Fall 2015 Notes

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Contents

1 McClure's 571 Problems

1.1 Midterm I (Fall 2015)

Problem 1.1.1. Let $A \subset X$ and $B \subset Y$. Show that the space $X \times Y$,

$$\overline{A \times B} = \overline{A} \times \overline{B}.$$

Proof. ■

Problem 1.1.2. Let X bea topological space and let A be a dense subset of X. Let Y be a Hausdorff space and let $g, h \colon X \to Y$ be continuous functions which agree on A. Prove that $g = h$.

Proof. ■

Problem 1.1.3. Let X and Y be topological spaces and let $f \colon X \to Y$ be a continuous function. Let G_f (called the *graph* of f) be the subspace $\{\, x \times f(x) \mid x \in X \,\}$ of $X \times Y$. Prove that if Y is Hausdorff then G_f is closed.

Proof. ■

Problem 1.1.4. Let X be a topological space and let $f, g \colon X \to \mathbf{R}$ be continuous. Define $h \colon X \to \mathbf{R}$ by

$$h(x) = \min\{(f(x), g(x)\}.$$

Use the pasting lemma to prove that h is continuous. (You will not get full credit for any other method.)

Proof. ■

Problem 1.1.5. Let X and Y be topological spaces and let $f \colon X \to Y$ be a function with the property that

$$f(\overline{A}) \subset \overline{f(A)}$$

for all subsets A of X. Prove that f is continuous.

Proof. ■

Problem 1.1.6. Let X and Y be topological spaces and let $f \colon X \to Y$ be a continuous function. Prove that

$$f(\overline{A}) \subset \overline{f(A)}$$

for all subsets A of X.

Proof. ■

Problem 1.1.7. Let X be any topological space and let Y be a Hausdorff space. Let $f, g \colon X \to Y$ be continuous functions. Prove that the set $\{\, x \in X \mid f(x) = g(x) \,\}$ is closed.

Proof. ■

Problem 1.1.8. Let X be a topological space and A a subset of X. Suppose that

$$A \subset \overline{X \setminus \overline{A}}.$$

Prove that $\overline{A}$ does not contain any nonempty open set.

Proof. ■

Problem 1.1.9. Let X be a topological space with a countable basis. Prove that every open cover of X has a countable subcover.

Proof. ■

Problem 1.1.10. Let X_α be an infinite family of topological spaces.

(a) Define the product topology on $\prod X_\alpha$.
(b) For each α, let A_α be a subspace of X_α. Prove that $\overline{\prod A_\alpha} = \prod \overline{A_\alpha}$.

Proof. ■

Problem 1.1.11. Suppose that we are given an indexing set A, and for each $\alpha \in A$ a topological space X_α. Suppose also that for each $\alpha \in A$ we are given a point $b_\alpha \in X_\alpha$. Let $Y = \prod X_\alpha$ with the product topology. Let $\pi_\alpha : Y \to X_\alpha$ be the projection. Prove that the set

$$S = \{ y \in Y \mid \pi_\alpha(y) = b_\alpha \text{ except for finitely many } \alpha \}$$

is dense in Y (that is, its closure is Y).

Proof. ■

Problem 1.1.12. Let X be the Cartesian product $\mathbf{R}^\omega = \prod_{i=1}^\infty \mathbf{R}$ with the box topology (recall that a basis for this topology consists of all sets of the form $\prod_{i=1}^\infty U_i$, where each U_i is open in $\mathbf{R}$). Let $f\colon \mathbf{R} \to X$ be the function which takes t to $(t, t, t, ...)$. Prove that f is not continuous.

Proof. ■

Problem 1.1.13. Prove that the countable product $\mathbf{R}^\omega$ (with the product topology) has the following property: there is a countable family $\mathcal{F}$ of neighborhoods of the point $\mathbf{0} = (0, 0, 0, ...)$ such that for every neighborhood V of $\mathbf{0}$ there is a $U \in \mathcal{F}$ with $U \subset V$.

Note: the book proves that $\mathbf{R}^\omega$ is a metric space, but you may not use this in your proof. Use the definition of the product topology.

Proof. ■

Problem 1.1.14. Let X be the two-point set $\{0, 1\}$ with the discrete topology. Let Y be a countable product of copies of X, thus an element of Y is a sequence of 0's and 1's. For each $n \geq 1$, let $y_0 \in Y$ be the element $(1, 1, 1, ..., 1, 0, 0, 0, ..)$, with n 1's at the beginning and all other entries 0. Let $y \in Y$ be the element with all 1s. Prove that the set $\{y_n\}_{n\geq 1} \cup \{y\}$ is closed. Give a clear explanation. Do not use a metric.

Proof. ■

Problem 1.1.15. Let X be the two-point set $\{0, 1\}$ with the discrete topology. Let Y be a countable product of copies of X; thus an element of Y is a sequence of 0's and 1's. Let A be the subset of Y consisting of sequences with only a finite number of 1's. Is A closed? Prove or disprove.

Proof. ■

Problem 1.1.16. Let Y be a topological space.Let X be a set and let $f\colon X \to Y$ be a function. Give X the topology in which the open sets are the sets $f^{-1}(V)$ with V open in Y (you do not have to verify that this is a topology). Let $a \in X$ and let B be a closed set in X not containing a. Prove that $f(a)$ is not in the closure of $f(B)$.

Proof. ■

Problem 1.1.17. Let $f\colon X \to Y$ be a function that takes closed sets to closed sets. Let $y \in Y$ and let U be an open set containing $f^{-1}(y)$. Prove that there is an open set V containing y such that $f^{-1}(V)$ is contained in U.

Proof. ■

Problem 1.1.18. Let X be a topological space with an equivalence relation $\sim$. Suppose that the quotient space $X/\sim$ is Hausdorff. Prove that the set $S = \{\, x \times y \in X \times X \mid x \sim y \,\}$ is a closed subset of $X \times X$.

Proof. ■

Problem 1.1.19. Let $p\colon X \to Y$ be a quotient map. Let us say that a subset S of X is *saturated* if it has the form $p^{-1}(T)$ for some subset T of Y. Suppose that for every $y \in Y$ and every open neighborhood U of $p^{-1}(y)$ there is a saturated open set V with $p^{-1}(y) \subset V \subset U$. Prove that p takes closed sets to closed sets.

Proof. ■

Problem 1.1.20. Let X be a topological space, let D be a connected subset of X, and let $\{E_\alpha\}$ be a collection of connected subsets of X.

Proof. ■

Problem 1.1.21. Let X and Y be connected. Prove that $X \times Y$ is connected.

Proof. ■

Problem 1.1.22. For any space X, let us say that two points are "inseparable" if there is no separation $X = U \cup V$ into disjoint open sets such that $x \in U$ and $y \in V$. Write $x \sim y$ if x and y are inseparable. Then $\sim$ is an equivalence relation (you don't have to prove this). Now suppose that X is locally connected (this means that for every point x and every open neighborhood U of x, there is a connected open neighborhood V of x contained in U). Prove that ecah equivalence class of the relation $\sim$ is connected.

Proof. ■

Problem 1.1.23. Let X be a topological space. Let $A \subset X$ be connected. Prove $\overline{A}$ is connected.

Proof. ■

Problem 1.1.24. Let $X_1, X_2, ...$ be topological spaces. Suppose $\prod_{n=1}^{\infty} X_n$ is locally connected. Prove that al lbut finitely many X_n are connected.

Proof. ■

Problem 1.1.25. LEt X be a connected space and let $f\colon X \to Y$ be a function which is continuous and onto. Prove that Y is connected. (This is a theorem in Munkres—prove it from the definitions).

Proof. ■

Problem 1.1.26. Give:

(i) $p\colon X \to Y$ is a quotient map.
(ii) Y is connected.
(iii) For every $y \in Y$, the set $p^{-1}(y)$ is connected.

Prove that X is connected.

Proof. ■

Problem 1.1.27. Let A be a subset of $\mathbf{R}^2$ which is homeomorphic to the open unit interval $(0, 1)$. Prove that A does not contain a nonempty set which is open in $\mathbf{R}^2$.

Proof. ■

Problem 1.1.28. Let X be a connected space. Let $\mathcal{U}$ be an open covering of X and let U be a nonempty set in $\mathcal{U}$. Say that a set V in $\mathcal{U}$ is *reachable from* U if there is a sequence $U = U_1, U_2, ..., U_n = V$ of sets in $\mathcal{U}$ such that $U_i \cap U_{i+1} \neq \emptyset$ for each i from 1 to $n - 1$. Prove that every nonempty V in $\mathcal{U}$ is reachable from U.

Proof. ■

Problem 1.1.29. Suppose that X is connected and every point of X has a path-connected open neighborhood. Prove that X is path-connected.

Proof. ■

Problem 1.1.30. Let X be a topological space and let $f, g\colon X \to [0, 1]$ be continuous functions. Suppose that X is connected and f is onto. Prove that there must be a point $x \in X$ with $f(x) = g(x)$.

Proof. ■

1.2 Midterm II (Fall 2015)

2 Kaufmann's 571 Problems

2.1 Midterm (Fall 2014)

2.2 Final (Fall 2014)

3 MA553 Qual Problems

3.1 Goins

3.2 Goldberg

3.3 Ulrich