

Math 113 Theorems.

1. **Prop.** The relation $\equiv \pmod{n}$ is an equivalence relation.
2. **Prop.** $\mathbb{Z}/n\mathbb{Z}$ has exactly n elements.
 - (a) **Prop 0.** If $i \in [j]$, then $j \in [i]$ (in $\mathbb{Z}/n\mathbb{Z}$).
 - (b) **Prop 1.** If $[i] \cap [j] \neq \emptyset$, then $[i] = [j]$.
 - (c) **Prop 2.** If $i \neq j$ and $0 \leq i, j \leq n-1$, then $[i] \cup [j] = \emptyset$.
 - (d) **Prop 3.** Every $x \in \mathbb{Z}$ belongs to one of $[0], \dots, [n-1]$.
3. **Prop.** Addition is correctly (well-defined) defined on $\mathbb{Z}/n\mathbb{Z}$ by $[a] + [b] = [a + b]$.
4. **Prop 3.17.** The identity element in any group is unique.
5. **Prop 3.18.** The inverse is unique for any element g in a group G .
6. **Prop 3.19.** For any $a, b \in G$, where G is a group, $(a \star b)^{-1} = b^{-1}a^{-1}$.
7. **Prop 3.20.** For any $g \in G$, where G is a group, then $(g^{-1})^{-1} = g$.
8. **Theorem 5.1.** S_n is a group with $n!$ elements where the binary operation is the composition of maps.
9. **Prop 5.8.** Let σ and τ be two disjoint cycles in S_X . Then, $\sigma\tau = \tau\sigma$.
10. **Theorem 5.9.** Every permutation in S_n can be written as the product of disjoint cycles.
11. **Prop 5.12.** Any permutation of a finite set containing at least 2 elements can be written as the product of transpositions.
12. **Lemma 5.14.** If the identity is written as the product of r transpositions, $\text{id} = \tau_1 \dots \tau_r$, then r is even.
13. **Theorem 5.15.** If a permutation σ can be expressed as the product of an even number of transpositions, then any other product of transpositions equaling σ must also contain an even number of transpositions. Similarly, in the case of when σ is odd.
14. **Prop 3.30.** A subset H of G is a subgroup iff:

- (a) $e \in G$ also satisfies $e \in H$.
 - (b) If $h_1, h_2 \in H$, then $h_1 h_2 \in H$.
 - (c) If $h \in H$, then $h^{-1} \in H$.
15. **Prop 3.31.** Let H be a subset of a group G . Then, H is a subgroup of G iff $H \neq \emptyset$ and if $g, h \in H$, then $gh^{-1} \in H$.
16. **Theorem 4.3.** Take a group G and an element $a \in G$. Consider a cyclic subgroup $\langle a \rangle$. Then, $\langle a \rangle$ is a minimal subgroup of G such that a is in it (minimality: if H is a subgroup of G and $a \in H$, then $\langle a \rangle$ is a subgroup of H).
17. **Theorem 4.9.** Every cyclic group is abelian.
18. **Prop 11.4.** Let $\phi : G \rightarrow H$ be a homomorphism. Then:
- (a) $\phi(e_G) = e_H$.
 - (b) $\phi(g^{-1}) = (\phi(g))^{-1}$ for all $g \in G$.
 - (c) If $K \leq G$, then $\phi(K) := \{\phi(k) \mid k \in K\}$ is a subgroup of H .
 - (d) $\phi(G) := \{\phi(g) \mid g \in G\}$ (the image of ϕ) is a subgroup of H .
 - (e) If $M \leq H$, then $\phi^{-1}(M) := \{g \in G \mid \phi(g) \in M\}$ is a subgroup of G .
19. **Lemma 6.3.** Let G be a group and H , a subgroup. Let $g_1, g_2 \in G$. Then, the following are equivalent:
- (a) $g_1 H = g_2 H$.
 - (b) $H g_1^{-1} = H g_2^{-1}$.
 - (c) $g_1 H \subseteq g_2 H$.
 - (d) $g_2 \in g_1 H$.
 - (e) $g_1^{-1} g_2 \in H$.
20. **Theorem 6.4.** Left H -cosets partition G .
21. **Lagrange's Theorem.** If G is a finite group and H is a subgroup of G , then $|G| = |H| \cdot [G : H]$, or $[G : H] = \frac{|G|}{|H|}$.
22. **Cor.** If G is a finite group and H is a subgroup of G , then $|H|$ divides $|G|$.

23. **Cor. 6.13.** If G is a finite group and $H \leq G$ and $G \geq H \geq K$, then $[G : K] = [G : H] \cdot [H : K]$.
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24. **Prop.** $(\langle(123 \dots n)\rangle, \circ)$ is isomorphic to $(\mathbb{Z}/n\mathbb{Z}, +)$.
25. **Theorem 9.7. and 9.8** If $G = (G, \star)$ is cyclic, then if:
- (a) G finite, then G is isomorphic to $(\mathbb{Z}/n\mathbb{Z}, +)$.
 - (b) G infinite, then G is isomorphic to $(\mathbb{Z}, +)$.
26. **Theorem.** Let $h \in (H, \circ)$ where H is a group. Then if $\langle h \rangle$ is cyclic, then $\langle h \rangle$ is either isomorphic to \mathbb{Z} or $\mathbb{Z}/n\mathbb{Z}$.
27. **Prop.** Assume G is abelian. Then every subgroup of G is normal.
28. **Prop.** Take $G = \mathbb{Z}$, $H = n\mathbb{Z}$, $a, b \in \mathbb{Z}$. Then $aH \otimes bH$ gives $(a + n\mathbb{Z}) \otimes (b + n\mathbb{Z}) = (a + b) + n\mathbb{Z}$ is correctly defined.
29. **Theorem.** Let G be a group and H a normal subgroup. Then \otimes (as in the above Prop.) defines a group structure on G/H , where G/H is called a quotient (factor) group.
30. **Prop.** Let $\phi : G \rightarrow K$ be a homomorphism. Then, $\ker \phi$ is a normal subgroup of G , with $\ker \phi \trianglelefteq G$.
31. **First Isomorphism Theorem.** Let $\phi : G \rightarrow H$ be a homomorphism. Then $G/\ker \phi \cong \text{Im} \phi$ and denote $\Phi : G/\ker \phi \rightarrow \text{Im} \phi$ with $g \cdot \ker \phi \mapsto \phi(g)$.