

Fundamental theorem proof

Theorem: Every positive integer *greater than 1* is a product of (one or more) primes.

Before we prove, let's try some examples:

$$20 =$$

$$100 =$$

$$5 =$$

Proof by strong induction, with $b = 2$ and $j = 0$.

Basis step: WTS property is true about 2.

Since 2 is itself prime, it is already written as a product of (one) prime.

Recursive step: Consider an arbitrary integer $n \geq 2$. Assume (as the strong induction hypothesis, IH) that the property is true about each of $2, \dots, n$. WTS that the property is true about $n + 1$: We want to show that $n + 1$ can be written as a product of primes. Notice that $n + 1$ is itself prime or it is composite.

Case 1: assume $n + 1$ is prime and then immediately it is written as a product of (one) prime so we are done.

Case 2: assume that $n + 1$ is composite so there are integers x and y where $n + 1 = xy$ and each of them is between 2 and n (inclusive). Therefore, the induction hypothesis applies to each of x and y so each of these factors of $n + 1$ can be written as a product of primes. Multiplying these products together, we get a product of primes that gives $n + 1$, as required.

Since both cases give the necessary conclusion, the proof by cases for the recursive step is complete.

Least greatest proofs

For a set of numbers X , how do you formalize “there is a greatest X ” or “there is a least X ”?

Prove or disprove: There is a least prime number.

Prove or disprove: There is a greatest integer.

Approach 1, De Morgan’s and universal generalization:

Approach 2, proof by contradiction:

Extra examples: Prove or disprove that \mathbb{N} , \mathbb{Q} each have a least and a greatest element.

Gcd definition

Definition: Greatest common divisor Let a and b be integers, not both zero. The largest integer d such that d is a factor of a and d is a factor of b is called the greatest common divisor of a and b and is denoted by $\gcd(a, b)$.

Gcd examples

Why do we restrict to the situation where a and b are not both zero?

Calculate $\gcd(10, 15)$

Calculate $\gcd(10, 20)$

Gcd basic claims

Claim: For any integers a, b (not both zero), $\gcd(a, b) \geq 1$.

Proof: *Show that 1 is a common factor of any two integers, so since the gcd is the greatest common factor it is greater than or equal to any common factor.*

Claim: For any positive integers a, b , $\gcd(a, b) \leq a$ and $\gcd(a, b) \leq b$.

Proof *Using the definition of gcd and the fact that factors of a positive integer are less than or equal to that integer.*

Claim: For any positive integers a, b , if a divides b then $\gcd(a, b) = a$.

Proof *Using previous claim and definition of gcd.*

Claim: For any positive integers a, b, c , if there is some integer q such that $a = bq + c$,

$$\gcd(a, b) = \gcd(b, c)$$

Proof *Prove that any common divisor of a, b divides c and that any common divisor of b, c divides a .*

Gcd lemma relatively prime

Lemma: For any integers p, q (not both zero), $\gcd\left(\frac{p}{\gcd(p, q)}, \frac{q}{\gcd(p, q)}\right) = 1$. In other words, can reduce to relatively prime integers by dividing by gcd.

Proof:

Let x be arbitrary positive integer and assume that x is a factor of each of $\frac{p}{\gcd(p, q)}$ and $\frac{q}{\gcd(p, q)}$. This gives integers α, β such that

$$\alpha x = \frac{p}{\gcd(p, q)} \qquad \beta x = \frac{q}{\gcd(p, q)}$$

Multiplying both sides by the denominator in the RHS:

$$\alpha x \cdot \gcd(p, q) = p \qquad \beta x \cdot \gcd(p, q) = q$$

In other words, $x \cdot \gcd(p, q)$ is a common divisor of p, q . By definition of \gcd , this means

$$x \cdot \gcd(p, q) \leq \gcd(p, q)$$

and since $\gcd(p, q)$ is positive, this means, $x \leq 1$.