

Practice problems for the Math Olympiad

<Problem #7>

Prove that there are infinitely many positive integers which are not representable as a sum of cubes of two other positive integers.

Proof: Let us fix a positive integer n and let $1 \leq x \leq n^3$. Let us assume the positive number x can be represented as a sum of two cubes of two positive integers, i.e. $x = a^3 + b^3$. Then it is clear that

$$1 \leq a \leq n \text{ and } 1 \leq b \leq n$$

So there are n distinct a for $1 \leq a \leq n$ and there are n distinct b for $1 \leq b \leq n$. Therefore, there are no more than n^2 such pairs of a, b for which $x = a^3 + b^3 \leq n^3$. And there are n^3 distinct x such that $1 \leq x \leq n^3$. So there are at least $n^3 - n^2$ integers not representable as a sum of cubes of two positive integers. Since $n^3 - n^2$ is a polynomial of positive degree with a leading coefficient 1, it can be made arbitrary large by making n sufficiently large. This proves the theorem.

<Problem #8>

Show that a positive integer is divisible by 9 if and only if the sum of its digits is divisible by nine.

Proof: The n -digit positive integer

$$\overline{a_n a_{n-1} \dots a_2 a_1 a_0} = a_n \times 10^n + a_{n-1} \times 10^{n-1} + \dots + a_2 \times 10^2 + a_1 \times 10 + a_0, \quad (8.1)$$

where $a_0, a_1, a_2, \dots, a_{n-1}, a_n$ are digits (meaning integers from 0 to 9) and $a_n \neq 0$.

Rewriting (8.1) by using $10^i = 10 \cdot 9 + 1$, we get

$$\begin{aligned} & \overline{a_n a_{n-1} \dots a_2 a_1 a_0} \\ &= a_n \times \left(\underset{9}{\overbrace{9 \cdot 9 + 1}} \right) + a_{n-1} \times \left(\underset{9}{\overbrace{9 \cdot 9 + 1}} \right) + \dots + a_2 \times (99 + 1) + a_1 \times (9 + 1) + a_0 \\ &= a_n \times \underset{9}{\overbrace{9 \cdot 9}} + a_{n-1} \times \underset{9}{\overbrace{9 \cdot 9}} + \dots + a_2 \times \underset{9}{\overbrace{99}} + a_1 \times 9 + (a_n + a_{n-1} + \dots + a_2 + a_1 + a_0) \end{aligned}$$

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