

MATH 251: TOPOLOGY II
SPRING 2026 PRACTICE PROBLEMS

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NOTE: All citations are to Munkres's textbook, *Topology*, 2nd Edition. When a problem statement has a proof in Munkres, try your best to find your own proof, before comparing with his.

0. REVIEW OF TOPOLOGY I

Problem 1. Show that the following conditions on a space X are equivalent:

- For any pair of distinct points $x, y \in X$, we can find an open set of X containing x but not y .
- For any $x \in X$, the singleton set $\{x\}$ is closed.
- All finite subsets of X are closed.

In this situation, we say that X is a *T_1 space*.

Problem 2. Suppose that $A \subseteq X$. Recall that the *interior* of A in X is

$$\text{Int}_X(A) := \{x \in X \mid x \in U \text{ for some } U \text{ open in } X \text{ such that } U \subseteq A\}$$

and the *closure* of A in X is

$$\text{Cl}_X(A) := \{x \in X \mid x \in K \text{ for all } K \text{ closed in } X \text{ such that } K \supseteq A\}.$$

Show the identity $\text{Cl}_X(A) = X \setminus \text{Int}_X(X \setminus A)$.

Problem 3. Suppose that $A \subseteq Y \subseteq X$, where Y is a subspace of X .

- (1) Show that $\text{Int}_Y(A) \supseteq \text{Int}_X(A)$.
- (2) Give an example where $\text{Int}_Y(A) \neq \text{Int}_X(A)$. *Hint:* You can assume $Y = A$.

Problem 4. Let X be the real line \mathbf{R} in its finite complement, or *cofinite*, topology. Show that every sequence of points in X converges to every point of X simultaneously. Deduce that X is not Hausdorff.

Problem 5. Show that any metric space is Hausdorff.

Problem 6. Show that for any integer $n \geq 1$, the analytic topology on \mathbf{R}^n matches the product topology on $\mathbf{R} \times \cdots \times \mathbf{R}$, where there are n factors.

Problem 7. Let $p: \mathbf{R} \rightarrow S^1$ be the map

$$p(t) = (\cos(2\pi t), \sin(2\pi t)).$$

For any $a, b \in \mathbf{R}$, we define the *(open) arc* $J_{a,b} \subseteq S^1$ to be

$$J_{a,b} = \{p(t) \mid a < t < b\}.$$

Show that the collection of arcs $\{J_{a,b} \mid a, b \in \mathbf{R}\}$ satisfies the definition of a basis (Munkres page 78).

Problem 8. Show that the following topologies on S^1 are all the same:

- The topology generated by the basis $\{J_{a,b} \mid a, b \in \mathbf{R}\}$ in Problem 7.
- The subspace topology that S^1 inherits from its inclusion into \mathbf{R}^2 .
- The quotient topology that S^1 inherits from the surjective map $p: \mathbf{R} \rightarrow S^1$.

Problem 9. Let $f_1, f_2, f_3: A \rightarrow X$ be continuous maps. Suppose that φ is a homotopy from f_1 to f_2 and ψ is a homotopy from f_2 to f_3 . Construct a homotopy from f_1 to f_3 explicitly in terms of φ and ψ .

Problem 10. Let $f, g: X \rightarrow Y$ and $F, G: Y \rightarrow Z$ be continuous. Show that

$$\text{if } f \sim g \text{ and } F \sim G, \quad \text{then } F \circ f \sim G \circ g.$$

Problem 11. Use Problem 10 to show: If X, Y are nonempty and Y is contractible, then any two continuous maps from X into Y are homotopic.

Problem 12. Suppose that:

- $f: X \rightarrow Y$ and $g: Y \rightarrow X$ define a homotopy equivalence between X and Y .
- $j: Y \rightarrow Z$ and $k: Z \rightarrow Y$ define a homotopy equivalence between Y and Z .

Show that $j \circ f: X \rightarrow Z$ and $g \circ k: Z \rightarrow X$ define a homotopy equivalence between X and Z .

Hint: You will need to show, for instance, that $g \circ k \circ j \circ f \sim \text{id}_X$. But you know that $k \circ j \sim \text{id}_Y$. Use Problem 10 to deduce the former statement from the latter.

Problem 13. In the setup of Problem 9, suppose that

$$A = [0, 1] \text{ and } f_1(0) = f_2(0) = f_3(0) \text{ and } f_1(1) = f_2(1) = f_3(1).$$

Show that in this case, if φ and ψ are path homotopies, then we can choose the solution of (1) to be a path homotopy as well.

1. FUNDAMENTAL GROUPS AND COVERING SPACES
2. SEPARATION THEOREMS IN THE PLANE
3. SIMPLICIAL COMPLEXES
4. HOMOLOGY