

Read: Lax, Chapter 1, pages 1–11.

1. Let X be a vector space over a field K . Let 0 be the zero element of K and $\mathbf{0}$ the zero-element of X . Using only the definitions of a group, a vector space, and a field, carefully prove each of the following:
 - (a) The identity element e of a group is unique.
 - (b) In any group G , the inverse of $g \in G$ is unique.
 - (c) $0x = \mathbf{0}$ for every $x \in X$;
 - (d) $k\mathbf{0} = \mathbf{0}$ for every $k \in K$;
 - (e) For every $k \in K$ and $x \in X$, if $kx = \mathbf{0}$, then $k = 0$ or $x = \mathbf{0}$.
2. Let X denote the vector space of polynomials in $\mathbb{R}[x]$ of degree less than n . Are the vectors $x^3 + 2x + 5$, $3x^2 + 2$, $6x$, 6 linearly independent in X ? (Assume that $n \geq 4$.)
3. The following is called the *Replacement Lemma*: Let X be a vector space over K , and let S be a linearly independent subset of X . Let $x_0 \in \text{Span}(S)$ with $x_0 \neq 0$. Then there exists $x_1 \in S$ such that the set $S' = (S \setminus \{x_1\}) \cup \{x_0\}$ is a basis for $\text{Span}(S)$.
 - (a) Prove the Replacement Lemma.
 - (b) Suppose that B is a basis for X containing n elements, and let B' be another basis for X . Use the Replacement Lemma to show that $|B'| = n$.
4. Let S be a set of vectors in a finite-dimensional vector space X . Show that S is a basis of X if every vector of X can be written in one and only one way as a linear combination of the vectors in S .
5. Let X_1, X_2 be vector spaces over a field K . Show that $\dim(X_1 \times X_2) = \dim X_1 + \dim X_2$.
6. If Y is a subspace of X , then two vectors $x_1, x_2 \in X$ are *congruent modulo* Y , denoted $x_1 \equiv x_2 \pmod{Y}$, if $x_1 - x_2 \in Y$. This is an equivalence relation; denote the equivalence class containing $x \in X$ by $\{x\}$, and let X/Y denote the set of equivalence classes. We can make X/Y into a vector space by defining addition and scalar multiplication as follows:

$$\{x\} + \{z\} = \{x + z\}, \quad \{ax\} = a\{x\}.$$

- (a) Show that these operations are well-defined. That is, they do not depend on the choice of congruence class representatives.
- (b) Assume $\dim X < \infty$. Show that X is isomorphic to $Y \times X/Y$ by defining an explicit map and showing that it is linear and a bijection.