## 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:

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20 = 100 =
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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  $2, \ldots, n$ . 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:
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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



## 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

<b>Claim</b> : For any integers $a, b$ (not both zero), $gcd((a, b)) \ge 1$ .
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**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	$divisor\ of\ a,b\ divid$	es c and that any com	$mon\ divisor\ of\ b, c\ divide$	es a.

## Gcd lemma relatively prime

**Lemma**: For any integers p,q (not both zero),  $\gcd\left(\left(\frac{p}{\gcd((p,q))},\frac{q}{\gcd((p,q))}\right)\right)=1$ . 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  $\alpha$ ,  $\beta$  such that

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

Multiplying both sides by the denominator in the RHS:

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

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

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

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