We have color-coded the exponents to show how the exponents of 2, 3, and 5 in the product 180 are the sums of the exponents of those primes in the decompositions of the two factors 18 and 10.

Another important fact about prime numbers is that there are infinitely many of them.

Theorem 1.8. *There are arbitrarily large prime numbers.*

"Arbitrarily large" means that for every $n > 0$, there is a prime number greater than n.

Proof. Pick some value of k for which we know there are at least k primes, and let $p_1, \ldots, p_k$ be the first k primes in increasing order. (Since $p_1 = 2$, $p_2 = 3$, $p_3 = 5$, we could certainly take $k = 3$.) We'll show how to find a prime number greater than p_k. Since this process could be repeated indefinitely, there must be infinitely many primes.

Consider the number N that is one more than the product of the first k primes:

$$N = (p_1 \cdot p_2 \cdot \ldots \cdot p_k) + 1. \tag{1.9}$$

Dividing N by any of $p_1, \ldots, p_k$ would leave a remainder of 1. So N has no prime divisors less than or equal to p_k. Therefore, either N is not prime but has a prime factor greater than p_k, or else N is prime itself. ∎

In the $k = 3$ case, for example, $N = 2 \cdot 3 \cdot 5 + 1 = 31$. Here N itself is prime; Problem 1.11 asks you to find an example of the case in which N is not prime.

A *common divisor* of two numbers is a number that divides both of them. For example, 21 and 36 have the common divisors 1 and 3, but 16 and 21 have no common divisor greater than 1.

With this by way of background, let's work a number theory example that uses the Pigeonhole Principle.

Example 1.10. *Choose m distinct numbers between 2 and 40 inclusive, where $m \geq 13$. Then at least two of the numbers have some common divisor greater than 1.*

"Between a and b *inclusive*" means including all numbers that are $\geq a$ and also $\leq b$—so including both 2 and 40 in this case.

Solution to example. Observe first that there are 12 prime numbers less than or equal to 40: 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, no two of which share a factor greater than 1. Let's define P to be this set of 12 prime numbers. (We needed to specify that $m \geq 13$, because the claim would be false with

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