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# Jβ-CLOSED SETS IN TOPOLOGICAL SPACES

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**Abstract:** In this paper, a new class of sets called Jβ-closed sets is introduced and its properties are studied. The relationships among closed, α-closed, β-closed and their generalized closed sets are investigated. Several examples are provided to illustrate the behavior of these new class of sets.

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**Keywords**: β-closed, Jβ-closed, gβ-closed and rgβ-closed sets.

## 1. Introduction

Many investigations related to generalized closed and open sets have been published in various forms of open and closed sets. In 1937, Stone [**13**] introduced the notion of regular open sets. In 1965, Njastad [**9**] introduced the concept of α-open sets. In 1968, the notion of π-open sets were introduced by Zaitsev [**20**] which are weaker form of regular open sets in topological spaces. Velicko [**18**] proposed δ-open sets which are stronger than open sets. In 1970, Levine [**5**] initiated the study of so called generalized closed (briefly g-closed) sets. In 1983, Abd EI-Monsef et al [**1**] introduced the notion of β-open sets. In 1993, Palaniappan and Rao [**10**] introduced the concept of rgβ-closed sets. Maki et. al [**7**] introduced the notion of gα-closed sets. In 1994, Maki et. al [**6**] introduced the notion of αg-closed sets. In 1995, Dontchev [**2**] introduced the notion of gβ-closed sets. In 1996, Dontchev [**3**] introduced the notion of δg-closed sets. In 2000, Veera Kumar [**15**] introduced the notion of g*-closed and ĝ-closed sets. In 2003, Veera Kumar [**16, 17**] introduced the notion of $g^{\#}$-closed sets. In 2008, Jafari [**4**] introduced the notion of *g-closed sets. In 2010, Viswanathan [**19**] introduced the notion of g*α-closed sets. Sarsak and Rajesh [**12**] introduced the concept of πgβ-closed sets. In 2012, Sudha [**14**] introduced the notion of δg*-closed sets. In 2016, Pious [**11**] introduced the notion of regular*-open sets. In 2019, Meenakshi et. al [**8**] have introduced a class of new sets namely η*-open sets which is placed between the classes of δ-open and open sets.

## 2. Preliminaries

Throughout this paper, spaces $(X, \Im)$, $(Y, \sigma)$, and $(Z, \gamma)$ (or simply X, Y and Z) always mean topological spaces. Let A be a subset of a space X. The closure of A and interior of A are denoted by cl(A) and int(A) respectively. A subset A is said to be **regular open** [13] (resp. **regular closed [13]**) if A = int(cl(A)) (resp. A = cl(int(A)). The finite union of regular open sets is said to be **π-open [20]**. The complement of a π-open set is said to be **π-closed [20]**.

**Definition 2.1**. A subset A of a topological space $(X, \Im)$ is said to be
(i) **α-open** [9] if $A \subset int(cl(int(A)))$.

(ii) **β-open** [**1**] if $A \subset cl(int(cl(A)))$.
The complement of a α-open (resp. β-open) set is called **α-closed** (resp. **β-closed)**. The intersection of all α-closed (resp. β-closed) sets containing A, is called **α-closure** (resp. **β-closure**) of A, and is denoted by **α-cl(A)** (resp. **β-cl(A))**. A subset A of a topological space $(X, \Im)$ is said to be **clopen** if it is both open and closed in $(X, \Im)$.

**Definition 2.2.** A subset A of a topological space $(X, \Im)$ is said to be **generalized closed** (briefly **g-closed**) [**5**] if $cl(A) \subset U$ whenever $A \subset U$ and $U \in \Im$.

The **generalized closure** of A is defined as the intersection of all g-closed sets in X containing A and is denoted by **cl*(A)**. The **generalized interior** of A is defined as the union of all g-open sets in X contained in A and is denoted by **int*(A)**.

**Definition 2.4.** The **δ-interior** of a subset A of X is the union of all regular open sets of X contained in A and is denoted by **δ-int(A)**. The subset A is called **δ-open** [**18**] if δ-int(A) = A. i.e. a set is δ-open if it is the union of regular open sets, the complement of a δ-open set is called **δ-closed**. Alternatively, a set $A \subset X$ is δ-closed if A = δ-cl(A), where δ-cl(A) is the intersection of all regular closed sets of $(X, \Im)$ containing A.

**Definition 2.5.** Let $(X, \Im)$ be a topological space. A subset A of $(X, \Im)$ is called **regular*-open** [**11**] (or r*-open) if A = int(cl*(A)). The complement of a regular*-open set is called **regular*-closed**. The union of all regular*-open sets of X contained in A is called **regular*-interior** and is denoted by **r*-int(A)**. The intersection of all regular*-closed sets of X containing A is called **regular*-closure** is denoted by **r*-cl(A)**.

**Definition 2.6.** A subset A of a topological space $(X, \Im)$ is called **η*-open** [**8**] set if it is a union of regular*-open sets (r*-open sets).The complement of a η*-open set is called **η*-closed**. A subset A of a topological space $(X, \Im)$ is called **η*-Interior** of A is the union of all η*-open sets of X contained in A and is denoted by **η*-int(A)**. The intersection of all η*-closed sets of X containing A is called as the **η*-closure** of A and is denoted by **η*-cl(A)**.

**Remark 2.7**.
(i) regular open ⇒ π-open ⇒ δ-open ⇒ η*-open ⇒ open ⇒ α-open ⇒ s-open ⇒ β-open
(ii) regular closed ⇒ π-closed ⇒ δ-closed ⇒ η*-closed ⇒ closed ⇒ α-closed ⇒ s-closed ⇒ β-closed
(iii) regular open ⇒ π-open ⇒ δ-open ⇒ η*-open ⇒ open ⇒ α-open ⇒ p-open ⇒ β-open
(iv) regular closed ⇒ π-closed ⇒ δ-closed ⇒ η*-closed ⇒ closed ⇒ α-closed ⇒ p-closed ⇒ β-closed

**Remark 2.8**. For every subset U of X,
(i) $\beta\text{-}cl(U) \subset s\text{-}cl(U) \subset \alpha\text{-}cl(U) \subset cl(U) \subset \eta^*\text{-}cl(U) \subset \delta\text{-}cl(U) \subset \pi\text{-}cl(U) \subset r\text{-}cl(U)$.
(ii) $g\text{-}cl(U) \subset cl(U)\ ) \subset \eta^*\text{-}cl(U) \subset \delta\text{-}cl(U) \subset \pi\text{-}cl(U) \subset r\text{-}cl(U)$.
(iii) $\beta\text{-}cl(U) \subset p\text{-}cl(U) \subset \alpha\text{-}cl(U) \subset cl(U) \subset \eta^*\text{-}cl(U) \subset \delta\text{-}cl(U) \subset \pi\text{-}cl(U) \subset r\text{-}cl(U)$.

**Definition 2.9.** A subset A of a topological space $(X, \Im)$ is said to be
(1) **δ-generalized closed** (briefly **δg-closed**) [**3**] if $\delta\text{-}cl(A) \subset U$ whenever $A \subset U$ and $U \in \Im$.
(2) **gβ-closed** [**2**] if $\beta\text{-}cl(A) \subset U$ whenever $A \subset U$ and $U \in \Im$.
(3) **α-generalized closed** (briefly **αg-closed**) [**6**] if $\alpha\text{-}cl(A) \subset U$ whenever $A \subset U$ and $U \in \Im$.
(4) **δg*-closed**) [**14**] if $\delta\text{-}cl(A) \subset U$ whenever $A \subset U$ and U is g-open in X.
(5) **generalized α-closed** (briefly **gα-closed**) [**7**] if $\alpha\text{-}cl(A) \subset U$ whenever $A \subset U$ and U is α-open in X.
(6) **generalized* α-closed** (briefly **g*α-closed**) [**19**] if $\alpha\text{-}cl(A) \subset U$ whenever $A \subset U$ and U is gα-open in X.
(7) **ĝ-closed** [**16**] if $cl(A) \subset U$ whenever $A \subset U$ and U is semi-open in X.
(8) ***g-closed** [**4**] if $cl(A) \subset U$ whenever $A \subset U$ and U is ĝ-open in X.
(9) **g*-closed** [**15**] if $cl(A) \subset U$ whenever $A \subset U$ and U is g-open in X.
(10) **$g^{\#}$-closed** [**17**] if $cl(A) \subset U$ whenever $A \subset U$ and U is αg-open in X.

(11) **πgβ-closed** [**12**] if β-cl(A) ⊂ U whenever A ⊂ U and U is π-open in X.
(12) **rgβ-closed** [**10**] if β-cl(A) ⊂ U whenever A ⊂ U and U is regular open in X.
(13) **g-open** (resp**. δg-open**, **gβ-open**, **αg-open, δg*-open, gα-open**, **g*α-open, ĝ-open, *g-open**, **g*-open, g#-open, πgβ-open, rgβ-open**) set if the complement of A is g-closed (resp. δg-closed, gβ-closed, αg-closed, δg*-closed, gα-closed, g*α-closed, ĝ-closed, *g-closed, g*-closed, g#-closed, πgβ-closed, rgβ-closed).

## 3. Jβ-closed Sets

In this section a new class of generalized closed sets, called Jβ-closed sets are introduced. The relations between Jβ-closed sets and various existing closed sets are investigated.

**3.1 Definition** A subset U of a topological space (X, ℑ) is said to be **Jβ-closed** if **β**-cl(U) ⊂ M whenever U ⊂ M and M is η*-open in (X, ℑ).

**3.2 Proposition.** Every g-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a g-closed set and M be any η*-open set containing U in X. Since every η*-open set is open, so M is open. Given that U is g-closed, cl(U) ⊂ M. Hence β-cl(U) ⊂ cl(U) ⊂ M, which implies that U is Jβ-closed.

**3.3 Proposition.** Every g*-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a g*-closed set and M be any η*-open set containing U in X. Since every η*-open set is g-open, so M is g-open. Given that U is g*-closed, cl(U) ⊂ M. Hence β-cl(U) ⊂ cl(U) ⊂ M, which implies that U is Jβ-closed.

**3.4 Proposition.** Every δ-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a δ-closed set and M be any η*-open set containing U in X. Since U is δ-closed, δ-cl(U) = U ⊂ M. As β-cl(U) ⊂ δ-cl(U) ⊂ M and hence U is Jβ-closed.

**3.5 Proposition.** Every δg-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a δg-closed set and M be any η*-open set containing U in X. Since every η*-open set is open, so M is open. Given that U is δg-closed, δ-cl(U) ⊂ M. As β-cl(U) ⊂ δ-cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.6 Proposition.** Every δg*-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a δg*-closed set and M be any η*-open set containing U in X. Since every η*-open set is g-open, so M is g-open. Given that U is δg*-closed, δ-cl(U) ⊂ M. As β-cl(U) ⊂ δ-cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.7 Proposition.** Every αg-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a αg-closed set and M be any η*-open set containing U in X. Since every η*-open set is open, so M is open. Given that U is αg-closed, α-cl(U) ⊂ M. As β-cl(U) ⊂ α-cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.8 Proposition.** Every gα-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a gα-closed set and M be any η*-open set containing U in X. Since every η*-open set is α-open, so M is α-open. Given that U is gα-closed, α-cl(U) ⊂ M. As β-cl(U) ⊂ α-cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.9 Proposition.** Every gα*-closed set is Jβ-closed but not conversely.

**Proof.** Let U be a gα*-closed set and M be any η*-open set containing U in X. Since every η*-open set is gα-open, so M is gα-open. Given that U is gα*-closed, α-cl(U) ⊂ M. As β-cl(U) ⊂ α-cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.10 Proposition.** Every $g^{\#}$-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a $g^{\#}$-closed set and M be any η*-open set containing U in X. Since every η*-open set is αg-open, so M is αg-open. Given that U is $g^{\#}$-closed, cl(U) ⊂ M. As β-cl(U) ⊂ cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.11 Proposition.** Every *g-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a *g-closed set and M be any η*-open set containing U in X. Since every η*-open set is ĝ-open, so M is ĝ-open. Given that U is *g-closed, cl(U) ⊂ M. As β-cl(U) ⊂ cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.12 Proposition.** Every ĝ-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a ĝ-closed set and M be any η*-open set containing U in X. Since every η*-open set is s-open, so M is s-open. Given that U is ĝ-closed, cl(U) ⊂ M. As β-cl(U) ⊂ cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

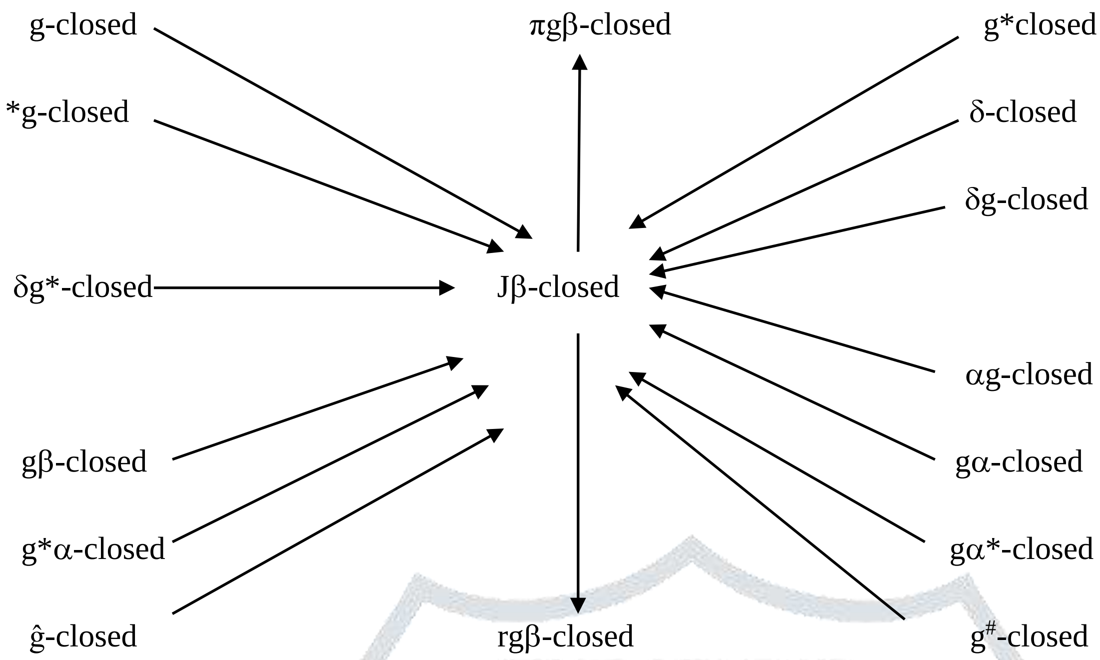
**3.13 Proposition.** Every g*α-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a g*α-closed set and M be any η*-open set containing U in X. Since every η*-open set is gα-open, so M is gα-open. Given that U is g*α-closed, α-cl(U) ⊂ M. As β-cl(U) ⊂ α-cl(U) ⊂ M. We get β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.14 Proposition.** Every gβ-closed set is Jβ-closed but not conversely.
**Proof.** Let U be a gβ-closed set and M be any η*-open set containing U in X. Since every η*-open set is open, so M is open. Given that U is gβ-closed, β-cl(U) ⊂ M. Hence U is Jβ-closed.

**3.15 Proposition.** Every Jβ-closed set is πgβ-closed but not conversely.
**Proof.** Let U be a Jβ-closed set and M be any π-open set containing U in X. Since every π-open set is η*-open, so M is η*-open. Given that U is πgβ-closed, β-cl(U) ⊂ M. Hence U is πgβ-closed.

**3.16 Proposition.** Every Jβ-closed set is rgβ-closed but not conversely.
**Proof.** Let U be a Jβ-closed set and M be any r-open set containing U in X. Since every r-open set is η*-open, so M is η*-open. Given that U is Jβ-closed, β-cl(U) ⊂ M. Hence U is rgβ-closed.

**3.17 Remark.** From the above definitions, theorems and known results the relationship between Jβ-closed sets and some other existing generalized closed sets are implemented in the following figure:




**Where none of the implications is reversible as can be seen from the following examples:**

**3.18 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a}, {a, b}, {a, c}}. Then the subset A = {a} is Jβ-closed but not g-closed in (X, $\Im$).

**3.19 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a}}. Then the subset A = {b} is Jβ-closed but not δ-closed in (X, $\Im$).

**3.20 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a, b}}. Then the subset A = {a} is Jβ-closed but not δg*-closed in (X, $\Im$).

**3.21 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a}, {a, b}}. Then the subset A = {b} is Jβ-closed but not δg-closed in (X, $\Im$).

**3.22 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a}, {b, c}}. Then the subset A = {a, b} is Jβ-closed but not gα*-closed in (X, $\Im$).

**3.23 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a}, {a, b}}. Then the subset A = {b} is Jβ-closed but not g#-closed in (X, $\Im$).

**3.24 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a}, {a, b}, {a, c}}. Then the subset A = {a} is Jβ-closed but not *g-closed in (X, $\Im$).

**3.25 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a, b}}. Then the subset A = {a} is Jβ-closed but not ĝ -closed in (X, $\Im$).

**3.26 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a}, {a, b}}. Then the subset A = {a, b} is Jβ-closed but not g*α-closed in (X, $\Im$).

**3.27 Example.** Let X = {a, b, c} and $\Im$ = {ϕ, X, {a}}. Then the subset A = {a, b} is Jβ-closed but not gα-closed in (X, $\Im$).

**3.28 Example.** Let X = {a, b, c} and $\mathfrak{I}$ = {ϕ, X, {a, b}}. Then the subset A = {a, c} is Jβ-closed but not αg-closed in (X, $\mathfrak{I}$).

**3.29 Example.** Let X = {a, b, c} and $\mathfrak{I}$ = {ϕ, X, {a}, {a, b}}. Then the subset A = {b} is Jβ-closed but not g*-closed in (X, $\mathfrak{I}$).

## 4. Properties of Jβ-closed sets

**4.1 Theorem**. The finite union of Jβ-closed sets is Jβ-closed.
**Proof.** Let $\{U_i$ / i = 1, 2, 3, ……n} be a finite class of Jβ-closed sets of (X, $\mathfrak{I}$). Let $U = \cup^n{}_{i=1} U_i$. Let M be a η*-open set containing U. This implies $U_i \subset M$ for every i. By assumption $\beta\text{-cl}(U_i) \subset M$ for every i. This implies $\cup^n{}_{i=1}$ β-cl(U) ⊂ M. Then $\beta\text{-cl}(\cup^n{}_{i=1} (U_i)) \subset M$. Thus β-cl(U) ⊂ M. Hence finite union of Jβ-closed sets is Jβ-closed in (X, $\mathfrak{I}$).

**4.2 Remark**. The intersection of two Jβ-closed sets need not be Jβ-closed.

**4.3 Example.** Let X = {a, b, c} and $\mathfrak{I}$ = {ϕ, X, {a}}. Here Jβ-closed sets are {ϕ, X, {b}, {c}, {a, b}, {a, c} {b, c}}. Then {a, c} ∩ {a, b} = {a} is not a Jβ-closed set.

**4.4 Theorem**. For x ∈ X, then the set X – {x} is Jβ-closed or η*-open.
**Proof**. Assume that X – {x} is not η*-open. So X is the only η*-open set containing X – {x}. That is β-cl(X – {x}) ⊂ X. Then X – {x} is a Jβ-closed set in X

**4.5 Theorem**. The subset S of X is Jβ-closed in X if and only if β-cl(S) – S contains no non empty η*-closed set in X.
**Proof**. **Necessity**: Let F be a η*-closed set in X such that F ⊂ β-cl(A) – A. Then A ⊂ X – F. Since A is a Jβ-closed set and X – F is η*-open then β-cl(A) ⊂ X – F. (i.e F ⊂ X – β-cl(A)). Then F ⊂ (X – β-cl(A)) ∩ β-cl(A) – A. Therefore F = ϕ.

**Sufficency**: Let us assume that β-cl(A) – A contains no non empty η*-closed set. Let A ⊂ U and U be η*-open. Suppose that β-cl(A) is not contained in U, then $\beta\text{-cl}(A) \cap U^c$ is non empty η*-closed set of β-cl(A) – A which is a contradiction. Therefore β-cl(A) ⊂ U. Hence A is a Jβ-closed set.

**4.6 Theorem**. If M is Jβ-closed set in X and M ⊂ N ⊂ β-cl(M), then N is Jβ-closed set in X.
**Proof**. Let U be a η*-open set in X, since M is Jβ-closed, we have β-cl(M) ⊂ U. Let ⊂ M ⊂ N ⊂ β-cl(M) ⊂ U. Since N ⊂ β-cl(M), we have β-cl(N) ⊂ β-cl(M). Then β-cl(N) – N ⊂ β-cl(M) – M ⊂ U. By the above theorem β-cl(M) – M contains no non empty η*-closed set in X. Therefore β-cl(N) – N contains no non empty η*-closed set in X. Hence N is a Jβ-closed set in X.

**4.7 Theorem**. Let D be a Jβ-closed set in (X, $\mathfrak{I}$). Then D is β-closed if and only if β-cl(D) – D is η*-closed.
**Proof**. (**Necessity**): Let D be a β-closed set in X. Then β-cl(D) = D and therefore β-cl(D) – D = ϕ which is a η*-closed.

(**Sufficiency**): Let β-cl(D) – D be a η*-closed set. Since D is Jβ-closed, By theorem β-cl(D) – D does not contain a non-empty η*-closed set which implies β-cl(D) – D = ϕ. That is β-cl(D) = D. Hence D is β-closed.

**4.8 Definition**. Let B ⊂ A ⊂ X. Then B is Jβ-closed relative to A if $\beta\text{-cl}_A(B) \subset M$, whenever B ⊂ M, M is η*-open in A.

**4.9 Theorem**. Let B ⊂ A ⊂ X. and suppose that B is Jβ-closed in X, then B is Jβ-closed relative to A. The converse is true if A is β-closed in X.

**Proof**. Suppose that B is Jβ-closed in X. Let $B \subset M$, M is η*-open in A. Since M is η*-open in A, $M = V \cap A$, where V is η*-open in X. Hence $B \subset M \subset V$. Since B is Jβ-closed in X, $\beta\text{-cl}_A(B) \subset M$. Hence $\beta\text{-cl}_A(B) \cap A \subset V \cap A$ which in turn implies that $\beta\text{-cl}_A(B) \subset V \cap A = M$. Therefore B is Jβ-closed relative to A.
Now to prove the converse, assume that $B \subset A \subset X$ where A is β-closed in X and B is Jβ-closed relative to A. Let $B \subset M$, M is η*-open in X. Then $A \cap M$ is η*-open in A by the definition of subspace topology. Since $B \subset A$ and $B \subset M$, $B \subset A \cap M$, Since B is Jβ-closed relative to A, $\beta\text{-cl}_A(B) \subset A \cap M$. Since $B \subset A$, $\beta\text{-cl}(B) \subset \beta\text{-cl}(A)$. Hence $\beta\text{-cl}(B) \subset A$. Therefore $\beta\text{-cl}(B) \cap A \subset \beta\text{-cl}(B)$ which implies $\beta\text{-cl}_A(B) = \beta\text{-cl}(B)$. Hence $\beta\text{-cl}(B) \subset A \cap M = M$. Thus B is Jβ-closed in X.

## 5. Conclusion

The concept of new closed set namely Jβ-closed set using η*-open sets is introduced and studied. The relationship of Jβ-closed sets using existing closed sets is established. Finally, some of their fundamental properties are studied. Hence I conclude that the defined set forms a topology which results in this work may be entered widely. The Jβ-closed set can be used to derive a new decomposition of unity, closed map and open map, homeomorphism, closure and interior and new separation axioms. This idea can be extended to bitopological and fuzzy topological spaces.

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