that G is a generalized reverse derivation for $A, B \in M(R)$, that is $G\{A \oplus B\}$ and the set $G(A) \oplus G(B)$ are equal and equal to the set $\left\{\begin{pmatrix} 0 & 0 \\ 0 & t \end{pmatrix} : t \in q + s\right\}$ also $G\{A \otimes B\} = G \begin{pmatrix} 0 & ps \\ 0 & qs \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & qs \end{pmatrix}$ and $G(B) \otimes A \oplus B \otimes \delta(A) = \begin{pmatrix} 0 & 0 \\ 0 & qs \end{pmatrix} \oplus \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & qs \end{pmatrix}$

Which proves that $G(A \otimes B) \in G(B) \otimes A \oplus B \otimes \delta(A)$

Hence, G is a generalized reverse derivation on $M(R)$.

3. Lemmas

Lemma 3.1 ([12], Lemma 1.3): Let R be a hyperring, and define $[a, b] = ab - ba$, for all $a, b \in R$. With, for all $a, b, a \in R$, we have,

(i) $[a + b, c] = [a, c] + [b.c]$,

(ii) $[ab, c] = a[b, c] + [a, c]b$,

(iii) If $a \in Z(R)$, then $[ab, c] = a[b, c]$.

Lemma 3.2 ([12], Lemma 2.2): Let U be a nonzero hyperideal of a prime hyperring R.Then, for all $a, b \in R$,

(i) If $Ua = 0$ or $aU = 0$, then $a = 0$,

(ii) If $aUb = 0$, then $a = 0$ or $b = 0$,

(iii) If $a \in Z(R)$ and $ab = 0$, then $a = 0$ or $b = 0$,

(iv) If $a \in R$ such that $[U, a] = 0$, then $a \in Z(R)$,

(v) If $a \in Z(R)$ and $ab \in Z(R)$, then $a = 0$ or $b \in Z(R)$.

Lemma 3.3 [12]: Let G be a nonzero generalized reverse derivation on a prime hyperring R and U be a nonzero hyperideal on R such that $G(U) = 0$ then $U \subseteq Z(R)$, R is a commutative.

Lemma 3.4 ([7], Lemma 3.1): Let U be a nonzero hyperideal of a prime hyperring R and let δ be a reverse derivation on R, for every $a \in R$.

(i) If $\delta(U) = 0$, then $\delta = 0$,
(ii) If $a\delta(U) = 0$ or $\delta(U)a = 0$, then $a = 0$ or $\delta = 0$,
(iii) If $a\delta(R) = 0$ or $\delta(R)a = 0$, then $a = 0$ or $\delta = 0$.

Lemma 3.5 ([7], Theorem 3.3): Let R be a two-torsion-free hyperring with a nonzero hyperideal U, and δ is a reverse derivation of R such that $\delta^2(u) = 0$, then $\delta = 0$.

Lemma 3.6 ([7], Theorem 3.4): Let R be a prime hyperring such that the center $Z(R)$ is a ring and let U be a nonzero hyperideal of R. Each of the following cases, hyperring R is commutative.
(i) If δ is a reverse derivation with that $\delta^2 \neq 0$ and $\delta(R) \subseteq Z(R)$,
(ii) Suppose R is a two-torsion free hyperring if there exists a nonzero reverse derivation δ such that $\delta(U) \subseteq Z(R)$.

4. Main Results

Throughout this section, wherever necessary, the associativity of multiplication, the distributivity of multiplication over hyperaddition, and the properties of canonical hypergroups are used. Since hyperaddition in Krasner hyperrings is set-valued, equalities involving hyperoperations are understood in the sense of set equality or set inclusion whenever appropriate.

Theorem 4.1: Let G be a generalized reverse derivation on a prime hyperring R and U be a nonzero hyperideal on R, for all $a \in R$
(i) If $G(U) = 0$, then $\delta = 0$,
(ii) If $aG(U) = 0$ or $G(U)a = 0$, then $a = 0$ or $\delta = 0$,
(iii) If $aG(R) = 0$ or $G(R)a = 0$, then $a = 0$ or $\delta = 0$.

Proof: (i) For all $u \in U$ and $a \in R$, we have $0 = G(au) \in G(u)a + u\delta(a) = u\delta(a)$.
So, $U\delta(a) = 0$ (1)
By using Lemma 3.2 (i) and (1), we obtain $\delta = 0$.
(ii) Suppose $aG(U) = 0$. Then we have
$0 = aG(uv) \in a(G(v)u + v\delta(u)) = av\delta(u)$
Hence $0 = aU\delta(u)$ (2)
By using Lemma 3.2 (ii) and (2), we conclude that either $a = 0$ or $\delta = 0$.
The case $G(U)a = 0$, we get a similar result and yield the same conclusion
(iii) Substituting U by R in condition (ii), we obtain the desired result.

Theorem 4.2: Let G be a nonzero generalized reverse derivation on a prime hyperring R such that $G(R) \subseteq Z(R)$. Let c be the constant element associated with G and let δ is reverse derivation with $c \notin Z(R)$, then $\delta = 0$.
Proof: Since $c \notin Z(R)$, there exists $a_0 \in R$ such that $ca_0 \neq a_0c$,
Now, for any $a \in R$, we have $G(ac) \in G(c)a + c\delta(a) = c\delta(a)$.
Thus, $c\delta(a) = \delta(ca) = \delta(ac) \in Z(R)$. It follows that $a_0c\delta(a) = a_0\delta(a)c = \delta(a)ca_0$
Which gives $(a_0c - ca_0)\delta(a) = 0$. Hence $0 \in [a_0, c]\delta(a)$.
Therefore $\exists x \in [a_0, c]$ such that $x\delta(a) = 0$ (3)
By using Lemma (3.2) (iii) and (3), we get $x = 0$ or $\delta = 0$.
If $x = 0$, then $0 \in [a_0, c] = a_0c - ca_0$ which contradicts $ca_0 \neq a_0c$ therefore, $\delta = 0$.

Theorem 4.3: Let R be a two-torsion-free prime hyperring and U a nonzero hyperideal of R. Let G be a generalized reverse derivation associated with a reverse derivation δ. If $G^2(u) = 0$ for all $u \in U$, then $\delta = 0$.

Proof: Let $u, v \in U$. Since $G^2(u) = 0$ for all $u \in U$, we have

$$0 = G^2(uv) \in G(G(v)u + v\delta(u))$$

$\subseteq G(G(v)u) + G(v\delta(u))$.
Thus, $0 \in G(u)G(v) + u\delta(G(v)) + G(\delta(u))v + \delta(u)\delta(v)$ (4)

Now, replacing $G(v)$ by $\delta(v)$ and $\delta(u)$ by $G(u)$ in (4), we obtain
$0 \in 2G(u)\delta(v) + u\delta^2(v)$. (5)

Since R is two-torsion-free, (5) implies

$$0 \in G(u)\delta(v) + u\delta^2(v). \tag{6}$$

Replacing u by $G(u)$ in (6), we get

$$0 \in G(u)\delta^2(v). \tag{7}$$

Hence, $G(U)\delta^2(v) = 0$.

The above equation can be rewritten as $G(U)R\delta^2(v) = 0$.
Since R is a prime hyperring, it follows that either $G(U) = 0$ or $\delta^2(v) = 0$.
If $G(U) = 0$, from Theorem 4.1 it follows that δ = 0.

Theorem 4.4: Let R be a prime hyperring whose center $Z(R)$ is a hyperring, and let G be a generalized reverse derivation, associated with a nonzero reverse derivation δ. If $G(R) \subseteq Z(R)$ and $G^2 \neq 0$, then R is commutative.

Proof: Since $G(R) \subseteq Z(R)$, we have $[G(a), b] = 0$ for all $a, b \in R$ (8)
Now, replace a by za in (8), we obtain $0 = [G(za), b] \in [G(a)z + a\delta(z), b]$
$\subseteq [G(a)z, b] + [a\delta(z), b]$

$$= G(a)[z, b] + [G(a), b]z + a[\delta(z), b] + [a, b]\delta(z) \tag{9}$$

From the Lemma 3.6, it follows that $\delta(R) \subseteq Z(R)$ then $[\delta(a), b] = 0$ (10)

Using (8) and (9) in (10), we obtain $0 = G(a)[z, b] + [a, b]\delta(z)$ (11)

Next, replace z by $\delta(z)$ in (11), we get $0 = [a, b]\, \delta^2(z)$ (12)

By Lemma (3.2) (iii) in (12), we conclude that either $\delta^2 = 0$ or $0 \in [a, b]$.
Since $\delta \neq 0$, we conclude that R is commutative.

5. Conclusion

In the present study, the notion of generalized reverse derivations on Krasner hyperrings was introduced, and its fundamental properties were investigated. Several commutativity results were established for prime hyperrings admitting generalized reverse derivations associated with reverse derivations. The obtained results extend earlier works on reverse derivations in the framework of Krasner hyperrings and further strengthen the connection between derivation theory and algebraic hyperstructures. In particular, generalized reverse derivations provide a useful tool for investigating structural properties of prime and semiprime hyperrings, centralizing mappings, and related commutativity conditions. It is expected that these results will motivate further research on generalized derivation-type mappings, Jordan-type derivations, and other algebraic operators in hyperring theory and related hyperstructures.

Acknowledgments

We would like to extend our sincere thanks to the referees for their constructive comments and reviews, which greatly improved the quality of this manuscript.

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