SOME NEW DECOMPOSITION THEOREMS

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Abstract. In 1968, N. V. Velic´ko [11] introduced the concepts of δ-closed sets, δ-open sets, δ-closure and δ-interior opertors in topological spaces. In [4], the con- cept of λ-closed sets was introduced. In this paper, α-δw-open sets, pre-δw-open sets, semi-δw-open sets, strongly β-δw-open sets and b-δw-open sets in topological spaces are introduced and investigated. We introduce new classes of sets by using λ-δw-closed sets in topological spaces and study their basic properties; and their connections with other types of topological sets. Furthermore, some new decompo- sition theorems are obtained.

1. Introduction and Preliminaries

By a space X, we always mean a topological space (X,τ) with no separation prop- erties assumed. If $H\subseteq X$, cl(H) and int(H) will, respectively, denote the closure and interior of H in (X,τ).

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Definition 1.1. [10] A subset H of a space X is said to be

(1) regular open if H=int(cl(H)). (2)

regular closed if H=cl(int(H)).

The complement of a regular open set is called regular closed.

Definition 1.2. A subset H of a space X is said to be

(1) α-open [9] if $H\subseteq int(cl(int(H)))$.

(2) preopen [8] if $H\subseteq int(cl(H))$.

(3) semi-open [6] if $H\subseteq cl(int(H))$.

(4) β-open [1] if $H\subseteq cl(int(cl(H)))$.

(5) b-open [3] if $H\subseteq int(cl(H))\cup cl(int(H))$.

Definition 1.3. A subset A of a space X is called a Λ-set if $A=A^{\Lambda}$ where $A^{\Lambda}=\cap\{G: A\subseteq G$ and $G\in\tau\}$ [7].

Definition 1.4. A subset O of a space X is called λ-closed [4] if $O=L\cap M$, where L is a Λ-set and M is closed.

Proposition 1.5. [7] In a space X, every open set is a Λ-set but not conversely.

A point $x\in X$ is called a δ-cluster [11] of $H\subseteq X$ if $H\cap G=\varphi$ for each regular open set G containing x.

The set of all δ-cluster points of H is called the δ-closure of H and is denoted by $cl_\delta(H)$.

A subset H of a space X is called δ-closed if $cl_\delta(H)=H$.

The complement of a δ-closed set is called δ-open.

The collection of all δ-open subsets of X forms a topology τ_δ on X. Indeed $\tau_\delta\subset\tau$. Let A be a subset of a space X. Then

(1) $cl_\delta(X - A)=X - int_\delta(A)$. (2)

$int_\delta(X - A)=X - cl_\delta(A)$.

Let us say that $w \subseteq \wp(X)$ is a weak structure (briefly WS) on X iff $\emptyset \in w$. Clearly each generalized topology and each minimal structure is a WS [5].

Each member of w is said to be w-open and the complement of a w-open set is called w-closed.

Let w be a weak structure on X and $H \subseteq X$. We define (as in the general case) $i_w(H)$ is the union of all w-open subsets contained in H and $c_w(H)$ is the intersection of all w-closed sets containing H [5].

Remark 1.6. [2] If w is a WS on X, then $i_w(\emptyset)=\emptyset$ and $c_w(X)=X$.

Theorem 1.7. [5] If w is a WS on X and $A,B \in w$ then

(1) $i_w(A) \subseteq A \subseteq c_w(A)$,

(2) $A \subseteq B \Rightarrow i_w(A) \subseteq i_w(B)$ and $c_w(A) \subseteq c_w(B)$, (3)
$i_w(i_w(A))=i_w(A)$ and $c_w(c_w(A))=c_w(A)$,

(4) $i_w(X-A)=X-c_w(A)$ and $c_w(X-A)=X-i_w(A)$.

Let w be a WS on X and $H \subseteq X$. Then $H \in \alpha(w)$ [resp. $H \in \sigma(w)$, $H \in \pi(w)$, $H \in \beta(w)$, $H \in b(w)$] if $H \subseteq i_w(c_w(i_w(H)))$ [resp. $H \subseteq c_w(i_w(H))$, $H \subseteq i_w(c_w(H))$, $H \subseteq c_w(i_w(c_w(H)))$, $H \subseteq i_w(c_w(H)) \cup c_w(i_w(H))$] [5].

2. Generalized δw-open sets

Definition 2.1. Let w be a weak structure on a space X. A subset G of X is called

(1) pre-δw-open if $G \subseteq i_w(cl_\delta(G))$. (2)
semi-δw-open if $G \subseteq cl_\delta(i_w(G))$. (3) α-
δw-open if $G \subseteq i_w(cl_\delta(i_w(G)))$.

(4) strongly β-δw-open if $G \subseteq cl_\delta(i_w(cl_\delta(G)))$. (5)
b-δw-open if $G \subseteq i_w(cl_\delta(G)) \cup cl_\delta(i_w(G))$.

The complement of a pre-δw-open (resp. a semi-δw-open, an α-δw-open, a strongly β-δw-open, a b-δw-open) set is called pre-δw-closed (resp. semi-δw-closed, α-δw-closed, strongly β-δw-closed, b-δw-closed).

Definition 2.2. For a WS w on a space X and a subset G of X, the intersection of all pre-δw-closed (resp. semi-δw-closed, α-δw-closed, strongly β-δw-closed, b-δw-closed) sets containing G is called the pre-δw-closure (resp. semi-δw-closure, α-δw-closure, strongly β-δw-closure, b-δw-closure) of G and is denoted by $pcl_{\delta w}(G)$ (resp. $scl_{\delta w}(G)$, $\alpha cl_{\delta w}(G)$, $s\beta cl_{\delta w}(G)$, $bcl_{\delta w}(G)$).

Proposition 2.3. For a WS w on a space X, we have

(1) Every w-open set is α-δw-open.

(2) Every α-δw-open is semi-δw-open. (3)

Every α-δw-open set is pre-δw-open.

(4) Every pre-δw-open set is strongly β-δw-open. (5)

Every semi-δw-open set is strongly β-δw-open.

Proof. (1) Let H be a w-open set. Then $H=i_w(H)$. Since $H\subseteq cl_\delta(H)$, $i_w(H)\subseteq cl_\delta(i_w(H))$ and $i_w(H)\subseteq i_w(cl_\delta(i_w(H)))\Rightarrow H\subseteq i_w(cl_\delta(i_w(H)))$. This shows that H is an α-δw- open set.

(2) Let H be an α-δw-open set. Then $H\subseteq i_w(cl_\delta(i_w(H)))\subseteq cl_\delta(i_w(H))$. This shows that H is a semi-δw-open set.

(3) Let H be an α-δw-open set. Then $H\subseteq i_w(cl_\delta(i_w(H)))\subseteq i_w(cl_\delta(H))$. This shows that H is a pre-δw-open set.

(4) Let H be a pre-δw-open set. Then $H\subseteq i_w(cl_\delta(H))$ and $cl_\delta(H) \subseteq cl_\delta(i_w(cl_\delta(H)))$. This shows that H is strongly β-δw-open.

(5) Let H be a semi-δw-open set. Then $H\subseteq cl_\delta(i_w(H))\subseteq cl_\delta(i_w(cl_\delta(H)))$. This shows that H is a strongly β-δw-open.

Remark 2.4. For several subsets defined above, we have the following implications. pre-

δw-open set −→ strongly β-δw-open set

↑ ↑

w-open set −→ α-δw-open set −→ semi-δw-open set

The reverse implications are not true.

Example 2.5. Let X={a, b, c, d}, τ={∅, {a}, {a, b, c}, X} and w={∅, {b, c}, {a, c, d}, X}. Then {a, b, c} is an α-δw-open set but it is not an w-open set.

Example 2.6. Let X={a, b, c, d}, τ={∅, {d}, {a, c}, {a, c, d}, X} and w={∅, {a}, {d}, {a, b, c}, X}. Then {b, d} is a semi-δw-open set but it is not an α-δw-open set.

Example 2.7. In Example 2.6, {c} is a pre-δw-open set but it is not an α-δw-open set.

Example 2.8. In Example 2.6, {b, d} is a strongly β-δw-open set but it is not a pre-δw-open set.

Example 2.9. In Example 2.6, {c, d} is a strongly β-δw-open set but it is not a semi-δw-open set.

Remark 2.10. For a WS on a space X and a subset A of X, we have

(1) $pcl_{\delta w}(A) = A \cup c_w(int_\delta(A))$. (2) $scl_{\delta w}(A) = A \cup int_\delta(c_w(A))$.
(3) $\alpha cl_{\delta w}(A) = A \cup c_w(int_\delta(c_w(A)))$. (4) $s\beta cl_{\delta w}(A) = A \cup int_\delta(c_w(int_\delta(A)))$. (5) $bcl_{\delta w}(A)= pcl_{\delta w}(A) \cap scl_{\delta w}(A)$.

Definition 2.11. Let w be a WS on a space X. A subset A of X is called

(1) a $\Lambda_{\alpha w}$-set if $A = \Lambda_{\alpha w}(A)$ where $\Lambda_{\alpha w}(A) = \cap\{G : A \subseteq G \text{ and } G \in \alpha(w)\}$. (2) a Λ_{sw}-set if $A = \Lambda_{sw}(A)$ where $\Lambda_{sw}(A) = \cap\{G : A \subseteq G \text{ and } G \in \sigma(w)\}$. (3) a Λ_{pw}-set if $A = \Lambda_{pw}(A)$ where $\Lambda_{pw}(A) = \cap\{G : A \subseteq G \text{ and } G \in \pi(w)\}$. (4) a $\Lambda_{\beta w}$-set if $A = \Lambda_{\beta w}(A)$ where $\Lambda_{\beta w}(A) = \cap\{G : A \subseteq G \text{ and } G \in \beta(w)\}$. (5) a Λ_{bw}-set if $A = \Lambda_{bw}(A)$ where $\Lambda_{bw}(A) = \cap\{G : A \subseteq G \text{ and } G \in b(w)\}$.

Definition 2.12. Let w be a WS on a space X. A subset K of X is called

(1) a $C_{\delta w}$-set if K = L ∩ F, where L is open and F is a pre-δw-closed set in X. (2) a $BC_{\delta w}$-set if K = L ∩ F, where L is open and F is a b-δw-closed set in X. (3) an $\eta_{\delta w}$-set if K = L ∩ F, where L is open and F is an α-δw-closed set in X.

Definition 2.13. Let w be a WS on a space X. A subset K of X is called

(1) λ-δw-α-closed if K = L ∩ F, where L is a Λ-set and F is an α-δw-closed set. (2) a $DC_{\delta w}$-set if K = L ∩ F, where L is open and F is a semi-δw-closed set.

(3) a $sFC_{\delta w}$-set if K = L ∩ F, where L is open and F is a strongly β-δw-closed set.

Lemma 2.14. Let w be a WS on a space X. Then the following statements hold. (1) Every α-δw-closed set is λ-δw-α-closed.

(2) Every Λ-set is λ-δw-α-closed.

Example 2.15. Let X = {a, b, c}, τ = {∅, X, {a}, {a, b}} and w={∅, {a, b}, X}. Then

(1) {a} is λ-δw-α-closed but not α-δw-closed. (2) {c} is λ-δw-α-closed but not a Λ-set.

Lemma 2.16. For a WS w on a space X and a subset A of X, then the following conditions are equivalent.

(1) A is λ-δw-α-closed.

(2) A = L ∩ $\alpha cl_{\delta w}(A)$ where L is a Λ-set. (3) A = A^{Λ} ∩ $\alpha cl_{\delta w}(A)$.

Lemma 2.17. For a WS w on a space X, the following statements hold. (1) Every open set is an $\eta_{\delta w}$-set.

(2) Every α-δw-closed set is an $\eta_{\delta w}$-set.

Example 2.18. In Example 2.15,

(1) {c} is an $\eta_{\delta w}$-set but not open.

(2) {a, b} is an $\eta_{\delta w}$-set but not an α-δw-closed.

Lemma 2.19. Let w be a WS on a space X. Then every $\eta_{\delta w}$-set is λ-δw-α-closed.

Proposition 2.20. Let w be a WS on a space X. Then the concepts of

(1) α-open sets and α-δw-open sets are independent.

(2) semi-open sets and semi-δw-open sets are independent. (3) preopen sets and pre-δw-open sets are independent.

(4) β-open sets and strongly β-δw-open sets are independent. (5) b-open sets and b-δw-open sets are independent.

Example 2.21. Let X = {a, b, c}, τ ={∅, X, {b}, {c}, {b, c}} and w={∅, {a}, {b, c}}. Then

(1) {a} is an α-δw-open set but it is not an α-open set. (2) {b} is an α-open set but it is not an α-δw-open set.

Example 2.22. In Example 2.21,

(1) {a} is a semi-δw-open set but it is not a semi-open set. (2) {b} is a semi-open set but it is not a semi-δw-open set.

Example 2.23. In Example 2.21,

(1) {a} is a pre-δw-open set but it is not a preopen set. (2) {b} is a preopen set but it is not a pre-δw-open set.

Example 2.24. In Example 2.21,

(1) {a} is a strongly β-δw-open set but it is not a β-open set. (2) {b} is a β-open set but it is not a strongly β-δw-open set.

Example 2.25. In Example 2.21,

(1) {a} is a b-δw-open set but it is not a b-open set. (2) {b} is a b-open set but it is not a b-δw-open set.

Definition 2.26. Let w be a WS on a space X. A subset A of X is said to be

(1) $\delta w_{\alpha g}$-closed if $\alpha cl_{\delta w}(A) \subseteq U$ whenever $A \subseteq U$ and U is open. (2) δw_{gs}-closed if $scl_{\delta w}(A) \subseteq U$ whenever $A \subseteq U$ and U is open. (3) δw_{gp}-closed if $pcl_{\delta w}(A) \subseteq U$ whenever $A \subseteq U$ and U is open. (4) δw_{gsp}-closed if $s\beta cl_{\delta w}(A) \subseteq U$ whenever $A \subseteq U$ and U is open. (5) δw_{gb}-closed if $bcl_{\delta w}(A) \subseteq U$ whenever $A \subseteq U$ and U is open.

Lemma 2.27. Let w be a WS on a space X. A subset $A \subseteq X$ is $\delta w_{\alpha g}$-closed if and only if $\alpha cl_{\delta w}(A) \subseteq A^{\Lambda}$.

Theorem 2.28. For a WS w on a space X and a subset A of X, the following conditions are equivalent.

(1) A is α-δw-closed.

(2) A is $\delta w_{\alpha g}$-closed and an $\eta_{\delta w}$-set.

(3) A is $\delta w_{\alpha g}$-closed and λ-δw-α-closed.

Proof. (1) ⇒ (2) and (2) ⇒ (3) : Obvious.

(3) ⇒ (1) : Since A is $\delta w_{\alpha g}$-closed, by Lemma 2.27, $\alpha cl_{\delta w}(A) \subseteq A^{\Lambda}$. Since A is λ-δw-α-closed, by Lemma 2.16, $A = A^{\Lambda} \cap \alpha cl_{\delta w}(A) = \alpha cl_{\delta w}(A)$. Hence A is α-δw- closed.

Remark 2.29. The following example shows that the concepts of $\delta w_{\alpha g}$-closed sets and $\eta_{\delta w}$-sets are independent of each other.

Example 2.30. (1) In Example 2.15, {a} is an $\eta_{\delta w}$-set but not $\delta w_{\alpha g}$-closed. (2) In Example 2.15, {a, c} is $\delta w_{\alpha g}$-closed but not an $\eta_{\delta w}$-set.

Remark 2.31. The following example shows that the concepts of $\delta w_{\alpha g}$-closed sets and λ-δw-α-closed sets are independent of each other.

Example 2.32. (1) In Example 2.15, {a} is λ-δw-α-closed but not $\delta w_{\alpha g}$-closed. (2) In Example 2.15, {a, c} is $\delta w_{\alpha g}$-closed but not λ-δw-α-closed.

Definition 2.33. Let w be a WS on a space X. A subset K of X is called

(1) λ-δw-semi-closed if K = L ∩ F, where L is a Λ-set and F is semi-δw-closed. (2) λ-δw-pre-closed if K = L ∩ F, where L is a Λ-set and F is pre-δw-closed

(3) λ-δw-β-closed if K = L ∩ F, where L is a Λ-set and F is strongly β-δw-closed. (4) λ-δw-b-closed if K = L ∩ F, where L is a Λ-set and F is b-δw-closed.

Lemma 2.34. Let w be a WS on a space X. A subset A ⊆ X is

(1) δw_{gs}-closed if and only if $scl_{\delta w}(A) \subseteq A^{\Lambda}$. (2) δw_{gp}-closed if and only if $pcl_{\delta w}(A) \subseteq A^{\Lambda}$. (3) δw_{gsp}-closed if and only if $s\beta cl_{\delta w}(A) \subseteq A^{\Lambda}$. (4) δw_{gb}-closed if and only if $bcl_{\delta w}(A) \subseteq A^{\Lambda}$.

Corollary 2.35. For a WS w on a space X and a subset A of X, the following conditions are equivalent.

(1) (i) A is semi-δw-closed.
(ii) A is δw_{gs}-closed and a $DC_{\delta w}$-set.
(iii) A is δw_{gs}-closed and λ-δw-semi-closed.

(2) (i) A is pre-δw-closed.
(ii) A is δw_{gp}-closed and a $C_{\delta w}$-set.
(iii) A is δw_{gp}-closed and λ-δw-pre-closed.

(3) (i) A is strongly β-δw-closed.
(ii) A is δw_{gsp}-closed and a $sFC_{\delta w}$-set. (iii) A is δw_{gsp}-closed and λ-δw-β-closed.

(4) (i) A is b-δw-closed.
(ii) A is δw_{gb}-closed and a $BC_{\delta w}$-set. (iii) A is δw_{gb}-closed and λ-δw-b-closed.

Proof. The proof is similar to that of Lemma 2.16 and Theorem 2.28.

Remark 2.36. The following examples show that the concepts of

(1) δw_{gs}-closed sets and $DC_{\delta w}$-sets are independent of each other.

(2) δw_{gs}-closed sets and λ-δw-semi-closed sets are independent of ech other. (3) δw_{gp}-closed sets and $C_{\delta w}$-sets are independent of each other.

(4) δw_{gp}-closed sets and λ-δw-pre-closed sets are independent of each other. (5) δw_{gsp}-closed sets and $sFC_{\delta w}$-sets are independent of each other.

(6) δw_{gsp}-closed sets and λ-δw-β-closed sets are independent of each other. (7) δw_{gb}-closed sets and $BC_{\delta w}$-sets are independent of each other.

(8) δw_{gb}-closed sets and λ-δw-b-closed sets are independent of each other.

Example 2.37. (1) In Example 2.15, {a} is a $DC_{\delta w}$-set but not δw_{gs}-closed. (2) In Example 2.15, {a, c} is δw_{gs}-closed but not a $DC_{\delta w}$-set.

Example 2.38. (1) In Example 2.15, {a} is λ-δw-semi-closed but not δw_{gs}-closed. (2) In Example 2.15, {a, c} is δw_{gs}-closed but not λ-δw-semi-closed.

Example 2.39. Let X={a, b, c}, τ={∅, {b}, {c}, {b, c}, X} and w={∅, {a}, {b, c}, X}. Then

(1) {b} is a $C_{\delta w}$-set but not δw_{gp}-closed.

(2) {a, b} is δw_{gp}-closed but not a $C_{\delta w}$-set.

Example 2.40. (1) In Example 2.39, {b} is λ-δw-pre-closed but not δw_{gp}-closed. (2) In Example 2.39, {a, b} is δw_{gp}-closed but not λ-δw-pre-closed.

Example 2.41. (1) In Example 2.39, {b} is a $sFC_{\delta w}$-set but not δw_{gsp}-closed. (2) In Example 2.39, {a, b} is δw_{gsp}-closed but not a $sFC_{\delta w}$-set.

Example 2.42. (1) In Example 2.39, {b} is λ-δw-β-closed but not δw_{gsp}-closed. (2) In Example 2.39, {a, b} is δw_{gsp}-closed but not λ-δw-β-closed.

Example 2.43. (1) In Example 2.39, {b} is a $BC_{\delta w}$-set but not δw_{gb}-closed. (2) In Example 2.39, {a, b} is δw_{gb}-closed but not a $BC_{\delta w}$-set.

Example 2.44. (1) In Example 2.39, {b} is λ-δw-b-closed but not δw_{gb}-closed.

(2) In Example 2.39, {a, b} is δw_{gb}-closed but not λ-δw-b-closed.

Definition 2.45. Let w be a WS on a space X. A subset A of X is called

(1) λ-δw-αg*-closed if A = L ∩ F, where L is a $\Lambda_{\alpha w}$-set and F is δ-closed. (2) λ-δw-sg*-closed if A = L ∩ F, where L is a Λ_{sw}-set and F is δ-closed. (3) λ-δw-pg*-closed if A = L ∩ F, where L is a Λ_{pw}-set and F is δ-closed. (4) λ-δw-βg*-closed if A = L ∩ F, where L is a $\Lambda_{\beta w}$-set and F is δ-closed. (5) λ-δw-bg*-closed if A = L ∩ F, where L is a Λ_{bw}-set and F is δ-closed.

Definition 2.46. Let w be a WS on a space X. A subset A of X is called

(1) an δw-αlc-set if A = L ∩ F where L∈α(w) and F is δw-closed. (2) an δw-slc-set if A = L ∩ F where L∈σ(w) and F is δw-closed.

Lemma 2.47. Every $\Lambda_{\alpha w}$-set (resp. Λ_{sw}-set, Λ_{pw}-set, $\Lambda_{\beta w}$-set, Λ_{bw}-set) is λ-δw-αg*- closed (resp. λ-δw-sg*-closed, λ-δw-pg*-closed, λ-δw-βg*-closed, λ-δw-bg*-closed).

Example 2.48. In Example 2.39, {c} is λ-δw-αg*-closed but not a $\Lambda_{\alpha w}$-set.

Example 2.49. In Example 2.39, {b} is λ-δw-sg*-closed but not Λ_{sw}-set.

Example 2.50. Let X = {a, b, c}, τ={∅, X, {b}, {c}, {b, c}} and w={∅, X, {b}, {b, c}}. Then {a} is λ-δw-pg*-closed but not a Λ_{pw}-set.

Example 2.51. In Example 2.50, {c} is λ-δw-βg*-closed but not $\Lambda_{\beta w}$-set.

Example 2.52. In Example 2.50, {a} is λ-δw-bg*-closed but not Λ_{bw}-set.

Lemma 2.53. For a WS w on a space X and a subset A of X, the following conditions are equivalent.

(1) A is λ-δw-αg*-closed.

(2) A = L ∩ $cl_\delta(A)$ where L is a $\Lambda_{\alpha w}$-set. (3) A = $\Lambda_{\alpha w}(A)$ ∩ $cl_\delta(A)$.

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