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DERIVATIONS OF PSEUDO *BE*-ALGEBRAS

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ABSTRACT

A BE-algebra $(B;*,1)$ is a non-empty set B with a binary operation $*$ and a constant 1 that satisfies the following axioms: (BE1) $a*a=1$, (BE2) $a*1=1$, (BE3) $1*a=a$, and (BE4) $a*(b*c)=b*(a*c)$ for all $a,b,c\in B$. A generalization of BE-algebra, the concept of pseudo BE-algebra is introduced, which is an algebra $(E;*,\circ,1)$ that satisfies the following axioms: (pBE1) $a*a=1$ and $a\circ a=1$, (pBE2) $a*1=1$ and $a\circ 1=1$, (pBE3) $1*a=a$ and $1\circ a=a$, (pBE4) $a*(b\circ c)=b\circ(a*c)$, and (pBE5) $a*b=1 \Leftrightarrow a\circ b=1$ for all $a,b,c\in E$. In BE-algebra $(B;*,1)$, a self-map $\delta: B\to B$ is called derivation of B if it satisfies $\delta(x*y)=\big(x*\delta(y)\big)\vee\big(\delta(x)*y\big)$ for all $x,y\in B$, where $x\vee y=(y*x)*x$. In this article, the concept of derivation in pseudo BE-algebra is defined, by first defining operations $\ominus$ and $\oplus$ in pseudo BE-algebra $(E;*,\circ,1)$ as $x\ominus y=(y\circ x)*x$ and $x\oplus y=(y*x)\circ x$ for each $x,y\in E$. Building on the definition of derivation of BE-algebra, the operation $\vee$ is replaced by operations $\ominus$ and $\oplus$ to produce definitions of derivations in pseudo BE-algebra. The results are two types of derivations on pseudo BE-algebra, namely type 1 derivation involving operation $\ominus$ and type 2 derivation involving operation $\oplus$. From these two definitions, the properties are derived, including the existence of type 1 and type 2 derivations in pseudo BE-algebra, simple formulas for both types of derivations, and the relationship between the binary operations $*$ and $\circ$ in both derivation types.

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1. INTRODUCTION

BE-algebra [1] was first introduced as a development of the algebraic structure used in mathematical logic and set theory. This algebraic structure plays a crucial role in various applications, from information theory to fuzzy logic [2]. In the context of mathematical logic, *BE*-algebra is important because it provides a framework for understanding and analyzing logical implications in more complex systems. In practical applications, *BE*-algebra is used in fuzzy logic to handle uncertainty and in rough set theory to model incomplete or imprecise information. Other forms of algebraic applications as discussed in [3] and [4].

Since its introduction, *BE*-algebra has undergone many developments and variations, including pseudo *BE*-algebra [5], which is an extension of *BE*-algebra with more general properties. This variation allows for broader applications of *BE*-algebra in fields such as computational algorithms, dynamic systems analysis, and optimization in computer science. Pseudo *BE*-algebra was introduced to accommodate more flexible algebraic structures within the context of fuzzy logic and rough set theory. As an extension of *BCK*-algebra, pseudo *BE*-algebra contains basic operations that are similar but have more general characteristics and properties. Several studies have explored various aspects of pseudo *BE*-algebra, as seen in [6]-[10].

In algebra, the concept of derivation has long been an essential and widely researched topic. A derivation is a function that satisfies Leibniz's law and plays a significant role in analyzing algebraic structures. The concept of derivation allows for the study of elemental changes within algebra and aids in understanding the properties of algebraic structures.

Derivation in *BE*-algebra [11] provides a way to study changes in the elements of the algebra. By using derivation, deeper insights into the properties of these elements and the relationships between them can be obtained. This is important for understanding the structure and dynamics of *BE*-algebra, especially in practical applications such as fuzzy logic and information theory.

The primary motivation for applying the concept of derivation in pseudo *BE*-algebra is to expand and deepen our understanding of this algebraic structure. By adopting the concept of derivation from ring theory, it is hoped that new properties of pseudo *BE*-algebra can be discovered. Derivation in pseudo *BE*-algebra is expected to provide better insights into the existence of type 1 and type 2 derivations, simple formulas for these derivations, and the relationship between the two new operations in both types of derivations. Additionally, research on the concept of derivation in (2, 0) algebraic structures has been widely conducted, as seen in [12]-[18]. However, research on derivation in (2, 2, 0) algebraic structures remains relatively limited [19].

This study aims to construct the definition of derivation in pseudo *BE*-algebra, adopting concepts from both ring theory and *BE*-algebra derivation, involving two new operations, leading to the development of type 1 and type 2 derivations in pseudo *BE*-algebra. The study will then analyze the influence of these derivations on the algebraic elements, the existence of type 1 and type 2 derivations, simple formulas for both types of derivations, the relationship between the two binary operations in pseudo *BE*-algebra with respect to both types of derivations, and the fixed set in the derivation of pseudo *BE*-algebra. The findings of this research are expected to make a significant contribution to the field of mathematics and computer logic, as well as provide a solid foundation for further research on the structure of algebra and its applications. Discovering new properties of pseudo BE-algebra through derivation can open opportunities for innovation in various practical applications.

The research method employed in this study is a literature review, involving the identification, collection, and analysis of relevant literature. The literature was selected based on its relevance to the development of *BE*-algebra and pseudo *BE*-algebra, particularly regarding the concept of derivation. Sources were chosen from peer-reviewed journals, conference proceedings, and authoritative books on algebraic structures. The process of literature collection involved systematic searching through academic databases to ensure that the most relevant and up-to-date research was included.

Data analysis was carried out by reviewing definitions, propositions, and examples presented in the selected literature. The findings were synthesized to propose new derivation concepts and understand their relationships within pseudo *BE*-algebra. This analysis provides insights into the new operations, their impact on the algebraic structure, and their applications in fuzzy logic and information theory.

By adopting a detailed literature analysis approach, this study aims to make a significant contribution to algebraic research and provide a solid foundation for further studies on pseudo BE-algebra and its applications.

2. RESEARCH METHODS

The research method used in this study is a literature review, focusing on various materials related to derivation and pseudo BE-algebra. The following section presents the basic theory necessary for constructing the derivation in pseudo BE-algebra.

Definition 1. [1] An algebra $(X; *, 1)$ is said to be *BE-algebra* if it satisfies the following axioms:

($BE1$) $x * x = 1$,

($BE2$) $x * 1 = 1$,

($BE3$) $1 * x = x$,

($BE4$) $x * (y * z) = y * (x * z)$,

for each $x, y, z \in X$.

Suppose $(X; *, 1)$ be BE-algebra. Defined the relation $\leq$ on X as $x \leq y$ if and only if $x * y = 1$ for each $x, y \in X$.

Example 1. Suppose $A = \{1, 2, 3, 4, 5, 6\}$ is a set defined in Table 1.

Table 1. Table for $(A; *, 1)$

$*$	1	2	3	4	5	6
1	1	2	3	4	5	6
2	1	1	2	4	4	5
3	1	1	1	4	4	4
4	1	2	3	1	2	3
5	1	1	2	1	1	2
6	1	1	1	1	1	1

Based on Table 1 it can be shown that it is $(A; *, 1)$ is a BE-algebra.

Proposition 1. [1] *Suppose* $(X; *, 1)$ *is BE-algebra, then* $x * (y * x) = 1$ *for each* $x, y, z \in X$.

Definition 2. [1] Let $(X; *, 1)$ be a *BE-algebra* and F be a non-empty subset *of* X. F is said to be filter of X if

(F1) $1 \in F$,

(F2) $x \in F$ *and* $x * y \in F$ *imply* $y \in F$.

By **Example 1**, we obtain that $F_1 = \{1, 2, 3\}$ is a filter of A, whereas $F_2 = \{1, 2\}$ is not a filter of A, because $2 \in F_2$ and $2 * 3 = 2 \in F_2$, but $3 \notin F_2$.

Definition 3. [1] A *BE-algebra* $(X; *, 1)$ is said to be self-distributive if $x * (y * z) = (x * y) * (x * z)$ for all $x, y, z \in X$.

Example 2. Let $X = \{1, a, b, c, d,\}$ be a set defined in Table 2.

Table 2. Table for $(X;*,1)$

$*$	1	a	b	c	d
1	1	a	b	c	d
a	1	1	b	c	d
b	1	a	1	c	c
c	1	1	b	1	b
d	1	1	1	1	1

By Table 2, it can be proven that $(X;*,1)$ is a BE-algebra satisfying self-distributive. Whereas, BE-algebra in **Example 2** is not self-distributive, due to $x=5, y=2$, and $z=6$ obtained $5*(2*6)=5*5=1$, whereas $(5*2)*(5*6)=1*2=2$.

Proposition 2. [11] *Let $(X;*,1)$ be a $BE-algebra$, then the following identity applies for all $x, y, z \in X$.*

(P1) $x*((x*y)*y)=1$,

(P2) Let $(X;*,1)$ be a self-distributive BE-algebra. If $x \leq y$, then $z*x \leq z*y$ and $y*z \leq x*z$.

Let $(X;*,1)$ is BE-algebra. We define $x \vee y=(y*x)*x$ for each $x, y \in X$.

Definition 4. [11] A self-map δ on *BE-algebra* $(X;*,1)$ is called a derivation on X if for each $x, y \in X$:

$$\delta(x*y)=(x*\delta(y)) \vee (\delta(x)*y).$$

Definition 5. [11] Let $(X;*,1)$ is *BE-algebra.* A self-map δ from X is called regular if $\delta(1)=1$. Suppose $(X;*,1)$ is BE-algebra and δ is derivation in X. Defined fixed set of δ as:

$$Fix_{\delta}(X)=\{x \in X : \delta(x)=x\},$$

for each $x \in X$ and kernel of d as:

$$Kerd(X)=\{x \in X \mid \delta(x)=1\}, \text{ for each } x \in X.$$

Definition 6. [5] An algebra $(E;*,\circ,1)$ is said to be pseudo *BE-algebra* if it satisfies the following axioms:

(PBE1) $x*x=1$ and $x \circ x=1$,

(PBE2) $x*1=1$ and $x \circ 1=1$,

(PBE3) $1*x=x$ and $1 \circ x=x$,

(PBE4) $x*(y \circ z)=y \circ (x*z)$,

(PBE5) $x*y=1$ if and only if $x \circ y=1$,

for all $x, y, z \in E$.

Let $(E;*,\circ,1)$ is pseudo BE-algebra. Defined relation $\leq$ on E as $x \leq y$ if and only if $x*y=1$ if and only if $x \circ y=1$ for each $x, y \in E$.

Proposition 3. [5] *If $(E;*,\circ,1)$ is pseudo BE-algebra, then identity following applies, for every $x, y, z \in E$:*

(i) $x*(y \circ x)=1$, $x \circ (y*x)=1$,

(ii) $x \circ (y \circ x)=1$, $x*(y*x)=1$,

(iii) $x \circ ((x \circ y)*y)=1$, $x*((x*y) \circ y)=1$,

(iv) $x*((x \circ y)*y=1$, $x \circ ((x*y) \circ y=1$,

(v) *If $x \leq y*z$, then $y \leq x \circ z$,*

(vi) *If $x \leq y \circ z$, then $y \leq x*z$,*

(vii) $1 \leq x$, *implies* $x=1$,

(viii) *If* $x \leq y$, *then* $x \leq z * y$ *and* $x \leq z \circ y$,

(ix) *If* $x * y = z$, *then* $y * z = y \circ z = 1$ *(if* $x * y = z$, *then* $y * z = y \circ z = 1$*)*,

(x) *If* $x * y = x$ *and* $x \neq 1$, *then* $x \circ y \neq y$,

(xi) *If* $x * y = y$ *and* $x \neq 1$, *then* $x \circ y \neq x$,

(xii) *If* $x * y = x$ *and* $x \circ y = z$, *then* $x * z = x \circ z = 1$.

3. RESULTS AND DISCUSSION

The research results presented here focus on the definition of derivation in pseudo BE-algebra and its properties. The findings include the existence of type 1 and type 2 derivations in pseudo BE-algebra, simple formulas for type 1 and type 2 derivations, and the relationship between the binary operations $*$ and $\circ$ in both types of derivation. The purpose of this discussion is to provide an in-depth analysis of these key findings, explore their implications, and contextualize them within the broader framework of BE-algebra and pseudo BE-algebra. Each step in the derivation process is discussed in detail, starting with the foundational concepts and progressing to the specific properties and relationships uncovered through the study.

Let $(E; *, \circ, 1)$ is pseudo BE-algebra. Defined operation $\ominus$ and $\oplus$ on E as $x \ominus y = (y \circ x) * x$ and $x \oplus y = (y * x) \circ x$ for each $x, y \in E$. From two operations the defined derivation type 1 and derivations type 2.

Definition 7. *Let* $(E; *, \circ, 1)$ is a pseudo *BE-algebra.* A mapping $\delta: E \to E$ is called a type 1 derivation in E if it satisfies $\delta(x * y) = (x * \delta(y)) \ominus (\delta(x) * y)$ and it is called a type 2 derivation in E if it holds $\delta(x \circ y) = (x \circ \delta(y)) \oplus (\delta(x) \circ y)$ for every $x, y \in E$.

Example 3. Suppose $E = \{1, a, b, c\}$. Defined operation $*$ and $\circ$ as follows:

Table 3: Table for $(E; *, 1)$

$*$	1	a	b	c
1	1	a	b	c
a	1	1	1	b
b	1	a	1	c
c	1	1	1	1

Table 4: Table for $(E; \circ, 1)$

$\circ$	1	a	b	c
1	1	a	b	c
a	1	1	1	a
b	1	a	1	a
c	1	1	1	1

We can show that $(E; *, \circ, 1)$ is pseudo BE-algebra, but $(E; *, 1)$ and $(E; \circ, 1)$ both are not BE-algebras. Defined mapping $\delta: E \to E$ as

$$\delta(x) = \begin{cases} 1 & if\ x = 1, a, b \\ a & if\ x = c \end{cases}$$

Then, δ is a type 1 derivation in E, but not a type 2 derivation.

Considering these characteristics, derivation types 1 and 2 in pseudo BE-algebra involve the existence of derivation within pseudo BE-algebra, a straightforward formula for derivation, and the connection between the binary operations $*$ and $\circ$ on the derivation.

Lemma 1. *Let* $(E; *, \circ, 1)$ *is pseudo BE-algebra. If* δ *is a type 1 derivation of* E, *then* $\delta(1) = 1$.

Proof. Let $(E; *, \circ, 1)$ is pseudo BE-algebra. Given that δ is a type 1 derivation in E, by applying the **Axioms *PBE3*** and ***PBE2***, we obtain the following result:

$$\begin{aligned}\delta(1) &= \delta(1 * 1)\\ &= (1 * \delta(1)) \ominus (\delta(1) * 1)\\ &= \delta(1) \ominus 1\\ &= \big(1 \circ \delta(1)\big) * \delta(1)\\ &= \delta(1) * \delta(1)\\ \delta(1) &= 1.\end{aligned}$$

Thus, it is proven that if δ is a type 1 derivation of E, then $\delta(1) = 1$.

Lemma 2. *Let $(E; *, \circ, 1)$ is pseudo BE-algebra. If δ is a type 1 derivation in E, then $\delta(x) = \delta(x) \ominus x$ for every $x \in E$.*

Proof. Let $(E; *, \circ, 1)$ is pseudo BE-algebra. Since δ is a type 1 derivation in E, it follows from the **Axiom *PBE3*** and **Lemma 1** are obtained

$$\begin{aligned}\delta(x) &= \delta(1 * x)\\ &= (1 * \delta(x)) \ominus (\delta(1) * x)\\ &= \delta(x) \ominus (1 * x)\\ \delta(x) &= \delta(x) \ominus x.\end{aligned}$$

Hence, it is proven that if δ is a type 1 derivation of E, then $\delta(x) = \delta(x) \ominus x$ for every $x \in E$.

Lemma 3. *Suppose $(E; *, \circ, 1)$ is pseudo BE-algebra. If δ is a type 2 derivation of E, then $\delta(1) = 1$.*

Proof. Let $(E; *, \circ, 1)$ is pseudo BE-algebra. Since δ is a type 2 derivation in E, then based on the **Axioms *PBE3*** and ***PBE2*** we obtain

$$\begin{aligned}\delta(1) &= \delta(1 \circ 1)\\ &= (1 \circ \delta(1)) \oplus (\delta(1) \circ 1)\\ &= \delta(1) \oplus 1\\ &= \big(1 * \delta(1)\big) \circ \delta(1)\\ &= \delta(1) \circ \delta(1)\\ \delta(1) &= 1.\end{aligned}$$

So, proven that if δ is a type 2 derivation of E, then $\delta(1) = 1$.

Lemma 4. *Let $(E; *, \circ, 1)$ is pseudo BE-algebra. If δ is a type 2 derivation in E, then $\delta(x) = \delta(x) \oplus x$ for each $x \in E$.*

Proof. Let $(E; *, \circ, 1)$ is pseudo BE-algebra. Since δ is a type 2 derivation in E, it follows from the **Axiom *PBE3*** and **Lemma 3** are obtained

$$\begin{aligned}\delta(x) &= \delta(1 \circ x)\\ &= (1 \circ \delta(x)) \oplus (\delta(1) \circ x)\\ &= \delta(x) \oplus (1 \circ x)\\ \delta(x) &= \delta(x) \oplus x.\end{aligned}$$

Hence, it is proven that if δ is a type 2 derivation in E, then $\delta(x) = \delta(x) \oplus x$ for each $x \in E$.

Theorem 1. *Suppose $(E; *, \circ, 1)$ is pseudo BE-algebra. If δ is both a type 1 and type 2 derivation in E, then $\delta(x * \delta(x)) = \delta(\delta(x) \circ x) = 1$ for each $x \in E$.*

Proof. Suppose $(E; *, \circ, 1)$ is pseudo BE-algebra. Given that δ be both a type 1 and type 2 derivation in E, then based on **Axioms *PBE1*, *PBE2*,** and ***PBE3***, we obtain the following results:

$$
\begin{aligned}
\delta(x * \delta(x)) &= \left(x * \delta\big(\delta(x)\big)\right) \ominus (\delta(x) * \delta(x)) \\
&= \left(x * \delta\big(\delta(x)\big)\right) \ominus 1 \\
&= \left(1 \circ \left(x * \delta\big(\delta(x)\big)\right)\right) * \left(x * \delta\big(\delta(x)\big)\right) \\
&= \left(x * \delta\big(\delta(x)\big)\right) * \left(x * \delta\big(\delta(x)\big)\right) \\
\delta(x * \delta(x)) &= 1.
\end{aligned}
$$

On the other hand,

$$
\begin{aligned}
\delta(\delta(x) \circ x) &= (\delta(x) \circ \delta(x)) \oplus (\delta(\delta(x)) \circ x) \\
&= 1 \oplus (\delta(\delta(x)) \circ x) \\
&= ((\delta\big(\delta(x)\big) \circ x) * 1) \circ 1 \\
&= 1 \circ 1 \\
\delta(\delta(x) \circ x) &= 1.
\end{aligned}
$$

Thus, it is proven that if δ is both a type 1 and type 2 derivation in E, then $\delta(x * \delta(x)) = \delta(\delta(x) \circ x) = 1$ for each $x \in E$.

Let $(E; *, \circ, 1)$ is pseudo BE-algebra and δ is derivation in E. We define a fixed set of δ as $Fix_\delta(E) = \{x \in E: \delta(x) = x\}$, for each $x \in E$.

Theorem 2. *Suppose $(E; *, \circ, 1)$ is pseudo BE-algebra. If δ is a type 1 derivation of E, then $Fix_\delta(E)$ is subalgebra.*

Proof. Suppose $(E; *, \circ, 1)$ is pseudo BE-algebra and δ is derivation type 1 in E. Using **Lemma 1**, we establish that $\delta(1) = 1$, ensuring that $Fix_\delta(E)$ is a non-empty set. Let $x, y \in Fix_\delta(E)$, then $\delta(x) = x$ and $\delta(y) = y$. Since δ is a type 1 derivation in E, and applying **Axioms *PBE1 and PBE3*** for every $x, y \in E$, we obtain

$$
\begin{aligned}
\delta(x * y) &= \big(x * \delta(y)\big) \ominus (\delta(x) * y) \\
&= (x * y) \ominus (x * y) \\
&= \big((x * y) \circ (x * y)\big) * (x * y) \\
&= 1 * (x * y) \\
\delta(x * y) &= x * y.
\end{aligned}
$$

Thus, $x * y \in Fix_\delta(E)$. Therefore, it is proven that $Fix_\delta(E)$ is a subalgebra of E.

Theorem 3. *Let $(E; *, \circ, 1)$ is pseudo BE-algebra and δ is both a type 1 and type 2 derivation in E. If $x, y \in Fix_\delta(E)$, then $x \ominus y \in Fix_\delta(E)$ for each $x, y \in E$.*

Proof. Let $(E; *, \circ, 1)$ is pseudo BE-algebra and δ is derivation type 1 at once type 2 in E. Since $x \in Fix_\delta(E)$, then $\delta(x) = x$ for each $x \in X$. Then, by **Axioms *PBE1*** and ***PBE3***, for every $x, y \in E$ we obtain

$$
\begin{aligned}
\delta(x \ominus y) &= \delta\big((y \circ x) * x\big) \\
&= [(y \circ x) * \delta(x)] \ominus [\delta(y \circ x) * x] \\
&= [(y \circ x) * x] \ominus \left[\left(\big(y \circ \delta(x)\big) \oplus (\delta(y) \circ x)\right) * x\right] \\
&= [(y \circ x) * x] \ominus \left[\big((y \circ x) \oplus (y \circ x)\big) * x\right]
\end{aligned}
$$

$$= [(y \circ x) * x] \ominus [(((y \circ x) * (y \circ x)) \circ (y \circ x)) * x]$$
$$= [(y \circ x) * x] \ominus [(1 \circ (y \circ x)) * x]$$
$$= [(y \circ x) * x] \ominus [(y \circ x) * x]$$
$$= (((y \circ x) * x) \circ ((y \circ x) * x)) * ((y \circ x) * x)$$
$$= 1 * ((y \circ x) * x)$$
$$= (y \circ x) * x$$
$$\delta(x \ominus y) = x \ominus y.$$

Hence, it is proven that $x \ominus y \in Fix_\delta(E)$.

Let $(E; *, \circ, 1)$ is pseudo BE-algebra in **Example 2**. We have δ is a type 1 derivation in E. Since $\delta(1) = 1$, then $1 \in Fix_\delta(E)$. We obtain $\delta(\delta(1)) = \delta(1) = 1$. Based on this illustration, **Theorem 4** is constructed.

Theorem 4. *Let $(E; *, \circ, 1)$ is pseudo BE-algebra and δ is a type 1 or type 2 derivation in E. If $x \in Fix_\delta(E)$, then $\delta(\delta(x)) = x$ for each $x \in E$.*

Proof. Let $(E; *, \circ, 1)$ is pseudo BE-algebra and δ is type 1 or type 2 derivation in E. Since $x \in Fix_\delta(E)$, then $\delta(x) = x$. Such that, for every $x \in E$ we obtain

$$\delta(\delta(x)) = \delta(\delta(x)) = \delta(x) = x.$$

Thus, it is proven that $\delta(\delta(x)) = x$ for each $x \in E$.

4. CONCLUSIONS

This article constructs a definition of derivation in pseudo BE-algebra involving two new operations, $\ominus$ and $\oplus$. The operation $\ominus$ is used to define type 1 derivation, while the operation $\oplus$ is used for type 2 derivation in pseudo BE-algebra. The properties acquired include the existence of type 1 and type 2 derivations, simple formulas for both types of derivations, the relationship between the operations $*$ and $\circ$ for these two types of derivations, and the properties of the fixed set in derivations of pseudo BE-algebra.

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