Madad Khan | Florentin Smarandache | Tariq Aziz

Fuzzy Abel Grassmann Groupoids

second updated and enlarged version
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Contents

1 Generalized Fuzzy Ideals of AG-groupoids 7
   1.1 Introduction / 7
   1.2 Abel Grassmann Groupoids / 8
   1.3 Preliminaries / 9
   1.4 ($\varepsilon; \in \vee q_k$)-fuzzy Ideals in AG-groupoids / 13

2 Generalized Fuzzy Ideals of Abel Grassmann Groupoids 37
   2.1 Some Characterizations of AG-groupoids by ($\varepsilon; \in \vee q_k$)-fuzzy Ideals / 41
   2.2 Medial and Para–medial Laws in Fuzzy AG-groupoids / 47
   2.3 Certain Characterizations of Regular AG-groupoids / 50

3 Generalized Fuzzy Left Ideals in AG-groupoids 61
   3.1 ($\varepsilon_\gamma, \varepsilon_\gamma \vee q_\delta$)-fuzzy Ideals of AG-groupoids / 61
   3.2 Some Basic Results / 62
   3.3 ($\varepsilon_\gamma, \varepsilon_\gamma \vee q_\delta$)-fuzzy Ideals of Intra Regular AG-groupoids / 68

4 Generalized Fuzzy Prime and Semiprime Ideals
   of Abel Grassmann Groupoids 75
   4.1 ($\varepsilon_\gamma, \varepsilon_\gamma \vee q_\delta$)-fuzzy Prime Ideals of AG-groupoids / 80
   4.2 ($\varepsilon_\gamma, \varepsilon_\gamma \vee q_\delta$)-Fuzzy Semiprime Ideals of Intra-regular AG-groupoids / 84

5 Fuzzy Soft Abel Grassmann Groupoids 89
   5.1 ($\varepsilon_\gamma, \varepsilon_\gamma \vee q_\delta$)-fuzzy Soft Ideals of AG-groupoids / 89
   5.2 ($\varepsilon_\gamma, \varepsilon_\gamma \vee q_\delta$)-fuzzy Soft Ideals in Regular AG-groupoids / 91
   5.3 References / 108
Preface

Usually the models of real world problems in almost all disciplines like engineering, medical sciences, mathematics, physics, computer science, management sciences, operations research and artificial intelligence are mostly full of complexities and consist of several types of uncertainties while dealing them in several occasion. To overcome these difficulties of uncertainties, many theories have been developed such as rough sets theory, probability theory, fuzzy sets theory, theory of vague sets, theory of soft ideals and the theory of intuitionistic fuzzy sets, theory of neutrosophic sets, Dezert-Smarandache Theory (DSmT), etc. Zadeh introduced the degree of membership/truth (t) in 1965 and defined the fuzzy set. Atanassov introduced the degree of nonmembership/falsehood (f) in 1986 and defined the intuitionistic fuzzy set. Smarandache introduced the degree of indeterminacy/neutrality (i) as independent component in 1995 (published in 1998) and defined the neutrosophic set. He has coined the words “neutrosophy” and “neutrosophic”. In 2013 he refined the neutrosophic set to n components: $t_1, t_2, \ldots; i_1, i_2, \ldots; f_1, f_2, \ldots$.

Zadeh discovered the relationships of probability and fuzzy set theory which has appropriate approach to deal with uncertainties. Many authors have applied the fuzzy set theory to generalize the basic theories of Algebra. Mordeson et al. [27] has discovered the grand exploration of fuzzy semigroups, where theory of fuzzy semigroups is explored along with the applications of fuzzy semigroups in fuzzy coding, fuzzy finite state mechanics and fuzzy languages and the use of fuzzification in automata and formal language has widely been explored. Moreover the complete l-semigroups have wide range of applications in the theories of automata, formal languages and programming. It is worth mentioning that some recent investigations of l-semigroups are closely connected with algebraic logic and non-classical logics.

An AG-groupoid is a mid structure between a groupoid and a commutative semigroup. Mostly it works like a commutative semigroup. For instance $a^2b^2 = b^2a^2$, for all $a, b$ holds in a commutative semigroup, while this equation also holds for an AG-groupoid with left identity $e$. Moreover $ab = (ba)e$ for all elements $a$ and $b$ of the AG-groupoid. Now our aim is to discover some logical investigations for regular and intra-regular AG-groupoids using the new generalized concept of fuzzy sets. It is therefore concluded that this research work will give a new direction for applications of fuzzy set theory particularly in algebraic logic, non-classical logics, fuzzy coding, fuzzy finite state mechanics and fuzzy languages.
To overcome these difficulties of uncertainties, many theories have been developed such as rough sets theory, probability theory, fuzzy sets theory, theory of vague sets, theory of soft ideals and the theory of intuitionistic fuzzy sets.

In [29], Murali defined the concept of belongingness of a fuzzy point to a fuzzy subset under a natural equivalence on a fuzzy subset. The idea of quasi-coincidence of a fuzzy point with a fuzzy set is defined in [33]. Bhakat and Das [1, 2] gave the concept of \((\alpha, \beta)\)-fuzzy subgroups by using the “belongs to” relation \(\in\) and “quasi-coincident with” relation \(q\) between a fuzzy point and a fuzzy subgroup, and introduced the concept of an \((\in, \in \lor q)\)-fuzzy subgroups, where \(\alpha, \beta \in \{\in, q, \in \lor q, \in \land q\}\) and \(\alpha \neq \in \land q\). Davvaz defined \((\in, \in \lor q)\)-fuzzy subnearrings and ideals of a near ring in [4]. Jun and Song initiated the study of \((\alpha, \beta)\)-fuzzy interior ideals of a semigroup in [14]. In [37] regular semigroups are characterized by the properties of their \((\in, \in \lor q)\)-fuzzy ideals. In [36] semigroups are characterized by the properties of their \((\in, \in \lor q_k)\)-fuzzy ideals.

In chapter one we have introduced the concept of \((\in, \in \lor q_k)\)-fuzzy ideals in an AG-groupoid. We have discussed several important features of a right regular AG-groupoid.

In chapter two, we investigate some characterizations of regular and intra-regular Abel-Grassmann’s groupoids in terms of \((\in, \in \lor q_k)\)-fuzzy ideals and \((\in, \in \lor q_k)\)-fuzzy quasi-ideals.

In chapter three we introduce \((\in, \in \lor q_k)\)-fuzzy left ideals in an AG-groupoid. We characterize intra-regular AG-groupoids using the properties of \((\in, \in \lor q_k)\)-fuzzy subsets and \((\in, \in \lor q_k)\)-fuzzy left ideals.

In chapter four we introduce \((\in, \in \lor q_k)\)-fuzzy prime (semiprime) ideals in AG-groupoids. We characterize intra regular AG-groupoids using the properties of \((\in, \in \lor q_k)\)-fuzzy semiprime ideals.

In chapter five we introduce generalized fuzzy soft ideals in a non-associative algebraic structure namely Abel Grassmann groupoid. We discuss some basic properties concerning these new types of generalized fuzzy ideals in Abel-Grassmann groupoids. Moreover we characterize a regular Abel Grassmann groupoid in terms of its classical and \((\in, \in \lor q_k)\)-fuzzy soft ideals.
1

Generalized Fuzzy Ideals of AG-groupoids

In this chapter, we have introduced the concept of \((\varepsilon, \in \vee q)\)-fuzzy and \((\varepsilon, \in \vee q_k)\)-fuzzy ideals in an AG-groupoid. We have discussed several important features of right regular AG-groupoid by using the \((\varepsilon, \in \vee q_k)\)-fuzzy ideals. We proved that the \((\varepsilon, \in \vee q_k)\)-fuzzy left (right, two-sided), \((\varepsilon, \in \vee q_k)\)-fuzzy (generalized) bi-ideals, and \((\varepsilon, \in \vee q_k)\)-fuzzy interior ideals coincide in a right regular AG-groupoid.

1.1 Introduction

Fuzzy set theory and its applications in several branches of Science are growing day by day. Since pacific models of real world problems in various fields such as computer science, artificial intelligence, operation research, management science, control engineering, robotics, expert systems and many others, may not be constructed because we are mostly and unfortunately uncertain in many occasions. For handling such difficulties we need some natural tools such as probability theory and theory of fuzzy sets [42] which have already been developed. Associative Algebraic structures are mostly used for applications of fuzzy sets. Mordeson, Malik and Kuroki [27] have discovered the vast field of fuzzy semigroups, where theoretical exploration of fuzzy semigroups and their applications are used in fuzzy coding, fuzzy finite-state machines and fuzzy languages. The use of fuzzification in automata and formal language has widely been explored. Moreover the complete l-semigroups have wide range of applications in the theories of automata, formal languages and programming.

The fundamental concept of fuzzy sets was first introduced by Zadeh [42] in 1965. Given a set \(X\), a fuzzy subset of \(X\) is, by definition an arbitrary mapping \(f : X \rightarrow [0, 1]\) where \([0, 1]\) is the unit interval. Rosenfeld introduced the definition of a fuzzy subgroup of a group [34]. Kuroki initiated the theory of fuzzy bi ideals in semigroups [18]. The thought of belongingness of a fuzzy point to a fuzzy subset under a natural equivalence on a fuzzy subset was defined by Murali [29]. The concept of quasi-coincidence of a fuzzy point to a fuzzy set was introduce in [33]. Jun and Song introduced \((\alpha, \beta)\)-fuzzy interior ideals in semigroups [14].

In [29], Murali defined the concept of belongingness of a fuzzy point to a fuzzy subset under a natural equivalence on a fuzzy subset. The idea of
1. Generalized Fuzzy Ideals of AG-groupoids

quasi-coincidence of a fuzzy point with a fuzzy set is defined in [33]. Bhakat and Das [1, 2] gave the concept of \((\alpha, \beta)\)-fuzzy subgroups by using the “belongs to” relation \(\in\) and “quasi-coincident with” relation \(q\) between a fuzzy point and a fuzzy subgroup, and introduced the concept of an \((\in, \in \lor q)\)-fuzzy subgroups, where \(\alpha, \beta \in \{\in, q, \in \lor q, \in \land q\}\) and \(\alpha \neq \in \land q\). Davvaz defined \((\in, \in \lor q)\)-fuzzy subnearrings and ideals of a near ring in [4]. Jun and Song initiated the study of \((\alpha, \beta)\)-fuzzy interior ideals of a semigroup in [14]. In [37] regular semigroups are characterized by the properties of their \((\in, \in \lor q)\)-fuzzy ideals. In [36] semigroups are characterized by the properties of their \((\in, \in \lor q_k)\)-fuzzy ideals.

In this paper, we have introduced the concept of \((\in, \in \lor q_k)\)-fuzzy ideals in a new non-associative algebraic structure, that is, in an AG-groupoid and developed some new results. We have defined regular and intra-regular AG-groupoids and characterized them by \((\in, \in \lor q_k)\)-fuzzy ideals and \((\in, \in \lor q_k)\)-fuzzy quasi-ideals.

An AG-groupoid is a mid structure between a groupoid and a commutative semigroup. Mostly it works like a commutative semigroup. For instance \(a^2b^2 = b^2a^2\), for all \(a, b\) holds in a commutative semigroup, while this equation also holds for an AG-groupoid with left identity \(e\). Moreover \(ab = (ba)e\) for all elements \(a\) and \(b\) of the AG-groupoid. Now our aim is to discover some logical investigations for regular and intra-regular AG-groupoids using the new generalized concept of fuzzy sets. It is therefore concluded that this research work will give a new direction for applications of fuzzy set theory particularly in algebraic logic, non-classical logics, fuzzy coding, fuzzy finite state mechanics and fuzzy languages.

1.2 Abel Grassmann Groupoids

The concept of a left almost semigroup (LA-semigroup) [16] or an AG-groupoid was first given by M. A. Kazim and M. Naseeruddin in 1972. An AG-groupoid \(M\) is a groupoid having the left invertive law,

\[(ab)c = (cb)a, \text{ for all } a, b, c \in M.\] (1)

In an AG-groupoid \(M\), the following medial law [16] holds,

\[(ab)(cd) = (ac)(bd), \text{ for all } a, b, c, d \in M.\] (2)

The left identity in an AG-groupoid if exists is unique [28]. In an AG-groupoid \(M\) with left identity the following paramedial law holds [32],

\[(ab)(cd) = (dc)(ba), \text{ for all } a, b, c, d \in M.\] (3)

If an AG-groupoid \(M\) contains a left identity, then,
1. Generalized Fuzzy Ideals of AG-groupoids

\[ a(bc) = b(ac), \text{ for all } a, b, c \in M. \quad (4) \]

1.3 Preliminaries

Let \( S \) be an AG-groupoid. By an AG-subgroupoid of \( S \), we means a non-empty subset \( A \) of \( S \) such that \( A^2 \subseteq A \). A non-empty subset \( A \) of an AG-groupoid \( S \) is called a left (right) ideal of \( S \) if \( SA \subseteq A \) (\( AS \subseteq A \)) and it is called a two-sided ideal if it is both left and a right ideal of \( S \). A non-empty subset \( A \) of an AG-groupoid \( S \) is called quasi-ideal of \( S \) if \( SA \setminus AS \subseteq A \). A non-empty subset \( A \) of an AG-groupoid \( S \) is called a quasi-ideal if \( SA \setminus AS \subseteq A \). A non-empty subset \( A \) of an AG-groupoid \( S \) is called a bi-ideal of \( S \) if \( (AS)A \subseteq A \) and an AG-subgroupoid \( A \) of \( S \) is called a bi-ideal if \( (AS)A \subseteq A \). A non-empty subset \( A \) of an AG-groupoid \( S \) is called an interior ideal of \( S \) if \( (SA)S \subseteq A \).

If \( S \) is an AG-groupoid with left identity \( e \), then \( S = S^2 \). It is easy to see that every one sided ideal of \( S \) is quasi-ideal of \( S \). In [31] it is given that \( L[a] = a \cup Sa, I[a] = a \cup Sa \cup aS \) and \( Q[a] = a \cup (aS \cap Sa) \) are principal left ideal, principal two-sided ideal and principal quasi-ideal of \( S \) generated by \( a \). Moreover using (1), left invertive law, paramedial law and medial law we get the following equations

\[ a(Sa) = S(aa) = Sa^2, \quad (Sa)a = (aa)S = a^2S \quad \text{and} \quad (Sa)(Sa) = (SS)(aa) = Sa^2. \]

To obtain some more useful equations we use medial, paramedial laws and (1), we get

\[
(Sa)^2 = (Sa)(Sa) = (SS)a^2 = (aa)(SS) = S((aa)S) \\
= (SS)((aa)S) = (Sa^2)SS = (Sa^2)S.
\]

Therefore

\[ Sa^2 = a^2S = (Sa^2)S. \quad (2) \]

The following definitions are available in [27].

A fuzzy subset \( f \) of an AG-groupoid \( S \) is called a fuzzy AG-subgroupoid of \( S \) if \( f(xy) \geq f(x) \wedge f(y) \) for all \( x, y \in S \). A fuzzy subset \( f \) of an AG-groupoid \( S \) is called a fuzzy left (right) ideal of \( S \) if \( f(xy) \geq f(y) \) \((f(xy) \geq f(x))\) for all \( x, y \in S \). A fuzzy subset \( f \) of an AG-groupoid \( S \) is called a fuzzy two-sided ideal of \( S \) if it is both a fuzzy left and a fuzzy right ideal of \( S \). A fuzzy subset \( f \) of an AG-groupoid \( S \) is called a fuzzy quasi-ideal of \( S \) if \( f \circ C_S \cap C_S \circ f \subseteq f \). A fuzzy subset \( f \) of an AG-groupoid \( S \) is called a fuzzy generalized bi-ideal of \( S \) if \( f((xa)y)) \geq f(x) \wedge f(y) \), for all \( x, a \) and \( y \in S \). A fuzzy AG-subgroupoid \( f \) of an AG-groupoid \( S \) is called a
1. Generalized Fuzzy Ideals of AG-groupoids

A fuzzy bi-ideal of $S$ if $f((xa)y) \geq f(x) \land f(y)$, for all $x$, $a$ and $y \in S$. A fuzzy AG-subgroupoid $f$ of an AG-groupoid $S$ is called a fuzzy interior ideal of $S$ if $f((xa)y) \geq f(a)$, for all $x$, $a$ and $y \in S$. Let $f$ be a fuzzy subset of an AG-groupoid $S$, then $f$ is called a fuzzy prime if $\max\{f(a), f(b)\} \geq f(ab)$, for all $a, b \in S$. $f$ is called a fuzzy semiprime if $f(a) \geq f(a^2)$, for all $a \in S$.

Let $f$ and $g$ be any two fuzzy subsets of an AG-groupoid $S$, then the product $f \circ g$ is defined by,

\[
(f \circ g)(a) = \begin{cases} 
\bigvee_{a=bc} \{f(b) \land g(c) \}, & \text{if there exist } b, c \in S, \text{ such that } a = bc. \\
0, & \text{otherwise.}
\end{cases}
\]

The symbols $f \cap g$ and $f \cup g$ will means the following fuzzy subsets of $S$

\[
(f \cap g)(x) = \min\{f(x), g(x)\} = f(x) \land g(x), \text{ for all } x \in S
\]

and

\[
(f \cup g)(x) = \max\{f(x), g(x)\} = f(x) \lor g(x), \text{ for all } x \in S.
\]

Let $f$ be a fuzzy subset of an AG-groupoid $S$ and $t \in (0, 1]$. Then $x_t \in f$ means $f(x) \geq t$, $x_t q f$ means $f(x) + t > 1$, $x_t \alpha \lor \beta f$ means $x_t \alpha f$ or $x_t \beta f$, where $\alpha, \beta$ denotes any one of $\in, q, \in \lor q, \in \land q, x_t \alpha \land \beta f$ means $x_t \alpha f$ and $x_t \beta f$, $x_t \alpha \lor f$ means $x_t \alpha f$ does not holds. Generalizing the concept of $x_t q f$,

Jun [13, 14] defined $x_t q_k f$, where $k \in (0, 1)$, as $f(x) + t + k > 1$. $x_t \in \lor q k f$ if $x_t \in f$ or $x_t q_k f$.

Let $f$ and $g$ be any two fuzzy subsets of an AG-groupoid $S$, then for $k \in (0, 1)$, the product $f \circ_k g$ is defined by,

\[
(f \circ_k g)(a) = \begin{cases} 
\bigvee_{a=bc} \{f(b) \land g(c) \land \frac{1-k}{2} \}, & \text{if there exist } b, c \in S, \text{ such that } a = bc. \\
0, & \text{otherwise.}
\end{cases}
\]

The symbols $f \land g$ and $f \lor g$ will means the following fuzzy subsets of an AG-groupoid $S$.

\[
(f \land g)(x) = \min\{f(x), g(x)\} \text{ for all } x \in S.
\]

\[
(f \lor g)(x) = \max\{f(x), g(x)\} \text{ for all } x \in S.
\]

**Definition 1** A fuzzy subset $f$ of an AG-groupoid $S$ is called fuzzy AG-subgroupoid of $S$ if for all $x, y \in S$ and $k \in (0, 1)$ such that $f(xy) \geq \min\{f(x), f(y), \frac{1-k}{2} \}$.

**Definition 2** A fuzzy subset $f$ of an AG-groupoid $S$ is called fuzzy left (right) ideal of $S$ if for all $x, y \in S$ and $k \in (0, 1)$ such that $f(xy) \geq \min\{f(y), \frac{1-k}{2} \}$ ($f(xy) \geq \min\{f(x), \frac{1-k}{2} \}$).

A fuzzy subset $f$ of an AG-groupoid $S$ is called fuzzy ideal if it is fuzzy left as well as fuzzy right ideal of $S$. 
A fuzzy subset $f$ of an AG-groupoid $S$ is called fuzzy quasi ideal of $S$, if
\[
    f(a) \geq \min\{(f \circ \zeta)(a), (\zeta \circ f)(a), \frac{1-k}{2}\},
\]
where $\zeta$ is the fuzzy subset of $S$ mapping every element of $S$ on 1.

A fuzzy subset $f$ is called a fuzzy generalized bi-ideal of $S$ if $f((xa)y) \geq \min\{f(x), f(y), \frac{1-k}{2}\}$, for all $x, a$ and $y \in S$. A fuzzy AG-subgroupoid $f$ of $S$ is called a fuzzy bi-ideal of $S$ if $f((xa)y) \geq \min\{f(x), f(y), \frac{1-k}{2}\}$, for all $x, a, y \in S$ and $k \in [0, 1)$.

An $(\in, \in \cup \lambda)$-fuzzy subset $f$ of an AG-groupoid $S$ is called prime if for all $a, b \in S$ and $t \in (0, 1]$, it satisfies,
\[
    (ab)_t \in f \quad \text{implies that} \quad a_t \in \gamma_k f \quad \text{or} \quad b_t \in \gamma_k f.
\]

An $(\in, \in \cup \lambda)$-fuzzy ideal $f$ of an AG-groupoid $S$ is prime if for all $a, b \in S$, it satisfies,
\[
    \max\{f(a), f(b)\} \geq \min\{f(ab), \frac{1-k}{2}\}.
\]

Proof. It is straightforward. ■

A fuzzy subset $f$ of an AG-groupoid $S$ is called $(\in, \in \cup \lambda)$-fuzzy semiprime if it satisfies,
\[
    a^2 \in f \quad \text{this implies that} \quad a_t \in \gamma_k f \quad \text{for all} \quad a \in S \quad \text{and} \quad t \in (0, 1].
\]

An $(\in, \in \cup \lambda)$-fuzzy ideal $f$ of an AG-groupoid $S$ is called semiprime if for any $a \in S$ and $k \in [0, 1)$, if it satisfies,
\[
    f(a) \geq \min\{f(a^2), \frac{1-k}{2}\}.
\]

Proof. It is easy. ■

For a fuzzy subset $F$ of an AG-groupoid $M$ and $t \in (0, 1]$, the crisp set $U(F; t) = \{x \in M \; \text{such that} \; F(x) \geq t\}$ is called a level subset of $F$.

A fuzzy subset $F$ of an AG-groupoid $M$ of the form
\[
    F(y) = \begin{cases} 
        t \in (0, 1] & \text{if} \; y = x \\
        0 & \text{if} \; y \neq x
    \end{cases}
\]
is said to be a fuzzy point with support $x$ and value $t$ and is denoted by $x_t$.

A fuzzy subset $F$ of an AG-groupoid $M$ is a fuzzy interior ideal of $M$ if and only if $U(F; t)(\neq \emptyset)$ is an interior ideal of $M$.

A fuzzy subset $F$ of an AG-groupoid $M$ is called an $(\in, \in \cup \lambda)$-fuzzy interior ideal of $M$ if for all $t, r \in (0, 1]$, and $x, y \in M$.
\begin{enumerate}
    \item[(A1)] $x_t \in F$ and $y_r \in F$ implies that $(xy)_{\min\{t, r\}} \in \gamma F$.
    \item[(A2)] $a_t \in F$ implies $((xa)y)_t \in \gamma F$.
\end{enumerate}
1. Generalized Fuzzy Ideals of AG-groupoids

Definition 13 A fuzzy subset \( F \) of an AG-groupoid \( M \) is called an \((\epsilon, \in \mathcal{V} q)\)-fuzzy bi-ideal of \( M \) if for all \( t, r \in (0, 1] \) and \( x, y, z \in M \).

1. \( x_t \in F \) and \( y_r \in F \) implies that \((xy)_{\min\{t, r\}} \in \mathcal{V} q F\).
2. \( x_t \in F \) and \( z_r \in F \) implies \( ((xy)z)_{\min\{t, r\}} \in \mathcal{V} q F\).

Theorem 14 For a fuzzy subset \( F \) of an AG-groupoid \( M \). The conditions \((B1)\) and \((B2)\) of Definition 5, are equivalent to the following,

\begin{align*}
(B3) & \quad (\forall x, y \in M) F(xy) \geq \min\{F(x), F(y), 0.5\} \\
(B4) & \quad (\forall x, y, z \in M) F((xy)z) \geq \min\{F(x), F(y), 0.5\}.
\end{align*}

Proof. It is similar to proof of theorem ??.

Definition 15 A fuzzy subset \( F \) of an AG-groupoid \( M \) is called an \((\epsilon, \in \mathcal{V} q)\)-fuzzy \((1, 2)\) ideal of \( M \) if

1. \( F(xy) \geq \min\{F(x), F(y), 0.5\} \), for all \( x, y \in M \).
2. \( F((xa)yz) \geq \min\{F(x), F(y), F(z), 0.5\} \), for all \( x, a, y, z \in M \).

Example 16 Let \( M = \{1, 2, 3\} \) be a right regular modular groupoid and ‘∗’ be any binary operation defined as follows:

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Let \( F \) be a fuzzy subset of \( M \) such that

\[ F(1) = 0.6, \quad F(2) = 0.3, \quad F(3) = 0.2. \]

Then we can see easily \( F(1 \cdot 3) \geq F(3) \wedge 0.5 \) that is \( F \) is an \((\epsilon, \in \mathcal{V} q)\)-fuzzy left ideal but \( F \) is not an \((\epsilon, \in \mathcal{V} q)\)-fuzzy right ideal.

Definition 17 A fuzzy subset \( f \) is called \((\epsilon, \in \mathcal{V} q_{k})\)-fuzzy quasi-ideal of AG-groupoid \( S \), if

\[ f(x) \geq \left\{ (f \circ S)(x) \wedge (S \circ f)(x) \wedge \frac{1 - k}{2} \right\} \text{ for all } x \in S. \]

Now we are going to develop \((\epsilon, \in \mathcal{V} q_{k})\)-fuzzy \((1, 2)\) ideals in AG-groupoids.

Definition 18 Let \( S \) be an AG-groupoid, and \( f \) be an \((\epsilon, \in \mathcal{V} q_{k})\)-fuzzy AG-subgroupoid of \( S \). Then \( f \) is an \((\epsilon, \in \mathcal{V} q_{k})\)-fuzzy \((1, 2)\) ideal of \( S \), if for all \( x, a, y, z \in S \) and \( t, r, s \in (0, 1) \), we have \( x_t \in f \), \( y_r \in f \) and \( z_s \in f \implies ((xa)(yz))(t \wedge r)_{\wedge s} \in \mathcal{V} q_{k} f \).

Theorem 19 Let \( f \) be a non-zero \((\alpha, \beta)\)-fuzzy \((1, 2)\) ideal of \( S \). Then the set \( f_{0} = \{x \in S \mid f(x) > 0\} \) is \((1, 2)\) ideal of \( S \).
Proof. Let \( x, y \in f_0 \subseteq S \), then \( f(x) > 0 \) and \( f(y) > 0 \). Assume that \( f(xy) = 0 \). If \( \alpha \in \{\varepsilon, \in \} \) then \( x_{f(x)} \alpha f \) and \( y_{f(y)} \alpha f \) but \( f(xy) = 0 < f(x) \land f(y) \) and \( f(xy) + \min\{f(x), f(y)\} \leq 0 + 1 = 1 \). So \((xy)_f(x) \land f(y)_f(\beta)f \) for every \( \beta \in \{\varepsilon, q, \in \} \), a contradiction. Note that \( x_{q_f}f \) and \( y_{q_f}f \) but \((xy)_f(x)_f(\beta)f \) for every \( \beta \in \{\varepsilon, q, \in \} \), a contradiction. Hence \( f(xy) > 0 \), that is \( xy \in f_0 \). Thus \( f_0 \) is an AG-subgroupoid of \( S \).

Let \( x, y, z \in f_0 \) and \( a \in S \), then \( f(x) > 0 \), \( f(y) > 0 \) and \( f(z) > 0 \). Assume that \( f((xa)(yz)) = 0 \). If \( \alpha \in \{\varepsilon, \in \} \) then \( x_{f(x)} \alpha f \) and \( z_{f(z)} \alpha f \) but \( f((xa)(yz)) = 0 < \min\{f(x), f(y), f(z)\} \) and \( f((xa)(yz)) + \min\{f(x), f(y), f(z)\} \leq 0 + 1 = 1 \). So \((xa)(yz))_{f(x) \land f(y) \land f(z)} f \) for every \( \beta \in \{\varepsilon, q, \in \} \), a contradiction. Note that \( x_{q_f}f \) and \( z_{q_f}f \) but \((ya)(yz))_{min\{t, r, s\}} f \) for every \( \beta \in \{\varepsilon, q, \in \} \), a contradiction. Hence \( f((xa)(yz)) > 0 \), that is, \((xa)(yz) \in f_0 \). Consequently, \( f_0 \) is an \((1, 2)\) ideal of \( S \).

Theorem 20 For a fuzzy subset \( f \) of an AG-groupoid \( S \), the following are equivalent,

(i) \( f \) is a fuzzy \((1, 2)\) ideal of \( S \)

(ii) \( f \) is an \((\varepsilon, \in)\)-fuzzy \((1, 2)\) ideal.

Proof. (i) \( \implies \) (ii)

Let \( x, y \in S \) and \( t, r \in (0, 1] \) be such that \( x_t, y_r \in f \). Then \( f(x) \geq t \) and \( f(y) \geq r \). Now by definition \( f(xy) \geq \min f(x, f(y)) \geq t \land r \), implies that \( (xy)_f(x)_f(\beta)f \). Now let \( x, a, y, z \in S \) and \( t, r, s \in (0, 1] \) be such that \( x_t, y_r, z_s \in f \). Then \( f(x) \geq t \) \( f(y) \geq r \) and \( f(z) \geq s \). Now by definition \( f((xa)(yz)) = \min f(x) \land f(y) \land f(z) \geq t \land r \land s \), which implies that \((xa)(yz))_{min\{t, r, s\}} f \). Therefore \( f \) is an \((\varepsilon, \in)\)-fuzzy \((1, 2)\) ideal of \( S \).

(ii) \( \implies \) (i)

Let \( x, y \in S \). Since \( x_{f(x)} \in f \) and \( y_{f(y)} \in f \), since \( f \) is an \((\varepsilon, \in)\)-fuzzy \((1, 2)\) ideal, so \((xa)(yz))_{f(x) \land f(y) \land f(z)} f \), it follows that \( f(xy) \geq f(x) \land f(y) \), and let \( x, a, y, z \in S \). Since \( x_{f(x)} \in f \) and \( y_{f(y)} \in f \) and \( z_{f(z)} \in f \) and \( f \) is an \((\varepsilon, \in)\)-fuzzy \((1, 2)\) ideal so \((xa)(yz))_{f(x) \land f(y) \land f(z)} f \), it follows that \( f((xa)(yz)) \geq f(x) \land f(y) \land f(z) \), so \( f \) is a fuzzy \((1, 2)\) ideal of \( S \).

### 1.4 \((\varepsilon, \in \lor q_k)\)-fuzzy Ideals in AG-groupoids

Theorem 21 Let \( A \) be a \((1, 2)\) ideal of \( S \) and let \( f \) be a fuzzy subset of \( S \) such that,

\[
f(x) = \begin{cases} 
\geq \frac{1-k}{2} & \text{if } x \in A \\
0 & \text{otherwise.}
\end{cases}
\]

Then

1. \( f \) is a \((q, \in \lor q_k)\)-fuzzy subsemigroup of \( S \).
2. \( f \) is an \((\varepsilon, \in \lor q_k)\)-fuzzy subsemigroup of \( S \).
1. Generalized Fuzzy Ideals of AG-groupoids

Proof. (1) Let \( x, a, y, z \in S \) and \( t, r, s \in (0, 1] \), be such that \( x_q f, y_q f \) and \( z_q f \). Then \( x, y, z \in A \), \( f(x) + t > 1 \) \( f(y) + r > 1 \) and \( f(z) + s > 1 \). Since \( A \) is an \((1,2)\) ideal of \( S \), we have \((xa)(yz) \in A \) for \( a \in S \). Thus \( f((xa)(yz)) \geq \frac{1-k}{2} \). If \( \min\{t, r, s\} \leq \frac{1-k}{2} \), then \( f((xa)(yz)) \geq \min\{t, r, s\} \) and so \(( (xa)(yz))_{\min\{t, r, s\}} \in f \). If \( \min\{t, r, s\} > \frac{1-k}{2} \), then \( f((xa)(yz)) + \min\{t, r, s\} + k > \frac{1-k}{2} + \frac{1-k}{2} + k = 1 \) and so \(( (xa)(yz))_{\min\{t, r, s\}} \in \vee q_k f \). Hence \( f \) is a \((q_i \in \vee q)-fuzzy \) \((1,2)\) ideal of \( S \).

(2) Let \( x, a, y, z \in S \) and \( t, r, s \in (0,1] \) be such that \( x_i \in f \), \( y_r \in f \), and \( z_s \in f \). Then \( f(x) \geq t \), \( f(y) \geq r \), and \( f(z) \geq s \). Thus \( f(x) \geq \frac{1-k}{2} \) \( f(y) \geq \frac{1-k}{2} \) and \( f(z) \geq \frac{1-k}{2} \), this implies that \( x, y, z \in A \). Since \( A \) is an \((1,2)\) ideal of \( S \), we have \((xa)(yz) \in A \). Thus \( f((xa)(yz)) \geq \frac{1-k}{2} \). If \( \min\{t, r, s\} \leq \frac{1-k}{2} \), then \( f((xa)(yz)) \geq \min\{t, r, s\} \) and so \(( (xa)(yz))_{\min\{t, r, s\}} \in f \). If \( \min\{t, r, s\} > \frac{1-k}{2} \), then \( f(xy) + \min\{t, r, s\} + k > \frac{1-k}{2} + \frac{1-k}{2} + k = 1 \) and so \(( (xa)(yz))_{\min\{t, r, s\}} \in \vee q_k f \). Hence \( f \) is a \((\in, \in \vee q)-fuzzy \) \((1,2)\) ideal of \( S \).

Lemma 22 Let \( f \) be a fuzzy subset of AG-groupoid \( S \), then \( f \) is an \((\in, \in \vee q_k)-fuzzy \) \((1,2)\) ideal of \( S \) if and only if
\[
\begin{align*}
(1) & \ f(x) \geq \min\{f(x), f(y), \frac{1-k}{2}\}, \text{ for all } x, y \in S, \\
(2) & \ f((xa)(yz)) \geq \min\{f(x), f(y), f(z), \frac{1-k}{2}\}, \text{ for all } x, y, z \in S.
\end{align*}
\]

Proof. Let \( f \) be \((\in, \in \vee q_k)-fuzzy \) \((1,2)\) ideal of \( S \), then \( f(xy) \geq \min\{f(x), f(y), \frac{1-k}{2}\} \), for all \( x, y \in S \) is automatically satisfied. On contrary suppose that there exists \( x, a, y, z \in S \) such that \( f((xa)(yz)) < \min\{f(x), f(y), f(z), \frac{1-k}{2}\} \).

Choose \( t \in (0,1] \) such that \( f((xa)(yz)) < t \leq \min\{f(x), f(y), f(z), \frac{1-k}{2}\} \), then \( f((xa)(yz)) + t + k < \frac{1-k}{2} + \frac{1-k}{2} + k = 1 \), so \(( (xa)(yz))_{\min\{t, r, s\}} \in \vee q_k f \), which is contradiction. Hence \( f((xa)(yz)) \geq \min\{f(x), f(y), f(z), \frac{1-k}{2}\} \), for all \( x, a, y, z \in S \).

Conversely suppose that \((1) \) and \((2) \) holds. From \((1) \) and it is clear that \( f \) is \((\in, \in \vee q_k)-fuzzy \) AG-subgroupoid of \( S \). Now let \( x_i \in f \), \( y_r \in f \) and \( z_s \in f \) for \( t, r, s \in (0,1] \), then \( f(x) \geq t \), \( f(y) \geq r \) and \( f(z) \geq s \). Now \( f((xa)(yz)) \geq \min\{f(x), f(y), f(z), \frac{1-k}{2}\} \), \( \geq \min\{t, r, s, \frac{1-k}{2}\} \). If \( \min\{t, r, s\} > \frac{1-k}{2} \), then \( f((xa)(yz)) \geq \frac{1-k}{2} \). So \( f((xa)(yz)) + t + k > \frac{1-k}{2} + \frac{1-k}{2} + k = 1 \), which implies that \(( (xa)(yz))_{\min\{t, r, s\}} \in \vee q_k f \). If \( \min\{t, r, s\} \leq \frac{1-k}{2} \), then \( f((xa)(yz)) \geq \min\{t, r, s\} \). So \(( (xa)(yz))_{\min\{t, r, s\}} \in f \). Thus \(( (xa)(yz))_{\min\{t, r, s\}} \in \vee q_k f \). Therefore \( f \) is an \((\in, \in \vee q_k)-fuzzy \) \((1,2)\)-ideal of \( S \).

Proposition 23 Let \( f \) be an \((\in, \in \vee q_k)-fuzzy \) \((1,2)\)-ideal of \( S \), then \( f_k \) is fuzzy \((1,2)\)-ideal of \( S \).

Proof. Let \( f \) be an \((\in, \in \vee q_k)-fuzzy \) \((1,2)\)-ideal of \( S \), then for all \( x, a, y, z \in S \), we have \( f((xa)(yz)) \geq f(x) \wedge f(y) \wedge f(z) \wedge \frac{1-k}{2} \). This implies that \( f((xa)(yz)) \wedge \frac{1-k}{2} \geq f(x) \wedge f(y) \wedge f(z) \wedge \frac{1-k}{2} \). So \( f_k((xa)(yz)) \geq f_k(x) \wedge f_k(y) \wedge f_k(z) \). Thus \( f_k \) is fuzzy \((1,2)\)-ideal of \( S \).
Lemma 24 For a fuzzy subset $f$ of an AG-groupoid $S$, the following conditions are true.

(i) $f_k$ is a fuzzy left (right) ideal of $S$ if and only if $S \circ_k f \leq f_k$ ($f \circ_k S \leq f_k$).
(ii) $f_k$ is a fuzzy AG-subgroupoid of $S$ if and only if $f \circ_k f \leq f_k$.

Lemma 25 Let $A$ be a non-empty subset of an AG-groupoid $S$. Then the following properties holds.

(i) $A$ is an AG-subgroupoid of $S$ if and only if $(C_A)_k$ is an $(\varepsilon, \varepsilon \lor q_k)$-fuzzy AG-subgroupoid of $S$.
(ii) $A$ is a left (right, two-sided) ideal of $S$ if and only if $C_A$ is an $(\varepsilon, \varepsilon \lor q_k)$-fuzzy left (right, two-sided) ideal of $S$.

Lemma 26 For any non-empty subsets $A$ and $B$ of an AG-groupoid $S$, the following conditions are true.

(i) $C_A \circ_k C_B = (C_{AB})_k$
(ii) $C_A \land_k C_B = (C_{A \land B})_k$

Lemma 27 Let $f$ and $g$ be fuzzy subset of AG-groupoid $S$. Then the following holds,

(i) $(f \land_k g) = (f \land g)_k$
(ii) $(f \lor_k g) = (f \lor g)_k$
(iii) $(f \circ_k g) = (f \circ g)_k$
(iv) $f_k(x) = f(x) \land \frac{1-k}{2}$.

Proof. It is easy. ■

Lemma 28 Let $A$ and $B$ be non-empty subsets of a AG-groupoid $S$, then the following holds.

(i) $(C_A \land_k C_B) = (C_{A \land B})_k$
(ii) $(C_A \lor_k C_B) = (C_{A \lor B})_k$
(iii) $(C_A \circ_k C_B) = (C_{AB})_k$.

Definition 29 Let $f$ and $g$ be any two fuzzy subsets of an AG-groupoid $S$, then the product $f \circ_k g$ is defined by,

$$(f \circ_k g)(a) = \begin{cases} \bigvee_{a=bc} \{f(b) \land g(c) \land \frac{1-k}{2} \}, & \text{if there exists } b, c \in S, \text{ such that } a = bc. \\ 0, & \text{otherwise.} \end{cases}$$

Example 30 Let $S = \{a, b, c, d, e\}$ be an AG-groupoid with left identity $d$ with the following multiplication table.
1. Generalized Fuzzy Ideals of AG-groupoids

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Note that $S$ is non-commutative as $ed \neq de$ and also $S$ is non-associative because $(cc)d \neq c(cd)$.

Clearly $S$ is right regular because, $a = a^2d$, $b = b^2c$, $c = c^2c$, $d = d^2d$, $e = e^2e$.

Define a fuzzy subset $f$ of $S$ as follows: $f(a) = 1$ and $f(b) = f(c) = f(d) = f(e) = 0$, then clearly $f$ is a $(\varepsilon, \varepsilon \in \mathbb{Q}_k)$-fuzzy two-sided ideal of $S$.

It is easy to observe that every $(\varepsilon, \varepsilon \in \mathbb{Q}_k)$-fuzzy two sided ideal of an AG-groupoid $S$ is a $(\varepsilon, \varepsilon \in \mathbb{Q}_k)$-fuzzy AG-subgroupoid of $S$ but the converse is not true in general which is discussed in the following.

Let us define a fuzzy subset $f$ of $S$ as follows: $f(a) = 1$, $f(b) = 0$ and $f(c) = f(d) = f(e) = 0.5$, then $f$ is a $(\varepsilon, \varepsilon \in \mathbb{Q}_k)$-fuzzy AG-subgroupoid of $S$ but it is not a $(\varepsilon, \varepsilon \in \mathbb{Q}_k)$-fuzzy two sided ideal of $S$ because $f(db) \notin f(d) \wedge \frac{1-k}{2}$ or $f(bd) \notin f(d) \wedge \frac{1-k}{2}$.

**Definition 31** An element $a$ of an AG-groupoid $S$ is called a right regular if there exists $x \in S$ such that $a = a^2x$ and $S$ is called right regular if every element of $S$ is right regular.

An AG-groupoid $S$ considered in Example 30 is right regular because, $a = a^2d$, $b = b^2c$, $c = c^2c$, $d = d^2d$, $e = e^2e$.

**Example 32** Let $S = \{a, b, c, d, e\}$ be a right regular AG-groupoid with left identity $c$ in the following multiplication table.

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**Theorem 33** Let $S$ be an AG-groupoid with left identity and let $f$ be any fuzzy subset of $S$, then $S$ is right regular if $f_k(x) = f_k(x^2)$ holds for all $x$ in $S$.

**Proof.** Assume that $S$ is an AG-groupoid with left identity. Clearly $x^2S$ is a subset of $S$ and therefore its characteristic function $C_{x^2S}$ is a fuzzy subset of
1. Generalized Fuzzy Ideals of AG-groupoids

Let $x \in S$. Now by given assumption $(C_{x \ast S})_k(x^2) = (C_{x \ast S})_k(x)$ holds for all $x \in S$. As $x^2 \in x^2S$ therefore $(C_{x \ast S})_k(x^2) = \frac{1-k}{2} \Rightarrow (C_{x \ast S})_k(x) = \frac{1-k}{2}$ which implies that $x \in x^2S$. Thus $S$ is right regular.

The converse is not true in general. For this, let us consider a right regular AG-groupoid $S$ in Example 32. Define a fuzzy subset $f$ of $S$ as follows:

$f(a) = 0.6$, $f(b) = 0$, and $f(c) = f(d) = f(e) = 0.9$, then it is easy to see that $f_k(a) \neq f_k(a^2)$ for $a \in S$.

Lemma 34 A fuzzy subset $f$ of a right regular AG-groupoid $S$ is an $(\bar{\vee}_k)-$fuzzy left ideal of $S$ if and only if it is an $(\bar{\vee}_k)$-fuzzy right ideal of $S$.

Proof. Let $S$ be a right regular AG-groupoid and let $a \in S$, then there exists $x \in S$ such that $a = a^2x$. Let $f$ be a $(\bar{\vee}_k)$-fuzzy left ideal of $S$, then by using (1), we have

$f(ab) = f(((aa)x)b) = f(((xa)a)b) = f((ba)(xa)) \geq \left\{ f(xa) \wedge \frac{1-k}{2} \right\}$

$\geq \left\{ f(a) \wedge \frac{1-k}{2} \wedge \frac{1-k}{2} \right\} = f(a) \wedge \frac{1-k}{2}$.

Similarly we can show that every $(\bar{\vee}_k)$-fuzzy right ideal of $S$ is an $(\bar{\vee}_k)$-fuzzy left ideal of $S$.

Example 35 Let us consider an AG-groupoid $S = \{a, b, c, d, e\}$ with left identity $d$ in the following Cayley’s table.

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Note that $S$ is not right regular because for $c \in S$ there does not exists $x \in S$ such that $c = c^2x$.

Definition 36 The symbols $f \wedge_k g$ and $f \vee_k g$ will means the following fuzzy subsets of $S$

$(f \wedge_k g)(x) = \min \left\{ f(x), g(x), \frac{1-k}{2} \right\}$, for all $x$ in $S$.

$(f \vee_k g)(x) = \max \left\{ f(x), g(x), \frac{1-k}{2} \right\}$, for all $x$ in $S$. 

1. Generalized Fuzzy Ideals of AG-groupoids

Lemma 37 If $f$ is a $(\in, \in \vee q_k)$-fuzzy interior ideal of a right regular AG-groupoid $S$ with left identity, then $f_k(ab) = f_k(ba)$ holds for all $a, b \in S$.

Proof. Let $f$ be a $(\in, \in \vee q_k)$-fuzzy interior ideal of a right regular AG-groupoid $S$ with left identity and let $a \in S$, then $a = a^2 x$ for some $x \in S$. Then we have

$$f_k(a) = f(a) \wedge \frac{1-k}{2} = f((aa)x) \wedge \frac{1-k}{2}$$

$$= f((xa)a) \wedge \frac{1-k}{2} = f((xa)(aa)x) \wedge \frac{1-k}{2}$$

$$= f((aa)((xa)x)) \wedge \frac{1-k}{2} = f((ea^2)((xa)x)) \wedge \frac{1-k}{2}$$

$$\geq f(a^2) \wedge \frac{1-k}{2} \wedge \frac{1-k}{2} = f_k(a^2) = f(aa) \wedge \frac{1-k}{2}$$

$$= f(a(aa)x) \wedge \frac{1-k}{2} = f((aa)(ax)) \wedge \frac{1-k}{2}$$

$$= f((xa)(aa)) \wedge \frac{1-k}{2} = f((xa)a^2) \wedge \frac{1-k}{2}$$

$$\geq f(a) \wedge \frac{1-k}{2} \wedge \frac{1-k}{2} = f_k(a).$$

Which implies that $f_k(a) = f_k(a^2)$ for all $a \in S$.

Now we have

$$f_k(ab) = f(ab) \wedge \frac{1-k}{2} = f((ab)^2) \wedge \frac{1-k}{2}$$

$$= f((ab)(ab)) \wedge \frac{1-k}{2} = f((ba)(ba)) \wedge \frac{1-k}{2}$$

$$= f((e(ba))(ba)) \wedge \frac{1-k}{2} \geq f(ba) \wedge \frac{1-k}{2} \wedge \frac{1-k}{2}$$

$$= f(ba) \wedge \frac{1-k}{2} = f(b(aa)x)) \wedge \frac{1-k}{2}$$

$$= f((aa)(bx)) \wedge \frac{1-k}{2} = f((ab)(ax)) \wedge \frac{1-k}{2}$$

$$= f((e(ab))(ax)) \wedge \frac{1-k}{2} \geq f(ab) \wedge \frac{1-k}{2}$$

$$= f_k(ab).$$

Therefore $f_k(ab) = f_k(ba)$ holds for all $a, b \in S$. ■

The converse is not true in general, for this, let us define a fuzzy subset $f$ of a right regular AG-groupoid $S$ in Example 30 as follows: $f(a) = 0$, $f(b) = 0.2$, $f(c) = 0.6$, $f(d) = 0.4$ and $f(e) = 0.6$, then it is easy to see that $f(ab) = f(ba)$ holds for all $a$ and $b$ in $S$ but $f$ is not a fuzzy interior ideal of $S$ because $f((ab)c) \notin f(b) \wedge \frac{1-k}{2}$.

Theorem 38 Let $S$ be an AG-groupoid with left identity and. Let $f$ be any
1. Generalized Fuzzy Ideals of AG-groupoids

(\varepsilon, \in \vee q_k)-fuzzy interior ideal of S, then \( f_k(ab) = f_k(ba) \) holds for all \( a, b \) in \( S \) if \( S \) right regular.

**Proof.** Assume that \( S \) is a right regular AG-groupoid with left identity and let \( f \) be a fuzzy interior ideal of \( S \), then by using Lemma 37, \( f_k(ab) = f_k(ba) \) holds for all \( a, b \) in \( S \).

The converse is not true in general. For this, let us consider an AG-groupoid \( S \) in Example 35 with left identity \( d \). Let us define a fuzzy subset \( f \) of \( S \) as follows:

\[
\begin{align*}
    f(a) &= 0, \\
    f(b) &= 0, \\
    f(c) &= 0, \\
    f(d) &= 0, \\
    f(e) &= 0.
\end{align*}
\]

Then it is easy to see that \( f \) is an \((\varepsilon, \in \vee q_k)\)-fuzzy interior ideal of \( S \) such that \( f_k(ab) = f_k(ba) \) holds for all \( a, b \) in \( S \) but \( S \) is not right regular.

Note that \( S \) itself is a fuzzy subset such that \( S(x) = 1 \) for all \( x \in S \).

**Lemma 39** For any fuzzy subset \( f \) of a right regular AG-groupoid \( S \), \( S \circ_k f = f_k \).

**Proof.** It is simple. ■

Note that for any two fuzzy subsets \( f \) and \( g \) of \( S \), \( f \subseteq g \) means that \( f(x) \leq g(x) \) for all \( x \) in \( S \).

**Lemma 40** In a right regular AG-groupoid \( S \), \( f \circ_k S = f_k \) and \( S \circ_k f = f_k \) holds for every \((\varepsilon, \in \vee q_k)\)-fuzzy two-sided ideal \( f \) of \( S \).

**Proof.** Let \( S \) be a right regular AG-groupoid. Now for every \( a \in S \) there exists \( x \in S \) such that \( a = ax^2a \). Then by using (1), we have \( a = (aa)x = (xa)a \), therefore

\[
\begin{align*}
    (f \circ_k 1)(a) &= (f \circ 1)(a) \wedge \frac{1-k}{2} = \bigvee_{a=(xa)a} \{f(xa) \wedge S(a)\} \wedge \frac{1-k}{2} \\
    &\geq f(xa) \wedge 1(a) \wedge \frac{1-k}{2} = f(a) \wedge 1 \wedge \frac{1-k}{2} \\
    &\geq f(a) \wedge \frac{1-k}{2} = f_k(a).
\end{align*}
\]

It is easy to observe from Lemma 39 that \( S \circ_k f = f_k \) holds for every fuzzy two-sided ideal \( f \) of \( S \).

**Lemma 41** In a right regular AG-groupoid \( S \), \( S \circ S = S \).

**Proof.** It is simple. ■

**Theorem 42** In a right regular AG-groupoid \( S \) with left identity, the following statements are equivalent.

(i) \( f \) is an \((\varepsilon, \in \vee q_k)\)-fuzzy two-sided ideal of \( S \).

(ii) \( f \) is an \((\varepsilon, \in \vee q_k)\)-fuzzy bi-ideal of \( S \).

**Proof.** (i) \( \Rightarrow \) (ii) is simple.
(ii) \implies (i): Let S be a right regular AG-groupoid with left identity, then for \( b \in S \) there exists \( y \in S \) such that \( b = b^2y \) and let \( f \) be a \((\in, \in \And q_k)\)-fuzzy bi-ideal of \( S \), then we have

\[
\begin{align*}
 f(ab) &= f(a(bb)y) = f((bb)(ay)) = f(((ay)b)b) = f(((ay)((bb)y)b) \\
 &= f(((ay)((yb)b)b) = f(((a(yb))(yb)b) = f(((by)((yb)a)b) \\
 &= f(((yb)((by)a)b) = f(((a(by))(by)b) = f((b((a(by))y)b) \\
 &\geq f(b) \wedge f(b) \wedge \frac{1-k}{2} = f(b) \wedge \frac{1-k}{2}.
\end{align*}
\]

Which shows that \( f \) is a \((\in, \in \And q_k)\)-fuzzy left ideal of \( S \). Now we have

\[
\begin{align*}
 f(ab) &= f(((aa)x)b) = f(((xa)a)b) = f((ba)(xa)) = f((ax)(ab)) \\
 &= f(((ab)x)a) = f(((aa)(x)x)a) = f(((xb)(aa)x)a) \\
 &= f(((aa)((xb)x)a) = f(((a(xb))(ax)a) \\
 &= f((a((a xb)x)a) \geq f(a) \wedge f(a) \wedge \frac{1-k}{2} \\
 &= f(a) \wedge \frac{1-k}{2}.
\end{align*}
\]

Which shows that \( f \) is a \((\in, \in \And q_k)\)-fuzzy right ideal of \( S \) and therefore \( f \) is a \((\in, \in \And q_k)\)-fuzzy two-sided ideal of \( S \). \( \blacksquare \)

**Theorem 43** In a right regular LA-semigroup \( S \) with left identity, the following statements are equivalent.

(i) \( f \) is an \((\in, \in \And q_k)\)-fuzzy \((1,2)\)-ideal of \( S \).

(ii) \( f \) is an \((\in, \in \And q_k)\)-fuzzy two-sided ideal of \( S \).

**Proof.** (i) \implies (ii): Assume that \( f \) is an \((\in, \in \And q_k)\)-fuzzy \((1,2)\)-ideal of a right regular LA-semigroup \( S \) with left identity and let \( a \in S \), then there exists \( y \in S \) such that \( a = a^2y \). Now we have

\[
\begin{align*}
 f(xa) &= f(x((aa)y)) = f((aa)(xy)) = f(((aa)y)a)(xy) \\
 &= f(((ay)(aa))(xy)) = f(((aa)(ya))(xy)) \\
 &= f(((xy)(ya))(aa)) = f(((ay)(yx))a^2) \\
 &= f(((aa)(y)(yx))a^2) = f(((yy)(aa))(yx)a^2) \\
 &= f(((aa)(y)^2)(yx)a^2) = f(((yx)(y)^2)(aa)a^2) \\
 &= f((a((yx)(y)^2)a))(aa) \geq f(a) \wedge f(a) \wedge f(a) \wedge \frac{1-k}{2} \\
 &= f(a) \wedge \frac{1-k}{2}.
\end{align*}
\]

This shows that \( f \) is an \((\in, \in \And q_k)\)-fuzzy left ideal of \( S \) and \( f \) is an \((\in, \in \And q_k)\)-fuzzy two-sided ideal of \( S \).

(ii) \implies (i) is obvious. \( \blacksquare \)
Lemma 44. In a right regular AG-groupoid $S$ with left identity, the following statements are equivalent.

(i) $f$ is an $(\varepsilon, \in \vee q_k)$-fuzzy bi-ideal of $S$.
(ii) $f$ is an $(\varepsilon, \in \vee q_k)$-fuzzy generalized bi-ideal of $S$.

Proof. (i) $\implies$ (ii) is obvious.

(ii) $\implies$ (i) : Let $S$ be a right regular AG-groupoid with left identity and let $a \in S$, then there exists $x \in S$ such that $a = a^2 x$. Let $f$ be a $(\varepsilon, \in \vee q_k)$-fuzzy generalized bi-ideal of $S$, then

$$f(ab) = f(((aa)x)b) = f(((aa)(ex))b) = f(((xe)(aa))b)$$
$$= f((a(xe)a))b \geq f(a) \wedge f(b) \wedge \frac{1-k}{2}.$$ 

Which shows that $f$ is an $(\varepsilon, \in \vee q_k)$-fuzzy bi-ideal of $S$.  

Lemma 45. Every $(\varepsilon, \in \vee q_k)$-fuzzy right ideal of an AG-groupoid $S$ with left identity becomes an $(\varepsilon, \in \vee q_k)$-fuzzy left ideal of $S$.

Proof. Let $S$ be an AG-groupoid with left identity and let $f$ be an $(\varepsilon, \in \vee q_k)$-fuzzy right ideal. Now

$$f(ab) = f((ea)b) = f((ba)e) \geq f(b) \wedge \frac{1-k}{2}.$$ 

Therefore $f$ is an $(\varepsilon, \in \vee q_k)$-fuzzy left ideal of $S$.  

The converse is not true in general. For this, let us define a fuzzy subset $f$ of an AG-groupoid $S$ in Example 35 as follows: $f(a) = 0.8$, $f(b) = 0.5$, $f(c) = 0$, $f(d) = 0.3$ and $f(e) = 0.6$, then it is easy to observe that $f$ is an $(\varepsilon, \in \vee q_k)$-fuzzy left ideal of $S$ but it is not an $(\varepsilon, \in \vee q_k)$-fuzzy right ideal of $S$, because $f(bd) \not\geq f(b) \wedge \frac{1-k}{2}$.

Theorem 46. In a right regular AG-groupoid $S$ with left identity, the following statements are equivalent.

(i) $f$ is an $(\varepsilon, \in \vee q_k)$-fuzzy interior ideal of $S$.
(ii) $f$ is an $(\varepsilon, \in \vee q_k)$-fuzzy bi-ideal of $S$.

Proof. Let $S$ be a right regular AG-groupoid with left identity then for any $a, b, x$ and $y \in S$ there exists $a^*, b^*, x$ and $y \in S$ such that $a = a^2 a^*$, $b = b^2 b^*$, $x = x^2 x$ and $y = y^2 y$.

(i) $\implies$ (ii) : Let $f$ be a $(\varepsilon, \in \vee q_k)$-fuzzy interior ideal of $S$, then

$$f((xa)y) = f(((xx)x^* a)y) = f(((x^* x)x)a)y) = f(((ax)(x^* x)y)$$
$$= f(((xx^* )(xa)y) = f(((xa)^*(x)y \geq f(x) \wedge \frac{1-k}{2}.$$ 

Again we have

$$f((xa)y) = f((xa)((yy)y^*)) = f((yy)((xa)y^*))$$
$$= f(((xa)y^*)(y)y) \geq f(y) \wedge \frac{1-k}{2}.$$ 

Which implies that \( f((xa)y) \geq f(x) \land f(y) \land \frac{1-k}{2} \). Now

\[
f(ab) = f(((aa)a^{'})b) = f(((a^{'})a)b) = f((ba)(a^{'})a)) \geq f(a) \land \frac{1-k}{2}
\]

and

\[
f(ab) = f(a((bb)b^{'})) = f((bb)(ab^{'})) \geq f(b) \land \frac{1-k}{2}.
\]

Thus \( f \) is an \((\varepsilon, \varepsilon \lor \varepsilon)\)-fuzzy bi-ideal of \( S \).

(ii) \( \implies \) (i): Let \( f \) be an \((\varepsilon, \varepsilon \lor \varepsilon)\)-fuzzy bi-ideal of \( S \), then

\[
f((xa)y) = f((x(aa)a^{'})y) = f(((aa)(xa^{'})y) = f(((ax)(aa^{'})y)
\]

\[
= f((y(aa^{'}))(ax)) = f((a(ya^{'}))(ax)) = f(((ax)(ya^{'})a)
\]

\[
= f(((a^{'})y)(xa))a = f(((a^{'})y)(aa)(a^{'})a))a
\]

\[
= f(((a^{'})y)((aa)(xa)))a = f(((a^{'}y)((a^{'}x)(aa)))a)
\]

\[
= f(((a^{'})y)(a((a^{'})x)a))a = f((a(a^{'})(a^{'})x)a))(a)
\]

\[
\geq f(a) \land f(a) \land \frac{1-k}{2} = f(a) \land \frac{1-k}{2}.
\]

Which shows that \( f \) is an \((\varepsilon, \varepsilon \lor \varepsilon)\)-fuzzy interior ideal of \( S \). ■

**Theorem 47** In a right regular AG-groupoid \( S \) with left identity, the following statements are equivalent.

(i) \( f \) is an \((\varepsilon, \varepsilon \lor \varepsilon)\)-fuzzy bi-ideal of \( S \).

(ii) \( f \) is an \((\varepsilon, \varepsilon \lor \varepsilon)\)-fuzzy \((1, 2)\) ideal of \( S \).

**Proof.** (i) \( \implies \) (ii): Let \( S \) be a right regular AG-groupoid with left identity and let \( x, a, y, z \in S \), then there exists \( x' \in S \) such that \( x = x^2x' \). Let \( f \) be
an \((\varepsilon, \varepsilon \lor q_k)\)-fuzzy bi-ideal of \(S\), then

\[
f((xa)(yz)) = f((zy)(ax)) = f(((ax)y)z) \geq f((ax)y) \land f(z) \land \frac{1-k}{2}
\]
\[
\geq f(ax) \land f(y) \land f(z) \land \frac{1-k}{2} \land \frac{1-k}{2}
\]
\[
= f(ax) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f(a((xx)x')) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f((xx)(ax')) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f(((ax')x)x) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f(((ax')(xx')x) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f((ax')(xx')(ax')) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f((ax')(xx')x) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f(x)((ax')(ax')) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f(x)((ax')(ax')) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
\geq f(x) \land f(y) \land f(z) \land \frac{1-k}{2}
\]
\[
= f(x) \land f(y) \land f(z) \land \frac{1-k}{2}.
\]

Which shows that \(f\) is an \((\varepsilon, \varepsilon \lor q_k)\)-fuzzy \((1, 2)\) ideal of \(S\).

(ii) \(\Rightarrow\) (i): Again let \(S\) be a right regular AG-groupoid with left identity, then for any \(a, b, x\) and \(y \in S\) there exists \(a', b', x\) and \(y' \in S\) such that \(a = a^2a', b = b^2b', x = x^2x\) and \(y = y^2y'\). Let \(f\) be a \((\varepsilon, \varepsilon \lor q_k)\)-fuzzy \((1, 2)\) ideal of \(S\), then

\[
f((xa)y) = f((xa)((yy)y')) = f((yy)((xa)y')) = f((y'(xa))(yy)) = f((x(y'a))(yy))
\]
\[
\geq f(x) \land f(y) \land f(y) \land \frac{1-k}{2} \geq f(x) \land f(y) \land \frac{1-k}{2}.
\]

Now

\[
f(ab) = f(a(bb)b') = f((bb)(ab')) = f((b'a)(bb)) = f(b'(aa)a')(bb)
\]
\[
= f((aa)(b'a'))(bb) = f((aa)((b'a')(bb)) \geq f(a((b'a')(aa))(bb) \land \frac{1-k}{2}
\]
\[
= f(a) \land f(b) \land f(b) \land \frac{1-k}{2} = f(a) \land f(b) \land \frac{1-k}{2}.
\]
1. Generalized Fuzzy Ideals of AG-groupoids

Which shows that \( f \) is an \((\in, \in \vee q_k)\)-fuzzy bi-ideal of \( S \). 

**Theorem 48** In a right regular AG-groupoid \( S \) with left identity, the following statements are equivalent.

(i) \( f \) is an \((\in, \in \vee q_k)\)-fuzzy \((1, 2)\) ideal of \( S \).

(ii) \( f \) is an \((\in, \in \vee q_k)\)-fuzzy interior ideal of \( S \).

**Proof.** (i) \( \implies \) (ii): Let \( S \) be a right regular AG-groupoid with left identity and let \( x, a, y, z \in S \), then there exists \( a' \in S \) such that \( a = a'^2a \). Let \( f \) be a \((\in, \in \vee q_k)\)-fuzzy \((1, 2)\) ideal of \( S \), then

\[
\begin{align*}
  f((xa)(yz)) &= f((x((aa)a'))(yz)) = f(((aa)(xa'))(yz)) = 1
\end{align*}
\]

Which shows that \( f \) is an \((\in, \in \vee q_k)\)-fuzzy bi-ideal of \( S \).

(ii) \( \implies \) (i): Again let \( S \) be a right regular AG-groupoid with left identity and let \( x, a, y, z \in S \), then there exists \( x' \) and \( z \in S \) such that \( x = x'^2x \) and \( z = z^2z \). Now

\[
\begin{align*}
  f((xa)(yz)) &= f((zy)(ax)) \geq f(y) \wedge \frac{1-k}{2}.
\end{align*}
\]

Now

\[
\begin{align*}
  f((xa)(yz)) &= f((((xx)x')a)(yz)) = f(((ax')(xx))(yz)) \\
  &= f((((xx)(x')a)(yz)) = f(((x'a)x)(yz)) \\
  &\geq f(x) \wedge \frac{1-k}{2}.
\end{align*}
\]

Now by using (4), we have

\[
\begin{align*}
  f((xa)(yz)) &= f((xa)(y((zz)z')))) = f((xa)(zz)(yz')) \\
  &= f((zz)((xa)(yz')))) \geq f(z) \wedge \frac{1-k}{2}.
\end{align*}
\]

Thus we get \( f((xa)(yz)) \geq f(x) \wedge f(y) \wedge f(z) \wedge \frac{1-k}{2} \).
Let \( a \) and \( b \in S \) then there exists \( a' \) and \( b' \in S \) such that \( a = a^2a' \) and \( b = b^2b' \). Now

\[
f(ab) = f(((aa)a')b) = f((ba')(aa)) = f((aa)(a'b)) \geq f(a) \wedge \frac{1-k}{2}
\]

and

\[
f(ab) = f(a((bb)b')) = f((bb)(ab')) \geq f(b) \wedge \frac{1-k}{2}.
\]

Thus \( f \) is an \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy \((1,2)\) ideal of \( S \).

Note that \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy two-sided ideals, \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy bi-ideals, \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy generalized bi-ideals, \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy \((1,2)\) ideals, \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy interior ideals and \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy quasi-ideals coincide in a right regular AG-groupoid with left identity.

**Lemma 49** Let \( S \) be an AG-groupoid with left identity, then the following conditions are equivalent.

(i) \( S \) is right regular.

(ii) \( f \circ_k f = f_k \) for every \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy left (right, two-sided) ideal of \( S \).

**Proof.** (i) \( \Rightarrow \) (ii) : Let \( S \) be an AG-groupoid with left identity and let (i) holds. Let \( a \in S \), then since \( S \) is right regular so by using (1), \( a = (aa)x = (xa)a \). Let \( f \) be an \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy left ideal of \( S \), then clearly \( f \circ_k f \leq f_k \) and also we have

\[
(f \circ_k f)(a) = \bigvee_{a=(xa)a} \{ f(xa) \wedge f(a) \wedge \frac{1-k}{2} \}
\]

\[
\geq f(a) \wedge f(a) \wedge \frac{1-k}{2} \wedge \frac{1-k}{2} = f(a) \wedge \frac{1-k}{2} = f_k(a).
\]

Thus \( f \circ_k f = f_k \).

(ii) \( \Rightarrow \) (i) : Assume that \( f \circ_k f = f_k \) for \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy left ideal of \( S \). Since \( Sa \) is a left ideal of \( S \), therefore, \((C_{Sa})_k \) is an \((\varepsilon, \varepsilon \cup \eta)\)-fuzzy left ideal of \( S \). Since \( a \in Sa \) therefore \((C_{Sa})_k(a) = \frac{1-k}{2} \). Now by using the given assumption and we get

\[
(C_{Sa})_k \circ_k (C_{Sa})_k = (C_{Sa})_k \text{ and } (C_{Sa})_k \circ_k (C_{Sa})_k = (C_{(Sa)^2})_k
\]

Thus we have \((C_{(Sa)^2})_k(a) = (C_{Sa})_k(a) = \frac{1-k}{2} \), which implies that \( a \in (Sa)^2 \). Now

\[
a \in (Sa)^2 = (Sa)(Sa) = (aS)(aS) = a^2S.
\]

This shows that \( S \) is right regular. ■

Note that if an AG-groupoid has a left identity then \( S \circ S = S \).
Theorem 50 For an AG-groupoid $S$ with left identity, then the following conditions are equivalent.

(i) $S$ is right regular.
(ii) $f_k = (S \circ f) \circ_k (S \circ f)$, where $f$ is any $(\epsilon, \in \vee q_k)$-fuzzy left (right, two-sided) ideal of $S$.

Proof. $(i) \implies (ii)$: Let $S$ be a right regular AG-groupoid and let $f$ be any $(\epsilon, \in \vee q_k)$-fuzzy left ideal of $S$, then clearly $S \circ f$ is also an $(\epsilon, \in \vee q_k)$-fuzzy left ideal of $S$. Now

$$(S \circ f) \circ_k (S \circ f) (a) = (S \circ f)(a) \wedge \frac{1-k}{2} \wedge \frac{1-k}{2} \leq f(a) \wedge \frac{1-k}{2} = f_k(a).$$

Now let $a \in S$, since $S$ is right regular therefore there exists $x \in S$ such that $a = a^2 x$ and we have

$$a = (aa)x = (xa)a = (xa)((aa)x) = (xa)((xa)a).$$

Therefore

$$(S \circ f) \circ_k (S \circ f) (a) = \bigvee_{a=(xa)((xa)a)} \{(S \circ f)(xa) \wedge (S \circ f)((xa)a) \wedge \frac{1-k}{2} \}$$

$$\geq (S \circ f)(xa) \wedge (S \circ f)((xa)a) \wedge \frac{1-k}{2}$$

$$= \bigvee_{xa=xa} \{S(x) \wedge f(a)\} \wedge \bigvee_{(xa)a=(xa)a} \{S(xa) \wedge f(a)\} \wedge \frac{1-k}{2}$$

$$\geq S(x) \wedge f(a) \wedge S(xa) \wedge f(a) \wedge \frac{1-k}{2} = f(a) \wedge \frac{1-k}{2}$$

$$= f_k(a).$$

Thus we get the required $f_k = (S \circ f) \circ_k (S \circ f)$.

$(ii) \implies (i)$: Let $f_k = (S \circ f) \circ_k (S \circ f)$ holds for any $(\epsilon, \in \vee q_k)$-fuzzy left ideal $f$ of $S$, then by given assumption, we have

$$f_k(a) = ((S \circ f) \circ_k (S \circ f))(a) \leq (f \circ_k f)(a)$$

$$\leq (S \circ_k f)(a) \leq f_k(a).$$

Thus $S$ is right regular. □

Lemma 51 In a right regular LA-semigroup $S$ with left identity, the following statements are equivalent.

(i) $f$ is an $(\epsilon, \in \vee q_k)$-fuzzy quasi ideal of $S$.
(ii) $(f \circ S) \circ_k (S \circ f) = f_k$.

Proof. $(i) \implies (ii)$ is easy.

$(ii) \implies (i)$ is obvious. □
Theorem 52 Let $S$ be a right regular AG-groupoid with left identity, then the following statements are equivalent.

(i) $f$ is an $(\in, \in \vee q_k)$-fuzzy left ideal of $S$.
(ii) $f$ is an $(\in, \in \vee q_k)$-fuzzy right ideal of $S$.
(iii) $f$ is an $(\in, \in \vee q_k)$-fuzzy two-sided ideal of $S$.
(iv) $f$ is an $(\in, \in \vee q_k)$-fuzzy bi-ideal of $S$.
(v) $f$ is an $(\in, \in \vee q_k)$-fuzzy generalized bi-ideal of $S$.
(vi) $f$ is an $(\in, \in \vee q_k)$-fuzzy $(1, 2)$ ideal of $S$.
(vii) $f$ is an $(\in, \in \vee q_k)$-fuzzy interior ideal of $S$.
(viii) $f$ is an $(\in, \in \vee q_k)$-fuzzy quasi ideal of $S$.
(ix) $f \circ_k S = f_k$ and $S \circ_k f = f_k$.

Proof. (i) $\implies$ (ix) : Let $f$ be an $(\in, \in \vee q_k)$-fuzzy left ideal of a right regular AG-groupoid $S$. Let $a \in S$ then there exists $a' \in S$ such that $a = a^2a'$. Now

$$a = (aa)a' = (a'a)a \quad \text{and} \quad a = (aa)a' = (aa)(ea') = (a'e)(aa).$$

Therefore

$$(f \circ_k S)(a) = \bigvee_{a=(a'a)a} \left\{ f(a'a) \land S(a) \land \frac{1-k}{2} \right\} \geq \left\{ f(a'a) \land 1 \land \frac{1-k}{2} \right\}$$

and

$$(S \circ_k f)(a) = \bigvee_{a=(a'e)(aa)} \left\{ S(a'e) \land f(aa) \land \frac{1-k}{2} \right\} \geq \left\{ 1 \land f(aa) \land \frac{1-k}{2} \right\}$$

Now we get the required $f \circ_k S = f_k$ and $S \circ_k f = f_k$.

(ix) $\implies$ (viii) is obvious.

(viii) $\implies$ (vii) : Let $f$ be an $(\in, \in \vee q_k)$-fuzzy quasi ideal of a right regular AG-groupoid $S$. Now for $a \in S$ there exists $a' \in S$ such that $a = a^2a'$ and therefore by using (3) and (4), we have

$$(xa)y = (xa)(ey) = (ye)(ax) = a((ye)x)$$

and

$$(xa)y = (x(aa)a')y = ((aa)(xa'))y = ((a'x)(aa))y = (a((a'x)a))y = (y((a'x)a))a.$$
1. Generalized Fuzzy Ideals of AG-groupoids

Now
\[(f \circ S)((xa)y) = \bigvee_{(xa)y=a((ye)x)} \{f(a) \wedge S((ye)x)\} \geq f(a)\]

and
\[(S \circ f)((xa)y) = \bigvee_{(xa)y=(y(a'x)a)} \{S(y((a'x)a)) \wedge f(a)\} \geq f(a).\]

Which implies that \(f_k((xa)y) \geq f(a) \wedge \frac{1-k}{2} \implies f((xa)y) \geq f(a) \wedge \frac{1-k}{2}.\)

Thus \(f\) is an \((\varepsilon, \in \vee q_k)\)-fuzzy interior ideal of \(S.\)

\((vii) \implies (vi)\) is followed by Theorem 48.

\((vi) \implies (v)\) is followed by Theorem 47.

\((v) \implies (iv)\) is followed by Lemma 44.

\((iv) \implies (iii)\) is followed by Lemma 42.

\((iii) \implies (ii)\) and \((ii) \implies (i)\) are simple consequences of Lemma 34.

**Theorem 53** In a right regular AG-groupoid \(S\) with left identity, the following statements are equivalent.

\((i)\) \(f\) is an \((\varepsilon, \in \vee q_k)\)-fuzzy bi-(generalized bi-) ideal of \(S.
\((ii)\) \((f \circ k) S \circ k f = f_k\) and \(f \circ k f = f_k.\)

**Proof.** \((i) \implies (ii) :\) Let \(f\) be an \((\varepsilon, \in \vee q_k)\)-fuzzy bi-ideal of a right regular AG-groupoid \(S\) with left identity and let \(a \in S\) then there exists \(x \in S\) such that \(a = a^2 x.\) Now by using (1), (4) and (3), we have
\[
a = (aa)x = (xa)a = (x((aa)x))a = ((aa)(xx))a = ((aa)x)a = (x(aa)x)a = (x(aa)(xx))a = (((aa)(xx))a)a = (((aa)(xx)a)x)a = ((a^2a)a)x a.
\]

Therefore
\[
((f \circ k) S)(a) = \bigvee_{a=((a^2a)a)x a} \{f((a^2a)a)x a \wedge f(a) \wedge \frac{1-k}{2}\}
\]

\[
\geq (f \circ k) S(((a^2a)a)x a) \wedge f(a) \wedge \frac{1-k}{2}
\]

\[
= \bigvee_{a=(a^2a)x=(a^2a)x a} \left\{f((a^2a)a) \wedge S(x) \wedge \frac{1-k}{2}\right\} \wedge f(a) \wedge \frac{1-k}{2}
\]

\[
\geq f((a^2a)a) \wedge 1 \wedge f(a) \wedge \frac{1-k}{2} \geq \left\{f(a) \wedge f(a) \wedge \frac{1-k}{2}\right\} \wedge f(a) \wedge \frac{1-k}{2}
\]

\[
= f(a) \wedge \frac{1-k}{2} = f_k(a).
\]

Now
\[
a = (aa)x = (xa)a = (x((aa)x))a = ((aa)(xx))a = ((xx)(aa))a = (a^2a)a.
\]
Therefore

\[(f \circ_k S) \circ_k f)(a) = \bigvee_{a=(a(x^2)a)} \left\{ (f \circ_k S)((a(x^2)a)) \wedge f(a) \wedge \frac{1-k}{2} \right\} \]

\[= \bigvee_{a=(a(x^2)a)} \left( \bigvee_{a(x^2)a=a(x^2)a} \left\{ f(a) \wedge S(a^2)a \wedge \frac{1-k}{2} \right\} \wedge f(a) \wedge \frac{1-k}{2} \right) \]

\[= \bigvee_{a=(a(x^2)a)} \left( \bigvee_{a(x^2)a=a(x^2)a} \{ f(a) \wedge 1 \} \wedge f(a) \wedge \frac{1-k}{2} \right) \]

\[= \bigvee_{a=(a(x^2)a)} \left\{ f(a) \wedge f(a) \wedge \frac{1-k}{2} \right\} \wedge \frac{1-k}{2} \]

\[\leq \bigvee_{a=(a(x^2)a)} \{ f((a(x^2)a)a) \} \wedge \frac{1-k}{2} \]

\[= f(a) \wedge \frac{1-k}{2} = f_k(a). \]

Thus \((f \circ_k S) \circ_k f = f_k.\)

Now

\[a = (aa)x = (xa)a = ((aa)x)a = ((aa)(xx))a = ((ax)aa)a \]

\[= (((xx)((aa)x))a)a = (((xx)((xx)a))a)a = ((xx)((aa)(ax))a)a \]

\[= (((xx)((aa)(ax))a)a) = ((aa)((xx)((ax)x))a)a \]

Therefore

\[ (f \circ_k f)(a) = \bigvee_{a=((aa)((xx)(ax)))a} \left\{ f((a((xx)((ax)x))a) \wedge f(a) \wedge \frac{1-k}{2} \right\} \]

\[\geq \left\{ f((a((xx)((ax)x))a) \wedge f(a) \wedge \frac{1-k}{2} \right\} \]

\[\geq f(a) \wedge f(a) \wedge \frac{1-k}{2} = f(a) \wedge \frac{1-k}{2} = f_k(a). \]

Now by using Lemma 24, \(f \circ_k f = f_k.\)

\( (ii) \implies (i) : \) Let \(f\) be a fuzzy subset of a right regular AG-groupoid \(S\),
then
\[ f((xy)z) = ((f \circ k) \circ f)((xy)z) = \bigvee_{(xy)z=(xy)z} \left\{ (f \circ k) S((xy)z) \wedge f(z) \wedge \frac{1-k}{2} \right\} \]
\[ \geq \bigvee_{xy=xy} \left\{ f(x) \wedge S(y) \wedge \frac{1-k}{2} \right\} \wedge f(z) \wedge \frac{1-k}{2} \]
\[ \geq f(x) \wedge 1 \wedge f(z) \wedge \frac{1-k}{2} = f(x) \wedge f(z) \wedge \frac{1-k}{2}. \]

Since \( f \circ f = f_k \), therefore by Lemma 24, \( f \) is a \((\in, \in \vee q_k)\)-fuzzy AG-subgroupoid of \( S \). This shows that \( f \) is an \((\in, \in \vee q_k)\)-fuzzy bi ideal of \( S \).

**Theorem 54** In a right regular AG-groupoid \( S \) with left identity, the following statements are equivalent.

(i) \( f \) is an \((\in, \in \vee q_k)\)-fuzzy interior ideal of \( S \).

(ii) \((S \circ f) \circ f_k \circ S = f_k\).

**Proof.** It is simple. ■

**Theorem 55** In a right regular AG-groupoid \( S \) with left identity, the following statements are equivalent.

(i) \( f \) is an \((\in, \in \vee q_k)\)-fuzzy \((1, 2)\) ideal of \( S \).

(ii) \((f \circ f_k) = f_k \) and \( f \circ f = f_k \).

**Proof.** \((i) \Rightarrow (ii) : \) Let \( f \) be an \((\in, \in \vee q_k)\)-fuzzy \((1, 2)\) ideal of a right regular AG-groupoid \( S \) with left identity and let \( a \in S \) then there exists \( x \in S \) such that \( a = a^2 x \). Now
\[ a = (aa)x = (xa)a = (xa)((aa)x) = (aa)((xa)x) = (a((aa)x))((xa)x) \]
\[ = ((aa)(xa))((xa)x) = (((xa)x)(ax))(aa) = (a((xa):x)(ax))(aa). \]

Therefore
\[ ((f \circ f_k) \circ f)((aa)(xa)x)(ax)) = \bigvee_{a=a((xa)x)(ax)} \left\{ (f \circ f_k) S((aa)\wedge (xa)(x)(aa) \wedge a^1k \wedge (aa) \wedge (1-k) \wedge 2) \right\} \]
\[ \geq \left\{ (f \circ f_k) S((aa)\wedge (xa)(x)(aa) \wedge a^1k \wedge (aa) \wedge (1-k) \wedge 2) \right\}. \]

Now
\[ (f \circ f_k) S((aa)\wedge (xa)(x)(aa) \wedge a^1k \wedge (aa) \wedge (1-k) \wedge 2) \]
\[ = \bigvee_{a=(aa)x)(ax)} \left\{ (f(a) \wedge S((aa)\wedge (xa)(x)(aa) \wedge a^1k \wedge (aa) \wedge (1-k) \wedge 2) \right\} \]
\[ \geq f(a) \wedge S((aa)\wedge (xa)(x)(aa) \wedge a^1k \wedge (aa) \wedge (1-k) \wedge 2) \]
\[ = f_k(a). \]
1. Generalized Fuzzy Ideals of AG-groupoids

and

\[(f \circ_k f)(aa) = \left\{ (f \circ f)(aa) \land \frac{1-k}{2} \right\} = \bigvee_{aa=aa} \left\{ f(a) \land f(a) \land \frac{1-k}{2} \right\},\]

\[\geq f(a) \land \frac{1-k}{2} = f_k(a).\]

Thus we get

\[((f \circ_k S) \circ_k (f \circ_k f))(a) \geq f_k(a).\]

Now

\[a = \begin{array}{c}
(aa)x = ((aa)x)((aa)x)x = ((aa)(((aa)x)x)x = ((aa)(x(aa))x) = (x(aa)(aa)) = x(a(aa)(aa))
\end{array}\]

\[= (a(x(aa)))x = (a(x(aa)))x = (a(x(aa)))x = (a((aa)x))(aa) = (a((aa)x))(aa) = (a((aa)x))(aa).\]

Therefore

\[((f \circ_k S) \circ_k (f \circ_k f))(a) = \bigvee_{a=(a(x((aa)x)))x} \left\{ (f \circ_k S)(a(x((aa)x))) \land (f \circ_k f)(a) \land \frac{1-k}{2} \right\}.\]

Now

\[(f \circ_k S)(a(x((aa)x))) = \bigvee_{a(x((aa)x))=a(x((aa)x))} \left\{ f(a) \land S(x((aa)x)) \land \frac{1-k}{2} \right\} \]

\[= \bigvee_{a(x((aa)x))=a(x((aa)x))} \left\{ f(a) \land \frac{1-k}{2} \right\} \]

and

\[(f \circ_k f)(aa) = \bigvee_{aa=aa} \left\{ f(a) \land f(a) \land \frac{1-k}{2} \right\} = \bigvee_{aa=aa} \left\{ f(a) \land \frac{1-k}{2} \right\}.\]

Therefore

\[(f \circ_k S)(a(x((aa)x))) \land (f \circ_k f)(aa) = \bigvee_{a(x((aa)x))=a(x((aa)x))} \left\{ f(a) \land \frac{1-k}{2} \right\} \land \bigvee_{aa=aa} \left\{ f(a) \land \frac{1-k}{2} \right\}.\]
Thus from above, we get

\[
((f \circ_k S) \circ_k (f \circ_k f))(a) = \bigvee_{a=(a(x((aa)x^3)))}(a) \left\{ \begin{array}{l}
 f(a) \wedge f(a) \\
 \wedge \frac{1-k}{2}
\end{array} \right. \\
= \bigvee_{a=(a(x((aa)x^3)))}(a) \left\{ f(a) \wedge f(a) \wedge \frac{1-k}{2} \right. \\
\leq \bigvee_{a=(a(x((aa)x^3)))}(a) \left\{ f((a(x((aa)x^3))))(aa) \wedge \frac{1-k}{2} \right. \\
= f(a) \wedge \frac{1-k}{2} = f_k(a).
\]

Thus \((f \circ_k S) \circ_k (f \circ_k f) = f_k\).

Now by using (1) and (4), we have

\[
a = (aa)x = (xa)a = (x((aa)x))a = ((aa)(aa)x^3)a = ((a(aa)x)x^2)a \\
= (((aa)(ax))x^2)a = ((x^2(ax))(aa))a = ((ax^3)(aa))a.
\]

Therefore

\[
(f \circ_k f)(a) = (f \circ f)(a) \wedge \frac{1-k}{2} \\
= \bigvee_{a=(ax^3)(aa)} \left\{ f((ax^3)(aa)) \wedge f(a) \right\} \wedge \frac{1-k}{2} \\
\geq \left\{ f((ax^3)(aa)) \wedge f(a) \right\} \wedge \frac{1-k}{2} \\
\geq \left\{ f(a) \wedge \frac{1-k}{2} \right\} \wedge f(a) \wedge \frac{1-k}{2} \\
= f(a) \wedge \frac{1-k}{2} = f_k(a).
\]

Now by using Lemma 24, \(f \circ_k f = f_k\).

(ii) \implies (i): Let \(f\) be a fuzzy subset of a right regular AG-groupoid \(S\). Now since \(f \circ_k f = f_k\) therefore by Lemma 24, \(f\) is a \((\varepsilon, \varepsilon \vee q_k)\)-fuzzy
1. Generalized Fuzzy Ideals of AG-groupoids

AG-subgroupoid of $S$

\[ f((xa)(yz)) = ((f \circ_k S) \circ_k (f \circ_k f))((xa)(yz)) \]
\[ = ((f \circ S) \circ (f \circ f))((xa)(yz)) \land \frac{1-k}{2} \]
\[ = ((f \circ S) \circ f)((xa)(yz)) \land \frac{1-k}{2} \]
\[ = \bigvee_{(xa)(yz)=(xa)(yz)} \{(f \circ S)(xa) \land f(yz)\} \land \frac{1-k}{2} \]
\[ \geq (f \circ S)(xa) \land f(yz) \land \frac{1-k}{2} \]
\[ = \bigvee_{(xa)=(xa)} \{f(x) \land S(a)\} \land f(yz) \land \frac{1-k}{2} \]
\[ \geq f(x) \land 1 \land f(y) \land f(z) \land \frac{1-k}{2} \]
\[ = f(x) \land f(y) \land f(z) \land \frac{1-k}{2}. \]

Thus we get $f((xa)(yz)) \geq f(x) \land f(y) \land f(z) \land \frac{1-k}{2}$ and thus $f$ is an $(e, \in \lor q_k)$-fuzzy $(1, 2)$ ideal of $S$. □

A subset $A$ of an AG-groupoid $S$ is called semiprime if $a^2 \in A$ implies $a \in A$.

The subset $\{a, b\}$ of an AG-groupoid $S$ in Example 30 is semiprime.

A fuzzy subset $f$ of an AG-groupoid $S$ is called a fuzzy semiprime if $f(a) \geq f(a^2)$ for all $a$ in $S$.

**Definition 56** A fuzzy subset $f$ is called an $(e, \in \lor q_k)$-fuzzy semiprime if for all $x \in S$, $t \in (0, 1]$ we have the following condition

\[ x_t^2 \in f \implies x_t \in \lor q_k f. \]

**Lemma 57** Let $f$ be a fuzzy subset of AG-groupoid $S$, then $f$ is an $(e, \in \lor q_k)$-fuzzy semiprime if and only if $f(x) \geq \min\{f(x^2), \frac{1-k}{2}\}$, for all $x \in S$.

**Proof.** It is similar to the proof of Lemma 22. □

Let us define a fuzzy subset $f$ of an AG-groupoid $S$ in Example 35 as follows: $f(a) = 0.2$, $f(b) = 0.5$, $f(c) = 0.6$, $f(d) = 0.1$ and $f(e) = 0.4$, then $f$ is an $(e, \in \lor q_k)$-fuzzy semiprime.

**Lemma 58** For a right regular AG-groupoid $S$, the following holds.

(i) Every $(e, \in \lor q_k)$-fuzzy right ideal of $S$ is an $(e, \in \lor q_k)$-fuzzy semiprime.

(ii) Every $(e, \in \lor q_k)$-fuzzy left ideal of $S$ is an $(e, \in \lor q_k)$-fuzzy semiprime if $S$ has a left identity.
1. Generalized Fuzzy Ideals of AG-groupoids

**Proof.** (i) It is simple. (ii) Let \( f \) be a \( (\varepsilon, \in \forall q_k) \)-fuzzy left ideal of a right regular AG-groupoid \( S \) and let \( a \in S \) then there exists \( x \in S \) such that \( a = a^2x \). Now by using (3), we have

\[
f(a) = f((aa)(ex)) = f((xe)a^2) \geq f(a^2) \wedge \frac{1-k}{2}.
\]

Which shows that \( f \) is an \( (\varepsilon, \in \forall q_k) \)-fuzzy semiprime. ■

**Lemma 59** A right (resp: left and two-sided) ideal \( R \) of an AG-groupoid \( S \) is semiprime if and only if \( (C_R)_k \) are \( (\varepsilon, \in \forall q_k) \)-fuzzy semiprime.

**Proof.** Let \( R \) be any right ideal of an AG-groupoid \( S \), then by Lemma 25, \( (C_R)_k \) is a \( (\varepsilon, \in \forall q_k) \)-fuzzy right ideal of \( S \). Now let \( a \in S \) then by given assumption \( (C_R)_k(a) \geq (C_R)_k(a^2) \). Let \( a^2 \in R \), then \( (C_R)_k(a^2) = \frac{1-k}{2} \implies (C_R)_k(a) = \frac{1-k}{2} \) which implies that \( a \in R \). Thus every right ideal of \( S \) is semiprime. The converse is simple.

Similarly every left and two-sided ideal of an AG-groupoid \( S \) is semiprime if and only if their characteristic functions are \( (\varepsilon, \in \forall q_k) \)-fuzzy semiprime. ■

**Lemma 60** Let \( S \) be an AG-groupoid, then every right (left, two-sided) ideal of \( S \) is semiprime if every fuzzy right (left, two-sided) ideal of \( S \) is an \( (\varepsilon, \in \forall q_k) \)-fuzzy semiprime.

**Proof.** The direct part can be easily followed by Lemma 59. ■

The converse is not true in general. For this, let us consider an AG-groupoid \( S \) in Example 35. It is easy to observe that the only left ideals of \( S \) are \( \{a, b, c\}, \{a, c, e\}, \{a, b, c, e\} \) and \( \{a, e\} \) which are semiprime. Clearly the right and two sided ideals of \( S \) are \( \{a, b, c, e\} \) and \( \{a, e\} \) which are also semiprime. Now on the other hand, if we define a fuzzy subset \( f \) of \( S \) as follows: \( f(a) = f(b) = f(c) = 0.2, f(d) = 0.1 \) and \( f(e) = 0.3 \), then \( f \) is a fuzzy right (left, two-sided) ideal of \( S \) but \( f \) is not an \( (\varepsilon, \in \forall q_k) \)-fuzzy semiprime because \( f(c) \nsubseteq f(c^2) \wedge \frac{1-k}{2} \).

**Lemma 61** Let \( S \) be an AG-groupoid with left identity, then the following statements are equivalent.

(i) \( S \) is right regular.

(ii) Every \( (\varepsilon, \in \forall q_k) \)-fuzzy right (left, two-sided) ideal of \( S \) is \( (\varepsilon, \in \forall q_k) \)-fuzzy semiprime.

**Proof.** (i) \( \implies \) (ii) is followed by Lemma 58.

(ii) \( \implies \) (i) : Let \( S \) be an AG-groupoid with left identity and let every fuzzy right (left, two-sided) ideal of \( S \) is \( (\varepsilon, \in \forall q_k) \)-fuzzy semiprime. Since \( a^2S \) is a right and also a left ideal of \( S \), therefore by using Lemma 60, \( (C_{a^2S})_k \) is \( (\varepsilon, \in \forall q_k) \)-semiprime. Now clearly \( a^2 \in a^2S \), therefore \( a \in a^2S \), which shows that \( S \) is right regular. ■
**Theorem 62** For an AG-groupoid $S$ with left identity, the following conditions are equivalent.

(i) $S$ is regular.
(ii) Every $(\epsilon, \in \vee q_k)$-fuzzy right ideal of $S$ is $(\epsilon, \in \vee q_k)$-fuzzy semiprime.
(iii) Every $(\epsilon, \in \vee q_k)$-fuzzy left ideal of $S$ is $(\epsilon, \in \vee q_k)$-fuzzy semiprime.

**Proof.** (i) $\implies$ (ii) and (ii) $\implies$ (i) are followed by Lemma 61.

(iii) $\implies$ (ii): Let $S$ be an AG-groupoid and let $f$ be a $(\epsilon, \in \vee q_k)$-fuzzy right ideal of $S$, then by using Lemma 45, $f$ is a $(\epsilon, \in \vee q_k)$-fuzzy left ideal of $S$ and therefore by given assumption $f$ is a $(\epsilon, \in \vee q_k)$-fuzzy semiprime.

**Theorem 63** For an AG-groupoid $S$ with left identity, the following conditions are equivalent.

(i) $S$ is right regular.
(ii) $R \cap L = RL$, $R$ is any right ideal and $L$ is any left ideal of $S$ where $R$ is semiprime.
(iii) $f \wedge_k g = f \circ_k g$, where $f$ is any $(\epsilon, \in \vee q_k)$-fuzzy right ideal and $g$ is any $(\epsilon, \in \vee q_k)$-fuzzy left ideal of $S$ where $f$ is a $(\epsilon, \in \vee q_k)$-fuzzy semiprime.

**Proof.** (i) $\implies$ (iii): Let $S$ be a right regular AG-groupoid and let $f$ is any $(\epsilon, \in \vee q_k)$-fuzzy right ideal and $g$ is any $(\epsilon, \in \vee q_k)$-fuzzy left ideal of $S$. Now for $a \in S$ there exists $x \in S$ such that $a = a^2x$. Now by using (1), we have

$$a = (aa)x = (xa)a = ((ax)a)a = ((ax)e)a.$$ 

Therefore

$$(f \circ_k g)(a) = \bigvee_{a=(ax)e} \left\{ f((ax)e) \wedge g(a) \wedge \frac{1-k}{2} \right\} \geq f(a) \wedge g(a) \wedge \frac{1-k}{2}$$

Which implies that $f \circ_k g \geq f \wedge_k g$ and obviously $f \circ_k g \leq f \wedge_k g$. Thus $f \circ_k g = f \wedge_k g$ and by Lemma 58, $f$ is a $(\epsilon, \in \vee q_k)$-fuzzy semiprime.

(iii) $\implies$ (ii): Let $R$ be any right ideal and $L$ be any left ideal of an AG-groupoid $S$, then by Lemma 25, $(C_R)_k$ and $(C_L)_k$ are $(\epsilon, \in \vee q_k)$-fuzzy right and $(\epsilon, \in \vee q_k)$-fuzzy left ideals of $S$ respectively. As $RL \subseteq R \cap L$ is obvious therefore let $a \in R \cap L$, then $a \in R$ and $a \in L$. Now by using Lemma 26 and given assumption, we have

$$(C_{RL})_k(a) = (C_R \circ_k C_L)(a) = (C_R \wedge_k C_L)(a)$$

$$= C_R(a) \wedge C_L(a) \wedge \frac{1-k}{2} = \frac{1-k}{2}.$$ 

Which implies that $a \in RL$ and therefore $R \cap L = RL$. Now by using Lemma 59, $R$ is semiprime.
$(ii) \implies (i)$: Let $S$ be an AG-groupoid, then clearly $Sa$ is a left ideal of $S$ such that $a \in Sa$ and $a^2S$ is a right ideal of $S$ such that $a^2 \in a^2 S$. Since by assumption, $a^2 S$ is semiprime therefore $a \in a^2 S$. Now by using (3), (1) and (4), we have

\[
\begin{align*}
a & \in a^2 S \cap Sa = (a^2 S)(Sa) = (aS)(Sa^2) = ((Sa^2)S)a = ((Sa^2)(SS))a \\
& = ((SS)(a^2 S))a = (a^2((SS)S))a \subseteq (a^2 S)S = (SS)(aa) = a^2 S.
\end{align*}
\]

Which shows that $S$ is right regular. □
Generalized Fuzzy Ideals of Abel Grassmann Groupoids

In this chapter, we investigate some characterizations of regular and intra-regular Abel-Grassmann’s groupoids in terms of \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy ideals and \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy quasi-ideals.

An element \(a\) of an AG-groupoid \(S\) is called **regular** if there exist \(x \in S\) such that \(a = (ax)a\) and \(S\) is called **regular**, if every element of \(S\) is regular.

An element \(a\) of an AG-groupoid \(S\) is called **intra-regular** if there exist \(x, y \in S\) such that \(a = (xa^2)y\) and \(S\) is called **intra-regular**, if every element of \(S\) is intra-regular.

The following definitions for AG-groupoids are same as for semigroups in [36].

**Definition 64**  
(1) A fuzzy subset \(\delta\) of an AG-groupoid \(S\) is called an \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy AG-subgroupoid of \(S\) if for all \(x, y \in S\) and \(t, r \in (0, 1]\), it satisfies,

\[
x_t \in \delta, \quad y_r \in \delta \implies (xy)_{\min\{t,r\}} \in \mathbb{V}_qk\delta.
\]

(2) A fuzzy subset \(\delta\) of \(S\) is called an \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy left (right) ideal of \(S\) if for all \(x, y \in S\) and \(t, r \in (0, 1]\), it satisfies,

\[
x_t \in \delta \implies (yx)_t \in \mathbb{V}_qk\delta \quad \text{and} \quad y_r \in \delta \implies (xy)_r \in \mathbb{V}_qk\delta.
\]

(3) A fuzzy AG-subgroupoid \(f\) of an AG-groupoid \(S\) is called an \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy interior ideal of \(S\) if for all \(x, y, z \in S\) and \(t, r \in (0, 1]\) the following condition holds.

\[
y_t \in f \implies (xy)_t \in \mathbb{V}_qk f.
\]

(4) A fuzzy subset \(f\) of an AG-groupoid \(S\) is called an \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy quasi-ideal of \(S\) if for all \(x \in S\) it satisfies, \(f(x) \geq \min(f \circ C_S(x), C_S \circ f(x), \frac{1-k}{2})\), where \(C_S\) is the fuzzy subset of \(S\) mapping every element of \(S\) on \(1\).

(5) A fuzzy subset \(f\) of an AG-groupoid \(S\) is called an \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy generalized bi-ideal of \(S\) if \(x_t \in f\) and \(z_r \in S\) implies \((xy)_{\min\{t,r\}} \in \mathbb{V}_qk f\), for all \(x, y, z \in S\) and \(t, r \in (0, 1]\).

(6) A fuzzy subset \(f\) of an AG-groupoid \(S\) is called an \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy bi-ideal of \(S\) if for all \(x, y, z \in S\) and \(t, r \in (0, 1]\) the following conditions hold

(i) If \(x_t \in f\) and \(y_r \in S\) implies \((xy)_{\min\{t,r\}} \in \mathbb{V}_qk f\),

(ii) If \(x_t \in f\) and \(z_r \in f\) implies \((xy)_{\min\{t,r\}} \in \mathbb{V}_qk f\).

**Theorem 65**  
[36] (1) Let \(\delta\) be a fuzzy subset of \(S\). Then \(\delta\) is an \((\varepsilon, \in \mathbb{V}_qk)\)-fuzzy AG-subgroupoid of \(S\) if \(\delta(xy) \geq \min\{\delta(x), \delta(y), \frac{1-k}{2}\}\).
2. Generalized Fuzzy Ideals of Abel Grassmann Groupoids

(2) A fuzzy subset $\delta$ of an AG-groupoid $S$ is called an $(\varepsilon, \in \vee q_k)$-fuzzy left (right) ideal of $S$ if
\[
\delta(xy) \geq \min\{\delta(y), \frac{1-k}{2}\} \quad \text{and} \quad \delta(xy) \geq \min\{\delta(x), \frac{1-k}{2}\}.
\]

(3) A fuzzy subset $f$ of an AG-groupoid $S$ is an $(\varepsilon, \in \vee q_k)$-fuzzy interior ideal of $S$ if and only if it satisfies the following conditions.
(i) $f(xy) \geq \min\{f(x), f(y), \frac{1-k}{2}\}$ for all $x, y \in S$ and $k \in [0, 1)$.
(ii) $f((xy)z) \geq \min\{f(y), f(z), \frac{1-k}{2}\}$ for all $x, y, z \in S$ and $k \in [0, 1)$.

(4) Let $f$ be a fuzzy subset of $S$. Then $f$ is an $(\varepsilon, \in \vee q_k)$-fuzzy bi-ideal of $S$ if and only if
(i) $f(xy) \geq \min\{f(x), f(y), \frac{1-k}{2}\}$ for all $x, y \in S$ and $k \in [0, 1)$,
(ii) $f((xy)z) \geq \min\{f(x), f(z), \frac{1-k}{2}\}$ for all $x, y, z \in S$ and $k \in [0, 1)$.

Here we begin with examples of an AG-groupoid.

Example 66 Let us consider an AG-groupoid $S = \{1, 2, 3\}$ in the following multiplication table.

\[
\begin{array}{c|ccc}
\times & 1 & 2 & 3 \\
\hline
1 & 2 & 2 & 2 \\
2 & 3 & 3 & 3 \\
3 & 3 & 3 & 3 \\
\end{array}
\]

Note that $S$ has no left identity. Define a fuzzy subset $F : S \rightarrow [0, 1]$ as follows:

\[
F(x) = \begin{cases} 
0.9 & \text{for } x = 1 \\
0.5 & \text{for } x = 2 \\
0.6 & \text{for } x = 3 
\end{cases}
\]

Then clearly $F$ is an $(\varepsilon, \in \vee q_k)$-fuzzy ideal of $S$.

Example 67 Let us consider an AG-groupoid $S = \{1, 2, 3\}$ in the following multiplication table.

\[
\begin{array}{c|ccc}
* & 1 & 2 & 3 \\
\hline
1 & 3 & 1 & 2 \\
2 & 2 & 3 & 1 \\
3 & 1 & 2 & 3 \\
\end{array}
\]

Obviously 3 is the left identity in $S$. Define a fuzzy subset $G : S \rightarrow [0, 1]$ as follows:

\[
G(x) = \begin{cases} 
0.8 & \text{for } x = 1 \\
0.6 & \text{for } x = 2 \\
0.5 & \text{for } x = 3 
\end{cases}
\]

Then clearly $G$ is an $(\varepsilon, \in \vee q_k)$-fuzzy bi-ideal of $S$.

Lemma 68 Intersection of two ideals of an AG-groupoid is an ideal.

Proof. It is easy.
Lemma 69 Let $S$ be an AG-groupoid. If $a = a(ax)$, for some $x$ in $S$. Then $a = a^2 y$, for some $y$ in $S$.

Proof. Using medial law, we get $a = a(ax) = (a(ax))(ax) = (aa)((ax)x) = a^2 y$, where $y = (ax)x$. ■

Lemma 70 Let $S$ be an AG-groupoid with left identity. If $a = a^2 x$, for some $x$ in $S$. Then $a = (ay)a$, for some $y$ in $S$.

Proof. Using medial law, left invertive law, (1), paramedial law and medial law, we get

$$a = a^2 x = (aa)x = ((a^2 x)(a^2 x))x = ((a^2)(xx))(a) a = ((a^2)(xx))(a) a = (a^2 x)(a^2 a) a = [a^2 (x^2 a)] a = [a(a^2 x)] (aa) a = [a(a^2 x)] a$$

$$= (ay)a, \text{ where } y = \{a(x^2 x)\} a.$$ ■

Lemma 71 Let $S$ be an AG-groupoid with left identity. Then the following holds.

(i) $(aS)a^2 = (aS)a$, $(aS)((aS)a) = (aS)a$, $S((aS)a) = (aS)a$.

(ii) $(Sa)(aS) = a(aS)$, $(aS)(Sa) = (aS)a$, $[a(aS)] S = (aS)a$.

(iii) $[(Sa)S](Sa) = (aS)(Sa)$, $(Sa)S = (aS)$, $S(Sa) = Sa$, $Sa^2 = a^2 S$.

Proof. Straightforward. ■

Lemma 72 Any $(\varepsilon, \in \sqrt[k]{q})$-fuzzy left ideal of an intra regular AG-groupoid is an $(\varepsilon, \in \sqrt[k]{q})$-fuzzy quasi-ideal.

Proof. We get

$$S \circ_k f(a) = \bigvee_{a=pq} \left\{ S(p) \wedge f(q) \wedge \frac{1-k}{2} \right\}$$

$$\geq \left\{ S((y \cdot xa)) \wedge f(a) \wedge \frac{1-k}{2} \right\}$$

$$= \left\{ 1 \wedge f(a) \wedge \frac{1-k}{2} \right\}$$

$$= f(a) \wedge \frac{1-k}{2} \geq f_k(a).$$
2. Generalized Fuzzy Ideals of Abel Grassmann Groupoids

Also

\[
S \circ_k f(a) = \bigvee_{a=pq} S(p) \wedge f(q) \wedge \frac{1-k}{2} \\
= \bigvee_{a=pq} 1 \wedge f(q) \wedge \frac{1-k}{2} \\
= \bigvee_{a=pq} f(q) \wedge \frac{1-k}{2} \wedge \frac{1-k}{2} \\
\leq f(pq) \wedge \frac{1-k}{2} \\
= f_k(a).
\]

Thus \(S \circ_k f(a) = f_k(a) \leq f(a)\).

\[
f(a) \geq S \circ_k f(a) \wedge f \circ_k S(a) \\
= S \circ f(a) \wedge \frac{1-k}{2} \wedge f \circ S(a) \wedge \frac{1-k}{2} \\
= \min\{S \circ f(a), f \circ S(a), \frac{1-k}{2}\}
\]

Lemma 73 Any \((\varepsilon, \varepsilon \vee q_k)\)-fuzzy right ideal of an intra regular AG-groupoid is an \((\varepsilon, \varepsilon \vee q_k)\)-fuzzy quasi-ideal.

Proof. We see that

\[
f \circ_k S(a) = \bigvee_{a=pq} \left\{ f(p) \wedge S(q) \wedge \frac{1-k}{2} \right\} \\
\geq \left\{ f(a) \wedge S([x \cdot y_2y_1]a) \wedge \frac{1-k}{2} \right\} \\
= \left\{ f(a) \wedge 1 \wedge \frac{1-k}{2} \right\} \\
= f_k(a).
\]
Also
\[ f \circ_k S (a) = \bigvee_{a=pq} f(p) \land S(q) \land \frac{1-k}{2} \]
\[ = \bigvee_{a=pq} f(p) \land 1 \land \frac{1-k}{2} \]
\[ = \bigvee_{a=pq} f(p) \land \frac{1-k}{2} \land \frac{1-k}{2} \]
\[ \leq \bigvee_{a=pq} f(pq) \land \frac{1-k}{2} \]
\[ = f_k(a). \]

Thus \( f \circ_k S(a) = f_k(a) \leq f(a). \)

\[ f(a) \geq S \circ_k f(a) \land f \circ_k S(a) \]
\[ = S \circ f(a) \land \frac{1-k}{2} \land f \circ S(a) \land \frac{1-k}{2} \]
\[ = \min\{S \circ f(a), f \circ S(a), \frac{1-k}{2}\}. \]

\[ \square \]

2.1 Some Characterizations of AG-groupoids by \((\epsilon, \in \lor q_k)\)-fuzzy Ideals

**Theorem 74** For an AG-groupoid with left identity, the following are equivalent.

(i) \( S \) is intra-regular

(ii) \( I[a] \cap J[a] \subseteq I[a], J[a], \) for all \( a \) in \( S. \)

(iii) \( I \cap J \subseteq IJ, \) for any left ideal \( I \) and quasi-ideal \( J \) of \( S. \)

(iv) \( f \land_k g \leq f \circ_k g, \) for any \((\epsilon, \in \lor q_k)\)-fuzzy left ideal \( f \) and \((\epsilon, \in \lor q_k)\)-fuzzy quasi-ideal \( g \) of \( S. \)

**Proof.** (i) \( \Rightarrow \) (iv)

Let \( f \) and \( g \) be \((\epsilon, \in \lor q)\)-fuzzy left and quasi-ideals of an intra-regular AG-groupoid \( S \) with left identity. For each \( a \) in \( S \) there exists \( x, y \) in \( S \) such
that $a = (xa^2)y$. Then we get
\[(f \circ_k g)(a) = \bigvee_{a=pq} \left\{ f(p) \wedge g(q) \wedge \frac{1-k}{2} \right\} \]
\[\geq f(sa) \wedge g(a) \wedge \frac{1-k}{2} \]
\[= \left\{ f(sa) \wedge \frac{1-k}{2} \wedge g(a) \right\} \]
\[= f_k(sa) \wedge g(a) \]
\[= S \circ_k f(sa) \wedge g(a) \]
\[= \bigvee_{sa} S(s) \wedge f(a) \wedge g(a) \wedge \frac{1-k}{2} \]
\[= f \wedge_k g(a). \]

Therefore $f \circ_k g \geq f \wedge_k g$.

(iv) $\implies$ (iii)

Let $I$ and $J$ be left and quasi-ideals of an AG-groupoid $S$ with left identity and let $a \in I \cap J$. Then we get
\[(C_{IJ})_k(a) = (C_I \circ_k C_J)(a) = (C_I \wedge_k C_J)(a) \]
\[= (C_{I \cap J})_k(a) \geq \wedge \frac{1-k}{2}. \]

Thus $I \cap J \subseteq IJ$.

(iii) $\implies$ (ii) It is obvious.

(ii) $\implies$ (i)

Since $a \cup Sa$ is a principal left and $a \cup Sa \cap aS$ is a principal quasi-ideal of an AG-groupoid $S$ with left identity containing $a$. Using by (ii), medial law, left invertive law and paramedial law, we get
\[\begin{align*}
(a \cup Sa) \cap [a \cup (Sa \cap aS)] &\subseteq (a \cup Sa) \cup (Sa \cap aS) \\
&\subseteq (a \cup Sa) \cap (a \cup Sa) \\
&= a^2 \cup a(Sa) \cup (Sa)a \cup (Sa)(Sa) \\
&= a^2 \cup Sa^2 \cup a^2S \cup Sa^2 \\
&= a^2 \cup Sa^2 \\
&= Sa^2 = Sa^2 \cdot S
\end{align*} \]

Hence $S$ is intra-regular. ■

Similarly we can prove the following theorem.

**Theorem 75** For an AG-groupoid with left identity, the following are equivalent.

(i) $S$ is intra-regular
(ii) \( I[a] \cap J[a] \subseteq I[a] J[a] \), for all \( a \) in \( S \).

(iii) \( I \cap J \subseteq IJ \), for any quasi-ideal \( I \) and left-ideal \( J \) of \( S \).

(iv) \( f \wedge_k g \leq f \circ_k g \), for any \((\varepsilon, \varepsilon \in \vee_{qk})\)-fuzzy quasi-ideal \( f \) and \((\varepsilon, \varepsilon \in \vee_{qk})\)-fuzzy left ideal \( g \) of \( S \).

**Theorem 76** For an AG-groupoid with left identity \( e \), the following are equivalent.

(i) \( S \) is intra-regular,

(ii) \( Q[a] \cap L[a] \subseteq Q[a] L[a] \), for all \( a \) in \( S \).

(iii) \( A \cap B \subseteq BA \), for any quasi-ideal \( A \) and left ideal \( B \) of \( S \).

(iv) \( f \wedge_k g \leq g \circ_k f \), where \( f \) is any \((\varepsilon, \varepsilon \in \vee_{qk})\)-fuzzy quasi-ideal and \( g \) is an \((\varepsilon, \varepsilon \in \vee_{qk})\)-fuzzy left ideal.

**Proof.** (i) \( \Rightarrow \) (iv)

Let \( f \) and \( g \) be \((\varepsilon, \varepsilon \in \vee_{qk})\)-fuzzy quasi and left ideals of an intra-regular AG-groupoid \( S \) with left identity. Since \( S \) is intra-regular so for each \( a \) in \( S \) there exists \( x, y \) in \( S \) such that \( a = xa^2 \cdot y \). The we get

\[
(g \circ_k f)(a) = \bigvee_{a=px} \left\{ g(p) \wedge f(q) \wedge \frac{1-k}{2} \right\}
\]

\[
\geq g(sa) \wedge f(a) \wedge \frac{1-k}{2}
\]

\[
= (S \circ_k g(sa)) \wedge f(a)
\]

\[
= \bigvee_{s=cd} S(c) \wedge g(d) \wedge f(a) \wedge \frac{1-k}{2}
\]

\[
\geq S(s) \wedge g(a) \wedge f(a) \wedge \frac{1-k}{2}
\]

\[
= g(a) \wedge f(a) \wedge \frac{1-k}{2}
\]

\[
= f(a) \wedge g(a) \wedge \frac{1-k}{2} = f \wedge_k g(a).
\]

Thus \( g \circ_k f \geq f \wedge_k g \).

(iv) \( \Rightarrow \) (iii) Let \( A \) and \( B \) be quasi and left ideals of \( S \) and \( a \in A \cap B \), then we get

\[
(C_{AB})_k(a) = (C_A \circ_k C_B)(a) \geq (C_B \wedge_k C_A)(a)
\]

\[
= (C_{B \wedge A})_k(a) \geq \frac{1-k}{2}.
\]

Therefore \( A \cap B \subseteq BA \).

(iii) \( \Rightarrow \) (ii) is obvious

(ii) \( \Rightarrow \) (i)

Since \( a \cup Sa \) is a principal left and \( a \cup Sa \cap aS \) is a principal quasi-ideal
of an AG-groupoid $S$ with left identity containing $a$. Using by (ii), we get

$$(a \cup Sa) \cap [a \cup (Sa \cap aS)] \subseteq [a \cup (Sa \cap aS)](a \cup Sa)$$
$$\subseteq (a \cup Sa) \cap (a \cup Sa)$$
$$= a^2 \cup a(Sa) \cup (Sa)a \cup (Sa)(Sa)$$
$$= a^2 \cup Sa^2 \cup a^2 S \cup Sa^2$$
$$= a^2 \cup Sa^2$$
$$= Sa^2 = Sa \cdot S$$

Hence $S$ is intra regular. ■

Similarly we can prove the following theorem.

**Theorem 77** For an AG-groupoid with left identity $e$, the following are equivalent.

(i) $S$ is intra-regular,

(ii) $Q[a] \cap L[a] \subseteq Q[a]L[a]$, for all $a$ in $S$.

(iii) $A \cap B \subseteq BA$, for any left ideal $A$ and quasi-ideal $B$ of $S$.

(iv) $f \wedge_k g \leq g \circ_k f$, where $f$ is any $(\varepsilon, \in \vee q_k)$-fuzzy left ideal and $g$ is an $(\varepsilon, \in \vee q_k)$-fuzzy quasi-ideal.

**Lemma 78** If $I$ is an ideal of an intra-regular AG-groupoid $S$ with left identity, then $I = I^2$.

**Proof.** It is easy. ■

**Theorem 79** Let $S$ be an AG-groupoid with left identity. Then the following are equivalent

(i) $S$ is intra-regular.

(ii) $L[a] \cap B \cap Q[a] \subseteq L[a]B \cdot Q[a]$, for all $a$ in $S$ and $B$ is any subset of $S$.

(iii) $A \cap B \cap C \subseteq AB \cdot C$, for any left ideal $A$, subset $B$ and every quasi-ideal $C$ of $S$.

(iv) $f \wedge_k g \wedge_k h \leq (f \circ_k g) \circ_k h$, for any $(\varepsilon, \in \vee q_k)$-fuzzy left ideal $f$, $(\varepsilon, \in \vee q_k)$-fuzzy subset $g$ and $(\varepsilon, \in \vee q_k)$-fuzzy quasi-ideal $h$ of $S$.

**Proof.** (i) $\implies$ (iv)

Let $f$, $g$ and $h$ be $(\varepsilon, \in \vee q_k)$-fuzzy left ideal, fuzzy subset and $(\varepsilon, \in \vee q_k)$-fuzzy quasi-ideal of an intra-regular AG-groupoid $S$ with left identity. Then
we get

\[
((f \circ_k g) \circ_k h) (a) = \bigvee_{a=\alpha \beta} \left\{ f \circ_k g(p) \land h(a) \land \frac{1-k}{2} \right\}
\]

\[
\geq \left\{ f \circ_k g(ua^2 \cdot a) \land h(a) \land \frac{1-k}{2} \right\}
\]

\[
= \bigvee_{ua^2 \cdot a = \alpha \beta} f(c) \land g(d) \land h(a) \land \frac{1-k}{2}
\]

\[
\geq f(ua^2) \land \frac{1-k}{2} \land g(a) \land h(a) \land \frac{1-k}{2}
\]

\[
= f_k(ua^2) \land g(a) \land h(a) \land \frac{1-k}{2}
\]

\[
= S \circ_k f(ua^2) \land g(a) \land h(a) \land \frac{1-k}{2}
\]

\[
= \bigvee_{ua^2 = \alpha \beta} S(r) \land f(r) \land g(a) \land h(a) \land \frac{1-k}{2}
\]

\[
\geq 1 \land f(a^2) \land g(a) \land h(a) \land \frac{1-k}{2}
\]

\[
= f(a) \land g(a) \land h(a) \land \frac{1-k}{2}
\]

\[
= f(a) \land g(a) \land h(a)
\].

Thus \( f \land_k g \land_k h \leq (f \circ_k g) \circ_k h \).

(iv) \implies (iii) We get

\[
(C_{AB \cdot C})_k (a) = (C_A \circ_k C_B) \circ_k C_C (a) = (C_A \land_k C_B \land_k C_C) (a)
\]

\[
= (C_{A \land B \land C})_k (a) \geq \frac{1-k}{2}
\]

Therefore \( A \cap B \cap C \subseteq AB \cdot C \).

(iii) \implies (ii) is obvious.

(ii) \implies (i)

\[
(a \cup Sa) \cap Sa \cap [a \cup (Sa \cap aS)] \subseteq [(a \cup Sa)]Sa[a \cup (Sa \cap aS)]
\]

\[
\subseteq [(a \cup Sa)]Sa[a \cup Sa]
\]

\[
= [Sa \cdot Sa] \cdot Sa
\]

\[
\subseteq Sa^2 \cdot S.
\]

Hence \( S \) is intra-regular. ■

Similarly we can prove the following theorems.

**Theorem 80** Let \( S \) be an AG-groupoid with left identity. Then the following are equivalent.
(i) $S$ is intra-regular.
(ii) $L[a] \cap Q[a] \cap B \subseteq L[a]Q[a] \cdot B$, for all $a$ in $S$ and $B$ is any subset of $S$.
(iii) $A \cap B \cap C \subseteq AB \cdot C$, for any left ideal $A$, subset $C$ and every quasi-ideal $B$ of $S$.
(iv) $f \wedge_k g \wedge_k h \leq (f \circ_k g) \circ_k h$, for any $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy left ideal $f$, $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy subset $f$ and $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy quasi-ideal $g$ of $S$.

**Theorem 81** Let $S$ be an AG-groupoid with left identity. Then the following are equivalent

(i) $S$ is intra-regular.
(ii) $Q[a] \cap L[a] \cap A \subseteq Q[a]L[a] \cdot A$, for all $a$ in $S$ and for any subset $A$ of $S$.
(iii) $Q \cap L \cap A \subseteq QL \cdot A$, for any quasi-ideal $Q$, subset $A$ and every left ideal $L$ of $S$.
(iv) $f \wedge_k g \wedge_k h \leq (f \circ_k g) \circ_k h$, for any $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy left ideal $g$, $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy subset $h$ and $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy quasi-ideal $f$ of $S$.

**Theorem 82** For an AG-groupoid $S$ with left identity, the following conditions are equivalent.

(i) $S$ is intra-regular.
(ii) $(f \wedge_k g) \wedge_k h \leq (f \circ_k g) \circ_k h$, for any $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy quasi-ideal $f$ and for any $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy left ideal $g$ and $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy subset $h$ of $S$.

**Proof.** (i) $\implies$ (ii) It is same as (i) $\implies$ (iii) of theorem 82.
(ii) $\implies$ (i)

Let $f$ and $g$ be an $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy quasi, left ideals and $(\varepsilon, \varepsilon \in \vee q_k)$-fuzzy subset of an AG-groupoid $S$ with left identity. Then

\[
(f \wedge_k g)(a) = (f \wedge_k g)(a) \wedge S(a) \wedge \frac{1-k}{2} = f(a) \wedge g(a) \wedge \frac{1-k}{2} = f(a) \wedge g(a) \wedge \frac{1-k}{2} = f \wedge_k g(a).
\]

Therefore $((f \wedge_k g) \wedge_k S) = f \wedge_k g$. Also
(f \circ_k g) \circ_k S = (S \circ_k g) \circ_k f$. Now
\[
S \circ_k g(a) = \bigvee_{a=pq} S(p) \land g(q) \land \frac{1-k}{2}
\]
\[
= \bigvee_{a=pq} g(q) \land \frac{1-k}{2}
\]
\[
\leq f(pq) \land \frac{1-k}{2}
\]
\[
= f(a) \land \frac{1-k}{2} \leq f(a).
\]
Thus $S \circ_k g \leq g$. Now using (ii), we get
\[
(f \land_k g)(a) = ((f \land_k g) \land_k S)(a) \leq ((f \circ_k g) \circ_k S)(a)
\]
\[
= ((S \circ_k g) \circ_k f)(a) \leq g \circ_k f(a).
\]
Therefore by theorem 76, $S$ is intra-regular. □

Similarly we can prove the following theorems.

Theorem 83 For an AG-groupoid $S$ with left identity, the following conditions are equivalent.

(i) $S$ is intra-regular.

(ii) $(f \land_k g) \land_k h \leq (f \circ_k g) \circ_k h$, for any $(\varepsilon, \in \lor q_k)$-fuzzy left ideal $f$ and for any $(\varepsilon, \in \lor q_k)$-fuzzy quasi-ideal $g$ and $(\varepsilon, \in \lor q_k)$-fuzzy subset $h$ of $S$.

Theorem 84 For an AG-groupoid $S$ with left identity, the following conditions are equivalent.

(i) $S$ is intra-regular.

(ii) $(f \land_k g) \land_k h \leq (f \circ_k g) \circ_k h$, for any $(\varepsilon, \in \lor q_k)$-fuzzy subset $f$ and for any $(\varepsilon, \in \lor q_k)$-fuzzy left ideal $g$ and $(\varepsilon, \in \lor q_k)$-fuzzy quasi-ideal $h$ of $S$.

Theorem 85 For an AG-groupoid $S$ with left identity, the following conditions are equivalent.

(i) $S$ is intra-regular.

(ii) $(f \land_k g) \land_k h \leq (f \circ_k g) \circ_k h$, for any $(\varepsilon, \in \lor q_k)$-fuzzy left ideal $f$ and for any $(\varepsilon, \in \lor q_k)$-fuzzy subset ideal $g$ and $(\varepsilon, \in \lor q_k)$-fuzzy quasi-ideal $h$ of $S$.

2.2 Medial and Para-medial Laws in Fuzzy AG-groupoids

Lemma 86 Let $S$ be an AG-groupoid with left identity. Then the following holds.
(i) $(f \circ_k g) \circ_k (h \circ_k \gamma) = (f \circ_k h) \circ_k (g \circ_k \gamma)$.

(ii) $(f \circ_k g) \circ_k (h \circ_k \gamma) = (\gamma \circ_k g) \circ_k (h \circ_k f)$.

(iii) $f \circ_k (g \circ_k h) = g \circ_k (f \circ_k h)$.

**Proof.** (i) Using medial law we have,

\[
(f \circ_k g) \circ_k (h \circ_k \gamma) (a) = \bigvee_{a=mn} (f \circ_k g) (m) \land (h \circ_k \gamma) (n) \land \frac{1-k}{2}
\]

\[
= \bigvee_{a=mn} \left\{ \left( \bigvee_{m=op} f (o) \land g (p) \land \frac{1-k}{2} \right) \land \left( \bigvee_{n=qr} h (q) \land \gamma (r) \land \frac{1-k}{2} \right) \right\} \land \frac{1-k}{2}
\]

\[
= \bigvee_{a=mn=(op)(qr)} \left( f (o) \land g (p) \land h (q) \land \gamma (r) \land \frac{1-k}{2} \right)
\]

\[
= \bigvee_{a=mn=(oq)(pr)} \left( f (o) \land h (q) \land g (p) \land \gamma (r) \land \frac{1-k}{2} \right)
\]

\[
= \bigvee_{a=m'n'} \left\{ \left( \bigvee_{m'=oq} f (o) \land h (q) \land \frac{1-k}{2} \right) \land \left( \bigvee_{n'=pr} g (p) \land \gamma (r) \land \frac{1-k}{2} \right) \right\} \land \frac{1-k}{2}
\]

\[
= \bigvee_{a=m'n'} \left\{ (f \circ_k g) (m') \land (h \circ_k \gamma) (n') \land \frac{1-k}{2} \right\}
\]

\[
= (f \circ_k g) \circ_k (h \circ_k \gamma) (a).
\]
(ii) Using paramedial law we get,

\[
(f \circ_k g) \circ_k (h \circ_k \gamma)(a) = \bigvee_{a=mn} \left( (f \circ_k g)(m) \land (h \circ_k \gamma)(n) \land \frac{1-k}{2} \right)
\]

\[
= \bigvee_{a=mn} \left\{ \left( \bigvee_{m=op} f(o) \land g(p) \land \frac{1-k}{2} \right) \land \left( \bigvee_{n=qr} h(q) \land \gamma(r) \land \frac{1-k}{2} \right) \right\} \land \frac{1-k}{2}
\]

\[
= \bigvee_{a=mn=(op)(qr)} \left( f(o) \land g(p) \land h(q) \land \gamma(r) \land \frac{1-k}{2} \right)
\]

\[
= \bigvee_{a=mn=(rp)(qo)} \left( \gamma(r) \land g(p) \land h(q) \land f(o) \land \frac{1-k}{2} \right)
\]

\[
= \bigvee_{a=m'n'} \left\{ \left( \bigvee_{m'=xp} \gamma(r) \land g(p) \land \frac{1-k}{2} \right) \land \left( \bigvee_{n'=qo} h(q) \land f(o) \land \frac{1-k}{2} \right) \right\} \land \frac{1-k}{2}
\]

\[
= \bigvee_{a=m'n'} \left\{ (\gamma \circ_k g)(m') \land (h \circ_k f)(n') \right\} \land \frac{1-k}{2}
\]

\[
= (\gamma \circ_k g) \circ_k (h \circ_k f)(a).
\]
Using (1) we get,

\[
((f \circ k \circ (g \circ k \circ h))(a) = \bigvee_{a=mn} f(m) \wedge (g \circ k \circ h)(n) \wedge \frac{1-k}{2}
\]

\[
= \bigvee_{a=mn} \left( f(m) \wedge \left( \bigvee_{n=op} g(o) \wedge h(p) \wedge \frac{1-k}{2} \right) \right) \wedge \frac{1-k}{2}
\]

\[
= \bigvee_{a=mn=op} (f(m) \wedge \{g(o) \wedge h(p)\}) \wedge \frac{1-k}{2}
\]

\[
= \bigvee_{a=mn=op} \left( g(o) \wedge (f(m) \wedge h(p)) \wedge \frac{1-k}{2} \right)
\]

\[
= \bigvee_{a=m'n'} \left\{ g\left(m'\right) \circ k \left( \bigvee_{n'=mp} f(m) \wedge h(p) \wedge \frac{1-k}{2} \right) \right\} \wedge \frac{1-k}{2}
\]

\[
= \bigvee_{a=m'n'} \left( g\left(m'\right) \circ k \left( f \circ k \circ h\left(n'\right) \right) = g \circ k \left( f \circ k \circ h\right). \right)
\]

\[\blacksquare\]

2.3 Certain Characterizations of Regular AG-groupoids

**Theorem 87** Let \( S \) be an AG-groupoid with left identity. Then the following are equivalent.

(i) \( S \) is regular.

(ii) For left ideals \( L_1, L_2 \) and ideal \( I \) of \( S \), \( L_1 \cap I \cap L_2 \subseteq (L_1I) L_2 \).

(iii) \( L[a] \cap I[a] \cap L[a] \subseteq (L[a] I[a]) L[a] \),

for some \( a \in S \).

**Proof.** (i) \(\Rightarrow\) (ii)

Assume that \( L_1, L_2 \) are left ideal and \( I \) is an ideal of a regular AG-groupoid \( S \). Let \( a \in L_1 \cap I \cap L_2 \). This implies that \( a \in L_1, a \in I \) and \( a \in L_2 \). Now since \( S \) is regular so for \( a \in S \), there exist \( x \in S \), such that \( a = (ax)a \). Therefore using left invertive law we get

\[
a = [(ax)a]x = [(xa)(ax)]a = [(SL_1)(IS)]L_2 \subseteq (L_1I) L_2.
\]

Hence \( L_1 \cap I \cap L_2 \subseteq (L_1I) L_2 \).
(ii) ⇒ (iii) is obvious.
(iii) ⇒ (i)
Since \( a \cup Sa \cup aS \) and \( a \cup Sa \) are principle ideal and left ideal of \( S \) generated by \( a \) respectively. Thus by (iii) and paramedial law, we have

\[
(a \cup Sa) \cap (a \cup Sa \cup aS) \cap (a \cup Sa) \subseteq ((a \cup Sa) (a \cup Sa \cup aS)) (a \cup Sa)
\]
\[
\subseteq ((a \cup Sa) S) (a \cup Sa)
\]
\[
= \{aS \cup (Sa) S \} (a \cup Sa) = (aS) (a \cup Sa)
\]
\[
= (aS) a \cup (Sa) (Sa) = (aS) a.
\]

Hence \( S \) is regular. ■

**Theorem 88** Let \( S \) be an AG-groupoid with left identity. Then the following are equivalent.

(i) \( S \) is regular

(ii) For \((\varepsilon, \in \lor q_k)\)-fuzzy left ideals \( f, h \) and \((\varepsilon, \in \lor q_k)\)-fuzzy ideal \( g \) of \( S \), \((f \land_k g) \land_k h \leq (f \circ_k g) \circ_k h\).

(iii) For \((\varepsilon, \in \lor q_k)\)-fuzzy quasi-ideals \( f, h \) and \((\varepsilon, \in \lor q_k)\)-fuzzy ideal \( g \) of \( S \), \((f \land_k g) \land_k h \leq (f \circ_k g) \circ_k h\).

**Proof.** (i) ⇒ (iii) Assume that \( f, g \) are \((\varepsilon, \in \lor q_k)\)-fuzzy quasi-ideals and \( g \) is an \((\varepsilon, \in \lor q_k)\)-fuzzy ideal of a regular AG-groupoid \( S \), respectively. Now since \( S \) is regular so for \( a \in S \), there exist \( x \in S \), such that \( a = (ax) a \). Therefore using left invertive law and (1), we get

\[
a = [(ax) a] a = [(xa)(ax)] a = [a(xa)(x)] a.
\]
Thus

$$(f \circ_k g) \circ_k h(a) = \bigvee_{a=uv} (f \circ_k g)(p) \wedge h(q) \wedge \frac{1-k}{2}$$

$$= \bigvee_{a=uv} \left( \left\{ \bigvee_{p=uv} f(u) \wedge g(v) \wedge \frac{1-k}{2} \right\} \wedge h(q) \wedge \frac{1-k}{2} \right)$$

$$= \left( \left\{ f(u) \wedge g(v) \right\} \wedge h(q) \wedge \frac{1-k}{2} \right)$$

$$\geq \left\{ f(a) \wedge g((xa)x) \right\} \wedge h(a) \wedge \frac{1-k}{2}$$

$$\geq \left\{ f(a) \wedge \left( g(a) \wedge \frac{1-k}{2} \right) \right\} \wedge h(a) \wedge \frac{1-k}{2}$$

$$= \left\{ f(a) \wedge g(a) \wedge \frac{1-k}{2} \right\} \wedge h(a) \wedge \frac{1-k}{2}$$

$$= ((f \wedge_k g) \wedge_k h)(a).$$

Thus $(f \wedge_k g) \wedge_k h \leq (f \circ_k g) \circ_k h$.

$(iii) \Rightarrow (ii)$ is obvious.

$(ii) \Rightarrow (i)$ Assume that $L_1$, $L_2$ left ideals and $I$ is an ideal of $S$. Then $(C_{L_1})_k$, $(C_I)_k$ and $(C_{L_2})_k$ are $(\varepsilon, \varepsilon \vee q_k)$-fuzzy left ideal, $(\varepsilon, \varepsilon \vee q_k)$-fuzzy ideal and $(\varepsilon, \varepsilon \vee q_k)$-fuzzy left ideal of $S$ respectively. Therefore we have,

$$(C_{L_1} \cap I \cap C_{L_2})_k = (C_{L_1} \wedge_k C_I)_k \wedge_k C_{L_2} \leq (C_{L_1} \circ_k C_I)_k \circ_k C_{L_2} = (C_{(L_1 \cap I) L_2})_k.$$ 

Thus $L_1 \cap I \cap L_2 \subseteq (L_1 I) L_2$. Hence $S$ is regular. $\blacksquare$

**Theorem 89** Let $S$ be an AG-groupoid with left identity. Then the following are equivalent.

(i) $S$ is regular.

(ii) For ideal $I$ and quasi-ideal $Q$ of $S$, $I \cap Q \subseteq IQ$.

(iii) $I \left[ a \right] \cap Q \left[ a \right] \subseteq I \left[ a \right] Q \left[ a \right]$, for some $a \in S$.

**Proof.** $(i) \Rightarrow (ii)$ Assume that $I$ and $Q$ are ideal and quasi-ideal of a regular AG-groupoid $S$ respectively. Let $a \in I \cap Q$. This implies that $a \in I$ and $a \in Q$. Since $S$ is regular so for $a \in S$ there exist $x \in S$ such that $a = (ax) a \in (IS) Q \subseteq IQ$. Thus $I \cap Q \subseteq IQ$.

$(ii) \Rightarrow (iii)$ is obvious.

$(iii) \Rightarrow (i)$
Since $I[a] = a \cup Sa \cup aS$ and $Q[a] = a \cup (Sa \cap aS)$ are principle ideal and principle quasi-ideal of $S$ generated by $a$ respectively. Thus by $(ii)$, $(1)$, Left invertive law, paramedial law we have,

$$(a \cup Sa \cup aS) \cap (a \cup (Sa \cap aS)) \subseteq (a \cup Sa \cup aS) \cup (Sa \cap aS)$$

$$\subseteq (a \cup Sa \cup aS) (a \cup Sa)$$

$$= aa \cup a (Sa) \cup (Sa) a \cup (Sa) (Sa)$$

$$\cup (aS) a \cup (aS) (Sa)$$

$$= a^2 \cup a^2 S \cup a^2 S \cup a^2 S \cup (aS) a \cup (aS) a$$

$$= a^2 \cup (aS) a \cup a^2 S.$$  

If $a = a^2$, then $a = a^2 a$. If $a = a^2 x$, for some $x$ in $S$, then $S$ is regular. ■

**Theorem 90** Let $S$ be an AG-groupoid with left identity. Then the following are equivalent.

(i) $S$ is regular.

(ii) For $(\epsilon, \in \vee q_k)$-fuzzy ideal $f$, and $(\epsilon, \in \vee q_k)$-fuzzy quasi-ideal $g$ of $S$, $f \wedge_k g \leq f \circ_k g$.

**Proof.** $(i) \Rightarrow (ii)$ Assume that $f$ and $g$ are $(\epsilon, \in \vee q_k)$-fuzzy ideal and $(\epsilon, \in \vee q_k)$-fuzzy quasi-ideal of a regular AG-groupoid $S$ respectively. Now since $S$ is regular so for $a \in S$ there exist $x \in S$ such that $a = (ax) a$. Thus,

$$(f \circ_k g)(a) = \bigvee_{a=pg} f(p) \wedge g(q) \wedge \frac{1-k}{2} = \bigvee_{a=pg=(ax)a} f(p) \wedge g(q) \wedge \frac{1-k}{2}$$

$$\geq f(ax) \wedge g(a) \wedge \frac{1-k}{2} \geq \left(f(a) \wedge \frac{1-k}{2}\right) \wedge g(a) \wedge \frac{1-k}{2}$$

$$= (f \wedge_k g)(a).$$

Hence $(f \wedge_k g) \leq (f \circ_k g)$.

$(ii) \Rightarrow (i)$

Assume that $I$ and $Q$ are ideal and quasi-ideal of $S$ respectively. Then $(C_I)_k$ and $(C_Q)_k$ are $(\epsilon, \in \vee q_k)$-fuzzy ideal and $(\epsilon, \in \vee q_k)$-fuzzy quasi-ideal of $S$. Therefore we have, $(C_I \cap Q)_k = (C_I \wedge_k C_Q) \subseteq (C_I \circ_k C_Q) = (C_I Q)_k$. Therefore $I \cap Q \subseteq IQ$. Hence $S$ is regular. ■

**Theorem 91** Let $S$ be an AG-groupoid with left identity. Then the following are equivalent.

(i) $S$ is regular.

(ii) For bi-ideals $B_1$, $B_2$ and ideal $I$ of $S$, $B_1 \cap I \cap B_2 \subseteq (B_1 I) B_2$.

(iii) $B[a] \cap I[a] \cap B[a] \subseteq (B[a] I[a]) B[a]$,
for some \( a \in S \).

**Proof.** \((i) \Rightarrow (ii)\)

Assume that \( B_1, B_2 \) are bi-ideal and \( I \) is an ideal of regular AG-groupoid \( S \). Let \( a \in B_1 \cap I \cap B_2 \). This implies that \( a \in B_1 \), \( a \in I \) and \( a \in B_2 \). Now since \( S \) is regular so for \( a \in S \), there exist \( x \in S \), such that \( a = (ax)a \). Therefore \( a = (a((xa)x))a \in (B_1((SI)S))B_2 \subseteq (B_1I)B_2 \). Thus \( B_1 \cap I \cap B_2 \subseteq (B_1I)B_2 \).

\((ii) \Rightarrow (iii)\) is obvious.

\((iii) \Rightarrow (i)\)

Since \( B[a] = a \cup a^2 \cup (aS)a \) and \( I[a] = a \cup Sa \cup aS \) are principle bi-ideal and principle ideal of \( S \) generated by \( a \) respectively. Thus by \((iii), (1)\), and left invertive law, medial law and paramedial law, we have

\[
\begin{align*}
(a \cup a^2 \cup (aS)a) \cap (a \cup Sa \cup aS) \cap (a \cup a^2 \cup (aS)a) & \\
\subseteq & \{(a \cup a^2 \cup (aS)a)[(a \cup Sa \cup aS)]\} (a \cup a^2 \cup (aS)a) \\
\subseteq & \{(a \cup a^2 \cup (aS)a)[(a \cup Sa \cup aS)]\}S \\
= & [a^2 \cup a(Sa) \cup a(Sa) \cup a^2(Sa) \cup a^2(Sa) \cup (aS)a \cup ((aS)a)(Sa) \cup ((aS)a)(Sa)]S \\
\subseteq & [a^2 \cup a^2S \cup a(Sa)(aS)]S \subseteq [a^2 \cup a^2S \cup a(Sa)]S \\
= & a^2S \cup (aS)S \cup (aS)aS = a^2S \cup a^2S \cup (aS)a \\
= & a^3S \cup (aS)a.
\end{align*}
\]

Therefore \( a = a^2u \) or \( a = (ax)a \), for some \( u \) and \( x \) in \( S \). Hence \( S \) is regular.

**Theorem 92** Let \( S \) be an AG-groupoid with left identity. Then the following are equivalent.

\((i)\) \( S \) is regular.

\((ii)\) For \((\xi, \in \vee q_k)\)-fuzzy bi-ideals \( f, h \) and \((\xi, \in \vee q_k)\)-fuzzy ideal \( g \) of \( S \), \((f \wedge_k g) \wedge_k h \leq (f \circ_k g) \circ_k h \).

\((iii)\) For \((\xi, \in \vee q_k)\)-fuzzy generalized bi-ideals \( f, h \) and \((\xi, \in \vee q_k)\)-fuzzy ideal \( g \) of \( S \), \((f \wedge_k g) \wedge_k h \leq (f \circ_k g) \circ_k h \).

**Proof.** \((i) \Rightarrow (iii)\)

Assume that \( f, g \) and \( h \) are \((\xi, \in \vee q_k)\)-fuzzy generalized bi-ideal, \((\xi, \in \vee q_k)\)-fuzzy ideal and \((\xi, \in \vee q_k)\)-fuzzy generalized bi-ideal of a regular AG-groupoid \( S \) respectively. Now since \( S \) is regular so for \( a \in S \), there exist
\[x \in S, \text{ such that } a = (ax) a. \text{ Therefore } a = (a ((xa) x)) a \in \text{ Thus,}\]

\[(f \circ_k g) \circ_k h)(a) = \bigvee_{a=pq} (f \circ_k g)(p) \land h(q) \land \frac{1-k}{2} \]

\[= \bigvee_{a=pq} \left( \left\{ \bigvee_{p=uv} f(u) \land g(v) \land \frac{1-k}{2} \right\} \land h(q) \land \frac{1-k}{2} \right) \]

\[= \bigvee_{a=(uv)q} \left( \{f(u) \land g(v) \} \land h(q) \land \frac{1-k}{2} \right) \]

\[\geq \{f(a) \land g((xa)) \} \land h(a) \land \frac{1-k}{2} \]

\[\geq \{f(a) \land (g(a) \land \frac{1-k}{2}) \} \land h(a) \land \frac{1-k}{2} \]

\[= \{f (a) \land g (a) \land \frac{1-k}{2} \} \land h (a) \land \frac{1-k}{2} \]

\[= ((f \land_k g) \land_k h) (a).\]

Therefore \((f \land_k g) \land_k h \leq (f \circ_k g) \circ_k h.\)

(iii) \(\implies\) (ii) is obvious.

(ii) \(\implies\) (i)

Assume that \(B_1, B_2\) are bi-ideals and \(I\) is an ideal of \(S\) respectively. Then \((C_{B_1})_k, (C_I)_k\) and \((C_{B_2})_k\) are \((\varepsilon, \varepsilon)\)-fuzzy bi-ideal, \((\varepsilon, \varepsilon)\)-fuzzy ideal and \((\varepsilon, \varepsilon)\)-fuzzy bi-ideal of \(S\) respectively. Therefore we have, \((C_{B_1} \cap I \cap C_{B_2})_k = (C_{B_1} \land_k C_I) \land_k C_{B_2} \leq (C_{B_1} \circ_k C_I) \circ_k C_{B_2} = (C_{(B_1 I) B_2})_k.\) Therefore \(B_1 \cap I \cap B_2 \subseteq (B_1 I) B_2.\) Hence \(S\) is regular. 

**Theorem 93** Let \(S\) be an AG-groupoid with left identity. Then the following are equivalent.

(i) \(S\) is regular.

(ii) For ideals \(I_1, I_2\) and quasi-ideal \(Q\) of \(S\), \(I_1 \cap I_2 \cap Q \subseteq (I_1 I_2) Q.\)

(iii) \(I [a] \cap I [a] \cap Q [a] \subseteq (I [a] I [a]) Q [a],\)

for some \(a \in S.\)

**Proof.** (i) \(\implies\) (ii)

Assume that \(I_1, I_2\) are ideals and \(Q\) is quasi-ideal of a regular AG-groupoid \(S\), respectively. Let \(a \in I_1 \cap I_2 \cap Q\). This implies that \(a \in I_1, a \in I_1\) and \(a \in Q\). Now since \(S\) is regular so for \(a \in S\), there exist \(x \in S\), such that \(a = (ax) a\). Therefore \(a = a ((xa) x) a \in (I_1 ((SI_2) S)) Q \subseteq (I_1 I_2) Q.\) Thus \(I_1 \cap I_2 \cap Q \subseteq (I_1 I_2) Q.\)
(ii) ⇒ (iii) is obvious.

(iii) ⇒ (i)

Since \( I[a] = a \cup Sa \cup aS \) and \( Q[a] = a \cup (Sa \cap aS) \) are principle ideal and principle quasi-ideal of \( S \) generated by \( a \) respectively. Thus by left invertive law and medial law we have,

\[
(a \cup Sa \cup aS) \cap (a \cup Sa \cup aS) \cap (a \cup (Sa \cap aS)) \subseteq \frac{(a \cup Sa \cup aS)(a \cup Sa \cup aS)}{(a \cup (Sa \cap aS))}
\]

\[
\subseteq \left( \frac{(a \cup Sa \cup aS)S(a \cup aS)}{(a \cup aS)} \right)
\]

\[
= \left( \frac{aS \cup (Sa) S(aS)}{(a \cup aS)} \right)
\]

\[
= \left( \frac{aS \cup aS \cup Sa}{(a \cup aS)} \right)
\]

\[
= \left( \frac{aS \cup a(aS)}{(a \cup aS)} \right)
\]

\[
= aS \cup a(aS)
\]

Hence \( S \) is regular. ■

**Theorem 94** Let \( S \) be an AG-groupoid with left identity. Then the following are equivalent.

(i) \( S \) is regular.

(ii) For \( (\varepsilon, \in \vee q_k) \)-fuzzy ideals \( f, g \) and \( (\varepsilon, \in \vee q_k) \)-fuzzy quasi-ideal \( h \) of \( S \), \( (f \wedge_k g) \wedge_k h \leq (f \circ_k g) \circ_k h \).

**Proof.** (i) ⇒ (ii)

Assume that \( f, g \) are \( (\varepsilon, \in \vee q_k) \)-fuzzy ideals and \( h \) is an \( (\varepsilon, \in \vee q_k) \)-fuzzy quasi-ideal of a regular AG-groupoid \( S \), respectively. Now since \( S \) is regular so for \( a \in S \), there exist \( x \in S \), such that \( a = (ax)a \). Therefore
\[ a = (a ((xa)x))a. \] Thus,
\[
((f \circ k) \circ k h)(a) = \bigvee_{a=pq} (f \circ k g(p) \land h(q) \land \frac{1-k}{2})
\]
\[
= \bigvee_{a=pq} \left( \left\{ \bigvee_{p=uv} f(u) \land g(v) \land \frac{1-k}{2} \right\} \land h(q) \land \frac{1-k}{2} \right)
\]
\[
= \bigvee_{a=(uv)q} \left( \left\{ f(u) \land g(v) \land h(q) \land \frac{1-k}{2} \right\} \right)
\]
\[
\geq \left\{ f(a) \land g((xa)x) \land h(a) \land \frac{1-k}{2} \right\}
\]
\[
\geq \left\{ f(a) \land (g(a) \land \frac{1-k}{2}) \right\} \land h(a) \land \frac{1-k}{2}
\]
\[
= \left\{ f(a) \land g(a) \land \frac{1-k}{2} \right\} \land h(a) \land \frac{1-k}{2}
\]
\[
= ((f \land k g) \land k h)(a).
\]
Therefore \((f \land k g) \land k h \leq (f \circ k g) \circ k h.\)

(ii) \(\implies\) (i)

Assume that \(I_1, I_2\) are ideals and \(Q\) is a quasi-ideal of \(S\) respectively. Then \((C_{I_1})_k, (C_{I_2})_k\) and \((C_Q)_k\) are \((\leq, \leq, \land)\)-fuzzy ideal, \((\leq, \leq, \land)\)-fuzzy ideal and \((\leq, \leq, \land)\)-fuzzy quasi-ideal of \(S\) respectively. Therefore we have,
\[
(C_{I_1} \cap I_2 \cap Q)_k = (C_{I_1} \land k C_{I_2} \land k C_Q \leq (C_{I_1} \circ k C_{I_2} \circ k C_Q = (C_{I_1 I_2})_k Q_k.
\]

Thus \(I_1 \cap I_2 \cap Q \subseteq (I_1 I_2)Q\). Hence \(S\) is regular. \(\blacksquare\)

**Theorem 95** Let \(S\) be an AG-groupoid with left identity. Then the following are equivalent.

(i) \(S\) is regular.

(ii) \(I[a] \cap J[a] = I[a] J[a]\) for some \(a\) in \(S\).

(iii) For ideals \(I, J\) of \(S\), \(I \cap J = IJ (I \cap J = JJ)\).

(iv) For bi-ideal \(B\) of \(S\), \(B = (BS) B\).

**Proof.** (i) \(\Rightarrow\) (iv)

Assume that \(B\) is a bi-ideal of a regular AG-groupoid \(S\). Clearly \((BS) B \subseteq B\). Let \(b \in B\). Since \(S\) is regular so for \(b \in S\) there exist \(x \in S\) such that \(b = (bx)x) b \in (BS) B\). Thus \(B = (BS) B\).

(iv) \(\Rightarrow\) (iii)
Assume that $I$ and $J$ are ideals of regular AG-groupoid $S$. Now,

$$(I \cap J)S (I \cap J) \subseteq (SS) (I \cap J) = S (I \cap J) = SI \cap SJ \subseteq I \cap J$$

and

$$I \cap J = ((I \cap J)S) (I \cap J) \subseteq (IS) J \subseteq IJ.$$  

Moreover $IJ \subseteq SJ \subseteq J$, also $IJ \subseteq IS \subseteq I$. Therefore $IJ \subseteq I \cap J$. Thus $I \cap J = IJ$.

(iii) $\Rightarrow$ (ii) is obvious.

(ii) $\Rightarrow$ (i)

Since $I [a] = a \cup Sa \cup aS$ is a principle ideal of $S$ generated by $a$. Thus by (ii), (1), left invertive law and paramedial law, we have,

$$(a \cup Sa \cup aS) \cap (a \cup Sa \cup aS) = (a \cup Sa \cup aS) \cap (a \cup Sa \cup aS) = a^2 \cup a (Sa) \cup a (aS) \cup (Sa) a$$

$$\cup (Sa) (Sa) \cup (Sa) (aS) \cup (Sa) a$$

$$\cup (aS) (Sa) \cup (aS) (Sa)$$

$$ = a^2 \cup a (aS) \cup (aS) a \cup a^2 S.$$  

Hence $S$ is regular.  

**Theorem 96** Let $S$ be an AG-groupoid with left identity. Then the following are equivalent.

(i) $S$ is regular.

(ii) For $(\epsilon, \in \vee q_k)$-fuzzy ideals $f, g$ of $S$, $(f \wedge_k g) \leq (f \circ_k g)$.

(iii) For $(\epsilon, \in \vee q_k)$-fuzzy right ideals $f, g$ of $S$, $(f \wedge_k g) \leq (f \circ_k g)$.

**Proof.** (i) $\Rightarrow$ (iii)

Assume that $f$ and $g$ are $(\epsilon, \in \vee q_k)$-fuzzy right ideals of a regular AG-groupoid $S$. Now since $S$ is regular so for $a \in S$ there exist $x \in S$ such that $a = (ax) a$. Thus,

$$(f \circ_k g) (a) = \bigvee_{a=px} f (p) \wedge g (q) \wedge \frac{1-k}{2} = \bigvee_{a=px= (ax) a} f (p) \wedge g (q) \wedge \frac{1-k}{2}$$

$$\geq f (ax) \wedge g (a) \wedge \frac{1-k}{2} \geq \left( f (a) \wedge \frac{1-k}{2} \right) \wedge g (a) \wedge \frac{1-k}{2}$$

$$ = f (a) \wedge g (a) \wedge \frac{1-k}{2} = (f \wedge_k g) (a).$$  

Hence $(f \wedge_k g) \leq (f \circ_k g)$.

(iii) $\Rightarrow$ (ii) is obvious.

(ii) $\implies$ (i)

Assume that $I$ and $J$ are ideals $S$. Then $(C_I)_k$, and $(C_J)_k$ are $(\epsilon, \in \vee q_k)$-fuzzy ideals of $S$. Therefore we have, $(C_{I \cap J})_k = (C_I \wedge_k C_J) \leq (C_I \circ_k C_J) = (C_{I \cap J})_k$. Thus $I \cap J \subseteq IJ$. Hence $S$ is regular.
Theorem 97 Let $S$ be an AG-groupoid with left identity. Then the following are equivalent.

(i) $S$ is regular.

(ii) For $(\in, \in \vee q_k)$-fuzzy ideals $f, g$ of $S$, $(f \land_k g) \leq (g \circ_k f)$.

(iii) For $(\in, \in \vee q_k)$-fuzzy right ideals $f, g$ of $S$, $(f \land_k g) \leq (g \circ_k f)$.

Proof. It is easy.

Theorem 98 Let $S$ be an AG-groupoid with left identity. Then the following are equivalent.

(i) $S$ is regular.

(ii) For $(\in, \in \vee q_k)$-fuzzy ideals $f, g$ and $h$ of $S$, $f \land_k g \land_k h \leq (f \circ_k g) \circ_k h$.

(iii) For $(\in, \in \vee q_k)$-fuzzy right ideals $f, g$ and $h$ of $S$, $f \land_k g \land_k h \leq (f \circ_k g) \circ_k h$.

Proof. $(i) \Rightarrow (iii)$

Assume that $f, g$ and $h$ are $(\in, \in \vee q_k)$-fuzzy right ideals of a regular AG-groupoid $S$. Now since $S$ is regular so for $a \in S$ there exist $x \in S$ such that using paramedial law and medial law we have, $a = (ax) a = (ax) ((ax) a) = (a (ax)) (xa)$. Thus,

\[
((f \circ_k g) \circ_k h)(a) = \bigvee_{a = pq} (f \circ_k g)(p) \land h(q) \land \frac{1 - k}{2}
\]

\[
= \bigvee_{a = pq} \left( \left\{ \bigvee_{u = uv} f(u) \land g(v) \land \frac{1 - k}{2} \right\} \land h(q) \land \frac{1 - k}{2} \right)
\]

\[
= \bigvee_{a = (uv)q} \left( \{f(u) \land g(v)\} \land h(q) \land \frac{1 - k}{2} \right)
\]

\[
= \bigvee_{a = (a(xa))(xa) = (uv)q} \left( \{f(u) \land g(v)\} \land h(q) \land \frac{1 - k}{2} \right)
\]

\[
\geq \{f(a) \land g(ax)\} \land h(xa) \land \frac{1 - k}{2}
\]

\[
\geq \left\{ f(a) \land \left( g(a) \land \frac{1 - k}{2} \right) \right\} \land h(a) \land \frac{1 - k}{2}
\]

\[
= \{ f(a) \land g(a) \land \frac{1 - k}{2} \} \land h(a) \land \frac{1 - k}{2}
\]

\[
= \{ (f \land_k g) \land_k h \} (a).
\]

Therefore $(f \land_k g) \land_k h \leq (f \circ_k g) \circ_k h$. 
(iii) $\Rightarrow$ (ii) is obvious.

(ii) $\Rightarrow$ (i)

Assume that $f$, $g$ and $h$ are $(\in, \notin \vee q_k)$-fuzzy ideals of $S$. Now by using left invertive law, we have, $(f \wedge_k g) \leq (f \wedge_k g) \wedge_k S \leq (f \circ_k g) \circ_k S = (S \circ_k g) \circ_k f \leq g \circ_k f$. Thus $(f \wedge_k g) \leq g \circ_k f$. Hence $S$ is regular. $\blacksquare$
Generalized Fuzzy Left Ideals in AG-groupoids

In this chapter, we introduce \((\in_\gamma, \in_\delta \triangleright q_\delta)\)-fuzzy right ideals in an AG-groupoid. We characterize intra-regular AG-groupoids using the properties of \((\in_\gamma, \in_\delta \triangleright q_\delta)\)-fuzzy subsets and \((\in_\gamma, \in_\delta \triangleright q_\delta)\)-fuzzy left ideals.

3.1 \((\in_\gamma, \in_\delta \triangleright q_\delta)\)-fuzzy Ideals of AG-groupoids

Let \(\in_\delta \in [0, 1]\) be such that \(\gamma < \delta\). For any \(B \subseteq A\), let \(X^\delta_B\) be a fuzzy subset of \(X\) such that \(X^\delta_B(x) \geq \delta\) for all \(x \in B\) and \(X^\delta_B(x) \leq \gamma\) otherwise. Clearly, \(X^\delta_B\) is the characteristic function of \(B\) if \(\gamma = 0\) and \(\delta = 1\).

For a fuzzy point \(x_r\) and a fuzzy subset \(F\) of \(X\), we say that

1. \(x_r \in_\gamma F\) if \(f(x) \geq r > \gamma\).
2. \(x_r \in_\delta \triangleright q_\delta F\) if \(f(x) + r > 2\delta\).
3. \(x_r \in_\gamma \triangleright q_\delta F\) if \(x_r \in_\gamma F\) or \(x_r \in_\delta \triangleright q_\delta F\).

Now we introduce a new relation on \(F(X)\), denoted by \(\subseteq \triangleright q_\gamma \delta\), as follows:

For any \(f, g \in F(X)\), by \(f \subseteq \triangleright q_\gamma \delta g\) we mean that \(x_r \in_\gamma F\) implies \(x_r \in_\gamma \triangleright q_\delta F\) for all \(x \in X\) and \(r \in (\gamma, 1]\). Moreover \(f\) and \(g\) are said to be \((\gamma, \delta)\)-equal, denoted by \(f =_{(\gamma, \delta)} g\), if \(f \subseteq \triangleright q_\gamma \delta g\) and \(g \subseteq \triangleright q_\gamma \delta f\).

The above definitions can be found in [41].

Lemma 99 [41] Let \(f\) and \(g\) be fuzzy subsets of \(F(X)\). Then \(f \subseteq \triangleright q_\gamma \delta g\) if and only if \(\max\{f(x), \gamma\} \geq \min\{g(x), \delta\}\) for all \(x \in X\).

Lemma 100 [41] Let \(f, g\) and \(h\) be \(F(X)\). If \(f \subseteq \triangleright q_\gamma \delta g\) and \(g \subseteq \triangleright q_\gamma \delta h\), then \(f \subseteq \triangleright q_\gamma \delta h\).

The relation \(=_{(\gamma, \delta)}\) is equivalence relation on \(F(X)\), see [41]. Moreover, \(f =_{(\gamma, \delta)} g\) if and only if \(\max\{\min\{f(x), \gamma\}, \delta\} = \max\{\min\{g(x), \delta\}, \gamma\}\) for all \(x \in X\).

Lemma 101 Let \(A, B\) be any non-empty subsets of an AG-groupoid \(S\) with a left identity. Then we have

1. \(A \subseteq B\) if and only if \(X^\gamma_A \subseteq \triangleright q_\gamma \delta X^\delta_B\), where \(r \in (\gamma, 1]\) and \(\gamma, \delta \in [0, 1]\).
2. \(X^\gamma_A \cap X^\delta_B =_{(\gamma, \delta)} X^\gamma_{(A \cap B)}\).
3. \(X^\gamma_A \triangleright q_\delta X^\delta_B =_{(\gamma, \delta)} X^\gamma_{(A \triangleright q_\delta B)}\).
3.2 Some Basic Results

Lemma 102 If $S$ is an AG-groupoid with a left identity then $(ab)^2 = a^2b^2 = b^2a^2$ for all $a$ and $b$ in $S$.

Proof. It follows by medial and paramedial laws. □

Definition 103 A fuzzy subset $f$ of an AG-groupoid $S$ is called an $(\in_\gamma, \in_\gamma \lor q_\delta)$-fuzzy AG-subgroupoid of $S$ if for all $x, y \in S$ and $t, s \in (\gamma, 1]$, such that $x_t \in_\gamma f$, $y_s \in_\gamma f$ we have $(xy)_{\min\{t, s\}} \in_\gamma \lor q_\delta f$.

Theorem 104 Let $f$ be a fuzzy subset of an AG groupoid $S$. Then $f$ is an $(\in_\gamma, \in_\gamma \lor q_\delta)$-fuzzy AG subgroupoid of $S$ if and only if $\max\{f(xy), \gamma\} \geq \min\{f(x), f(y), \delta\}$, where $\gamma, \delta \in [0, 1]$.

Proof. Let $f$ be a fuzzy subset of an AG-groupoid $S$ which is $(\in_\gamma, \in_\gamma \lor q_\delta)$-fuzzy subgroupoid of $S$. Assume that there exists $x, y \in S$ and $t \in (\gamma, 1]$, such that

$$\max\{f(xy), \gamma\} < t \leq \min\{f(x), f(y), \delta\}.$$  

Then $\max\{f(xy), \gamma\} < t$, this implies that $f(xy) < t \leq \gamma$, which further implies that $(xy)_{\min\{t, s\}} \in \lor q_\delta f$ and $\min\{f(x), f(y), \delta\} \geq t$, therefore $\min\{f(x), f(y)\} \geq t$ this implies that $f(x) \geq t > \gamma$, $f(y) \geq \gamma$, implies that $x_t \in_\gamma f$, $y_s \in_\gamma f$ but $(xy)_{\min\{t, s\}} \in_\gamma \lor q_\delta f$ a contradiction to the definition. Hence

$$\max\{f(xy), \gamma\} \geq \min\{f(x), f(y), \delta\}$$ for all $x, y \in S$.

Conversely, assume that there exist $x, y \in S$ and $t, s \in (\gamma, 1]$ such that $x_t \in_\gamma f$, $y_s \in_\gamma f$ by definition we write $f(x) \geq t > \gamma$, $f(y) \geq s > \gamma$, then $\max\{f(xy), \delta\} \geq \min\{f(x), f(y), \delta\}$ this implies that $f(xy) \geq \min\{t, s, \delta\}$. Here arises two cases,

Case(a): If $\{t, s\} \leq \delta$ then $f(xy) \geq \min\{t, s\} > \gamma$ this implies that $(xy)_{\min\{t, s\}} \in_\gamma f$.

Case(b): If $\{t, s\} > \delta$ then $f(xy) + \min\{t, s\} > 2\delta$ this implies that $(xy)_{\min\{t, s\}} \lor q_\delta f$.

From both cases we write $(xy)_{\min\{t, s\}} \in_\gamma \lor q_\delta f$ for all $x, y \in S$. □

Definition 105 A fuzzy subset $f$ of an AG-groupoid $S$ with a left identity is called an $(\in_\gamma, \in_\gamma \lor q_\delta)$-fuzzy left (resp right) ideal of $S$ if for all $x, y \in S$ and $t, s \in (\gamma, 1]$ such that $y_t \in_\gamma f$ we have $(xy)_t \in_\gamma \lor q_\delta f$ (resp $x_t \in_\gamma f$ implies that $(xy)_t \in_\gamma \lor q_\delta f$).

Theorem 106 A fuzzy subset $f$ of an AG-groupoid $S$ with left identity is called $(\in_\gamma, \in_\gamma \lor q_\delta)$-fuzzy left (resp right) ideal of $S$ if and only if

$$\max\{f(xy), \gamma\} \geq \min\{f(y), \delta\}$$ (resp $\max\{f(xy), \gamma\} \geq \min\{f(x), \delta\}$).
Proof. Let \( f \) be an \( (\in_\gamma, \in_\gamma \vee q_\delta) \)-fuzzy left ideal of \( S \). Let there exists \( x, y \in S \) and \( t \in (\gamma, 1] \) such that

\[
\max\{f(xy), \gamma\} < t \leq \min\{f(y), \delta\}.
\]

Then \( \max\{f(xy), \gamma\} < t \leq \gamma \) this implies that \((xy), \in_\gamma f\) which further implies that \((xy), \in_\gamma \vee q_\delta f\), As \( \min\{f(y), \delta\} \geq t > \gamma \) which implies that \( f(y) \geq t > \gamma \), this implies that \( y_t \in_\gamma f \). But \((xy), \in_\gamma \vee q_\delta f\) a contradiction to the definition. Thus

\[
\max\{f(xy), \gamma\} \geq \min\{f(y), \delta\}.
\]

Conversely, assume that there exist \( x, y \in S \) and \( t, s \in (\gamma, 1] \) such that

\[
y_t \in_\gamma f \quad \text{but} \quad (xy), \in_\gamma \vee q_\delta f,
\]

then \( f(y) \geq t > \gamma \), \( f(xy) < \min\{f(y), \delta\} \) and \( f(xy) + t \leq 2\delta \). It follows that \( f(xy) < \delta \) and so \( \max\{f(xy), \gamma\} < \min\{f(y), \delta\} \) which is a contradiction. Hence \( y_t \in_\gamma f \) this implies that \((xy), \in_\gamma \vee q_\delta f \) (resp \( x_t \in_\gamma f \) implies \((xy), \in_\gamma \vee q_\delta f \)) for all \( x, y \in S \).

**Definition 107** A fuzzy subset \( f \) of an AG-groupoid \( S \) is called \((\in_\gamma, \in_\gamma \vee q_\delta)\)-fuzzy bi-ideal of \( S \) if for all \( x, y \) and \( z \in S \) and \( t, s \in (\gamma, 1] \), the following conditions hold.

1. if \( x_t \in_\gamma f \) and \( y_s \in_\gamma f \) implies that \((xy), \in_\gamma \vee q_\delta f \).
2. if \( x_t \in_\gamma f \) and \( z_s \in_\gamma f \) implies that \((xz), \in_\gamma \vee q_\delta f \).

**Theorem 108** A fuzzy subset \( f \) of an AG-groupoid \( S \) with left identity is called \((\in_\gamma, \in_\gamma \vee q_\delta)\)-fuzzy bi-ideal of \( S \) if and only if

1. \( \max\{f(xy), \gamma\} \geq \min\{f(x), f(y), \delta\} \).
2. \( \max\{f((xy)z), \gamma\} \geq \min\{f(x), f(z), \delta\} \).

**Proof.** (1) \( \Leftrightarrow \) (I) is the same as theorem 104.

(2) \( \Rightarrow \) (II) Assume that \( x, y \in S \) and \( t, s \in (\gamma, 1] \) such that

\[
\max\{f((xy)z), \gamma\} < t \leq \min\{f(x), f(z), \delta\}.
\]

Then \( \max\{f((xy)z), \gamma\} < t \) which implies that \( f((xy)z) < t \) this implies that \((xy)z), \in_\gamma f\) which further implies that \((xy)z), \in_\gamma \vee q_\delta f\). Also \( \min\{f(x), f(z), \delta\} \geq t > \gamma \), this implies that \( f(x) \geq t > \gamma \), \( f(z) \geq t > \gamma \) implies that \( x_t \in_\gamma f \), \( z_t \in_\gamma f \). But \((xy)z), \in_\gamma \vee q_\delta f\), a contradiction. Hence

\[
\max\{f((xy)z), \gamma\} \geq \min\{f(x), f(z), \delta\}.
\]

(II) \( \Rightarrow \) (2) Assume that \( x, y \in S \) and \( t, s \in (\gamma, 1] \), such that \( x_t \in_\gamma f \), \( z_t \in_\gamma f \) but \((xy)z), \in_\gamma \vee q_\delta f\), then \( f(x) \geq t > \gamma \), \( f(z) \geq t > \gamma \), \( f((xy)z) < \min\{f(x), f(y), \delta\} \) and \( f((xy)z) = \min\{t, s\} \leq 2\delta \). It follows that \( f((xy)z) < \delta \) and so \( \max\{f((xy)z), \gamma\} < \min\{f(x), f(y), \delta\} \) a contradiction. Hence \( x_t \in_\gamma f \), \( z_t \in_\gamma f \) implies that \((xy)z), \in_\gamma \vee q_\delta f\) for all \( x, y \in S \).
Example 109 Consider an AG-groupoid $S = \{1, 2, 3\}$ in the following multiplication table.

<table>
<thead>
<tr>
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<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Define a fuzzy subset $f$ on $S$ as follows:

$f(x) = \begin{cases} 
0.41 & \text{if } x = 1, \\
0.44 & \text{if } x = 2, \\
0.42 & \text{if } x = 3.
\end{cases}$

Then, we have

- $f$ is an $(\in_{0.1}, \in_{0.1} \vee q_{0.11})$-fuzzy left ideal,
- $f$ is not an $(\in, \in \vee q_{0.11})$-fuzzy left ideal,
- $f$ is not a fuzzy left ideal.

Example 110 Let $S = \{1, 2, 3\}$ and the binary operation $\circ$ be defined on $S$ as follows:

<table>
<thead>
<tr>
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<tbody>
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</table>

Then clearly $(S, \circ)$ is an AG-groupoid. Defined a fuzzy subset $f$ on $S$ as follows:

$f(x) = \begin{cases} 
0.44 & \text{if } x = 1, \\
0.6 & \text{if } x = 2, \\
0.7 & \text{if } x = 3.
\end{cases}$

Then, we have

- $f$ is an $(\in_{0.4}, \in_{0.4} \vee q_{0.45})$-fuzzy left ideal of $S$.
- $f$ is not an $(\in_{0.4}, \in_{0.4} \vee q_{0.45})$-fuzzy right ideal of $S$.

Example 111 Let $S = \{1, 2, 3\}$, then binary operation $\cdot$ defined on $S$ as follows:

<table>
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<tr>
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<th>2</th>
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</thead>
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<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Clearly $(S, \cdot)$ is an AG-groupoid. Let us defined a fuzzy subset $f$ on $S$ as follows:

$f(x) = \begin{cases} 
0.6 & \text{if } x = 1, \\
0.4 & \text{if } x = 2, \\
0.3 & \text{if } x = 3.
\end{cases}$

Clearly $f$ is an $(\gamma, \gamma \vee q_{0.8})$-fuzzy left ideal of $S$. 
Lemma 112 Let \( f \) be a fuzzy subset of an AG-groupoid \( S \). Then \( f \) is an \((\in, \in \lor \notin)_q\)-fuzzy bi-ideal of \( S \) if and only if \( \max\{f(a), \gamma\} \geq \min\{(f \circ S \circ f)(a), \delta\} \).

Proof. Assume that \( f \) is an \((\in, \in \lor \notin)_q\)-fuzzy bi-ideal of an AG-groupoid \( S \). If \( a \in S \), then there exist \( c, d, p \) and \( q \) in \( S \) such that \( a = pq \) and \( p = cd \).
Since \( f \) is an \((\in, \in \lor \notin)_q\)-fuzzy bi-ideal of \( S \), we have \( \max\{f((cd)q), \gamma\} \geq \min\{f(c), f(q), \delta\} \). Therefore,

\[
\min\{(f \circ S \circ f)(a), \delta\} = \min \left\{ \bigvee_{a=pq} \{(f \circ S)(p) \land f(q)\}, \delta \right\}
\]
\[
= \min \left\{ \bigvee_{a=pq} \left( \bigvee_{p=cd} \{f(c) \land S(d) \land f(q)\}, \delta \right) \right\}
\]
\[
= \min \left\{ \bigvee_{a=(cd)q} \{f(c) \land 1 \land f(q)\}, \delta \right\}
\]
\[
= \min \left\{ \bigvee_{a=(cd)q} \{f(c) \land f(q)\}, \delta \right\}
\]
\[
\leq \bigvee_{a=(cd)q} \{\max\{f((cd)q), \gamma\}\}
\]
\[
= \max\{f(a), \gamma\}.
\]

Hence, \( \max\{f(a), \gamma\} \geq \min\{(f \circ S \circ f)(a), \delta\} \).

Conversely, assume that \( \max\{f(a), \gamma\} \geq \min\{(f \circ S \circ f)(a), \delta\} \). Let \( a \) in \( S \), there exist \( c, d \) and \( q \) in \( S \) such that \( a = (cd)q \). Then we have

\[
\max\{f((cd)q), \gamma\} = \max\{f(a), \gamma\}
\]
\[
\geq \min\{(f \circ S \circ f)(a), \delta\}
\]
\[
= \min \left\{ \bigvee_{a=bc} \{(f \circ S)(b) \land f(c)\}, \delta \right\}
\]
\[
\geq \min \left\{ \{(f \circ S)(cd) \land f(q)\}, \delta \right\}
\]
\[
= \min \left\{ \bigvee_{cd=st} \{f(s) \land S(t) \land f(q)\}, \delta \right\}
\]
\[
\geq \min\{\min(f(c), f(q), \delta)\}
\]
\[
= \min\{\min(f(c), f(q), \delta)\}.
\]

Hence \( \max\{f((cd)q), \gamma\} \geq \min\{f(c), f(q), \delta\} \). \( \blacksquare \)
Lemma 113 Every \((\varepsilon, \varepsilon \lor q_b)-\)fuzzy left ideal of an AG-groupoid \(S\) is an \((\varepsilon, \varepsilon \lor q_b)-\)fuzzy bi-ideal of \(S\).

Proof. Let \(f\) be an \((\varepsilon, \varepsilon \lor q_b)-\)fuzzy left ideal of an AG-groupoid \(S\). For any \(a\) in \(S\), there exist \(p, q\) and for \(p\) there exists \(s, t\) in \(S\), such that \(a = pq\) and \(p = st\). Then

\[
\min\{(f \circ f)(a), \delta\} = \min\{\bigvee_{a=pq} \{((f \circ S)(p) \land f(q)), \delta\}\}
\]

\[
= \min\{\bigvee_{a=pq} \bigvee_{p=st} \{f(s) \land S(t) \land f(q), \delta\}\}
\]

\[
= \min\{\bigvee_{a=(st)q} \{f(s) \land f(q), \delta\}\}
\]

\[
= \bigvee_{a=(st)q} \min\{\min\{f(s), \delta\}, \min\{f(q), \delta\}\}
\]

\[
\leq \bigvee_{a=(st)q} \min\{\max\{f(q)t, \gamma\}, \max\{f(st)q, \gamma\}\}
\]

\[
= \min\{\max\{f(a), \gamma\}, \max\{f(a), \gamma\}\}
\]

\[
= \max\{f(a), \gamma\}.
\]

Hence \(\max\{f(a), \gamma\} \geq \min\{((f \circ S) \circ f)(a), \delta\}\). Hence \(f\) is an \((\varepsilon, \varepsilon \lor q_b)-\)fuzzy bi-ideal of \(S\). \(\Box\)

Lemma 114 Let \(f\) and \(g\) be \((\varepsilon, \varepsilon \lor q_b)-\)fuzzy left ideals of an AG-groupoid \(S\) with left identity. Then \((f \circ g)\) is an \((\varepsilon, \varepsilon \lor q_b)-\)fuzzy left ideal of \(S\).

Proof. Let \(f\) be any \((\varepsilon, \varepsilon \lor q_b)-\)fuzzy AG-subgroupoid and \(g\) be an \((\varepsilon, \varepsilon \lor q_b)-\)fuzzy left ideal of an AG-groupoid \(S\) with left identity. So for any \(y\) in \(S\) there exists \(a\) and \(b\) in \(S\) such that \(y = ab\). Therefore

\[
xy = x(ab) = a(xb).
\]
Lemma 115 If \( L \) is a left ideal of an AG-groupoid \( S \) if and only if \( X^\delta_L \) is \((\in \gamma, \in \gamma \vee q_k)\)-fuzzy left ideal of \( S \).

Proof. (i) Let \( x, y \in L \) which implies that \( xy \in L \). Then by definition we get \( X^\delta_L(xy) \geq \delta \), \( X^\delta_L(x) \geq \delta \) and \( X^\delta_L(y) \geq \delta \) but \( \delta \geq \gamma \). Thus

\[
\max\{X^\delta_L(xy), \gamma\} = X^\delta_L(xy) \text{ and } \min\{X^\delta_L(y), \delta\} = \delta.
\]

Hence \( \max\{X^\delta_L(xy), \gamma\} \geq \min\{X^\delta_L(x), \delta\} \).

(ii) Let \( x \in L \) and \( y \notin L \), which implies that \( xy \notin L \). Then by definition \( X^\delta_L(x) \geq \delta \), \( X^\delta_L(y) \leq \gamma \) and \( X^\delta_L(xy) \leq \gamma \). Therefore

\[
\max\{X^\delta_L(xy), \gamma\} = \gamma \text{ and } \max\{X^\delta_L(x), \delta\} = X^\delta_L(y).
\]

Hence \( \max\{X^\delta_L(xy), \gamma\} \geq \min\{X^\delta_L(y), \delta\} \).

(iii) Let \( x \notin L \), \( y \in L \) which implies that \( xy \in L \). Then by definition, we get \( X^\delta_L(xy) \geq \delta \), \( X^\delta_L(y) \geq \delta \) and \( X^\delta_L(x) \leq \gamma \). Thus

\[
\max\{X^\delta_L(xy), \gamma\} = X^\delta_L(xy) \text{ and } \min\{X^\delta_L(y), \delta\} = \delta.
\]

Hence \( \max\{X^\delta_L(xy), \gamma\} \geq \min\{X^\delta_L(y), \delta\} \).

(iv) Let \( x, y \notin L \) which implies that \( xy \notin L \). Then by definition we get such that \( X^\delta_L(xy) < \gamma \), \( X^\delta_L(y) < \gamma \) and \( X^\delta_L(x) < \gamma \). Thus

\[
\max\{X^\delta_L(xy), \gamma\} = \gamma \text{ and } \min\{X^\delta_L(y), \delta\} = X^\delta_L(y).
\]

Hence \( \max\{X^\delta_L(xy), \gamma\} \geq \min\{X^\delta_L(y), \delta\} \).
Converse, let \( sl \in SL \), where \( l \in L \) and \( s \in S \). Now by hypothesis \( \max \{ X_{\gamma L}^\delta((sl), \gamma) \} \geq \min \{ X_{\gamma L}^\delta(l), \delta \} \). Since \( l \in L \), therefore \( X_{\gamma L}^\delta(l) \geq \delta \) which implies that \( \min \{ X_{\gamma L}^\delta(l), \delta \} = \delta \). Thus
\[
\max \{ X_{\gamma L}^\delta(sl), \gamma \} \geq \delta.
\]
This clearly implies that \( X_{\gamma L}^\delta(sl) \geq \delta \). Therefore \( sl \in L \). Hence \( L \) is a left ideal of \( S \). ■

Similarly we can prove the following lemma.

**Lemma 116** If \( B \) is a bi-ideal of an AG-groupoid \( S \) if and only if \( X_{\gamma B}^\delta \) is \((\gamma, \gamma \vee q_{\delta})\)-fuzzy bi-ideal ideal of \( S \).

### 3.3 \((\gamma, \gamma \vee q_{\delta})\)-fuzzy Ideals of Intra Regular AG-groupoids

An element \( a \) of an AG-groupoid \( S \) is called **intra-regular** if there exist \( x, y \in S \) such that \( a = (xa^2)y \) and \( S \) is called **intra-regular**, if every element of \( S \) is intra-regular.

**Theorem 117** Let \( S \) be an AG-groupoid with left identity then the following conditions are equivalent.

(i) \( S \) is intra regular.
(ii) \( L[a] \cap L[a] \subseteq L[a]L[a] \), for all \( a \) in \( S \).
(iii) \( L_1 \cap L_2 \subseteq L_1L_2 \), for all left ideals \( L_1, L_2 \) of \( S \).
(iv) \( f \cap g \subseteq \vee q_{(\gamma, \delta)}f \circ g \), for all \((\gamma, \gamma \vee q_{\delta})\)-fuzzy left ideals \( f \) and \( g \) of \( S \).

**Proof.** (i) \( \Rightarrow \) (iv) Since \( S \) is intra regular therefore for any \( a \) in \( S \) there exist \( x, y \) in \( S \) such that \( a = (xa^2)y \). Then
\[
a = (xa^2)y = (xa^2)(y_1y_2) = (y_2y_1)(a^2x) = a^2[(y_2y_1)x] = [a(y_2y_1)](ax) = (xa)[(y_2y_1)a].
\]

Let for any \( a \) in \( S \) there exist \( p \) and \( q \) in \( S \) such that \( a = pq \), then
\[
\max \{ (f \circ g)(a), \gamma \} = \max \left\{ \bigvee_{a=pq} \{ (f \wedge g)(q), \gamma \} \right\} \\
\geq \max \{ \min \{ f(xa)\}, g((y_2y_1)a) \}, \gamma \} \\
= \min \{ \max \{ f(a), \gamma \}, \max \{ g(a), \gamma \} \} \\
\geq \min \{ \min \{ f(a), \delta \}, \min \{ g(a), \delta \} \} \\
= \min \{ f(a), g(a), \delta \}.
\]

Thus \( f \cap g \subseteq \vee q_{(\gamma, \delta)}f \circ g \).
3. Generalized Fuzzy Left Ideals in AG-groupoids

\[ (iv) \implies (iii) \] If \( B \) is a bi-ideal of \( S \). Then by \((iii)\), we get

\[ X^\delta_{\gamma L_1 \cap L_2} = (\gamma, \delta) X^\delta_{\gamma L_1} \cap X^\delta_{\gamma L_2} \subseteq \vee q(\gamma, \delta) X^\delta_{\gamma L_1} \circ X^\delta_{\gamma L_2} = (\gamma, \delta) \vee q(\gamma, \delta) X^\delta_{\gamma L_1 L_2}. \]

Hence \( L_1 \cap L_2 \subseteq L_1 L_2 \).

\((iii) \implies (ii)\) It is obvious.

\((ii) \implies (i)\)

\[ (a \cup Sa) \cap (a \cup Sa) \subseteq (a \cup Sa) (a \cup Sa) \]
\[ = a^2 \cup a(Sa) \cup (Sa)a \cup (Sa)(Sa) \]
\[ = a^2 \cup S(aa) \cup (aa)S \cup (SS)(aa) \]
\[ = a^2 \cup Sa^2 \cup a^2S \cup Sa^2 \]
\[ = a^2 \cup Sa^2 \]

Thus \( a = a^2 \) or \( a \in Sa^2 \). Hence \( S \) is intra regular. \( \blacksquare \)

**Corollary 118** Let \( S \) be an AG-groupoid with left identity then the following conditions are equivalent.

(i) \( S \) is intra regular.

(ii) \( L[a] \subseteq L[a]L[a] \), for all \( a \) in \( S \).

(iii) \( L \subseteq L^2 \), for all left ideals \( L \) of \( S \).

(iv) \( f \subseteq \vee q(\gamma, \delta) f \circ f \), for all \((\in, \in \vee q_3)\)-fuzzy left ideals \( f \) of \( S \).

**Theorem 119** Let \( S \) be an AG-groupoid with left identity then the following conditions are equivalent.

(i) \( S \) is intra regular.

(ii) \( L[a] \cap L[a] \cap L[a] \subseteq (L[a]L[a])L[a] \), for all \( a \) in \( S \).

(iii) \( A \cap B \cap C \subseteq (AB)C \), for all left ideals \( A, B \) and \( C \) of \( S \).

(iv) \( f \cap g \cap h \subseteq \vee q(\gamma, \delta) (f \circ g) \circ h \), for all \((\in, \in \vee q_3)\)-fuzzy left ideals \( f, g \) and \( h \) of \( S \).

**Proof.** \((i) \implies (iv)\) For every \( a \) in \( S \), we have \( a = (xa^2)y \), this by (1) and left invertive law implies that \( a = (y(xa))a \). Now using (1), medial, paramedial laws, we get

\[ y(xa) = y[x(xa^2)y] = y[(xa^2)(xy)] = (xa^2)(y(xy)) = (xa^2)(xy^2) \]
\[ = (xx)(a^2y^2) = a^2(x^2y^2) = (ax^2)(ay^2) = (y^2a)(x^2a). \]
Let for any \( a \) in \( S \) there exist \( p \) and \( q \) in \( S \) such that \( a = pq \). Then

\[
\max\{(f \circ g) \circ h(a), \gamma\} = \max_{a=pq} \left\{ \{(f \circ g)(p) \wedge h(q), \gamma\} \right\}
\]

\[
= \max \{\min\{(f \circ g)(y(xa)), h(a), \gamma\}\}
\]

\[
= \max \left\{ \min_{y(xa)=rs} \{f(r) \wedge g(s), h(a), \gamma\} \right\}
\]

\[
\geq \min \{\max\{f(y^2a), g(x^2a), h(a), \gamma\}\}
\]

\[
= \min\{\max\{f(y^2a), \gamma\}, \max\{g(x^2a), \gamma\}, \max\{h(a), \gamma\}\}
\]

\[
\geq \min\{\min\{f(a), \delta\}, \min\{g(a), \delta\}, \min\{h(a), \delta\}\}
\]

\[
= \min\{\{f \cap g \cap h\}(a), \delta\}.
\]

Thus \( f \cap g \cap h \subseteq \forall_{(\gamma, \delta)}(f \circ g) \circ h \).

(iii) \(\Rightarrow\) (ii) If \( A, B \) and \( C \) are left ideals of \( S \). Then by (iii), we get

\[
X^\delta_{\gamma}(A \cap B \cap C) = (\gamma, \delta)X^\delta_{\gamma}A \cap X^\delta_{\gamma}C \subseteq \forall_{(\gamma, \delta)}(X^\delta_{\gamma}A \circ X^\delta_{\gamma}B) \circ X^\delta_{\gamma}C
\]

\[
= (\gamma, \delta) \circ X^\delta_{\gamma}A \circ X^\delta_{\gamma}B \circ X^\delta_{\gamma}C
\]

Hence we get \( A \cap B \cap C \subseteq (AB)C \).

(iii) \(\Rightarrow\) (ii) It is obvious.

(ii) \(\Rightarrow\) (i)

\[
(a \cup Sa) \cap (a \cup Sa) \cap (a \cup Sa)
\]

\[
\subseteq [(a \cup Sa) (a \cup Sa)] (a \cup Sa)
\]

\[
= [a^2 \cup Sa^2] (a \cup Sa) \subseteq (Sa^2)S.
\]

Hence \( S \) is intra regular. 

\textbf{Theorem 120} Let \( S \) be an AG- groupoid with left identity then the following conditions are equivalent.

(i) \( S \) is intra regular.

(ii) \( L[a] \cap L[a] \subseteq (L[a]L[a])L[a] \), for all \( a \) in \( S \).

(iii) \( A \cap B \subseteq (AB)A \), for all left ideals \( A \) and \( B \) of \( S \).

(iv) \( f \cap g \subseteq \forall_{(\gamma, \delta)}(f \circ g) \circ f \), for all \((\in_{\gamma}, \in_{\gamma} \forall_{\delta})\)-fuzzy left ideals \( f \) and \( g \) of \( S \).
Proof. (i) $\Rightarrow$ (iv) Let for any $a$ in $S$ there exist $p$ and $q$ in $S$ such that $a = pq$. Then

$$\max\{(f \circ g) \circ f(a), \gamma\} = \max_a \left\{ \left\{ (f \circ g)(p) \wedge f(q), \gamma \right\} \right\} \supseteq \max_a \left\{ \left\{ (f \circ g)((y^2a)(x^2a)) \wedge f(a), \gamma \right\} \right\}$$

$$= \max \left\{ \min \left\{ \bigvee_{(g^2a)\langle x^2a \rangle = rs} f(r) \wedge g(s), f(a), \gamma \right\} \right\}$$

$$\supseteq \max \left\{ \min \{ f(y^2a), g(x^2a), f(a), \gamma \} \right\} = \min \{ \max \{ f(y^2a), \gamma \}, \max \{ g(x^2a), \gamma \}, \min \{ f(a), \gamma \} \} \supseteq \min \{ \min \{ f(a), \delta \}, \min \{ g(a), \delta \}, \min \{ f(a), \delta \} \} \supseteq \min \{ (f \cap g \cap f)(a), \delta \}.$$

Thus $f \cap g \subseteq \vee q(\gamma, \delta)(f \circ g) \circ f$.

(iv) $\Rightarrow$ (iii) It is obvious.

(vi) $\Rightarrow$ (ii) If $A, B$ are any left ideals of $S$. Then by (iii), we get

$$X^\delta_{\gamma, A \cap B} = X^\delta_{\gamma, A \cap B \cap A} = (\gamma, \delta) X^\delta_{\gamma, A \cap B} \cap X^\delta_{\gamma, A} \subseteq \vee q(\gamma, \delta)(X^\delta_{\gamma, A} \circ X^\delta_{\gamma, B}) \circ X^\delta_{\gamma, A}$$

$$= (\gamma, \delta) \vee q(\gamma, \delta) X^\delta_{\gamma, A} \circ X^\delta_{\gamma, A} = (\gamma, \delta) \vee q(\gamma, \delta) X^\delta_{\gamma, (AB)\.}$$

Hence we get $A \cap B \subseteq (AB)\. A$.

(iii) $\Rightarrow$ (ii) It is obvious.

(ii) $\Rightarrow$ (i) It is same as (ii) $\Rightarrow$ (i) of theorem 119.

Definition 121 A fuzzy subset $f$ of an AG-groupoid $S$ is called an $(<\gamma, \in \gamma \vee q_\delta)$-fuzzy semiprime ideal if $x_t^\gamma \in \gamma f$ implies that $x_t^\gamma \in \gamma \vee q_\delta$ for all $x \in S$ and $t \in (\gamma, 1]$.

Example 122 Consider an AG-groupoid $S = \{1, 2, 3, 4, 5\}$ with the following multiplication table

<table>
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</table>

Clearly $(S, \cdot)$ is intra-regular because $1 = (3.1^2).2$, $2 = (1.2^2).5$, $3 = (5.3^2).2$, $4 = (2.4^2).1$, $5 = (3.5^2).1$. Define a fuzzy subset $f$ on $S$ as given:

$$f(x) = \begin{cases} 
0.7 & \text{if } x = 1, \\
0.6 & \text{if } x = 2, \\
0.68 & \text{if } x = 3, \\
0.63 & \text{if } x = 4, \\
0.52 & \text{if } x = 5. 
\end{cases}$$
Then it is easy to see that \( f \) is an \( (\varepsilon_{0.4}, \varepsilon_{0.4} \lor q_{0.5}) \)-fuzzy semiprime ideal of \( S \).

**Theorem 123** A fuzzy subset \( f \) of an AG-groupoid \( S \) is an \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \lor q_{\delta}) \)-fuzzy semiprime ideal if and only if \( \max\{f(x), \gamma\} \geq \min\{f(x^2), \delta\} \).

**Proof.** Let \( f \) be an \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \lor q_{\delta}) \)-fuzzy semiprime ideal of \( S \). Let there exists \( x, y \in S \) and \( t \in (\gamma, 1] \) such that \( \max\{f(x), \gamma\} < t \leq \min\{f(x^2), \delta\} \). Then \( \max\{f(x), \gamma\} < t \) implies that \( x \in \varepsilon x f \) implies that \( x > \varepsilon x q f \). As \( \min\{f(x^2), \delta\} \geq t > \gamma \) this implies that \( f(x^2) \geq t > \gamma \) implies that \( x^2 \in \varepsilon x f \).

Conversely, assume that there exist \( x, y \in S \) and \( t \in (\gamma, 1] \) such that \( x^2 \in \varepsilon x f \) but \( x \in \varepsilon x q f \), then \( f(x^2) \geq t > \gamma \) for all \( f(x) < \min\{f(x^2), \delta\} \) and \( f(x) < t \leq 2t \). It follows that \( f(x) < \delta \) and so \( \max\{f(x), \gamma\} < \min\{f(x^2), \delta\} \) which is a contradiction to the definition of semiprime ideals. Hence \( x^2 \in \varepsilon x f \) implies that \( (x^2)x \in \varepsilon x q f \) for all \( x, y \in S \).

**Theorem 124** For a non-empty subset \( I \) of an AG-groupoid \( S \) with left identity, the following conditions are equivalent.

1. \( I \) is semiprime.
2. \( X^4_{+I} \) is an \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \lor q_{\delta}) \)-fuzzy semiprime.

**Proof.** (i) \( \Rightarrow \) (ii) Let \( I \) be semiprime of an AG-groupoid \( S \). Let \( a \) be any element of \( S \) such that \( a \in I \), then \( I \) is an ideal so \( a^2 \in I \). Hence \( X^4_{+I}(a), X^4_{+I}(a^2) \geq \delta \) which implies that \( \max\{X^4_{+I}(a), \gamma\} \geq \min\{X^4_{+I}(a^2), \delta\} \).

Now let \( a \notin I \), since \( I \) is semiprime, thus \( a^2 \notin I \). This implies that \( X^4_{+I}(a) \leq \gamma \) and \( X^4_{+I}(a^2) \leq \gamma \). Therefore \( \max\{X^4_{+I}(a), \gamma\} \geq \min\{X^4_{+I}(a^2), \delta\} \).

Hence, we have \( \max\{X^4_{+I}(a), \gamma\} \geq \min\{X^4_{+I}(a^2), \delta\} \) for all \( a \in S \).

(ii) \( \Rightarrow \) (i) Let \( X^4_{+I} \) is fuzzy semiprime. Let \( a^2 \in I \), for some \( a \in S \), this implies that \( X^4_{+I}(a^2) \geq \delta \). Now since \( X^4_{+I} \) is an \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \lor q_{\delta}) \)-fuzzy semiprime. Thus \( \max\{X^4_{+I}(a), \gamma\} \geq \min\{X^4_{+I}(a^2), \delta\} \). Therefore \( \max\{X^4_{+I}(a), \gamma\} \geq \delta \).

But \( \delta > \gamma \), so \( X^4_{+I}(a) \geq \delta \). Thus \( a \in I \). Hence \( I \) is semiprime.

**Theorem 125** Let \( S \) be an AG-groupoid with left identity then the following conditions are equivalent.

1. \( S \) is intra-regular.
2. For every ideal of \( S \) is semiprime.
3. For every left ideal of \( S \) is semiprime.
4. For every \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \lor q_{\delta}) \)-fuzzy left ideal of \( S \) is fuzzy semiprime.

**Proof.** (i) \( \Rightarrow \) (iv) Let \( f \) be an \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \lor q_{\delta}) \)-fuzzy left ideal of an intra regular AG-groupoid \( S \). Now since \( S \) is intra-regular so for each \( a \in S \) there exists \( x, y \in S \) such that \( a = (xa^2)y \). Now using medial law, paramedial law and left inverse law, we get

\[
a = (xa^2)y = [(ex)(aa)]y = [(aa)(xe)]y = [y(xe)]a^2.
\]
Thus

$$\max\{f(a), \gamma\} = \max\{f([y(xe)]a^2), \gamma\}$$
$$\geq \min\{f(a^2), \delta\}.$$ 

(iv) ⇒ (iii) and (iii) ⇒ (ii) are obvious.

(ii) ⇒ (i) Assume that every ideal is semiprime and since $Sa^2$ is an ideal containing $a^2$. Thus

$$a \in Sa^2 = (SS)a^2 = (a^2S)S = (Sa^2)S.$$ 

Hence $S$ is an intra-regular AG-groupoid. ■
3. Generalized Fuzzy Left Ideals in AG-groupoids
Generalized Fuzzy Prime and Semiprime Ideals of Abel Grassmann Groupoids

In this chapter we introduce \((\in\gamma, \in\gamma \lor q\delta)\)-fuzzy prime (semiprime) ideals in AG-groupoids. We characterize intra regular AG-groupoids using the properties of \((\in\gamma, \in\gamma \lor q\delta)\)-fuzzy semiprime ideals.

**Lemma 126** If \(A\) is an ideal of an AG-groupoid \(S\) if and only if \(X^A_\delta\) is \((\in\gamma, \in\gamma \lor q\delta)\)-fuzzy ideal of \(S\).

**Proof.** (i) Let \(x, y \in A\) which implies that \(xy \in A\). Then by definition we get \(X^A_\gamma(xy) \geq \delta, X^A_\gamma(x) \geq \delta\) and \(X^A_\gamma(y) \geq \delta\) but \(\delta > \gamma\). Thus

\[
\max\{X^A_\gamma(xy), \gamma\} = X^A_\gamma(xy) \quad \text{and} \quad \min\{X^A_\gamma(x), X^A_\gamma(y), \delta\} = \min\{X^A_\gamma(x), X^A_\gamma(y)\} = \delta.
\]

Hence \(\max\{X^A_\gamma(xy), \gamma\} \geq \min\{X^A_\gamma(x), X^A_\gamma(y), \delta\}\).

(ii) Let \(x \notin A\) and \(y \in A\), which implies that \(xy \notin A\). Then by definition, we get \(X^A_\gamma(x) \leq \gamma, X^A_\gamma(y) \geq \delta\) and \(X^A_\gamma(xy) \leq \gamma\). Therefore

\[
\max\{X^A_\gamma(xy), \gamma\} = \gamma \quad \text{and} \quad \min\{X^A_\gamma(x), X^A_\gamma(y), \delta\} = X^A_\gamma(y).
\]

Hence \(\max\{X^A_\gamma(xy), \gamma\} \geq \min\{X^A_\gamma(x), X^A_\gamma(y), \delta\}\).

(iii) Let \(x \in A, y \notin A\) which implies that \(xy \notin A\). Then by definition, we get \(X^A_\gamma(xy) \leq \gamma, X^A_\gamma(y) \leq \gamma\) and \(X^A_\gamma(x) \geq \delta\). Thus

\[
\max\{X^A_\gamma(xy), \gamma\} = \gamma \quad \text{and} \quad \min\{X^A_\gamma(x), X^A_\gamma(y), \delta\} = X^A_\gamma(y).
\]

Hence \(\max\{X^A_\gamma(xy), \gamma\} \geq \min\{X^A_\gamma(x), X^A_\gamma(y), \delta\}\).

(iv) Let \(x, y \notin A\) which implies that \(xy \notin A\). Then by definition we get such that \(X^A_\gamma(xy) \leq \gamma, X^A_\gamma(y) \leq \gamma\) and \(X^A_\gamma(x) \leq \gamma\). Thus

\[
\max\{X^A_\gamma(xy), \gamma\} = \gamma \quad \text{and} \quad \min\{X^A_\gamma(x), X^A_\gamma(y), \delta\} = \{X^A_\gamma(x), X^A_\gamma(y)\} = \gamma.
\]
Hence \( \max\{X_{\gamma A}^\delta(xy), \gamma\} \geq \min\{X_{\gamma A}^\delta(x), X_{\gamma A}^\delta(y), \delta\} \).

Converse, let \((xy) \in AS\) where \(x \in A\) and \(y \in S\), and \((xy) \in SA\) where \(x \in A\) and \(y \in S\). Now by hypothesis \( \max\{X_{\gamma A}^\delta(xy), \gamma\} \geq \min\{X_{\gamma B}^\delta(x), X_{\gamma B}^\delta(y), \delta\} \).

Since \(x \in A\), therefore \(X_{\gamma A}^\delta(x) \geq \delta\), and \(y \in A\) therefore \(X_{\gamma A}^\delta(y) \geq \delta\) which implies that \( \min\{X_{\gamma A}^\delta(x), X_{\gamma A}^\delta(y), \delta\} = \delta\). Thus

\[
\max\{X_{\gamma A}^\delta(xy), \gamma\} \geq \delta.
\]

This clearly implies that \(X_{\gamma A}^\delta(xy) \geq \delta\). Therefore \(xy \in A\). Hence \(A\) is an ideal of \(S\).

**Example 127** Let \(S = \{1, 2, 3\}\), and the binary operation “\(\cdot\)” be defined on \(S\) as follows.

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Then \((S, \cdot)\) is an AG-groupoid. Define a fuzzy subset \(f : S \to [0, 1]\) as follows.

\[
f(x) = \begin{cases} 
0.31 & \text{for } x = 1 \\
0.32 & \text{for } x = 2 \\
0.30 & \text{for } x = 3 
\end{cases}
\]

Then clearly

- \(f\) is an \((\in_{0.2}, \in_{0.2} \lor \lambda_{0.3})\)-fuzzy ideal of \(S\),
- \(f\) is not an \((\in_{\gamma}, \in_{\gamma} \lor \lambda_{\gamma})\)-fuzzy ideal of \(S\), because \(f(1 \cdot 2) < f(2) \land \frac{1 - 0.3}{2}\),
- \(f\) is not a fuzzy ideal of \(S\), because \(f(1 \cdot 2) < f(2)\).

**Definition 128** A fuzzy subset \(f\) of an AG-groupoid \(S\) is called an \((\in_{\gamma}, \in_{\gamma} \lor \lambda_{\gamma})\)-fuzzy bi-ideal of \(S\) if for all \(x, y, z \in S\) and \(t, s \in (\gamma, 1]\), the following conditions hold.

1. \(x \in_{\gamma} f\) and \(y \in_{\gamma} f\) implies that \((xy)_{\min\{t, s\}} \in_{\gamma} \lambda_{\gamma} f\).
2. \(x \in_{\gamma} f\) and \(z \in_{\gamma} f\) implies that \(((xy)z)_{\min\{t, s\}} \in_{\gamma} \lambda_{\gamma} f\).

**Theorem 129** A fuzzy subset \(f\) of an AG-groupoid \(S\) is \((\in_{\gamma}, \in_{\gamma} \lor \lambda_{\gamma})\)-fuzzy bi-ideal of \(S\) if and only if

1. \(\max\{f(xy), \gamma\} \geq \min\{f(x), f(y), \delta\}\).
2. \(\max\{f((xy)z), \gamma\} \geq \min\{f(x), f(z), \delta\}\).

**Proof.** (1) \(\Leftrightarrow\) (I) is the same as theorem 104.

(2) \(\Rightarrow\) (II). Assume that \(x, y \in S\) and \(t, s \in (\gamma, 1]\) such that

\[
\max\{f((xy)z), \gamma\} < t \leq \max\{f(x), f(z), \delta\}.
\]

Then \(\max\{f((xy)z), \gamma\} < t\) which implies that \(f((xy)z) < t \leq \gamma\) this implies that \(((xy)z)_{\in_{\gamma} f}\) which further implies that \(((xy)z)_{\in_{\gamma} \lambda_{\gamma} f}\) also
\[ \min\{f(x), f(z), \delta\} \geq t > \gamma, \text{ this implies that } f(x) \geq t > \gamma, f(z) \geq t > \gamma \]
implies that \( x_t \in \gamma f, z_t \in \gamma f \) but \((x'y)_s \in \gamma \sqrt{q_2} f\), a contradiction. Hence
\[
\max\{f((xy)z), \gamma\} \geq \min\{f(x), f(z), \delta\}.
\]

(II) \(\Rightarrow (2)\) Assume that \( x, y, z \in S \) and \( t, s \in (\gamma, 1] \), such that \( x_t \in \gamma f, z_t \in \gamma f \) by definition we can write \( f(x) \geq t > \gamma, f(z) \geq s > \gamma \), then \( \max\{f((xy)z), \delta\} \geq \min\{f(x), f(y), \delta\} \) this implies that \( f((xy)z) \geq \min\{t, s, \delta\} \). We consider two cases here,

Case (i): If \( \{t, s\} \leq \delta \) then \( f((xy)z) \geq \min\{t, s\} > \gamma \) this implies that \((xy)z)_{\min\{t,s\}} \in \gamma f\.

Case (ii): If \( \{t, s\} > \delta \) then \( f((xy)z) + \{t, s\} > 2\delta \) this implies that \((xy)z)_{\min\{t,s\}} \notin S\).

From both cases we write \((xy)z)_{\min\{t,s\}} \in \gamma \sqrt{q_2} f\) for all \( x, y, z \in S \).

**Lemma 130** A subset \( B \) of an AG-groupoid \( S \) is a bi-ideal if and only if \( X^B_{\gamma} \) is an \((\in, \lambda, \gamma, \sqrt{q_2})\)-fuzzy bi-ideal of \( S \).

**Proof.** (i) Let \( B \) be a bi-ideal and assume that \( x, y \in B \) then for any \( a \in S \) we have \((xa)y \in B\), thus \( X^B_{\gamma}((xa)y) \geq \delta \). Now since \( x, y \in B \) so \( X^B_{\gamma}(x) \geq \delta, X^B_{\gamma}(y) \geq \delta \) which clearly implies that \( \min\{X^B_{\gamma}(x), X^B_{\gamma}(y)\} \geq \delta \). Thus
\[
\max\{X^B_{\gamma}((xa)y), \gamma\} = X^B_{\gamma}((xa)y)
\]
\[
\min\{X^B_{\gamma}(x), X^B_{\gamma}(y), \delta\} = \delta.
\]

Hence \( \max\{X^B_{\gamma}((xa)y), \gamma\} \geq \min\{X^B_{\gamma}(x), X^B_{\gamma}(y), \delta\} \).

(ii) Let \( x \in B, y \notin B \), then \((xa)y \notin B\), for all \( a \in S \). This implies that \( X^B_{\gamma}((xa)y) \leq \gamma, X^B_{\gamma}(x) \geq \delta \) and \( X^B_{\gamma}(y) < \gamma \). Therefore
\[
\max\{X^B_{\gamma}((xa)y), \gamma\} = \gamma \text{ and}
\]
\[
\min\{X^B_{\gamma}(x), X^B_{\gamma}(y), \delta\} = X^B_{\gamma}(y).
\]

Hence \( \max\{X^B_{\gamma}((xa)y), \gamma\} \geq \min\{X^B_{\gamma}(x), X^B_{\gamma}(y), \delta\} \).

(iii) Let \( x \notin B, y \in B \) implies that \((xa)y \notin B\), for all \( a \in S \). This implies that \( X^B_{\gamma}((xa)y) \leq \gamma, X^B_{\gamma}(x) \leq \gamma \). \( X^B_{\gamma}(y) \geq \delta \) then
\[
\max\{X^B_{\gamma}((xa)y), \gamma\} = \gamma \text{, and}
\]
\[
\min\{X^B_{\gamma}(x), X^B_{\gamma}(y), \delta\} = X^B_{\gamma}(x)
\]

Therefore
\[
\max\{X^B_{\gamma}((xa)y), \gamma\} \geq \min\{X^B_{\gamma}(x), X^B_{\gamma}(y), \delta\}.
\]

(iv) Let \( x, y \notin B \) which implies that \((xa)y \notin B\), for all \( a \in S \). This implies that \( \min\{X^B_{\gamma}(x), X^B_{\gamma}(y)\} \leq \gamma, X^B_{\gamma}((xa)y) \leq \gamma \). Thus
\[
\max\{X^B_{\gamma}((xa)y), \gamma\} = \gamma \text{ and}
\]
\[
\min\{X^B_{\gamma}(x), X^B_{\gamma}(y), \delta\} = \min\{X^B_{\gamma}(x), X^B_{\gamma}(y)\} \leq \gamma.
\]
Hence \( \max\{X^\delta_B((xa)y), \gamma\} \geq \min\{X^\delta_B(x), X^\delta_B(y), \delta\} \).

If \((xa)y \in B\), then \(\min\{X^\delta_B(x), X^\delta_B(y)\} \geq \delta\). Thus
\[
\max\{X^\delta_B((xa)y), \gamma\} = X^\delta_B((xa)y) \quad \text{and} \quad \min\{X^\delta_B(x), X^\delta_B(y), \delta\} = \delta.
\]

Hence \(\max\{X^\delta_B((xa)y), \gamma\} \geq \min\{X^\delta_B(x), X^\delta_B(y), \delta\}\).

Converse, let \((b_1s)b_2 \in (BS)B\), where \(b_1, b_2 \in B\) and \(s \in S\). Now by hypothesis \(\max\{X^\delta_B((b_1s)b_2), \gamma\} \geq \min\{X^\delta_B(b_1), X^\delta_B(b_2), \delta\}\). Since \(b_1, b_2 \in B\), therefore \(X^\delta_B(b_1) \geq \delta\) and \(X^\delta_B(b_2) \geq \delta\) which implies that \(\min\{X^\delta_B(b_1), X^\delta_B(b_2), \delta\} = \delta\). Thus
\[
\max\{X^\delta_B((b_1s)b_2), \gamma\} \geq \delta.
\]

This clearly implies that \(X^\delta_B((b_1s)b_2) \geq \delta\). Therefore \((b_1s)b_2 \in B\). Hence \(B\) is a bi-ideal of \(S\). \(\blacksquare\)

**Definition 131** A fuzzy AG-subgroupoid \(f\) of an AG-groupoid \(S\) is called an \((\in, \in, \gamma \vee \delta)\)-fuzzy interior ideal of \(S\) if for all \(x, y, z \in S\) and \(t \in (\gamma, 1]\) the following conditions holds.

1. \(x_t \in f\), \(y_s \in f\) implies that \((xy)_{\text{min}\{t,s\}} \in \gamma \vee \delta f\).
2. \(y_t \in f\) implies \(\{xy\}_{\text{min}\{t,s\}} \in \gamma \vee \delta f\).

**Lemma 132** A fuzzy subset \(f\) of \(S\) is an \((\in, \in, \gamma \vee \delta)\)-fuzzy interior ideal of an AG-groupoid \(S\) if and only if it satisfies the following conditions.

1. \(\max\{f(xy), \gamma\} \geq \min\{f(x), f(y), \delta\} \) for all \(x, y \in S\) and \(\gamma, \delta \in [0, 1]\).
2. \(\max\{f(xy), \gamma\} \geq \min\{f(y), \delta\} \) for all \(x, y, z \in S\) and \(\gamma, \delta \in [0, 1]\).

**Proof.** (I) \(\Rightarrow\) (II) Let \(f\) be an \((\in, \in, \gamma \vee \delta)\)-fuzzy interior ideal of \(S\). Let (I) holds. Let us consider on contrary. If there exists \(x, y \in S\) and \(t \in (\gamma, 1]\) such that
\[
\max\{f(xy), \gamma\} \leq t \leq \min\{f(x), f(y), \delta\}.
\]

Then \(\max\{f(xy), \gamma\} < t \leq \gamma\) this implies that \((xy)_t \in f\) again implies that \((xy)_t \in \gamma \vee \delta f\). As \(\min\{f(x), f(y), \delta\}\) \(\geq t > \gamma\) this implies that \(f(x) \geq t > \gamma\) and \(f(y) \geq t > \gamma\) implies that \(x_t \in f\) and \(y_t \in f\).

But \((xy)_t \in \gamma \vee \delta f\) a contradiction. Thus
\[
\max\{f(xy), \gamma\} \geq \min\{f(x), f(y), \delta\}.
\]

(III) \(\Rightarrow\) (I) Assume that \(x, y, \) in \(S\) and \(t, s \in (\gamma, 1]\) such that \(x_t \in f\) and \(y_s \in f\). Then \(f(x) \geq t > \gamma\), \(f(y) \geq t > \gamma\), \(\max\{f(xy), \gamma\} \geq \min\{f(x), f(y), \delta\} \geq \min\{t, s, \delta\}\). We consider two cases here.

Case(1): If \(\{t, s\} \leq \delta\) then \(\max\{f(xy), \gamma\} \geq \min\{t, s\} > \gamma\) this implies that \((xy)_{\text{min}\{t,s\}} \in f\).
Case (2): If \( \{t, s\} > \delta \) then \( f(xy) + \min\{t, s\} > 2\delta \) this implies that \( (xy)_{\min\{t, s\}} g f \).

Hence \( x_1 \in \gamma f_\gamma \), \( y_1 \in \gamma f \) implies that \( (xy)_{\min\{t, s\}} \in \gamma \vee g \delta f \).

(II) \( \Rightarrow \) (IV) Let \( f \) be an \( (\epsilon, \gamma) \vee g \delta f \)-fuzzy interior ideal of \( S \). Let (II) holds. Let us consider on contrary. If there exists \( y, x \in S \) and \( t \in (\gamma, 1] \) such that

\[
\max\{f((xy)z), \gamma\} < t \leq \min\{f(y), \delta\}.
\]

Then \( \max\{f((xy)z), \gamma\} < t \leq \gamma \) this implies that \( ((xy)z)_t \in \gamma f \) further implies that \( ((xy)z)_t \in \gamma \vee g \delta f \). As \( \min\{f(y), \delta\} \geq t > \gamma \) this implies that \( f(y) \geq t > \gamma \) implies that \( y_1 \in \gamma f \). But \( (xyz)_t \in \gamma \vee g \delta f \) a contradiction according to definition. Thus (IV) is valid

\[
\max\{f((xy)z), \gamma\} \geq \min\{f(y), \delta\}
\]

(IV) \( \Rightarrow \) (II) Assume that \( x, y, z \) in \( S \) and \( t, s \in (\gamma, 1] \) such that \( y_1 \in \gamma f \). Then \( f(y) \geq t > \gamma \), by (IV) we write \( \max\{f((xy)z), \gamma\} \geq \min\{f(y), \delta\} \geq \min\{t, \delta\} \).

We consider two cases here,

Case (i): If \( t \leq \delta \) then \( f((xy)z) \geq t > \gamma \) this implies that \( ((xy)z)_t \in \gamma f \).

Case (ii): If \( t > \delta \) then \( f((xy)z) + t > 2\delta \) this implies that \( ((xy)z)_t \in \gamma \vee g \delta f \).

From both cases \( ((xy)z)_t \in \gamma \vee g \delta f \). Hence \( f \) be an \( (\epsilon, \gamma) \vee g \delta f \)-fuzzy interior ideal of \( S \).

**Lemma 133** If \( I \) is a interior ideal of an AG-groupoid \( S \) if and only if \( X^\delta_{\gamma I} \) be an \( (\epsilon, \gamma) \vee g \delta f \) fuzzy interior ideal of \( S \).

**Proof.** (i) Let \( x, a, y \in I \) which implies that \( (xa)y \in I \). Then by definition we get \( X^\delta_{\gamma I}((xa)y) \geq \delta \) and \( X^\delta_{\gamma I}(a) \geq \delta \), but \( \delta > \gamma \). Thus

\[
\max\{X^\delta_{\gamma I}((xa)y), \gamma\} = X^\delta_{\gamma I}((xa)y) \quad \text{and} \quad \min\{X^\delta_{\gamma I}(a), \delta\} = \delta.
\]

Hence \( \max\{X^\delta_{\gamma I}((xa)y), \gamma\} \geq \min\{X^\delta_{\gamma I}(a), \delta\} \).

(ii) Let \( x \notin I, y \notin I \) and \( a \in I \), which implies that \( (xa)y \in I \). Then by definition \( X^\delta_{\gamma I}((xa)y) \geq \delta \) and \( X^\delta_{\gamma I}(a) \geq \delta \). Therefore

\[
\max\{X^\delta_{\gamma I}((xa)y), \gamma\} = X^\delta_{\gamma I}((xa)y), \quad \text{and} \quad \min\{X^\delta_{\gamma I}(a), \delta\} = \delta.
\]

Hence \( \max\{X^\delta_{\gamma I}((xa)y), \gamma\} \geq \min\{X^\delta_{\gamma I}(a), \delta\} \).

(iii) Let \( x \in I, y \in I \) and \( a \notin I \), which implies that \( (xa)y \notin I \). Then by definition, we get \( X^\delta_{\gamma I}((xa)y) \leq \gamma \), \( X^\delta_{\gamma I}(a) \leq \gamma \). Thus

\[
\max\{X^\delta_{\gamma I}((xa)y), \gamma\} = \gamma \quad \text{and} \quad \min\{X^\delta_{\gamma I}(a), \delta\} = X^\delta_{\gamma I}(a).
\]
Hence \( \max\{X_{\gamma I}^\delta((xa)y), \gamma\} \geq \min\{X_{\gamma I}^\delta(a), \delta\}. \)

(iv) Let \( x, a, y \notin I \) which implies that \( (xa)y \notin I. \) Then by definition we get such that \( X_{\gamma I}^\delta((xa)y) \leq \gamma, \) \( X_{\gamma I}^\delta(a) \leq \gamma. \) Thus

\[
\max\{X_{\gamma I}^\delta((xa)y), \gamma\} = \gamma \quad \text{and} \quad \min\{X_{\gamma I}^\delta(a), \delta\} = X_{\gamma I}^\delta(a).
\]

Hence \( \max\{X_{\gamma I}^\delta((xa)y), \gamma\} \geq \min\{X_{\gamma I}^\delta(a), \delta\}. \)

Conversely, let \((xa)y \in (SI)S,\) where \( a \in I \) and \( x, y \in S. \) Now by hypothesis \( \max\{X_{\gamma I}^\delta((xa)y), \gamma\} \geq \min\{X_{\gamma I}^\delta(a), \delta\}. \) Since \( a \in I, \) therefore \( X_{\gamma I}^\delta(a) \geq \delta \) which implies that \( \min\{X_{\gamma I}^\delta(a), \delta\} = \delta. \) Thus

\[
\max\{X_{\gamma I}^\delta((xa)y), \gamma\} \geq \delta.
\]

This clearly implies that \( X_{\gamma I}^\delta((xa)y) \geq \delta. \) Therefore \( (xa)y \in I. \) Hence \( I \) is an interior ideal of \( S. \)

**Example 134** Consider an AG-groupoid \( S = \{1, 2, 3\} \) in the following multiplication table.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
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<tbody>
<tr>
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<tr>
<td>3</td>
<td>1</td>
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</tbody>
</table>

**Definition 135** An \((\in_\gamma, \in_\gamma \lor q_\delta)-fuzzy subset \( f \) on \( S \) is said to be prime if for all \( a, b \in S \) and \( t \in (\gamma, 1]. \) It satisfies,

\[
(1) (ab)_t \in_\gamma f \implies (a)_t \in_\gamma q_\delta f \quad \text{or} \quad (b)_t \in_\gamma q_\delta f.
\]

**Theorem 136** An \((\in_\gamma, \in_\gamma \lor q_\delta)-fuzzy prime ideal \( f \) of an AG-groupoid \( S \)

if for all \( a, b \in S, \) and \( t \in (\gamma, 1]. \) It satisfies

\[
(2) \max\{f(a), f(b), \gamma\} \geq \min\{f(ab), \delta\}.
\]
Proof. Let $f$ be an $(\in, \in, \forall_q \delta)$-fuzzy prime ideal of an AG-groupoid $S$. If there exists $a, b \in S$ and $t \in (\gamma, 1]$, such that $\max\{f(a), f(b), \gamma\} < t \leq \min\{f(ab), \delta\}$ then $\min\{f(ab), \delta\} \geq t$ implies that $f(ab) \geq t > \gamma$ and $\min\{f(a), f(b), \gamma\} < t$ this implies that $f(a) < t \leq \gamma$ or $f(b) < t \leq \gamma$ again implies that $(a)_t \in \in f$ or $(b)_t \in \in f$ i.e. $(ab)_t \in \gamma f$ or $(a)_t \in \forall_q \delta f$ or $(b)_t \in \forall_q \delta f$, which is a contradiction. Hence (2) is valid.

Conversely, assume that (2) is holds. Let $(ab)_t \in \gamma f$. Then $f(ab) \geq t > \gamma$ and by (2) we have $\max\{f(a), f(b), \gamma\} \geq \min\{f(ab), \delta\} \geq \min\{t, \delta\}$. We consider two cases here,

Case(a): If $t \leq \delta$, then $f(a) \geq t > \gamma$ or $f(b) \geq t > \gamma$ this implies that $(a)_t \in \in f$ or $(b)_t \in \in f$.

Case(b): If $t > \delta$, then $f(a) + t > 2\delta$ or $f(b) + t > 2\delta$ this implies that $(a)_t \in \forall_q f$ or $(b)_t \in \forall_q f$. Hence $f$ is prime. ■

Theorem 137 Let $I$ be an non empty subset of an AG-groupoid $S$ with left identity. Then

(i) $I$ is a prime ideal.

(ii) $\chi^\delta_{\gamma I}$ is an $(\in, \in, \forall_q \delta)$-fuzzy prime ideal of $S$.

Proof. (i) $\Rightarrow$ (ii). Let $I$ be a prime ideal of an AG-groupoid $S$. Let $(ab) \in I$ then $\chi^\delta_{\gamma I}(ab) \geq \delta$, this implies that so $ab \in I$ and $I$ is prime, so $a \in I$ or $b \in I$, by definition we can get $\chi^\delta_{\gamma I}(a) \geq \delta$ or $\chi^\delta_{\gamma I}(b) \geq \delta$, therefore

$$
\min\{\chi^\delta_{\gamma I}(ab), \delta\} = \delta \quad \text{and}
\max\{\chi^\delta_{\gamma I}(a), \chi^\delta_{\gamma I}(b), \gamma\} = \max\{\chi^\delta_{\gamma I}(a), \chi^\delta_{\gamma I}(b)\} \geq \delta.
$$

which implies that $\max\{\chi^\delta_{\gamma I}(a), \chi^\delta_{\gamma I}(b), \gamma\} \geq \min\{\chi^\delta_{\gamma I}(ab), \delta\}$. Hence $\chi^\delta_{\gamma I}$ is an $(\in, \in, \forall_q \delta)$-fuzzy prime ideal of $S$.

(ii) $\Rightarrow$ (i). Assume that $\chi^\delta_{\gamma I}$ is a prime $(\in, \in, \forall_q \delta)$-fuzzy ideal of $S$, then $I$ is prime. Let $(ab) \in I$ by definition we can write $\chi^\delta_{\gamma I}(ab) \geq \delta$, therefore, by given condition we have $\max\{\chi^\delta_{\gamma I}(a), \chi^\delta_{\gamma I}(b), \gamma\} \geq \min\{\chi^\delta_{\gamma I}(ab), \delta\} = \delta$.

This implies that $\chi^\delta_{\gamma I}(a) \geq \delta$ or $\chi^\delta_{\gamma I}(b) \geq \delta$ this implies that $a \in I$ or $b \in I$. Hence $I$ is prime. ■

Example 138 Let $S = \{1, 2, 3\}$, and the binary operation “.” be defined on $S$ as follows.

<table>
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</table>

Then $(S, \cdot)$ is an intra-regular AG-groupoid with left identity 1. Define a fuzzy subset $f : S \rightarrow [0, 1]$ as follows.

$f(x) = \begin{cases} 
0.34 & \text{for } x = 1 \\
0.36 & \text{for } x = 2 \\
0.35 & \text{for } x = 3 
\end{cases}$
Then clearly

- $f$ is an $(\in_{0.2}, \in_{0.2} \lor q_{0.22})$-fuzzy prime ideal,
- $f$ is not an $(\in, \in \lor q_{0.22})$-fuzzy prime ideal,
- $f$ is not fuzzy prime ideal.

**Theorem 139** An $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy subset $f$ of an AG-groupoid $S$ is prime if and only if $U(f, t)$ is prime in AG-groupoid $S$, for all $0 < t \leq \delta$.

**Proof.** Let us consider an $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy subset $f$ of an AG-groupoid $S$ is prime and $0 < t \leq \delta$. Let $(ab) \in_{\gamma} U(f, t)$ this implies that $f(ab) \geq t > \gamma$. Then by theorem 136 $\max\{f(a), f(b), \gamma\} \geq \min\{f(ab), \delta\} \geq \min\{t, \delta\} = t$, so $f(a) \geq t > \gamma$ or $f(b) \geq t > \gamma$, which implies that $a \in_{\gamma} U(f, t)$ or $b \in_{\gamma} U(f, t)$. Therefore $U(f, t)$ is prime in AG-groupoid $S$, for all $0 < t \leq \delta$.

Conversely, assume that $U(f, t)$ is prime in AG-groupoid $S$, for all $0 < t \leq \delta$. Let $(ab)_t \in_{\gamma} f$ implies that $ab \in_{\gamma} U(f, t)$, and $U(f, t)$ is prime, so $a \in_{\gamma} U(f, t)$ or $b \in_{\gamma} U(f, t)$, that is $a_t \in_{\gamma} f$ or $b_t \in_{\gamma} f$. Thus $a_t \in_{\gamma} q_{\delta}f$ or $b_t \in_{\gamma} q_{\delta}f$. Therefore $f$ must be an $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy prime in AG-groupoid $S$. 

**Definition 140** A fuzzy subset $f$ of an AG-groupoid $S$ is said to be $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy semiprime for all $s, t \in (\gamma, 1)$ and $a \in S$. it satisfies

1. $a_t^2 \in_{\gamma} f$ implies that $a_t \in_{\gamma} q_{\delta}f$.

**Theorem 141** A fuzzy subset $f$ of an AG-groupoid $S$ is an $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy semiprime if and only if it satisfies

2. $\max\{f(a), \gamma\} \geq \min\{f(a^2), \delta\}$ for all $a \in S$.

**Proof.** (1) $\Rightarrow$ (2) Let $f$ be a fuzzy subset of an AG-groupoid $S$ which is $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy semiprime of $S$. Assume that there exists $a \in S$ and $t \in (\gamma, 1)$, such that

$$\max\{f(a), \gamma\} < t \leq \min\{f(a^2), \delta\}.$$ 

Then $\max\{f(a), \gamma\} < t$ this implies that $f(a) < t \leq \gamma$, implies that $f(a) + t < 2t \leq 2\delta$ this implies that $a_t \in_{\gamma} q_{\delta}f$ and $\min\{f(a^2), \delta\} \geq t$ this implies that $f(a^2) \geq t > \gamma$, further implies that $a_t^2 \in_{\gamma} f$ but $a_t \in_{\gamma} \sqrt{q_{\delta}f}$ a contradiction to the definition. Hence (2) is valid,

$$\max\{f(a), \gamma\} \geq \min\{f(a^2), \delta\}, \text{ for all } a \in S.$$ 

(2) $\Rightarrow$ (1). Assume that there exist $a \in S$ and $t \in (\gamma, 1]$, such that $a_t^2 \in_{\gamma} f$, then $f(a^2) \geq t > \gamma$, thus by (2), we have $\max\{f(a), \gamma\} \geq \min\{f(a^2), \delta\} \geq \min\{t, \delta\}$. We consider two cases here,

1. Case(i): if $t \leq \delta$, then $f(a) + t \geq t > \gamma$, this implies that $a_t \in_{\gamma} f$.
2. Case(ii): if $t > \delta$, then $f(a) + t > 2\delta$, that is $a_t \in_{\gamma} q_{\delta}f$. From (i) and (ii) we write $a_t \in_{\gamma} \sqrt{q_{\delta}f}$. Hence $f$ is semiprime for all $a \in S$. 

$\blacksquare$
4. Generalized Fuzzy Prime and Semiprime Ideals of Abel Grassmann Groupoids

**Theorem 142** For a non empty subset $I$ of an AG-groupoid $S$ with left identity the following conditions are equivalent.

(i) $I$ is semiprime.

(ii) $\chi_{\gamma}^{\delta}(a)$ is an $(\in_{\gamma}, \in_{\gamma} \vee q_{\delta})$-fuzzy semiprime.

**Proof.** (i) $\Rightarrow$ (ii) Let $I$ is semiprime of an AG-groupoid $S$.

Case (a): Let $a$ be any element of $S$ such that $a^2 \in I$. Then $I$ is semiprime, so $a \in I$. Hence $\chi_{\gamma}^{\delta}(a^2) \geq \delta$ and $\chi_{\gamma}^{\delta}(a) \geq \delta$. Therefore

\[
\max\{\chi_{\gamma}^{\delta}(a), \gamma\} = \chi_{\gamma}^{\delta}(a) \quad \text{and} \quad \min\{\chi_{\gamma}^{\delta}(a^2), \delta\} = \delta.
\]

which implies that $\max\{\chi_{\gamma}^{\delta}(a), \gamma\} \geq \min\{\chi_{\gamma}^{\delta}(a^2), \delta\}$.

Case (b): Let $a \notin I$, since $I$ is semiprime therefore $a^2 \notin I$. This implies that $\chi_{\gamma}^{\delta}(a) \leq \gamma$ and $\chi_{\gamma}^{\delta}(a^2) \leq \gamma$, such that

\[
\max\{\chi_{\gamma}^{\delta}(a), \gamma\} = \gamma \quad \text{and} \quad \min\{\chi_{\gamma}^{\delta}(a^2), \delta\} = \chi_{\gamma}^{\delta}(a^2).
\]

Therefore $\max\{\chi_{\gamma}^{\delta}(a), \gamma\} \geq \min\{\chi_{\gamma}^{\delta}(a^2), \delta\}$. Hence in both cases

\[
\max\{\chi_{\gamma}^{\delta}(a), \gamma\} \geq \min\{\chi_{\gamma}^{\delta}(a^2), \delta\} \quad \text{for all} \quad a \in S.
\]

(ii) $\Rightarrow$ (i) Let $\chi_{\gamma}^{\delta}$ be an $(\in_{\gamma}, \in_{\gamma} \vee q_{\delta})$-fuzzy semiprime. Let $a^2 \in I$ for some $a$ in $S$. Then $\chi_{\gamma}^{\delta}(a^2) \geq \delta$. Therefore $\max\{\chi_{\gamma}^{\delta}(a), \gamma\} \geq \min\{\chi_{\gamma}^{\delta}(a^2), \delta\} = \delta$ this implies that $\chi_{\gamma}^{\delta}(a) \geq \delta$ again this implies that $a \in I$. Hence $I$ is semiprime.

**Example 143** Let $S = \{1, 2, 3\}$, and the binary operation “.” be defined on $S$ as follows.

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Then $(S, \cdot)$ is an AG-groupoid. Define a fuzzy subset $f : S \to [0, 1]$ as follows.

\[
f(x) = \begin{cases} 
0.41 & \text{for } x = 1 \\
0.39 & \text{for } x = 2 \\
0.42 & \text{for } x = 3
\end{cases}
\]

Then clearly

- $f$ is $(\in_{0.1}, \in_{0.1} \vee q_{0.2})$-fuzzy semiprime,
- $f$ is not $(\in_{0}, \in \vee q_{0.2})$-fuzzy semiprime,
- $f$ is not fuzzy semiprime.
4. Generalized Fuzzy Prime and Semiprime Ideals of Abel Grassmann Groupoids

4.2 \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-Fuzzy Semiprime Ideals of Intra-regular AG-groupoids

Lemma 144 If \(f\) is a \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy ideal of an intra-regular AG-groupoid \(S\), then \(f\) is an \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy semiprime in \(S\).

Proof. Let \(S\) be a intra regular AG-groupoid. Then for any \(a \in S\) there exists some \(x, y \in S\) such that \(a = (xa^2)y\). Now

\[
\max \{f(a), \gamma\} = \max \{f(xa^2)y, \gamma\} \geq \min \{f(a^2), \delta\}.
\]

Hence \(f\) is a \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy semiprime in \(S\). \(\blacksquare\)

Theorem 145 Let \(S\) be an AG-groupoid then the following conditions are equivalent.

(i) \(S\) is intra regular.

(ii) For every ideal \(A\) of \(S\), \(A \subseteq A^2\) and \(A\) is semiprime.

(iii) For every \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\) fuzzy ideal \(f\) of \(S\), \(f \subseteq \lor q_{(\gamma, \delta)}f \circ f\), and \(f\) is fuzzy semiprime.

Proof. \((i) \Rightarrow (iii)\). Let \(f\) be an \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy ideal of an intra regular AG-groupoid \(S\) with left identity. Now since \(S\) is intra regular therefore for any \(a \in S\) there exist \(x, y \in S\) such that \(a = (xa^2)y\). Now using paramedial law, medial law and left invertive law, we get

\[
a = (xa^2)y = (x(aa))y = (a(xa))y = (y(xa))a.
\]

Let for any \(a \in S\) there exist \(p\) and \(q\) in \(S\) such that \(a = pq\), then

\[
\max \{(f \circ f)(a), \gamma\} = \max \left\{ \lor \{f(p) \land f(q)\}, \gamma \right\} \geq \max \{f(y(xa)), f(a)\}, \gamma\}
\]

\[
\geq \max \{f(y(xa)), f(a)\}, \gamma\}
\]

\[
= \min \{\max \{f(y(xa)), \gamma\}, \max \{f(a), \gamma\}\}
\]

\[
\geq \min \{\min \{f(a), \delta\}, \min \{f(a), \delta\}\}
\]

\[
= \min \{f(a), \delta\}.
\]

Thus \(f \subseteq \lor q_{(\gamma, \delta)}f \circ f\).

Now we show that \(f\) is a fuzzy semiprime ideal of intra-regular AG-groupoid \(S\). Since \(S\) is intra-regular therefore for any \(a \in S\) there exist \(x, y\) in \(S\) such that \(a = (xa^2)y\). Then

\[
\max \{f(a), \gamma\} = \max \{f((xa^2)y), \gamma\}
\]

\[
\geq \min \{f(a^2), \delta\}.
\]
(iii) \(\Rightarrow\) (ii). Suppose \(A\) be any ideal of \(S\). Then by (iii), we get
\[
\chi^\delta_{\gamma A} = \chi^\delta_{\gamma A \cap A} = \chi^\delta_{\gamma A} \cap \chi^\delta_{\gamma A} \subseteq \forall q(\gamma, \delta) \chi^\delta_{\gamma A} = (\gamma, \delta) \chi^\delta_{\gamma A^2}.
\]

Hence we get \(A \subseteq A^2\). Now we show that \(A\) is semiprime. Let \(A\) be an ideal then \((\chi^\delta_{\gamma A})\) be an \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy ideal of \(S\). Let \(a^2 \in A\), then since \(\chi^\delta_{\gamma A}\) be any \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy ideal of an AG-groupoid \(S\), hence by (iii), \(\max\{\chi^\delta_{\gamma A}(a), \gamma\} \geq \min\{\chi^\delta_{\gamma A}(a^2), \delta\} = \delta\) this implies that \(\chi^\delta_{\gamma A}(a) \geq \delta\). Thus \(a \in A\). This implies that \(A\) is semiprime.

(ii) \(\Rightarrow\) (i). Assume that every ideal is semiprime of \(S\). Since \(Sa^2\) is a ideal of an AG-groupoid \(S\) generated by \(a^2\). Therefore
\[
a \in (Sa^2) \subseteq (SS)a^2 \subseteq (a^2S)S = ((aa)(SS))S = ((SS)(aa))S = (Sa^2)S.
\]
Hence \(S\) is intra regular. □

**Lemma 146** Every \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy ideal of an AG-groupoid \(S\), is \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy interior ideal of \(S\).

**Proof.** Let \(S\) be an AG-groupoid then for any \(a, x, y \in S\) and \(f\) is an \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy ideal. Now
\[
\max\{f((xa)y), \gamma\} \geq \max\{f(xa), \gamma\} \geq \min\{f(a), \delta\}.
\]

Hence \(f\) is a \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy interior ideal of \(S\). □

**Theorem 147** For an AG-groupoid \(S\) with left identity the following are equivalent.

(i) \(S\) is intra regular.
(ii) Every two sided ideal is semiprime.
(iii) Every \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy two sided ideal \(f\) of \(S\) is fuzzy semiprime.
(iv) Every \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy interior ideal \(f\) of \(S\) is fuzzy semiprime.
(v) Every \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy generalized interior ideal \(f\) of \(S\) is semiprime.

**Proof.** (i) \(\Rightarrow\) (v) Let \(S\) be an intra-regular and \(f\) be an \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy generalized interior ideal of an AG-groupoid \(S\). Then for all \(a \in S\) there exists \(x, y \in S\) such that \(a = (xa^2)y\). We have
\[
\max\{f(a), \gamma\} = \max\{f((xa^2)y), \gamma\} \geq \min\{f(a^2), \delta\}.
\]

(v) \(\Rightarrow\) (iv) is obvious.
(iv) \(\Rightarrow\) (iii) it is obvious by lemma 146.
(iii) \(\Rightarrow\) (ii). Let \(A\) be a two sided ideal of an AG-groupoid \(S\), then \((\chi^\delta_{\gamma A})\) is an \((\in_\gamma, \in_\gamma \lor \forall q_\delta)\)-fuzzy two sided ideal of \(S\). Let \(a^2 \in A\), then since \(\chi^\delta_{\gamma A}\) is
an \((\in_\gamma, \in_\gamma \vee q_\delta)\)-fuzzy two sided ideal therefore \(\chi_{\gamma A}(a^2) \geq \delta\), thus by \((iii)\)
\[
\max\{\chi_{\gamma A}(a), \gamma\} \geq \min\{\chi_{\gamma A}(a^2), \delta\}\]
this implies that \(\chi_{\gamma A}(a) \geq \delta\). Thus \(a \in A\). Hence \(A\) is semiprime.

\((ii) \Rightarrow (i)\). Assume that every two sided ideal is semiprime and since \(Sa^2\) is a two sided ideal contain \(a^2\). Thus
\[
a \in (Sa^2) \subseteq (SS)a^2 \subseteq (a^2S)S = ((aa)(SS))S = ((SS)(aa))S = (Sa^2)S.
\]
Hence \(S\) is an intra-regular. ■

**Theorem 148** Let \(S\) be an AG-groupoid with left identity, then the following conditions equivalent

\(i)\) \(S\) is intra-regular.

\(ii)\) Every ideal of \(S\) is semiprime.

\(iii)\) Every bi-ideal of \(S\) is semiprime.

\(iv)\) Every \((\in_\gamma, \in_\gamma \vee q_\delta)\)-fuzzy bi-ideal \(f\) of \(S\) is semiprime.

\(v)\) Every \((\in_\gamma, \in_\gamma \vee q_\delta)\)-fuzzy generalized bi-ideal \(f\) of \(S\) is semiprime.

**Proof.** \((i) \Rightarrow (v)\). Let \(S\) be an intra-regular and \(f\) be an \((\in_\gamma, \in_\gamma \vee q_\delta)\)-generalized bi-ideal of \(S\). Then for all \(a \in S\) there exists \(x, y\) in \(S\) such that \(a = (xa^2)y\).

\[
a = (xa^2)y = (x(aa))y = (a(xa))y = (y(xa))a
\]
\[
= \{y(x((xa^2)y))\}a = \{x(y((xa^2)y))\}a = \{x((xa^2)y^2)\}a
\]
\[
= \{((xa^2)y)(x^2y^2)\}a^2 = \{(y^2x^2)(xa^2)\}a^2 = \{(y^2x^2)(y(xa^2))\}a^2
\]
\[
= \{(y^2x^2)((y_1y_2)(xa^2))\}a^2 = \{(y^2x^2)((a^2y_2)(x_1))\}a^2 = \{(y^2x^2)((a^2x)(y_2y_1))\}a^2
\]
\[
= \{(y^2x^2)((y_2y_1)(y)(aa))\}a^2 = \{(y^2x^2)((a)(x)(y_2y_1))\}a^2 = \{(aa)(x((x^2y^2))(y_2y_1))\}a^2
\]
\[
= \{(a^2((x^2y^2))(y_2y_1))\}a^2 = \{(a^2t)a^2\}, \text{where } t = (x(x^2y^2))(y_2y_1).
\]

we have
\[
\max\{f(a), \gamma\} = \max\{f(a^2)t, \gamma\} \geq \max\{\min\{f(a^2), f(a^2)\}, \delta\} = \min\{f(a^2), \delta\}.
\]
Therefore \(\max\{f(a), \gamma\} \geq \min\{f(a^2), \delta\}\).

\((v) \Rightarrow (iv)\) is obvious.

\((iv) \Rightarrow (iii)\). Let \(B\) is a bi-ideal of \(S\), then \(\chi_{\gamma B}(a^2) \geq \delta\), thus by \((iv)\),
\[
\max\{\chi_{\gamma B}(a^2), \gamma\} \geq \min\{\chi_{\gamma B}(a^2), \delta\} = \delta\this implies that \(\chi_{\gamma B}(a) \geq \delta\). Thus \(a \in B\). Hence \(B\) is semiprime.

\((iii) \Rightarrow (ii)\) is obvious.

\((ii) \Rightarrow (i)\) Assume that every ideal of \(S\) is semiprime and since \(Sa^2\) is an ideal containing \(a\). Thus
\[
a \in (Sa^2) \subseteq (SS)a^2 \subseteq (a^2S)S = ((aa)(SS))S = ((SS)(aa))S = (Sa^2)S.
\]
Hence \(S\) is an intra-regular. ■
Theorem 149 Let $S$ be an AG-groupoid with left identity, then the following conditions equivalent

(i) $S$ is intra-regular.
(ii) Every ideal of $S$ is semiprime.
(iii) Every quasi-ideal of $S$ is semiprime.
(iv) Every $(\in,\in \vee q_\delta)$-fuzzy quasi-ideal $f$ of $S$ is semiprime.

Proof. (i) $\Rightarrow$ (iv). Let $S$ be an intra-regular AG-groupoid with left identity and $f$ be an $(\in,\in \vee q_\delta)$-fuzzy quasi ideal of $S$. Then for all $a \in S$ there exists $x, y$ in $S$ such that $a = (xa^2)y$. Now using left invertive law and medial law, then

$$a = (xa^2)(y_1y_2) = (y_2y_1)(a^2x) = a^2((y_2y_1)x) = a^2t,$$

where $t = (y_2y_1)x$. We have

$$\max\{f(a), \gamma\} = \max\{f(a^2t), \gamma\} \geq \min\{f(a^2), \delta\}.$$ 

Therefore $\max\{f(a), \gamma\} \geq \min\{f(a^2), \delta\}$.

(iv) $\Rightarrow$ (iii). Let $Q$ be an quasi ideal of $S$, then $\chi^\delta_Q$ is an $(\in,\in \vee q_\delta)$-fuzzy quasi ideal of an AG-groupoid $S$. Let $a^2 \in Q$ then since $\chi^\delta_Q$ is an $(\in,\in \vee q_\delta)$-fuzzy quasi ideal as then $\chi^\delta_Q(a^2) \geq \delta$ therefore by (iv), $\max\{\chi^\delta_Q(a), \gamma\} \geq \min\{\chi^\delta_Q(a^2), \delta\} = \delta$ this implies that $\chi^\delta_Q(a) \geq \delta$. Thus $a \in Q$. Hence $Q$ is semiprime.

(iii) $\Rightarrow$ (ii) is obvious.

(ii) $\Rightarrow$ (i) Assume that every ideal of $S$ is semiprime and since $Sa^2$ is an ideal containing $a^2$. Thus

$$a \in (Sa^2) \subseteq (Sa)(Sa) = (SS)(aa) = (a^2S)S = (Sa^2)S.$$

Hence $S$ is an intra-regular. $\blacksquare$
4. Generalized Fuzzy Prime and Semiprime Ideals of Abel Grassmann Groupoids
5

Fuzzy Soft Abel Grassmann Groupoids

In this chapter we introduce generalized fuzzy soft ideals in a non-associative algebraic structure namely Abel Grassmann groupoid. We discuss some basic properties concerning these new types of generalized fuzzy ideals in Abel-Grassmann groupoids. Moreover we characterize a regular Abel Grassmann groupoid in terms of its classical and $(\in_{\gamma}, \in_{\gamma} \vee q_{\delta})$-fuzzy soft ideals.

5.1 $(\in_{\gamma}, \in_{\gamma} \vee q_{\delta})$-fuzzy Soft Ideals of AG-groupoids

Let $U$ be an initial universe set and $E$ the set of all possible parameters under consideration with respect to $U$. Then

A pair $(F, A)$ is called a fuzzy soft set over $U$, where $A \subseteq E$ and $F$ is a mapping given by $F: A \rightarrow \mathcal{F}(U)$, where $\mathcal{F}(U)$ is the set of all fuzzy subsets of $U$. In general, for every $\varepsilon \in A$, $F(\varepsilon)$ is a fuzzy set of $U$ and it is called fuzzy value set of parameter $\varepsilon$ [26].

The extended intersection of two fuzzy soft sets $(F, A)$ and $(G, B)$ over $U$ is a fuzzy soft set denoted by $(H, C)$, where $C = A \cup B$ and defined as

$$H(\varepsilon) = \begin{cases} F(\varepsilon) & \text{if } \varepsilon \in A - B, \\ G(\varepsilon) & \text{if } \varepsilon \in B - A, \\ F(\varepsilon) \cap G(\varepsilon) & \text{if } \varepsilon \in A \cap B. \end{cases}$$

for all $\varepsilon \in C$. This is denoted by $(H, C) = (F, A) \cap (G, B)$.

A new relation is defined on $\mathcal{F}(S)$ denoted as $\subseteq \vee q(\gamma, \delta)$, as follows. For any $f, g \in \mathcal{F}(S)$, by $f \subseteq \vee q(\gamma, \delta) g$, we mean that $x_{r} \in_{\gamma} f$ implies $x_{r} \in_{\gamma} \vee q g$ for all $x \in S$ and $r \in (\gamma, 1]$.

The following definition is available in [35].

Let $(F, A)$ and $(G, B)$ be two fuzzy soft sets over $U$. We say that $(F, A)$ is a fuzzy soft subset of $(G, B)$ and write $(F, A) \subseteq (G, B)$ if

(i) $A \subseteq B$;
(ii) For any $\varepsilon \in A$, $F(\varepsilon) \subseteq G(\varepsilon)$.

$(F, A)$ and $(G, B)$ are said to be fuzzy soft equal and write $(F, A) = (G, B)$ if $(F, A) \subseteq (G, B)$ and $(G, B) \subseteq (F, A)$.

Let $V \subseteq U$. A fuzzy soft set $(F, A)$ over $V$ is said to be a relative whole $(\gamma, \delta)$-fuzzy soft set (with respect to universe set $V$ and parameter set $A$), denoted by $\Sigma(V; A)$, if $F(\varepsilon) = X_{\varepsilon}^{\delta}$ for all $\varepsilon \in A$. 
5. Fuzzy Soft Abel Grassmann Groupoids

The product of two fuzzy soft sets \( (F, A) \) and \( (G, B) \) over an AG-groupoid \( S \) is a fuzzy soft set over \( S \), denoted by \( (F \circ G, C) \), where \( C = A \cup B \) and

\[
(F \circ G)(\varepsilon) = \begin{cases} 
F(\varepsilon) & \text{if } \varepsilon \in A - B, \\
G(\varepsilon) & \text{if } \varepsilon \in B - A, \\
F(\varepsilon) \circ G(\varepsilon) & \text{if } \varepsilon \in A \cap B.
\end{cases}
\]

for all \( \varepsilon \in C \). This is denoted by \( (F \circ G, C) = (F, A) \circ (G, B) \).

A fuzzy soft set \( (F, A) \) over an AG-groupoid \( S \) is called

- Fuzzy soft left (right) ideal over \( S \) if \( \Sigma(S, A) \circ (F, A) \subset (F, A) \circ \Sigma(S, E) \subset (F, A) \).
- Fuzzy soft bi-ideal over \( S \) if \( (F, A) \circ (F, A) \subset (F, A) \) and \( [\Sigma(S, A) \circ (F, A)] \subset (F, A) \).
- Fuzzy soft quasi-ideal over \( S \) if \( [\Sigma(S, A) \circ (F, A)] \subset (F, A) \).

\( (F, A) \) is an \((\gamma, \delta)\)-fuzzy subset of \( (G, B) \) and write \( (F, A) \subset_{(\gamma, \delta)} (G, B) \) if (i) \( A \subset B \), and (ii) For any \( \varepsilon \in A, F(\varepsilon) \subseteq \bigvee q_{\gamma, \delta} G(\varepsilon) \).

A fuzzy soft set \( (F, A) \) over an AG-groupoid \( S \) is called

- An \((e, \gamma, e \bigvee q_{\delta})\)-fuzzy soft left ideal over \( S \) if \( \Sigma(S, A) \circ (F, A) \subset_{(\gamma, \delta)} (F, A) \).
- An \((e, \gamma, e \bigvee q_{\delta})\)-fuzzy soft bi-ideal over \( S \) if (i) \( (F, A) \circ (F, A) \subset_{(\gamma, \delta)} (F, A) \) and (ii) \( [\Sigma(S, A) \circ (F, A)] \subset_{(\gamma, \delta)} (F, A) \).
- An \((e, \gamma, e \bigvee q_{\delta})\)-fuzzy soft quasi-ideal over \( S \) if \( [\Sigma(S, A) \circ (F, A)] \subset_{(\gamma, \delta)} (F, A) \).

**Example 150** Let \( S = \{1, 2, 3\} \) and the binary operation \( " \cdot " \) defines on \( S \) as follows:

\[
\begin{array}{c|ccc}
\cdot & 1 & 2 & 3 \\
\hline
1 & 2 & 2 & 3 \\
2 & 3 & 3 & 3 \\
3 & 3 & 3 & 3 \\
\end{array}
\]

Then \((S, \cdot)\) is an AG-groupoid. Let \( A = \{0.35, 0.4\} \) and define a fuzzy soft set \((F, A)\) over \( S \) as follows:

\[
F(\varepsilon)(x) = \begin{cases} 
2\varepsilon & \text{if } x \in \{1, 2\}, \\
\frac{2}{3} & \text{otherwise}.
\end{cases}
\]

Then \((F, A)\) is an \((e_{0.3}, e_{0.3} \bigvee q_{0.4})\)-fuzzy soft left ideal of \( S \).

Again let \( E = \{0.7, 0.8\} \) and define a fuzzy soft set \((G, E)\) over \( S \) as follows:

\[
G(\varepsilon)(x) = \begin{cases} 
\varepsilon & \text{if } x \in \{1, 2\}, \\
\frac{2}{3} & \text{otherwise}.
\end{cases}
\]

Then \((G, E)\) is an \((e_{0.2}, e_{0.2} \bigvee q_{0.4})\)-fuzzy soft bi-ideal of \( S \).
5.2 \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy Soft Ideals in Regular AG-groupoids

**Theorem 151** For an AG-groupoid \(S\), with left identity, the following are equivalent.

(i) \(S\) is regular.

(ii) For bi-ideal \(B\), ideal \(I\) and left ideal \(L\) of \(S\), \(B \cap L \subseteq (BS)L\).

(iii) \(\langle F, B \rangle \cap \langle G, L \rangle \subseteq (\gamma, \delta) \quad (\langle F, B \rangle \circ \Sigma(S, E) \circ (G, L))\), for any \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy soft bi-ideal \(\langle F, A \rangle\) and \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy soft left ideal \(\langle H, B \rangle\) of \(S\).

(iv) \(\langle F, B \rangle \cap \langle G, L \rangle \subseteq (\gamma, \delta) \quad (\langle F, B \rangle \circ \Sigma(S, E) \circ (G, L))\), for any \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy generalized soft bi-ideal \(\langle F, A \rangle\) and \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy generalized soft left ideal \(\langle H, B \rangle\) of \(S\).

**Proof.** (ii) \(\Rightarrow\) (iv)

Let \(\langle F, B \rangle\) and \(\langle G, L \rangle\) be any \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy generalized soft bi-ideal and \((\in_{\gamma}, \in_{\gamma} \lor q_{\delta})\)-fuzzy generalized soft left ideal over \(S\), respectively. Let \(a\) be any element of \(S\), \(\langle F, B \rangle \cap \langle G, L \rangle = \langle K_1, B \cup L \rangle\). For any \(\in \in B \cup L\). We consider the following cases,

Case 1: \(\in \in B - L\). Then \(K_1(\in) = F(\in) \cap G(\in)\) and \(K_2(\in) = (F \circ G)(\in)\), so we have \(K_1(\in) \subseteq \lor q_{(\gamma, \delta)}K_2(\in)\).

Case 2: \(\in \in L - B\). Then \(K_1(\in) = H(\in)\) and \(K_1(\in) = H(\in) = K_2(\in)\).

Case 3: \(\in \in B \cap L\). Then \(K_1(\in) = F(\in) \cap G(\in)\) and \(K_2(\in) = (F \circ G)(\in)\).

Now we show that \(F(\in) \cap G(\in) \subseteq \lor q_{(\gamma, \delta)}(F(\in) \circ G(\in))\). Now since \(S\) is regular AG-groupoid, so for \(a \in S\) there exist \(x \in S\) such that using left invertive law and also using law \(a(bc) = b(ac)\), we have,

\[ a = (ax) a = [(ax) a]a \in (BS)L.\]

Thus we have,

\begin{align*}
\max \{(F(\in) \circ \mathcal{X}_{q_{\delta}} G(\in))(a), \gamma\} & = \max \left\{ \left( \vphantom{\bigg)} \right. \right. \\
\left. \left. \bigg]\right. \bigg[ \left. \left. \left( F(\in) \circ \mathcal{X}_{q_{\delta}} G(\in)(a) \wedge G(\in)(a), \gamma \right) \right] \right. \right. \\
\max \{(F(\in) \circ \mathcal{X}_{q_{\delta}} G(\in))(a), \gamma\} & = \max \left\{ \left( \vphantom{\bigg)} \right. \right. \\
\left. \left. \bigg]\right. \bigg[ \left. \left. \left( F(\in)(a) \wedge \mathcal{X}_{q_{\delta}} G(\in)(a), \gamma \right) \right] \right. \right. \\
\max \{(F(\in)(a) \wedge \mathcal{X}_{q_{\delta}} G(\in)(a), \gamma\} & = \min \{(F(\in)(a), \delta)\}.
\end{align*}
Thus \( \min \{(F(\varepsilon) \cap G(\varepsilon))(a), \delta \} \leq \max \{(F(\varepsilon) \circ X_2^0) \circ G(\varepsilon)\}(a), \gamma \} \). This implies that \( F(\varepsilon) \cap G(\varepsilon) \subseteq \bigvee q_{(\gamma, \delta)}(F(\varepsilon) \circ X_2^0) \circ G(\varepsilon) \).

Therefore in any case, we have \( K_1(\varepsilon) \subseteq \bigvee q_{(\gamma, \delta)} K_2(\varepsilon) \). Hence

\[
(F, B) \cap (G, L) \subseteq \bigvee q_{(\gamma, \delta)}((F, B) \circ (S, E)) \circ (G, L).
\]

(iv) \implies (iii) is obvious.

(iii) \implies (ii)

Assume that \( B \) and \( L \) are bi-ideal and left ideal of \( S \), respectively, then \( \Sigma(B, E) \) and \( \Sigma(L, E) \) are \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy soft bi-ideal, \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy soft ideal and \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy soft left ideal over \( S \), respectively.

Now we have assume that (iv) holds, then we have

\[
\Sigma(B, E) \cap \Sigma(L, E) \subseteq \bigvee q_{(\gamma, \delta)} ((F, B) \circ (S, E)) \circ (G, L) \cap \Sigma(L, E).
\]

So,

\[
X_{(B \cap L)}^\delta = (\gamma, \delta) X_B^\delta \cap X_L^\delta \subseteq \bigvee q_{(\gamma, \delta)} (X_B^\delta \circ X_S^\delta) \circ X_L^\delta = (\gamma, \delta) X_{(B \cap L)}^\delta.
\]

Thus \( B \cap L \subseteq (BS) \).

(ii) \Rightarrow (i)

\( B[a] = a \cup a^2 \cup (aS) \ a \) and \( L[a] = a \cup Sa \) are principle bi-ideal and principal left ideal of \( S \) generated by \( a \) respectively. Thus by (ii) left invertive law, medial law, paramedial law and using law \( a(bc) = b(ac) \), we have,

\[
(Sa) \cap (Sa) \subseteq [Sa]S[Sa] = [S(aS)](Sa) = (aS)(Sa) \subseteq (aS)a.
\]

Hence \( S \) is regular. \( \blacksquare \)

**Theorem 152** For an AG-groupoid \( S \), with left identity, the following are equivalent.

(i) \( S \) is regular.

(ii) For an ideal \( I \) and left ideal \( L \) of \( S \), \( I \cap L \subseteq (IS) \).

(iii) \( (F, I) \cap (G, L) \subseteq (\gamma, \delta) \cap ((F, I) \circ (S, E) \circ (G, L)) \), for any \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy soft ideal \( (F, A) \) and \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy soft left ideal \((H, B) \) of \( S \).

(iv) \( (F, I) \cap (G, L) \subseteq (\gamma, \delta) \cap ((F, I) \circ (S, E)) \circ (G, L) \), for any \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy generalized soft ideal \( (F, A) \) and \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy generalized soft left ideal \((H, B) \) of \( S \).

**Proof.** (i) \Rightarrow (iv)

Let \( (F, I) \) and \( (G, L) \) be any \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy generalized soft ideal and \((\varepsilon, \varepsilon, \varepsilon, q_{q_0})\)-fuzzy generalized soft left ideal over \( S \), respectively. Let \( a \) be any element of \( S \), \( (F, I) \cap (G, L) = (K_1, I \cup L) \). For any \( \varepsilon \in I \cup L \). We consider the following cases,
Case 1: \( \varepsilon \in I - L \). Then \( K_1(\varepsilon) = F(\varepsilon) \cap G(\varepsilon) \) and \( K_2(\varepsilon) = (F \circ G)(\varepsilon) \), so we have \( K_1(\varepsilon) \subseteq \vee_{\gamma, \delta} K_2(\varepsilon) \).

Case 2: \( \varepsilon \in L - I \). Then \( K_1(\varepsilon) = H(\varepsilon) \) and \( K_1(\varepsilon) = H(\varepsilon) = K_2(\varepsilon) \).

Case 3: \( \varepsilon \in I \cap L \). Then \( K_1(\varepsilon) = F(\varepsilon) \cap G(\varepsilon) \) and \( K_2(\varepsilon) = F(\varepsilon) \circ G(\varepsilon) \).

Now we show that \( F(\varepsilon) \cap G(\varepsilon) \subseteq \vee_{\gamma, \delta} (F(\varepsilon) \circ G(\varepsilon)) \). Now since \( S \) is regular AG-groupoid, so for \( a \in S \) there exist \( x \in S \) such that using medial law, we have,

\[
a = (ax) a = (ax) ((ax) a) = (a(ax))(xa) \in (IS)L.
\]

Thus we have,

\[
\begin{align*}
\max \left\{ \left( (F(\varepsilon) \circ \mathcal{A}^\delta) \circ G(\varepsilon) \right)(a), \gamma \right\} \\
= \max \left\{ \left( F(\varepsilon) \circ \mathcal{A}^\delta \right)(a) \wedge G(\varepsilon)(q), \gamma \right\} \\
\geq \max \left\{ \left( F(\varepsilon) \circ \mathcal{A}^\delta \right)(a(ax)) \wedge G(\varepsilon)(xa), \gamma \right\} \\
= \max \left\{ \left( F(\varepsilon)(u) \wedge \mathcal{A}^\delta(v) \wedge G(\varepsilon)(xa), \gamma \right\} \\
\geq \max \left\{ \left( F(\varepsilon)(a) \wedge \mathcal{A}^\delta(a) \wedge G(\varepsilon)(xa), \gamma \right\} \\
= \max \left\{ \left( F(\varepsilon)(a), \gamma \right\} , \max \left\{ G(\varepsilon)(xa), \gamma \right\} \right\} \\
\geq \min \left\{ \left( F(\varepsilon)(a), \gamma \right\} , \min \left\{ G(\varepsilon)(xa), \delta \right\} \right\} \\
= \min \left\{ (F(\varepsilon) \wedge G(\varepsilon))(a), \delta \right\} \\
= \min \left\{ (F(\varepsilon) \cap G(\varepsilon))(a), \delta \right\}
\end{align*}
\]

Thus \( \min \left\{ (F(\varepsilon) \cap G(\varepsilon))(a), \delta \right\} \leq \max \left\{ \left( (F(\varepsilon) \circ \mathcal{A}^\delta) \circ G(\varepsilon) \right)(a), \gamma \right\} \). This implies that \( F(\varepsilon) \cap G(\varepsilon) \subseteq \vee_{\gamma, \delta} (F(\varepsilon) \circ \mathcal{A}^\delta) \circ G(\varepsilon) \).

Therefore in any case, we have \( K_1(\varepsilon) \subseteq \vee_{\gamma, \delta} K_2(\varepsilon) \). Hence

\[
(F, I) \cap (G, L) \subseteq (\gamma, \delta) \left( ((F, I) \circ \Sigma(S, E)) \circ (G, L) \right).
\]

(iv) \( \Rightarrow \) (iii) is obvious.

(iii) \( \Rightarrow \) (ii) \( \blacksquare \)

Assume that \( I \) and \( L \) are ideal and left ideal of \( S \), respectively, then \( \Sigma(I, E) \) and \( \Sigma(L, E) \) are \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \vee \varepsilon_{\delta}) \)-fuzzy soft ideal, \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \vee \varepsilon_{\delta}) \)-fuzzy soft ideal and \( (\varepsilon_{\gamma}, \varepsilon_{\gamma} \vee \varepsilon_{\delta}) \)-fuzzy soft left ideal over \( S \), respectively. Now we have that (iv) holds, then we have

\[
\Sigma(I, E) \cap \Sigma(L, E) \subseteq \left( \Sigma(I, E) \circ \Sigma(S, E) \right) \circ \Sigma(L, E).
\]

So,

\[
\begin{align*}
\mathcal{A}^\delta\left(\mathcal{A}^\delta \cap \mathcal{A}^\delta \right) & = \left( \gamma, \delta \right) \mathcal{A}^\delta \cap \mathcal{A}^\delta \\
& \subseteq \vee_{\gamma, \delta} \left( \mathcal{A}^\delta \circ \mathcal{A}^\delta \right) \circ \mathcal{A}^\delta \\
& = \left( \gamma, \delta \right) \mathcal{A}^\delta \left(\mathcal{A}^\delta \cap \mathcal{A}^\delta \right).
\end{align*}
\]
Thus \( I \cap L \subseteq (IS)L \).

**Proof.** (iii) \( \Rightarrow \) (i)

\( I [a] = aS \cup Sa \), and \( L [a] = a \cup Sa \) are principle ideal and principle left ideal of \( S \) generated by \( a \) respectively. Thus left invertive law, paramedial law and using law \( a(bc) = b(ac) \), we have,

\[
\{(aS) \cup (Sa)\} \cap (Sa) \subseteq \{((aS) \cup (Sa))S\}(Sa) \\
= \{(aS)S\} \cup \{(Sa)S\}(Sa) \\
= \{(S(Sa)) \cup \{(Sa)S\}\}(Sa) \\
= [Sa \cup \{(Sa)S\}](Sa) \\
= [(Sa)(Sa)] \cup \{(Sa)S\}(Sa) \\
\subseteq (Sa^2)S \cup (aS)a.
\]

Hence \( S \) is regular. \( \blacksquare \)

**Theorem 153** For an AG-groupoid \( S \), with left identity, the following are equivalent.

(i) \( S \) is regular.

(ii) For bi-ideal \( B \) of \( S \), \( B \subseteq B^2S \).

(iii) \( \langle F, B \rangle \subseteq_{(\gamma, \delta)} \langle (F, B) \cup (F, B) \rangle \cup \Sigma(S, E) \), for any \( (\in \gamma, \in \gamma \forall q \delta) \)-fuzzy soft bi-ideal \( (F, A) \) of \( S \).

(iv) \( \langle F, B \rangle \subseteq_{(\gamma, \delta)} \langle (F, B) \cup (F, B) \rangle \cup \Sigma(S, E) \), for any \( (\in \gamma, \in \gamma \forall q \delta) \)-fuzzy generalised soft bi-ideal \( (F, A) \) of \( S \).

**Proof.** (i) \( \Rightarrow \) (iv)

Let \( \langle F, B \rangle \) be any \( (\in \gamma, \in \gamma \forall q \delta) \)-fuzzy generalised soft bi-ideal. Let \( a \) be any element of \( S \), Now since \( S \) is regular AG-groupoid, so for \( a \in S \) there exist \( x \in S \) such that using left invertive law, medial law, paramedial law and also using law \( a(bc) = b(ac) \), we have,

\[
a = (ax)a = (ax)\{(ax)a\} \{a(ax)\}(xa) = x[\{a(ax)\}a] \\
= x[\{(xa)(ae)\}a] = x[\{(xa)(ae)\}a] = (ex)[\{(xa)(ae)\}a] \\
= [a\{(xa)(ae)\}](xe) = [a\{(ae)a\}](xe) = \{(xe)x\}a\{(ae)a\}] \\
= [\{(xe)x\}a\{(ae)a\}] = [\{(ae)x\}a\}a]e \\
= \{\{(ae)(ta)\}a\}e = \{\{(at)(ea)\}a\}e = \{\{(at)\}a\}e \in B^2S, \text{ where } t = \{(xe)x\}.
\]
Thus we have,
\[
\max \left\{ \left( (F(\varepsilon) \circ F(\varepsilon)) \circ (\mathcal{X}_{\gamma S}^\delta)(a), \gamma \right) \right\}
\]
\[
= \max \left\{ \bigvee_{a=pq} (F(\varepsilon) \circ F(\varepsilon))(p) \land (\mathcal{X}_{\gamma S}^\delta)(q), \gamma \right\}
\]
\[
\geq \max \left\{ (F(\varepsilon) \circ F(\varepsilon)) \{(at)a\} \land (\mathcal{X}_{\gamma S}^\delta)(e), \gamma \right\}
\]
\[
= \max \left\{ \bigvee_{\{(at)a\}=uv} \{F(\varepsilon)(u) \land F(\varepsilon)(v) \land \mathcal{X}_{\gamma S}^\delta(e), \gamma \right\}
\]
\[
\geq \max \left\{ F(\varepsilon)\{(at)a\} \land F(\varepsilon)(a) \land \mathcal{X}_{\gamma S}^\delta(e), \gamma \right\}
\]
\[
= \max \left\{ \{F(\varepsilon)(a), \delta\}, \min\{F(\varepsilon)(a), \delta\} \right\}
\]
\[
= \min \left\{ \{F(\varepsilon)(a), \delta\} \right\}
\]
Thus \( \min \left\{ \{F(\varepsilon)(a), \delta\} \right\} \leq \max \left\{ \left( (F(\varepsilon) \circ F(\varepsilon)) \circ (\mathcal{X}_{\gamma S}^\delta)(a), \gamma \right) \right\} \). This implies that \( F(\varepsilon) \subseteq \vee q(\gamma, \delta) (F(\varepsilon) \circ F(\varepsilon)) \circ \mathcal{X}_{\gamma S}^\delta \).

Therefore in any case, we have \( K_1(\varepsilon) \subseteq \vee q(\gamma, \delta) K_2(\varepsilon) \). Hence
\[
(F, B) \subset (\gamma, \delta) \left( (F, B) \circ (F, B) \right) \circ \Sigma(S, E).
\]

(iii) \( \Rightarrow \) (ii) is obvious.

Assume that \( B \) is bi-ideal of \( S \), then \( \Sigma(B, E) \) is \( (\in_{\gamma, \in \gamma} \vee q_{\delta}) \)-fuzzy soft bi-ideal, \( (\in_{\gamma, \in \gamma} \vee q_{\delta}) \)-fuzzy soft ideal over \( S \), respectively. Now we have assume that (iv) holds, then we have
\[
\Sigma(B, E) \subset (\gamma, \delta) \left( (\Sigma(B, E) \circ (\Sigma(B, E)) \right) \circ \Sigma(S, E).
\]
So,
\[
\mathcal{X}_{\gamma B}^\delta = \langle \gamma, \delta \rangle \mathcal{X}_{\gamma B}^\delta \cap \mathcal{X}_{\gamma S}^\delta
\]
\[
\subseteq \vee q(\gamma, \delta) \langle \mathcal{X}_{\gamma B}^\delta \circ \mathcal{X}_{\gamma B}^\delta \circ \mathcal{X}_{\gamma S}^\delta
\]
\[
= \langle \gamma, \delta \rangle \mathcal{X}_{\gamma B}^\delta B^2 S.
\]
Thus \( B \subseteq B^2 S \).

(ii) \( \Rightarrow \) (i)

\( B[a] = a \cup a^2 \cup (aS)a \), and \( L[a] = a \cup Sa \) are principle bi-ideal and principle left ideal of \( S \) generated by \( a \) respectively. Thus by (ii), left invertive law, paramedial law and using law \( a(bc) = b(ac) \), we have,
\[
Sa \subseteq [(Sa)(Sa)]S = [S(Sa)](Sa)
\]
\[
= (SS)[a(Sa)] = S[a(Sa)] \subseteq (aS)a.
\]

Hence \( S \) is regular. \( \blacksquare \)
Theorem 154 For an AG-groupoid $S$, with left identity, the following are equivalent.

(i) $S$ is regular.
(ii) For bi-ideal $B$, ideal $I$ and left ideal $L$ of $S$, $L \cap B \subseteq (LS)B$.
(iii) $(F, L) \cap (G, B) \subseteq (\gamma, \delta) \subseteq (F, L) \circ (S, E) \circ (G, B)$, for any $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy soft left ideal $\{F, A\}$ and $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy soft bi-ideal $\{H, B\}$ of $S$.
(iv) $(F, L) \cap (G, B) \subseteq (\gamma, \delta) \subseteq (F, L) \circ (S, E) \circ (G, B)$, for any $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy generalized soft left ideal $\{F, A\}$ and $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy generalized soft bi-ideal $\{H, B\}$ of $S$.

Proof. (i) $\Rightarrow$ (iv)

Let $(F, L)$ and $(G, B)$ be any $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy generalized soft left ideal and $(\in_{\gamma}, \in_{\gamma} \lor q_{\delta})$-fuzzy generalized soft bi-ideal over $S$, respectively. Let $a$ be any element of $S$, $(F, L) \cap (G, B) = (K_1, L \cup B)$. For any $x \in S$ such that using left invertive law, we have,

$$a = (ax)a = [(ax)a]a = [(xa)(ax)]a \in (LS)B.$$ 

Thus we have,

$$\max \left\{ \left( (F(\varepsilon) \circ X_{\gamma}^{\delta} \circ G(\varepsilon))(a), \gamma \right) \right\}$$

$$= \max \left\{ \left( (F(\varepsilon) \circ X_{\gamma}^{\delta})(p) \land G(\varepsilon)(q), \gamma \right) \right\}$$

$$\geq \max \left\{ (F(\varepsilon) \circ X_{\gamma}^{\delta})(\{xa\}(ax)) \land G(\varepsilon)(a), \gamma \right\}$$

$$= \max \left\{ \left( (F(\varepsilon)(u) \circ X_{\gamma}^{\delta}(v) \circ G(\varepsilon)(a), \gamma \right) \right\}$$

Thus $\min \left\{ (F(\varepsilon) \cap G(\varepsilon))(a), \delta \right\} \leq \max \left\{ (F(\varepsilon) \circ X_{\gamma}^{\delta} \circ G(\varepsilon))(a), \gamma \right\}$. This implies that $F(\varepsilon) \cap G(\varepsilon) \subseteq \land q_{\delta}(F(\varepsilon) \circ X_{\gamma}^{\delta} \circ G(\varepsilon))$. 

Therefore in any case, we have $K_1(\varepsilon) \subseteq \vee q_{(\gamma, \delta)} K_2(\varepsilon)$. Hence

$$(F, L) \cap (G, B) \subseteq (\gamma, \delta) \left( (F, L) \cap (S, E) \right) \cap (G, B).$$

$(iv) \implies (iii)$ is obvious.

$(iii) \implies (ii)$

Assume that $L$ and $B$ are left ideal and bi-ideal of $S$, respectively, then $\Sigma(L, E)$ and $\Sigma(B, E)$ are $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy soft left ideal, $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy soft ideal and $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy soft bi-ideal over $S$, respectively. Now we have assume that $(iv)$ holds, then we have

$$\Sigma(L, E) \cap \Sigma(B, E) \subseteq (\gamma, \delta) \left( \Sigma(L, E) \cap \Sigma(S, E) \right) \cap \Sigma(B, E).$$

So,

$$\chi_{\gamma(L \cap B)} = (\gamma, \delta) \chi_{\gamma L} \cup \chi_{\gamma B} \subseteq \vee q_{(\gamma, \delta)} \left( \chi_{\gamma L} \circ \chi_{\gamma S} \circ \chi_{\gamma B} \right) = (\gamma, \delta) \chi_{\gamma(L \cap B)}.$$ 

Thus $L \cap B \subseteq (LS)B$.

$(ii) \implies (i)$

$L [a] = a \cup Sa$, and $B [a] = a \cup a^2 \cup (aS) a$ are principle left ideal and principal bi-ideal of $S$ generated by $a$ respectively. Thus by $(ii)$, left invertive law and using law $a(bc) = b(ac)$, we have,

$$(Sa) \cap (Sa) \subseteq [(Sa)S](Sa) = [S(aS)](Sa) = (aS)(Sa) \subseteq (aS)a.$$ 

Hence $S$ is regular.$\blacksquare$

**Theorem 155** For an AG-groupoid $S$, with left identity, the following are equivalent.

$(i)$ $S$ is regular.

$(ii)$ For left ideal $L$, quasi ideal $Q$ and an ideal $I$ of $S$, $L \cap Q \cap I \subseteq (LQ) I$.

$(iii)$ $\left< F, L \right> \cap (G, Q) \cap (H, I) \subseteq (\gamma, \delta) \left< (F, L) \cap (G, Q) \cap (H, I) \right>$, for any $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy soft left ideal $\left< F, A \right>$, $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy quasi ideal $\left< G, B \right>$ and $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy soft ideal $\left< H, C \right>$ of $S$.

$(iv)$ $\left< F, L \right> \cap (G, Q) \cap (H, I) \subseteq (\gamma, \delta) \left< (F, L) \cap (G, Q) \cap (H, I) \right>$, for any $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy generalized soft left ideal $\left< F, A \right>$, $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy generalized soft quasi ideal $\left< G, B \right>$ and $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy generalized soft ideal $\left< H, C \right>$ of $S$.

**Proof.** $(i) \implies (iv)$

Let $\left< F, L \right>$, $\left< G, Q \right>$ and $\left< H, I \right>$ be any $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy generalized soft left ideal, $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy generalized soft quasi ideal and $(\varepsilon_a, \varepsilon_fq_b)$-fuzzy generalized soft ideal over $S$, respectively. Let $a$ be any element of $S$,
\( \langle F, A \rangle \hat{\cap} (G, A) \hat{\cap} (H, B) = \langle K_1, A \cup B \rangle \). For any \( \varepsilon \in A \cup B \). We consider the following cases,

Case 1: \( \varepsilon \in A - B \). Then \( K_1(\varepsilon) = F(\varepsilon) \cap G(\varepsilon) \) and \( K_2(\varepsilon) = (F \circ G)(\varepsilon) \), so we have \( K_1(\varepsilon) \subseteq \vee_{q(\gamma, \delta)} K_2(\varepsilon) \)

Case 2: \( \varepsilon \in B - A \). Then \( K_1(\varepsilon) = H(\varepsilon) \) and \( K_2(\varepsilon) = H(\varepsilon) = K_2(\varepsilon) \)

Case 3: \( \varepsilon \in A \cap B \). Then \( K_1(\varepsilon) = F(\varepsilon) \cap G(\varepsilon) \) and \( K_2(\varepsilon) = F(\varepsilon) \circ G(\varepsilon) \).

Now we show that \( F(\varepsilon) \cap G(\varepsilon) \subseteq \vee_{q(\gamma, \delta)} (F(\varepsilon) \circ G(\varepsilon)) \). Now since \( S \) is regular AG-groupoid, so for \( \alpha \in S \) there exist \( x \in S \) such that using medial law and left invertive law, we have,

\[
\begin{align*}
a &= (ax) a = (ax) \{ (ax) a \} = \{ a(ax) \} \langle xa \rangle \\
&= \{ (xa)(ax) \} a \in (LQ) I.
\end{align*}
\]

Thus we have,

\[
\begin{align*}
\max \{ &\{ (F(\varepsilon) \circ G(\varepsilon)) \circ (H(\varepsilon))(\alpha), \gamma \} \\
= &\max \left\{ \bigvee_{\alpha_{pq}} (F(\varepsilon) \circ G(\varepsilon))(p) \land H(\varepsilon)(q), \gamma \right\} \\
\geq &\max \{ (F(\varepsilon) \circ G(\varepsilon)) \{ (xa)(ax) \} \land H(\varepsilon)(\alpha), \gamma \} \\
= &\max \left\{ \bigvee_{\langle xa \rangle (ax) = uv} (F(\varepsilon)(u) \land G(\varepsilon)(v) \land H(\varepsilon)(\alpha), \gamma \right\} \\
\geq &\max \{ (F(\varepsilon)(xa) \land G(\varepsilon)(ax) \land H(\varepsilon)(\alpha), \gamma \} \\
= &\min \{ \max \{ (F(\varepsilon)(xa), \gamma \}, \max \{ G(\varepsilon)(ax), \gamma \}, \max \{ H(\varepsilon)(\alpha), \delta \} \} \\
\geq &\min \{ \min \{ (F(\varepsilon)(a), \alpha \}, \min \{ G(\varepsilon)(a), \delta \}, \min \{ H(\varepsilon)(\alpha), \delta \} \} \\
= &\min \{ (F(\varepsilon) \land G(\varepsilon) \land H(\varepsilon))(\alpha), \delta \} \\
= &\min \{ (F(\varepsilon) \cap G(\varepsilon) \cap H(\varepsilon))(\alpha), \delta \}
\end{align*}
\]

Thus \( \min \{ (F(\varepsilon) \cap G(\varepsilon) \cap H(\varepsilon))(\alpha), \delta \} \leq \max \{ (F(\varepsilon) \circ G(\varepsilon) \circ H(\varepsilon))(\alpha), \gamma \} \).

This implies that \( F(\varepsilon) \cap G(\varepsilon) \cap H(\varepsilon) \subseteq \vee_{q(\gamma, \delta)} (F(\varepsilon) \circ G(\varepsilon)) \circ H(\varepsilon) \).

Therefore in any case, we have \( K_1(\varepsilon) \subseteq \vee_{q(\gamma, \delta)} K_2(\varepsilon) \). Hence

\[
\langle F, L \rangle \hat{\cap} (G, Q) \hat{\cap} (H, I) \subset_{(\gamma, \delta)} ((F, L) \circ (G, Q)) \circ (H, I).
\]

(iv) \( \implies (iii) \) is obvious.

(iii) \( \implies (ii) \)

Assume that \( L, Q \) and \( I \) are left ideal, quasi ideal and ideal of \( S \), respectively, then \( \Sigma(L, E), \Sigma(Q, E) \) and \( \Sigma(H, E) \) are \( (\in \gamma, \in_{\Sigma} \vee q_{\delta}) \)-fuzzy soft left ideal, \((\in_{\Sigma}, \in_{\Sigma} \vee q_{\delta})\)-fuzzy soft quasi ideal and \((\in_{\Sigma}, \in_{\Sigma} \vee q_{\delta})\)-fuzzy soft ideal over \( S \), respectively. Now we have assume that (iv) holds, then we have

\[
\Sigma(L, E)\hat{\cap} \Sigma(Q, E)\hat{\cap} \Sigma(H, E) \subset_{(\gamma, \delta)} (\Sigma(L, E) \circ \Sigma(Q, E)) \circ \Sigma(I, E).
\]
Thus \( L \cap Q \cap I \subseteq (LQ)I \).

(ii) \( \Rightarrow \) (i)

Let \( L[a] = a \cup Sa \), \( Q[a] = a \) and \( I[a] = aS \cup Sa \), are principle bi-ideal and principle left ideal of \( S \) generated by \( a \) respectively. Thus by (ii), left invertive law, paramedial law and using law \( a(bc) = b(ac) \), we have

\[
\{(Sa) \cap (Sa)\} \cap (Sa) \subseteq \{(aS) \cup (Sa)\} \cap (Sa) = \{(aS)S\} \cup \{(Sa)S\} \cap (Sa) = \{(S(Sa)) \cup \{(Sa)S\}\} \cap (Sa) = [Sa \cup \{(Sa)S\}] \cap (Sa) = [(Sa)(Sa)] \cup \{(Sa)S\} \cap (Sa) \subseteq (aS) a.
\]

Hence \( S \) is regular. \( \blacksquare \)

**Theorem 156** For an AG-groupoid \( S \), with left identity, the following are equivalent.

(i) \( S \) is regular.

(ii) For an ideal \( I \) and bi-ideal \( B \) of \( S \), \( I \cap B \subseteq I (IB) \).

(iii) \( \langle F, I \rangle \cap (G, B) \subseteq (\gamma, \delta) \langle F, I \rangle \cap (\langle F, I \rangle \circ (G, B)) \), for any \( (\epsilon, \gamma, \epsilon, \gamma \cup q \gamma) \)-fuzzy soft ideal \( \langle F, A \rangle \) and \( (\epsilon, \gamma, \epsilon, \gamma \cup q \gamma) \)-fuzzy soft bi-ideal \( \langle H, B \rangle \) of \( S \).

(iv) \( \langle F, I \rangle \cap (G, B) \subseteq (\gamma, \delta) \langle F, I \rangle \cap (\langle F, I \rangle \circ (G, B)) \), for any \( (\epsilon, \gamma, \epsilon, \gamma \cup q \gamma) \)-fuzzy generalized soft ideal \( \langle F, A \rangle \) and \( (\epsilon, \gamma, \epsilon, \gamma \cup q \gamma) \)-fuzzy generalized soft bi-ideal \( \langle H, B \rangle \) of \( S \).

**Proof.** (i) \( \Rightarrow \) (iv)

Let \( \langle F, I \rangle \) and \( \langle G, B \rangle \) be any \( (\epsilon, \gamma, \epsilon, \gamma \cup q \gamma) \)-fuzzy generalized soft ideal and \( (\epsilon, \gamma, \epsilon, \gamma \cup q \gamma) \)-fuzzy generalized soft bi-ideal over \( S \), respectively. Let \( a \) be any element of \( S \), \( \langle F, I \rangle \cap (G, B) = \langle K_1, I \cup B \rangle \). For any \( \varepsilon \in I \cup B \). We consider the following cases,

Case 1: \( \varepsilon \in I - B \). Then \( K_1(\varepsilon) = F(\varepsilon) \cap G(\varepsilon) \) and \( K_2(\varepsilon) = (F \circ G)(\varepsilon) \), so we have \( K_1(\varepsilon) \subseteq \sqrt{q(\gamma, \delta)} K_2(\varepsilon) \).

Case 2: \( \varepsilon \in B - I \). Then \( K_1(\varepsilon) = H(\varepsilon) \) and \( K_1(\varepsilon) = H(\varepsilon) = K_2(\varepsilon) \).

Case 3: \( \varepsilon \in I \cap B \). Then \( K_1(\varepsilon) = F(\varepsilon) \cap G(\varepsilon) \) and \( K_2(\varepsilon) = F(\varepsilon) \circ G(\varepsilon) \). Now we show that \( F(\varepsilon) \cap G(\varepsilon) \subseteq \sqrt{q(\gamma, \delta)} (F(\varepsilon) \circ G(\varepsilon)) \). Now since \( S \) is regular AG-groupoid, so for \( a \in S \) there exist \( x \in S \) such that using left invertive law, we have,

\[
a = (ax) a = [(ax) a] x | a = (ax) [(ax) a] \in I(1B).
\]
Thus we have,

\[
\max \{ (F(\varepsilon) \circ (F(\varepsilon) \circ G(\varepsilon))(a), \gamma \}
\]

\[
= \max \left\{ \sum_{a=pq} F(\varepsilon)(p) \land (F(\varepsilon) \circ G(\varepsilon))(q) \right\}, \gamma \}
\]

\[\geq \max \{ (F(\varepsilon)(ax) \land (F(\varepsilon) \circ G(\varepsilon))(axa), \gamma \}
\]

\[= \max \{ (F(\varepsilon)(ax) \land (F(\varepsilon)(u) \land G(\varepsilon)(v)), \gamma \}
\]

\[\geq \max \{ (F(\varepsilon)(ax) \land (F(\varepsilon)(ax) \land G(\varepsilon)(a), \gamma \}
\]

Assume that \( \gamma \leq \delta \), max \{ (\gamma, \delta) \}

\[= \min \{ (\max \{ F(\varepsilon)(a), \gamma \}, \max \{ G(\varepsilon)(a), \gamma \})
\]

\[\geq \min \{ (\max \{ F(\varepsilon)(a, \delta \}, \min \{ G(\varepsilon)(ax), \delta \})
\]

\[= \min \{ (F(\varepsilon) \land G(\varepsilon))(a), \delta \}
\]

Thus \( \min \{ (F(\varepsilon) \land G(\varepsilon))(a), \delta \} \leq \max \{ (F(\varepsilon) \circ (F(\varepsilon) \circ G(\varepsilon))(a), \gamma \}. \)

This implies that \( F(\varepsilon) \land G(\varepsilon) \subseteq \forall \gamma, \delta \{ F(\varepsilon) \circ (F(\varepsilon) \circ G(\varepsilon)) \}
\]

Therefore in any case, we have \( K_1(\varepsilon) \subseteq \forall \gamma, \delta \{ K_2(\varepsilon) \}. Hence \)

\[\langle F, I \rangle \cap (G, B) \subseteq \langle \gamma, \delta \rangle \{ ((F, I) \circ ((F, I)) \cap (G, B)) \}
\]

(iv) \( \Rightarrow \) (iii) is obvious.

(iii) \( \Rightarrow \) (ii)

Assume that \( \gamma \) and \( \delta \) are ideal and bi-ideal of \( S \), respectively, then \( \Sigma(I, E) \) and \( \Sigma(B, E) \) are \( (\varepsilon, \varepsilon, \forall \varepsilon, \forall \gamma) \)-fuzzy soft ideal and \( (\varepsilon, \varepsilon, \forall \varepsilon, \forall \gamma) \)-fuzzy soft bi-ideal over \( S \), respectively. Now we have assume that (iv) holds, then we have

\[\Sigma(I, E) \cap \Sigma(B, E) \subseteq \langle \gamma, \delta \rangle \{ (\Sigma(I, E) \circ (\Sigma(I, E) \circ (\Sigma(B, E)) \}
\]

So,

\[
\chi_{(\gamma, \delta) I \cap B} = (\gamma, \delta) \chi_{\gamma I} \cap \chi_{\gamma B}
\]

\[\subseteq \forall \gamma, \delta \{ (\chi_{\gamma I} \circ (\chi_{\gamma B}) \}
\]

\[= \forall \gamma, \delta \{ (\chi_{\gamma I}) \circ (\chi_{\gamma B}) \}
\]

Thus \( I \cap B \subseteq I(\gamma, B) \).

(ii) \( \Rightarrow \) (i)

I[a] = aS \cup Sa, and B[a] = a \cup a^2 \cup (aS) a are principle ideal and principle bi-ideal of \( S \) generated by \( a \) respectively. Thus by (ii), left invertive law,
paramedial law and using law \( a(bc) = b(ac) \), we have,

\[
\{(aS) \cup (Sa)\} \cap (Sa) \subseteq \{(aS) \cup (Sa)\}S(Sa) \\
= \{(aS)S\} \cup \{(Sa)S\}(Sa) \\
= \{S(Sa)\} \cup \{(Sa)S\}(Sa) \\
= \{(Sa)(Sa)\} \cup \{(Sa)S\}(Sa) \\
\subseteq (aS)a.
\]

Hence \( S \) is regular. □

**Theorem 157** For an AG-groupoid \( S \), with left identity, the following are equivalent.

(i) \( S \) is regular.

(ii) For an ideal \( I \) and left ideal \( L \) of \( S \), \( I \cap L \subseteq (IS)L \).

(iii) \( (F,I) \cap (G,L) \subseteq (\gamma,\delta) \cap (\Sigma(S,E),G,L) \), for any \((\gamma,\delta)\)-fuzzy soft ideal \( (F,A) \) and \((\gamma,\delta)\)-fuzzy soft left ideal \( (H,B) \) of \( S \).

(iv) \( (F,I) \cap (G,L) \subseteq (\gamma,\delta) \cap (\Sigma(S,E),G,L) \), for any \((\gamma,\delta)\)-fuzzy generalized soft ideal \( (F,A) \) and \((\gamma,\delta)\)-fuzzy generalized soft left ideal \( (H,B) \) of \( S \).

**Proof.** (i) \(\Rightarrow\) (iv)

Let \( (F,I) \) and \( (G,L) \) be any \((\gamma,\delta)\)-fuzzy generalized soft ideal and \((\gamma,\delta)\)-fuzzy generalized soft left ideal over \( S \), respectively. Let \( a \) be any element of \( S \), \( (F,I) \cap (G,L) = (K_1,I \cap L) \). For any \( \varepsilon \in I \cup L \). We consider the following cases,

Case 1: \( \varepsilon \in I - L \). Then \( K_1(\varepsilon) = F(\varepsilon) \cap G(\varepsilon) \) and \( K_2(\varepsilon) = (F \circ G)(\varepsilon) \), so we have \( K_1(\varepsilon) \subseteq \cup\gamma,\delta K_2(\varepsilon) \).

Case 2: \( \varepsilon \in L - I \). Then \( K_1(\varepsilon) = H(\varepsilon) \) and \( K_1(\varepsilon) = H(\varepsilon) = K_2(\varepsilon) \).

Case 3: \( \varepsilon \in I \cap L \). Then \( K_1(\varepsilon) = F(\varepsilon) \cap G(\varepsilon) \) and \( K_2(\varepsilon) = F(\varepsilon) \circ G(\varepsilon) \). Now we show that \( F(\varepsilon) \cap G(\varepsilon) \subseteq \cup\gamma,\delta (F(\varepsilon) \circ G(\varepsilon)) \). Now since \( S \) is regular AG-groupoid, for any \( a \in S \) there exist \( x \in S \) such that using medial law, we have,

\[
a = (ax)a = (ax)(ax) = (a(ax))(ax) \in (IS)L.
\]
Thus we have,

$$\max \left\{ (F(\varepsilon) \circ \lambda_{\gamma S}^\delta) \circ G(\varepsilon))(a), \gamma \right\}$$

$$= \max \left\{ \bigcup_{a= pq} (F(\varepsilon) \circ \lambda_{\gamma S}^\delta)(p) \land G(\varepsilon)(q), \gamma \right\}$$

$$\geq \max \left\{ (F(\varepsilon) \circ \lambda_{\gamma S}^\delta)(a(ax)) \land G(\varepsilon)(xa), \gamma \right\}$$

$$= \max \left\{ \bigcup_{a(ax)= uv} (F(\varepsilon)(u) \land \lambda_{\gamma S}^\delta(v)) \land G(\varepsilon)(xa)), \gamma \right\}$$

$$\geq \max \left\{ (F(\varepsilon)(a) \land \lambda_{\gamma S}^\delta(ax)) \land G(\varepsilon)(xa), \gamma \right\}$$

$$= \max \left\{ \min \{\max\{F(\varepsilon)(a), \gamma\}, \max\{\gamma, \gamma\}\} \right\}$$

$$\geq \min \left\{ \min\{\min\{F(\varepsilon)(a), \delta\}, \min\{\gamma, \gamma\}\} \right\}$$

$$= \min \left\{ \{F(\varepsilon) \land G(\varepsilon))(a), \delta\} \right\}$$

$$\leq \min \left\{ \{F(\varepsilon) \land G(\varepsilon))(a), \delta\} \right\}$$

Thus min \{\{F(\varepsilon) \land G(\varepsilon))(a), \delta\} \leq \max \left\{ (F(\varepsilon) \circ \lambda_{\gamma S}^\delta) \circ G(\varepsilon))(a), \gamma \right\} .$$ This implies that $F(\varepsilon) \land G(\varepsilon) \subseteq q_{(\gamma, \delta)}(F(\varepsilon) \circ \lambda_{\gamma S}^\delta) \circ G(\varepsilon).$

Therefore in any case, we have $K_1(\varepsilon) \subseteq q_{(\gamma, \delta)}K_2(\varepsilon).$ Hence

$$(F, I) \cap (G, L) \subseteq (\gamma, \delta) ((F, I) \circ (S, E)) \circ (G, L).$$

$$(iv) \implies (iii)$$ is obvious.

$$(iii) \implies (ii)$$

Assume that $I$ and $L$ are ideal and left ideal of $S$, respectively, then $\Sigma(I, E)$ and $\Sigma(L, E)$ are $(\varepsilon_1, \varepsilon_2 \cup q_{\delta})$-fuzzy soft ideal and $(\varepsilon_1, \in_\gamma \cup q_{\delta})$-fuzzy soft left ideal over $S$, respectively. Now we have assume that $(iv)$ holds, then we have

$$\Sigma(I, E) \cap (L, E) \subseteq (\gamma, \delta) (\Sigma(I, E) \circ (S, E)) \circ (L, E).$$

So,

$$\lambda_{\gamma S}^\delta (I \cap L) = (\gamma, \delta) \lambda_{\gamma I}^\delta \cap \lambda_{\gamma L}^\delta$$

$$\subseteq q_{(\gamma, \delta)}(\lambda_{\gamma I}^\delta \circ \lambda_{\gamma S}^\delta) \circ \lambda_{\gamma L}^\delta$$

$$= (\gamma, \delta) \lambda_{\gamma (IS) L}^\delta.$$
paramedial law and using law $a(bc) = b(ac)$, we have,

$$\{(aS) \cup (Sa)\} \cap (Sa) \subseteq \{(aS) \cup (Sa)\} \cap (Sa)$$
$$= \{(aS) \cup \{(Sa)S\}\} \cap (Sa)$$
$$= \{(S(Sa)) \cup \{(Sa)S\}\} \cap (Sa)$$
$$= [Sa \cup \{(Sa)S\}] \cap (Sa)$$
$$= \{(Sa)(Sa) \cup \{(Sa)S\}\} \cap (Sa)$$
$$\subseteq (aS)a.$$

Hence $S$ is regular. ■

**Theorem 158** For an AG-groupoid $S$, with left identity, the following are equivalent.

(i) $S$ is regular.

(ii) For left ideal $L$ of $S$, $L \subseteq \{L (LS)\} L$.

(iii) $\langle F, L \rangle \subseteq \{(F, L) \circ (\{(F, L) \circ \Sigma(S, E)\}) \circ (F, L), \text{for any } (\in, \in, \in \vee \eta)\}-fuzzy soft left ideal $\langle H, B \rangle$ of $S$.

(iv) $\langle F, L \rangle \subseteq \{(F, L) \circ (\{(F, L) \circ \Sigma(S, E)\}) \circ (F, L), (\in, \in, \in \vee \eta)\}-fuzzy soft generalized left ideal $\langle F, B \rangle$ of $S$.

**Proof.** (i) $\Rightarrow$ (iv)

Let $\langle F, L \rangle$ be any $(\in, \in, \in \vee \eta)$-fuzzy generalized soft left ideal over $S$. Now we show that $F(\varepsilon) \cap G(\varepsilon) \subseteq \vee \eta \{F(\varepsilon) \circ G(\varepsilon)\}$. Now since $S$ is regular AG-groupoid, so for $a \in S$ there exist $x \in S$ such that using medial law, paramedial law, left invertive law and also using law $a(bc) = b(ac)$, we have,

$$a = (ax)a = [(ax)ax]a = (xa)(ax)a = \{a(ax)\} \{xa\}$$
$$= x[(a(ax)x)]a = (ex)[(a(ax)x)]a$$
$$= [a((ae)(ax))\{xe\}] = [a((ae)(ax))\{xe\}][\hat{x} = \{a((ae)(ax))\}]$$

and $x_1 = (\hat{x}x)$.
Thus we have,

$$\max \{ \mathcal{X}_S^\delta \circ (F(\varepsilon) \circ F(\varepsilon))(a), \gamma \}$$

$$= \max \left\{ \bigvee_{a=pq} F(\varepsilon)((F(\varepsilon) \circ \mathcal{X}_S^\delta)(p) \land F(\varepsilon)(q)), \gamma \right\}$$

$$\geq \max\{ F(\varepsilon)(F(\varepsilon) \circ \mathcal{X}_S^\delta)\} \{a(ax)\} \land F(\varepsilon))(a), \gamma \}$$

$$= \max\{\min\{ F(\varepsilon)(F(\varepsilon) \circ \mathcal{X}_S^\delta)\}\{a(ax)\}, F(\varepsilon))(a), \gamma \}$$

$$= \max\{\min\{ \bigvee_{a(ax)=uv} (F(\varepsilon)(F(\varepsilon) \land \mathcal{X}_S^\delta))(uv)], F(\varepsilon))(a), \gamma \}$$

Thus min \{ (F(\varepsilon))(a), \delta \} \leq \max \{ \mathcal{X}_S^\delta \circ (F(\varepsilon) \circ F(\varepsilon))(a), \gamma \} . This implies that F(\varepsilon) \subseteq \vee q_{(\gamma, \delta)}(\mathcal{X}_S^\delta \circ (F(\varepsilon) \circ F(\varepsilon))) .

Therefore in any case, we have K_1(\varepsilon) \subseteq \vee q_{(\gamma, \delta)}K_2(\varepsilon) . Hence

$$\langle F, L \rangle \subset (\gamma, \delta) (\Sigma(S, E) \circ (\langle F, L \rangle \circ \langle F, L \rangle)) .$$

$$(iv) \implies (iii)$$ is obvious.

$$(iii) \implies (ii)$$

Assume that L is left ideal of S, respectively, then \( \Sigma(L, E) \) is (\( \in_{(\gamma, \delta)}, \in_{(\gamma, \delta)} \vee q_{(\delta, \delta)} \)-fuzzy soft left ideal over S. Now we have assume that (iv) holds, then we have

$$\Sigma(F, L) \subset (\gamma, \delta) (\Sigma(I, E) \circ (\Sigma(S, E)) \circ \Sigma(L, E)) .$$

So,

$$\chi_{\gamma(I \cap L)}^\delta = (\gamma, \delta) \chi^\delta_I \cap \chi^\delta_L \subseteq \vee q_{(\gamma, \delta)}(\chi^\delta_I \circ \chi^\delta_S) \circ \chi^\delta_L = (\gamma, \delta) \chi^\delta_{(I \cap L)L} .$$

Thus \( I \cap L \subseteq (IS)L \).

$$(ii) \implies (i)$$
If \( aS \cup Sa \) and \( L[a] = a \cup Sa \) are principle bi-ideal and principle left ideal of \( S \) generated by \( a \) respectively. Thus by \((ii)\), left invertive law, paramedial law and using law \( a(bc) = b(ac) \), we have,

\[
((aS) \cup (Sa)) \cap (Sa) \subseteq \{((aS) \cup (Sa))S\}(Sa) = \{(aS)S\} \cup \{((Sa)S)(Sa) = \{S(Sa)\} \cup \{(Sa)S\}(Sa) = \[(Sa)(Sa)] \cup \{(Sa)S\}(Sa) = \[(Sa)(Sa)] \cup [(aS)(Sa)] \subseteq (Sa^2)S \cup (aS) a.
\]

Hence \( S \) is regular. □

**Theorem 159** If \( S \) is an AG-groupoid with left identity then the following are equivalent

(i) \( S \) is regular,

(ii) \( I \cap B \subseteq LB \) for left ideal \( I \) and bi-ideal \( B \),

(iii) \( \langle F, L \rangle \cap \{G, B\} \subseteq \gamma, \delta \) \( ((F, L) \circ (G, B)) \), where \( f \) and \( g \) are \((\in_\gamma, \in_\gamma \vee \eta)\)-fuzzy left ideal and bi-ideal of \( S \).

**Proof.** \((i) \Rightarrow (iii)\) Let \( a \in S \), then since \( S \) is regular so using left invertive law we get

\[
a = (ax)a = (ax)\{(ax)a\} = \{(xa)(ax)\}a = \{(xa)(ax)\} = \{(ax)a\}\{(ax)(xa)\}.
\]

\[
\max \{f \circ (\chi_\gamma^S \circ g), \gamma\} = \max \left\{ \frac{\max \{f(p) \wedge (\chi_\gamma^S \circ g)(q)\}}{x=pq}\right\}, \gamma
\]

\[
\geq \max \left\{ \frac{\max [f(ax) \wedge (\chi_\gamma^S \circ g)[x\{(ae)a\}], \gamma]\}}{x=(ae)a}\right\}, \gamma
\]

\[
\max \left\{ \frac{\min \{f(ax), \{\chi_\gamma^S \circ g\}[x\{(ae)a\}], \gamma]\}}{x=(ae)a}\right\}, \gamma
\]

\[
\geq \max \left\{ \frac{\min \{f(ax), \{(\chi_\gamma^S \circ g)(x\{(ae)a\)}, \gamma]\}}{x=(ae)a}\right\}, \gamma
\]

\[
\max \left\{ \frac{\min \{f(ax), \{(\chi_\gamma^S \circ g)(x\{(ae)a\)}, \gamma]\}}{x=(ae)a}\right\}, \gamma
\]

\[
\geq \max \{\min\{f(a), \delta\}, \min\{g(a), \delta\}\}
\]

\[
= \min\{f \cap g(a), \delta\}.
\]
Thus $f \cap g \subseteq \vee q(\gamma, \delta) f \circ (\mathcal{X}_S^\delta \circ g)$.

$(iii) \implies (ii)$ Let $L$ and $B$ are ideal and bi-ideal of $S$ respectively. Then $\mathcal{X}_L^\delta$ and $\mathcal{X}_B^\delta$ are $\langle \epsilon, \nu, v \rangle$-fuzzy left ideal and bi-ideal of $S$ respectively. Now by $(iii)$

$$\mathcal{X}_L^\delta \cap \mathcal{X}_B^\delta \subseteq \vee q(\gamma, \delta) \mathcal{X}_S^\delta \circ (\mathcal{X}_S^\delta \circ \mathcal{X}_B^\delta)$$

Thus $L \cap B \subseteq L(SB)$.

$(ii) \implies (i)$ Using $\{S(Sa)\} \subseteq (Sa)$ and we get

$$a \in (Sa) \cap \{a \cup a^2 \cup (aS)a\} \subseteq (Sa)\{(aS)a\} \subseteq (aS)a.$$ 

Hence $S$ is regular. $\blacksquare$

**Theorem 160** For an AG-groupoid $S$, with left identity, the following are equivalent.

(i) $S$ is regular.

(ii) For bi-ideal $B$ of $S$, $B \subseteq B^2 S$.

(iii) $\langle F, B \rangle \subseteq (\langle F \rangle \circ \langle F \rangle) \circ \Sigma(S, E)$, for any $\langle \epsilon, \nu, v \rangle$-fuzzy soft bi-ideal $(F, A)$ of $S$.

(iv) $\langle F, B \rangle \subseteq (\langle F \rangle \circ \langle F \rangle) \circ \Sigma(S, E)$, for any $\langle \epsilon, \nu, v \rangle$-fuzzy generalized soft bi-ideal $(F, A)$ of $S$.

**Proof.** $(i) \Rightarrow (iv)$

Let $(F, B)$ be any $\langle \epsilon, \nu, v \rangle$-fuzzy generalized soft bi-ideal. Let $a$ be any element of $S$. Now since $S$ is regular AG-groupoid, so for $a \in S$ there exist $x \in S$ such that using left invertive law, medial law, paramedial law and also using law $a(bc) = b(ac)$, we have,

$$a = (ax)a = (ax)\{(ax)a\} \{a(ax)\} \{xa\} = x\{a(ax)a\}$$

$$= x\{(xa)(ae)a\} = x\{(xa)(ae)\} = (ex)\{(xa)(ae)\}$$

$$= [a\{(xa)(ae)\}][xe] = a\{(ae)a\} \{xe\} = \{xe\} \{a(ce)\}$$

$$= \{a(ce)\} \{xe\}a = \{a(ce)\} \{xe\}a \in B^2 S, \text{ where } t = \{xe\}.$$

Thus $(F, B)$ is $(\langle F \rangle \circ \langle F \rangle) \circ \Sigma(S, E)$. 

$(iv) \Rightarrow (i)$

Let $\langle F, B \rangle \subseteq (\langle F \rangle \circ \langle F \rangle) \circ \Sigma(S, E)$. Then $\langle F, B \rangle \subseteq (\langle F \rangle \circ \langle F \rangle) \circ \Sigma(S, E)$. For any $a \in S$, we have

$$a = (ax)a = (ax)\{(ax)a\} \{a(ax)\} \{xa\} = x\{a(ax)a\}$$

$$= x\{(xa)(ae)a\} = x\{(xa)(ae)\} = (ex)\{(xa)(ae)\}$$

$$= [a\{(xa)(ae)\}][xe] = a\{(ae)a\} \{xe\} = \{xe\} \{a(ce)\}$$

$$= \{a(ce)\} \{xe\}a = \{a(ce)\} \{xe\}a \in B^2 S.$$ 

Hence $S$ is regular. $\blacksquare$
Thus we have,

$$\max \left\{ (F(\varepsilon) \circ F(\varepsilon)) \circ (\mathcal{X}^\delta_{\gamma S})(a), \gamma \right\}$$

$$= \max \left\{ \bigvee_{\gamma} (F(\varepsilon) \circ F(\varepsilon))(p \land (\mathcal{X}^\delta_{\gamma S})(q), \gamma \right\}$$

$$\geq \max \left\{ (F(\varepsilon) \circ F(\varepsilon))\{(at)a\} \land (\mathcal{X}^\delta_{\gamma S})(e), \gamma \right\}$$

$$= \max \left\{ \bigvee_{\gamma} \left\{ F(\varepsilon)(u) \land F(\varepsilon)(v) \land \mathcal{X}^\delta_{\gamma S}(e), \gamma \right\} \right\}$$

$$\geq \max \left\{ F(\varepsilon)\{(at)a\} \land F(\varepsilon)(a) \land \mathcal{X}^\delta_{\gamma S}(e), \gamma \right\}$$

$$= \max \left\{ (F(\varepsilon)(a), \delta \right\}$$

$$= \min \left\{ (F(\varepsilon)(a), \delta \right\}$$

Thus $\min \left\{ (F(\varepsilon)(a), \delta \right\} \leq \max \left\{ (F(\varepsilon) \circ F(\varepsilon)) \circ (\mathcal{X}^\delta_{\gamma S})(a), \gamma \right\}$. This implies that $F(\varepsilon) \subseteq \vee q(\gamma, \delta)\{(F(\varepsilon) \circ F(\varepsilon)) \circ \mathcal{X}^\delta_{\gamma S}\}$.

Therefore in any case, we have $K_1(\varepsilon) \subseteq \vee q(\gamma, \delta)K_2(\varepsilon)$. Hence

$$(F, B) \subset (\gamma, \delta) \left\{ (F, B) \circ (F, B) \right\} \circ (S, E).$$

$(iv) \implies (iii)$ is obvious.

$(iii) \implies (ii)$

Assume that $B$ is bi-ideal of $S$, then $\Sigma(B, E)$ is $(\in, \in \vee \lambda)$-fuzzy soft bi-ideal, $(\in, \in \vee \kappa)$-fuzzy soft ideal over $S$, respectively. Now we have assume that $(iv)$ holds, then we have

$$\Sigma(B, E) \subset (\gamma, \delta) \left\{ \Sigma(B, E) \circ \Sigma(B, E) \right\} \circ (S, E)$$

So,

$$\chi_{\gamma B}^\delta = (\gamma, \delta)\chi_{\gamma B} \cap \chi_{\gamma S}$$

$$\subseteq \vee q(\gamma, \delta)(\chi_{\gamma S}^\delta \circ \chi_{\gamma B}) \circ \chi_{\gamma S}$$

$$= (\gamma, \delta)\chi_{\gamma B}^\delta \Subset B^2 S.$$
5.3 References


5. Fuzzy Soft Abel Grassmann Groupoids


[22] M. Khan, Y.B. Jun and K. Ullah, Characterizations of right regular Abel-Grassmann’s groupoids by their $(e, e \vee q_k)$-fuzzy ideals, submitted.


5. Fuzzy Soft Abel Grassmann Groupoids


In this book we introduce $(\in, \in \lor q_{k})$-fuzzy ideals, $(\in, \in \lor q_{\delta})$-fuzzy ideals and $(\in, \in \lor q_{\delta})$-fuzzy soft ideals in a new non-associative algebraic structure called Abel-Grassmann’s groupoid, discuss several important features of a regular AG-groupoid, investigate some characterizations of regular and intra-regular AG-groupoids using the properties of classical ideals and these generalized fuzzy ideals.

We hope that this research work will give a new direction for applications of fuzzy set theory particularly in algebraic logics, non-classical logics, fuzzy finite state machines, fuzzy automata, fuzzy languages, cognitive modeling, multiagent decision analysis and mathematical morphology.