Proposition 1. *Find an infinite collection of open intervals in $\mathbb{R}$ whose intersection is not an open interval.*

Proof. $\bigcap\{(\frac{-1}{n}, \frac{1}{n}) : n \in \mathbb{Z}^+\} = \{0\}$ which is not an open interval or even open. □

Proposition 2. *Any finite union of closed sets is closed, and any arbitrary intersection of closed sets is closed.*

Proof. We proceed by showing that any finite union of closed sets is closed:
Let C, D be closed sets.
Let A, B be compliments of C, D so A, B are open.
Then, A $\cap$ B is also open.
Thus, X\(A $\cap$ B) is closed.
By Demorgan's Law, X\(A $\cap$ B) = X\A $\cup$ X\B = C $\cup$ D which is closed.

Now that we've shown that C $\cup$ D is closed for all C, D; Assume $C_1 \cup C_2 \cup ... \cup C_n$ is closed for closed sets C_i. Then for $C_1 \cup ... \cup C_n \cup C_{n+1}$, let $K = C_1 \cup ... \cup C_n$.
Thus $K \cup C_{n+1} = C_1 \cup ... \cup C_n \cup C_{n+1}$ is closed.
Now we show that any arbitrary intersection of closed sets is closed.
Let $\mathcal{C}$ be a collection of closed sets.
Let $\mathcal{U} = \{X \backslash C : C \in \mathcal{C}\}$, so $\mathcal{U}$ is a collection of open sets.
Then, $\bigcup\mathcal{U}$ is also open.
Thus, $X \backslash \bigcup\mathcal{U}$ is closed.
By Demorgan's Law, $X \backslash \bigcup\mathcal{U} = \bigcap\mathcal{C}$
Therefore, $\bigcap\mathcal{C}$ is closed. □

Lemma 3. *A set U is open if and only if for every point $x \in U$, there exists an open set U_x where $x \in U_x \subseteq U$*

Proof. Suppose U is open, then for all x $\in$ U there exists an open U_x = U, such that x $\in$ $U_x \subseteq$ U. To show the converse, suppose that for each x $\in$ U there is an open set U_x where x $\in$ $U_x \subseteq$ U. For $x \in U, x \in U_x$ so $x \in \bigcup\{U_x : x \in U\}$. Thus $U \subseteq \bigcup\{U_x : x \in U_x\}$. Now let y $\in$ U_x for some x $\in$ U, then $U_x \subseteq$ U. Thus U $\supseteq \bigcup\{ U_x : x \in U \}$. Therefore U = $\bigcup\{ U_x : x \in U \}$. □

Proposition 4. *A set K in a topological space X is closed if and only if K contains all its limit points.*

Proof. Suppose K contains all its limit points. If K = X, then K is closed because $\emptyset$ is open. Otherwise let x $\in$ X\K, so x is not a limit point of K. Then, $\exists$ $x \in U_x \in \tau$ such that $U_x \cap$ K = $\emptyset$ since $x \notin K$. So, $x \in U_x \subseteq$ X\K. By the lemma, X\K is open so K is closed.

To show the converse is true as well, let x $\in$ X\K, which is an open set by the lemma. Since (X\K)$\cap$K is the empty set, x is not a limit point of K. So, if ℓ is any limit point of K, then $\ell \notin$ X\K, so $\ell \in$ K and K contains all of its limit points. □

Proposition 5. *Verify the discrete and indiscrete topologies are topologies*

Proof. To prove the discrete topology is an actual topology, first we define that the discrete topology on a set X is $\tau = \mathcal{P}$(X). $\emptyset$, X $\in \mathcal{P}$(X), So $\emptyset$, X $\in \tau$. Now, let $\mathcal{U} \subseteq \tau = \mathcal{P}$(X), then the $\bigcup$U $\in \mathcal{P}$(X). Let U, V $\in \tau = \mathcal{P}$(X) then the intersection U $\cap$ V $\in \mathcal{P}$(X) $= \tau$. Now to show that the indiscrete topology is an actual topology, we define that the indiscrete topology on a set X is given as $\tau = \{\emptyset$, X$\}$. Clearly, $\emptyset$, X $\in \tau$. Let $\mathcal{U}$ be a collection of open sets in X, then $\bigcup\mathcal{U}$ = X, thus $\bigcup\mathcal{U} \in \tau$. ☐

Definition 6. A collection of sets $\mathcal{B} \subseteq \mathcal{P}(X)$ is called a basis if:

1. For all $x \in X$, there exists $B \in \mathcal{B}$ such that $x \in B$.
2. For all $B_1, B_2 \in \mathcal{B}$ with $x \in B_1 \cap B_2$, there exists $B_3 \in \mathcal{B}$ with $x \in B_3 \subseteq B_1 \cap B_2$.

The set $\{\bigcup\mathcal{B}' : \mathcal{B}' \subseteq \mathcal{B}\}$ is called the topology generated by $\mathcal{B}$.

Theorem 7. *The "topology generated by $\mathcal{B}$" is actually a topology.*

Proof. τ is $\{\bigcup\mathcal{B}' : \mathcal{B}' \subseteq \mathcal{B}\}$. So $\{\bigcup\mathcal{B}' : \mathcal{B}' \subseteq \mathcal{B}\} \subseteq \mathcal{P}(X)$. $\emptyset, X \in \tau$ because for $\mathcal{B}' = \emptyset, \bigcup\mathcal{B}' = \emptyset$ and for $\mathcal{B}' = X, \bigcup\mathcal{B}' = X$. Let $\mathcal{U} \subseteq \tau$ and $\bigcup\mathcal{U} \in \tau$ because for each $U \in \mathcal{U}, U = \bigcup\mathcal{B}'_U$ for some $\mathcal{B}'_U \subseteq \mathcal{B}$ So, $\bigcup\mathcal{U} = \bigcup\{\bigcup\mathcal{B}'_U : U \in \mathcal{U}\}$. Let $\mathcal{B}' = \bigcup\{\mathcal{B}'_U : U \in \mathcal{U}\}$. So, $\bigcup\mathcal{U} = \bigcup\mathcal{B}'$.
For $U, V \in \{\bigcup\mathcal{B}' : \mathcal{B}' \subseteq \mathcal{B}\}, U = B_1$ and $V = B_2, B_1, B_2 \in \mathcal{B}$ such that $B_1 = \mathcal{B}$ and $B_2 = \mathcal{B}$. Then $U \cap V \in \{\bigcup\mathcal{B}' : \mathcal{B}' \subseteq \mathcal{B}\} \supseteq W$ so there exists $x \in V, U : x \in U \cap V \supseteq W$. Therefore $x \in W \subseteq U \cap V \in \tau$. ☐

Theorem 8. *Let τ be a topology on X. Then $\mathcal{B} \subseteq \tau$ generates τ if:*
1. For all $x \in U \in \tau$, there exists $B \in \mathcal{B}$ where $x \in B \subseteq U \in \tau$
2. For all B_1, $B_2 \in \mathcal{B}$ with $x \in (B_1 \cap B_2)$, there exists $B_3 \in \mathcal{B}$ with $x \in B_3 \subseteq B_1 \cap B_2$.

Theorem 9. $\{\mathbb{X}\}$ *is a basis for* $\tau = \{\emptyset, \mathbb{X}\}$. *(indiscrete)*

Proof. Let $\mathcal{B} = \{\mathbb{X}\}$ and let $x \in \mathbb{X} = B \in \mathcal{B}$. Now consider $B_1, B_2 \in \mathcal{B}$. $B_1 = \mathbb{X}$ and $B_2 = \mathbb{X}$ Let $x \in B_1 \cap B_2$, then $x \in B_3 = \mathbb{X} : B_1 \cap B_2 = X$. ☐

Theorem 10. $\{\{x\} : x \in X\}$ *is a basis for* $\tau = \mathcal{P}(X) = \{ U : U \subseteq X\}$. *(discrete)*

Proof. Let $x \in U \in \tau = \mathcal{P}(\mathbb{X})$. Then for $B = \{x\} \in \mathcal{B}, x \in B \subseteq U$. Let $B_1, B_2 \in \mathcal{B}$. Let $y \in B_1 \cap B_2$ so $B_1 = B_2 = \{y\}$. Let $B_3 = \{y\}$ so $y \in B_3 = \{y\} \subseteq B_1 \cap B_2 = \{y\}$. ☐

Definition 11. The Euclidean topology on $\mathbb{R}$ is the topology generated by the basis $\{(a, b) : a < b \in \mathbb{R}\}$.

Theorem 12. $\{(a, b) : a < b \in \mathbb{R}\}$ *is a basis.*

Proof. Let $\mathcal{B} = \{(a, b) : a < b \in \mathbb{R}\}$. Let $x \in \mathbb{R}$ and let $B = (x - 1, x + 1)$, then $B \subseteq \mathbb{R}$ and $B \in \mathcal{B}$. For $B_1 = (a_1, b_1)$, $B_2 = (a_2, b_2)$, $a_1 < b_1$, $a_2 < b_2 \in \mathbb{R}$ with $x \in B_1 \cap B_2$, then there is $B_3 = (max(a_1, a_2), min(b_1, b_2)) \subseteq B_1 \cap B_2$ such that $a_1, a_2 < x < b_1, b_2 \in B_3$.

☐

Theorem 13. *$\{(a,\, b) : a < b \in \mathbb{Q}\}$ is a basis for the Euclidean topology.*

Proof. Let $\mathcal{B} = \{(a, b) : a < b \in \mathbb{Q}\}$. Let $x, y \in \mathbb{Q}$ and let $B = (x-y, x+y)$, so $B \subseteq \mathbb{Q}$ and $x \in B \in \mathcal{B}$. Now, for $B_1, B_2 \in \mathcal{B}, \exists x \in B_1 \cap B_2 : x \in B_1$ and $x \in B_2$. $a_1, a_2 < b_1, b_2 \in \mathbb{Q}$. Let $B_1 = (a_1, b_1)$ and $B_2 = (a_2, b_2)$. Now let $B_3 = (max(a_1, a_2), min(b_1, b_2))$ with $a_1, a_2 < x < b_1, b_2 \in \mathcal{B}$. So, $x \in B_3 \subseteq B_1 \cap B_2$. □

Definition 14. A subset K of a topological space X is said to be **compact** if for every open cover $\mathcal{U}$ of K (every collection $\mathcal{U}$ of open sets such that $\bigcup \mathcal{U} \supseteq K$) there exists a finite subcollection $\mathcal{F} \subseteq \mathcal{U}$ that also covers K (that is, $\bigcup \mathcal{F} \supseteq K$).

Theorem 15. *Any finite union of compact subsets is compact.*

Proof. By definition if K_1 and K_2 are compact then for each $\mathcal{U}_1$ and $\mathcal{U}_2$ of K_1 and K_2 such that $\bigcup \mathcal{U}_1 = K_1$ and $\bigcup \mathcal{U}_2 = K_2$. So, $\bigcup(\mathcal{U}_1 \cup \mathcal{U}_2) = K_1 \cup K_2$. Let $K_3 = K_1 \cup K_2$ and $\mathcal{U}_3 = \mathcal{U}_1 \cup \mathcal{U}_2$. Then for K_3 there exists $\mathcal{U}_3$ such that $\bigcup \mathcal{U}_3 = K_3$.
Also by definition there must exist $\mathcal{F}_1$ and $\mathcal{F}_2$ such that $\mathcal{F}_1, \mathcal{F}_2 \subseteq \mathcal{U}_1, \mathcal{U}_2$ respectively. Then, $\mathcal{F}_1$ and $\mathcal{F}_2 \subseteq \mathcal{U}_1 \cup \mathcal{U}_2$. Let $\mathcal{F}_3 = \mathcal{F}_1 \cup \mathcal{F}_2$, then $\mathcal{F}_3 \subseteq \mathcal{U}_3$. Now observe that $\bigcup \mathcal{F}_1 = K_1$ and $\bigcup \mathcal{F}_2 = K_2$. The $\bigcup(\mathcal{F}_1 \cup \mathcal{F}_2) = K_1 \cup K_2$ and $\bigcup \mathcal{F}_3 = K_1 \cup K_2$ so $K_1 \cup K_2$ must be compact. □

Proposition 16. *Any finite subset of a topological space is compact.*

Proof. A subset K of space $\mathbb{X}$ is compact if for every open cover $\mathcal{U}$ of K there exists $\mathcal{F} \subseteq \mathcal{U}$ such that $\bigcup \mathcal{F} = K$.
Let $K \subseteq \mathbb{X}$, let $\mathcal{U} = \{(a, b) : a < b \in K\}$ then $\bigcup \mathcal{U} = K$. Let $\mathcal{F} = \{F : F = U \in \mathcal{U}\}$, then $\bigcup \mathcal{F} = \bigcup \mathcal{U} = K$, so $\bigcup \mathcal{F} = K$.

□

Proposition 17. *The subset $\{0\} \cup \{\frac{1}{n} : n \in \mathbb{Z}^+\}$ of $\mathbb{R}$ is compact.*

Proof. Assume K is compact, then for all $\mathcal{U}$ of K, $\bigcup \mathcal{U} = K$. Now we find $\mathcal{F} \subseteq \mathcal{U}$ that also covers K. For $\bigcup \mathcal{U} = K$, then $0, 1 \in \bigcup \mathcal{U}$. Let $\mathbb{A} = \bigcap\{(\frac{-1}{n}, \frac{1}{n}) : n \in \mathbb{Z}^+\}$ and let $\mathbb{C} = \{\frac{1}{n} : n \in \mathbb{Z}^+$. So $\mathbb{A} \subseteq \mathcal{U}$ and $\mathbb{C} \subseteq \mathcal{U}$ so $\mathbb{A} \cup \mathbb{C} \subseteq \mathcal{U}$, let $\mathcal{F} = \mathbb{A} \cup \mathbb{C}$, then $\bigcup \mathcal{F} = \bigcup(\{0\} \cup \{\frac{1}{n} : n \in \mathbb{Z}^+\})$ so $\bigcup \mathcal{F} = K$.

□

Proposition 18. *Any unbounded subset of $\mathbb{R}$ is not compact.*

Proposition 19. *Any open interval $(a, b) \subseteq \mathbb{R}$ is not compact.*

Definition 20. A subset K of a topological space X is said to be **Lindelöf** if for every open cover $\mathcal{U}$ of K (every collection $\mathcal{U}$ of open sets such that $\bigcup \mathcal{U} \supseteq K$) there exists a countable subcollection $\mathcal{F} \subseteq \mathcal{U}$ that also covers K (that is, $\bigcup \mathcal{F} \supseteq K$).

Definition 21. A subset K of a topological space X is said to be **σ-compact** if there exist compact subspaces K_n of X for $n \in \mathbb{N}$ such that $K = \bigcup_{n \in \mathbb{N}} K_n$.

Definition 22. A subset K of a topological space X is said to be **hemicompact** if there exist compact subspaces K_n of X for $n \in \mathbb{N}$ such that $K = \bigcup_{n \in \mathbb{N}} K_n$, and for every compact subset $H \subseteq K$, $H \subseteq K_n$ for some $n \in \mathbb{N}$.