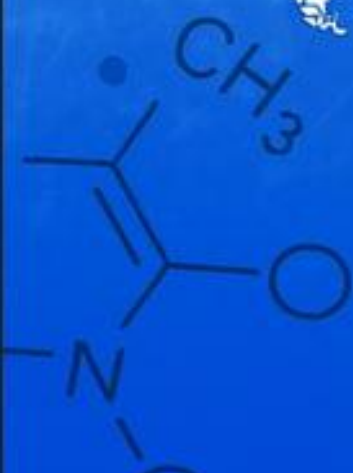


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τ -closed and τ -open sets and their properties

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Innovations

Annotation: The article presents the properties of the τ -closure operator and their proofs. Also, these properties help to better understand the definitions and examples of τ -closed sets, τ -open sets, τ -neighborhood, τ -interior, and τ -boundary of sets. As an innovation presented in the article, the theorem relating the τ -closure operator of a set to the Cartesian product of sets and its proof are presented in detail, and the conclusions arising from it are given.

Keywords: τ -closure, set power, τ -density, τ -closed set, τ -open set, τ -neighborhood of a point, τ -boundary, Cartesian product.

τ -замкнутые и τ -открытые множества и их свойства

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Аннотация: В статье представлены свойства оператора τ -замыкания и их доказательства. Кроме того, эти свойства помогают лучше понять определения и примеры τ -замкнутых множеств, τ -открытых множеств, τ -окрестности, τ -внутренности и τ -границы множеств. В качестве нововведения в статье подробно изложены теорема, связывающая оператор τ -замыкания множества с декартовым произведением множеств, её доказательство и вытекающие из неё выводы.

Ключевые слова: τ -замыкание, мощность множества, τ -плотность, τ -замкнутое множество, τ -открытое множество, τ -окрестность точки, τ -граница, декартово произведение.

τ -yopiq va τ -ochiq to‘plamlar va ularning xossalari

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Annotatsiya: Maqolada τ -yopilma operatorining xossalari va ularning isbotlari keltirilgan. Shuningdek, bu xossalari τ -yopiq to‘plamlar, τ -ochiq to‘plamlar, to‘plamlarning τ -atrofi, τ -ichi, τ -chegaralari haqidagi ta’rif va misollarni yaxshiroq anglashga yordam beradi. Maqolada keltirilgan yangilik sifatida to‘plamning τ -yopilma operatorini to‘plamlarning dekart ko‘paytmasi bilan aloqador teorema va uning isboti batafsil keltirilgan bo‘lib, undan kelib chiqadigan xulosalar berilgan.

Kalit so‘zlar: τ -yopilma, to‘plam quvvati, τ -zichlik, τ -yopiq to‘plam, τ -ochiq to‘plam, nuqtaning τ -atrofi, τ -chegara, dekart ko‘paytma.

Kirish.

Ta’rif. A to‘plamning τ -yopilmasi quyidagicha aniqlanadi:

$$[A]_{\tau} = \bigcup \{ \bar{B} : B \subset A, |B| \leq \tau \}.$$

Teorema. $X - T_1$ topologik fazo bo'lsin. To'plamning τ -yopilma operatori quyidagi xossalarga ega:

- 1) $[X]_\tau = X$;
- 2) $[\emptyset]_\tau = \emptyset$;
- 3) $A \subset [A]_\tau$;
- 4) $[A \cup B]_\tau = [A]_\tau \cup [B]_\tau$;
- 5) $[[A]_\tau]_\tau = [A]_\tau$.

Isbot. Har qanday X fazo uning to'plamotilari bilan qoplanishi mumkin, ularning quvvati τ dan oshmaydi. Bu shuni anglatadiki, har bir fazo o'zining τ -yopilmasiga to'g'ri keladi. Bo'sh to'plamning yagona to'plamosti yopilmasi o'ziga teng bo'lgan bo'sh to'plamdir. Va bu o'zining τ -yopilmasiga teng ekanligini anglatadi. 1) va 2) xossalar isbotlandi.

3) xossa to'g'ri, chunki har qanday A to'plam quvvati τ dan oshmaydigan B to'plamostilar bilan qoplanishi mumkin, ya'ni.

$$A = \bigcup \{B; |B| \leq \tau\} \subset \bigcup \{\bar{B}; |B| \leq \tau\} = [A]_\tau.$$

4) xossa uchun $A \subset A \cup B$ va $B \subset A \cup B$ ekanligidan $[A]_\tau \subset [A \cup B]_\tau$ va $[B]_\tau \subset [A \cup B]_\tau$. Bundan kelib chiqadiki

$$[A]_\tau \cup [B]_\tau \subset [A \cup B]_\tau$$

Har bir to'plam o'zining τ -yopilmasining to'plamostisi bo'lgani uchun, ya'ni $A \subset [A]_\tau, B \subset [B]_\tau$ (3-xossaga ko'ra), $A \cup B \subset [A]_\tau \cup [B]_\tau$ bo'ladi. Shuning uchun $[A \cup B]_\tau = [A]_\tau \cup [B]_\tau$.

5-xossani isbotlaylik. A to'plamostining τ -yopilmasi sifatida $[A]_\tau = \bigcup \{\bar{B}; B \subset A, |B| \leq \tau\}$ ni olaylik va uni M bilan belgilaymiz.

$$[[A]_\tau]_\tau = [M]_\tau = \bigcup \{\bar{C}; C \subset M, |C| \leq \tau\}.$$

Quvvati τ dan oshmaydigan har qanday $C \subset M$ to'plamostini uning elementlari orqali ifodalanishi mumkin, ya'ni $C = \{x_s; s \in S, |S| \leq \tau, C \subset \bigcup \{\bar{B}; B \subset A, |B| \leq \tau\}$ ekanli uchun $\{\bar{B}; B \subset A, |B| \leq \tau\}$ oiladan quyidagi qism oilani olishimiz mumkin $\{\bar{B}_s; x_s \in \bar{B}_s, s \in S\}$. $\{B_s; x_s \in \bar{B}_s, s \in S\}$ oilaning barcha elementlarining birlashmasini B^* bilan belgilaymiz. Har bir $s \in S$ uchun B_s to'plamning quvvati τ dan oshmaganligi uchun B^* ning quvvati τ dan oshmaydi. U holda, $\bar{C} \subset \bar{B}^*$. To'plam yopilmasining xossalarga ko'ra $\bar{C} \subset \bar{B}^*$. Bu degani barcha $C \subset M, |C| \leq \tau$ uchun $C \subset [A]_\tau$. Shuning uchun

$$[[A]_\tau]_\tau \subset [A]_\tau.$$

Ushbu munosabat $[A]_\tau \subset [[A]_\tau]_\tau$ 3-xossadan kelib chiqadi. Teorema isbotlandi. ■

Agar $[A]_\tau = X$ bo'lsa, A to'plamosti X da τ -zichdir. X fazoning har qanday A va B to'plamostilari uchun quyidagi munosabat o'rinli: agar $A \subset B$ bo'lsa, $[A]_\tau \subset [B]_\tau$.

Misol. Tabiiy topologiyaga ega haqiqiy sonlar to'plamida biz barcha ratsional sonlar to'plamini olaylik. Uning ω -yopilishini topamiz: $[Q]_\omega = \bigcup \{\bar{B}; B \subset Q, |B| \leq \omega\}$. To'plamosti sifatida $B \subset Q, |B| \leq \omega$ biz Q to'plamning o'zini olamiz, uning yopilmasi haqiqiy sonlar to'plamiga to'g'ri keladi. Bu shuni anglatadiki, $[Q]_\omega = \mathbb{R}$ va Evklid chizig'idagi ratsional sonlar to'plami ω -zich degan xulosaga kelishimiz mumkin.

Ta'rif. X topologik T_1 -fazo bo'lsin. Agar har bir $B \subset F$ uchun, bunda $|B| \leq \tau, B$ to'plamning yopilmasi F da yotsa, $F \subset X$ to'plam X da τ -yopiq deyiladi.

Misol. $\mathbb{R}$ haqiqiy sonlar to'plamida to'ldiruvchisi sanoqli bo'lgan barcha to'plamlar ochiq deb faraz qilamiz va bo'sh to'plamni ham ochiq deb olamiz, ya'ni $\mathbb{R}$ haqiqiy sonlar to'plami quyidagi topologiyaga ega:

$$\theta = \{\emptyset\} \cup \{U: U \subset \mathbb{R}, |\mathbb{R} \setminus U| \leq \omega\}$$

To'ldiruvchisining quvvati ω dan oshmaydigan har bir to'plam ushbu topologik fazoda ochiq bo'lgani uchun, ixtiyoriy sanoqli $B \subset X$ to'plam yopiqdir. Keling, ixtiyoriy $M \subset \mathbb{R}$ to'plamostini olaylik. $B \subset M$ quvvati ω dan oshmaydigan har bir to'plamosti o'zining yopilmasi bilan to'g'ri keladi, ya'ni hamma $|B| \leq \omega$ uchun $\bar{B} \subset M$. M to'plamning ixtiyoriy ekanligidan bu fazoning har bir to'plamostisi ω -yopiq ekanligi kelib chiqadi. Xususan, bu fazodagi barcha irratsional sonlar to'plami ω -yopiq, lekin yopiq emas.

Ta'rif. Agar G to'plamning $X \setminus G$ to'ldiruvchisi τ -yopiq bo'lsa, $G \subset X$ to'plam X da τ -ochiq deyiladi. $x \in X$ nuqtani o'z ichiga olgan har qanday τ -ochiq to'plamga bu nuqtaning τ -atrofi deyiladi.

Misol. $\mathbb{R}$ haqiqiy sonlar to'plamida quyidagi oilani ko'rib chiqamiz:

$$\theta = \{U \subset \mathbb{R}: |\mathbb{R} \setminus U| \leq \omega\} \cup \{\emptyset\}$$

$(\mathbb{R}, \theta)$ topologik fazo ekanligini tekshirish oson. Har qanday sanoqli to'plam yopiq bo'lgani uchun, $\mathbb{R}$ ning ixtiyoriy to'plamostisi θ topologiyaga nisbatan ω -yopiq bo'lib, xususan, barcha irratsional sonlar to'plami I ham shundaydir. Bundan barcha ratsional sonlar to'plami $\mathbb{Q}$ ω -ochiq, lekin ochiq emasligi kelib chiqadi.

Ta'rif. X topologik T_1 -fazo bo'lsin. X ning A to'plamostisining τ -ichi deb, A ning barcha τ -ochiq to'plamostilarining birlashmasiga aytiladi va $\text{Int}_\tau A$ bilan belgilanadi.

$$\text{Int}_\tau A = \bigcup \{U: U \subset A \text{ va } U \text{ } \tau\text{-ochiq}\}.$$

Tasdiq. Har bir $A \subset X$ uchun $\text{Int}_\tau A = X - [X - A]_\tau$ o'rinli.

Isbot: τ -yopilma operatorining ta'rifi bo'yicha

$$[X - A]_\tau = \bigcap \{M: X - A \subset M \text{ va } M \text{ to'plam } X \text{ da } \tau\text{-yopiq}\}.$$

Shuning uchun

$$X - [X - A]_\tau = X - \left(\bigcap \{M: X - A \subset M \text{ va } M \text{ to'plam } X \text{ da } \tau\text{-yopiq}\} \right).$$

De Morgan qonunlariga ko'ra

$$X - [X - A]_\tau = \bigcup \{X - M: X - A \subset M \text{ va } M \text{ to'plam } X \text{ da } \tau\text{-yopiq}\}$$

Shuning uchun,

$$X - [X - A]_\tau = \bigcup \{X - M: X - M \subset A \text{ va } M \text{ to'plam } X \text{ da } \tau\text{-yopiq}\} = \text{Int}_\tau A.$$

Ta'rif. Agar x nuqtaning ixtiyoriy τ -ochiq atrofi A to'plam va uning $X \setminus A$ to'ldiruvchisi bilan kesishmasi bo'sh bo'lmasa, $x \in X$ nuqta A to'plamostining τ -chegaraviy nuqtasi deyiladi. $A \subset X$ to'plamning barcha τ -chegaraviy nuqtalar to'plami A to'plamning τ -chegarasi deb ataladi va $\text{Fr}_\tau A$ bilan belgilanadi.

$A \subset X$ to'plamning τ -chegarasi A to'plamning τ -yopilmasi va uning $X \setminus A$ to'ldiruvchisining τ -yopilmasi kesishishidan iboratdir, ya'ni.

$$\text{Fr}_\tau A = [A]_\tau \cap [X \setminus A]_\tau.$$

Endi to'plamning τ -yopilmasini to'plamlarning dekart ko'paytmasiga qo'llaganda qanday xossalarga ega ekanligini ko'rib chiqamiz. Bunda dekart ko'paytmadagi to'plamlar τ -yopiq bo'lsa,

to'planning dekart ko'paytmasi ham τ -yopiq bo'lishi to'g'risida teoremani isbotini keltiramiz va kerakli xulosalar chiqaramiz.

Teorema. $X_1, X_2, \dots, X_n$ topologik fazolar va ularning $A_1 \subset X_1, A_2 \subset X_2, \dots, A_n \subset X_n$ qism to'plamlari berilgan bo'lsin. U holda quyidagi tenglik o'rinli bo'ladi:

$$[A_1 \times A_2 \times \dots \times A_n]_\tau = [A_1]_\tau \times [A_2]_\tau \times \dots \times [A_n]_\tau.$$

Isbot: Tenglikni birinchi qismida $([A_1 \times A_2 \times \dots \times A_n]_\tau \subset [A_1]_\tau \times [A_2]_\tau \times \dots \times [A_n]_\tau)$ ekanligini isbotlash kerak:

$z_0 = (x_1, x_2, \dots, x_n) \in [A_1 \times A_2 \times \dots \times A_n]_\tau$ bo'lsin, ya'ni z_0 nuqta $A_1 \times A_2 \times \dots \times A_n$ dekart ko'paytmaning τ -yopilmasiga tegishli. Demak, z_0 nuqta $A_1 \times A_2 \times \dots \times A_n$ dekart ko'paytmaning yopilmasiga tegishli bo'ladi.

Har bir $pr_i: X_1 \times X_2 \times \dots \times X_n \rightarrow X_i$ proyektiv akslantirishni ko'rib chiqaylik:

$$pr_i(z_0) = x_i, \quad i = 1, 2, \dots, n.$$

$f([A]_\tau) \subset [f(A)]_\tau$ ga ko'ra $pr_i([A_1 \times A_2 \times \dots \times A_n]_\tau) \subset [pr_i(A_1 \times A_2 \times \dots \times A_n)]_\tau = [A_i]_\tau$ bo'ladi va har bir $x_i \in [A_i]_\tau$.

Demak, $z_0 = (x_1, x_2, \dots, x_n) \in [A_1]_\tau \times [A_2]_\tau \times \dots \times [A_n]_\tau$, ya'ni:

$$[A_1 \times A_2 \times \dots \times A_n]_\tau \subset [A_1]_\tau \times [A_2]_\tau \times \dots \times [A_n]_\tau$$

Tenglikni ikkinchi qismida $([A_1]_\tau \times [A_2]_\tau \times \dots \times [A_n]_\tau \subset [A_1 \times A_2 \times \dots \times A_n]_\tau)$ ekanligini isbotlash kerak:

Endi, $z_0 = (x_1, x_2, \dots, x_n) \in [A_1]_\tau \times [A_2]_\tau \times \dots \times [A_n]_\tau$ bo'lsin.

$z_0 = (x_1, x_2, \dots, x_n) \in [A_1 \times A_2 \times \dots \times A_n]_\tau$ ekanligini isbotlaylik. τ -yopilma ta'rifiga bo'yicha

$$(x_1, x_2, \dots, x_n) \in \left(\bigcup \{ \overline{B_1} : B_1 \subset A_1, |B_1| \leq \tau \} \right) \times \left(\bigcup \{ \overline{B_2} : B_2 \subset A_2, |B_2| \leq \tau \} \right) \times \dots \\ \times \left(\bigcup \{ \overline{B_n} : B_n \subset A_n, |B_n| \leq \tau \} \right)$$

Bu degani, har bir x_i lar uchun shunday to'plamlar mavjudki:

$$x_1 \in [A_1]_\tau, \exists C_1 \subset A_1 \text{ va } C_1 \text{ ning yopig'i } \overline{C_1} \in \{ \overline{B_1} : B_1 \subset A_1, |B_1| \leq \tau \};$$

$$x_2 \in [A_2]_\tau, \exists C_2 \subset A_2 \text{ va } C_2 \text{ ning yopig'i } \overline{C_2} \in \{ \overline{B_2} : B_2 \subset A_2, |B_2| \leq \tau \};$$

....;

$$x_n \in [A_n]_\tau, \exists C_n \subset A_n \text{ va } C_n \text{ ning yopig'i } \overline{C_n} \in \{ \overline{B_n} : B_n \subset A_n, |B_n| \leq \tau \} \text{ bo'ladi.}$$

Bundan, $(x_1, x_2, \dots, x_n) \in \overline{C_1} \times \overline{C_2} \times \dots \times \overline{C_n} = \overline{C_1 \times C_2 \times \dots \times C_n}$ ekanligi kelib chiqadi.

U holda

$$(x_1, x_2, \dots, x_n) \in \left(\bigcup \{ \overline{B_1 \times B_2 \times \dots \times B_n} : B_1 \times B_2 \times \dots \times B_n \subset \right.$$

$$\left. A_1 \times A_2 \times \dots \times A_n, |B_1 \times B_2 \times \dots \times B_n| \leq \tau \} \right)$$

$(x_1, x_2, \dots, x_n) \in [A_1 \times A_2 \times \dots \times A_n]_\tau$ bilan mos keladi. Bundan kelib chiqadiki,

$$[A_1]_\tau \times [A_2]_\tau \times \dots \times [A_n]_\tau \subset [A_1 \times A_2 \times \dots \times A_n]_\tau$$

va shuning uchun, $[A_1 \times A_2 \times \dots \times A_n]_\tau = [A_1]_\tau \times [A_2]_\tau \times \dots \times [A_n]_\tau$ bo'ladi. Teorema isbotlandi. ■

Xulosa. Agar n ta elementdan tashkil topgan dekart ko'paytmaning elementlari τ -yopiq bo'lsa, n ta to'planning dekart ko'paytmasi τ -yopiq bo'ladi.

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