

Number Theory Problem Set III

Maths Olympiad Preparation

24th February 2024

Problems & Solutions

Find the smallest positive integer m such that for all prime numbers $p > 3$, we have

$$105 \mid 9^{p^2} - 29^p + m.$$

Since $105 = 3 \cdot 5 \cdot 7$, we must have

$$9^{p^2} - 29^p + m \equiv 0 \pmod{3, 5, 7}.$$

Since $3 \mid 9^{p^2}$, we have

$$0 \equiv 29^p + m \equiv -(1)^p + m \equiv 1 + m \pmod{3}.$$

This shows that $m \equiv 1 \pmod{3}$. Modulo 5 we also have

$$0 \equiv 9^{p^2} - 29^p + m \equiv (1)^{p^2} - (1)^p + m \equiv m \pmod{5}.$$

This shows that $m \equiv 0 \pmod{5}$. Finally, modulo 7, we have

$$0 \equiv 9^{p^2} - 29^p + m \equiv 2^{p^2} - 1^p + m \equiv 2^{p^2} - 1 + m \pmod{7}.$$

As $p^2 \equiv 1 \pmod{3}$ and $2^3 \equiv 1 \pmod{7}$, we have $2^{p^2} \equiv 2 \pmod{7}$. Therefore,

$$0 \equiv 2 - 1 + m \equiv m + 1 \pmod{7}.$$

Now, $m \equiv -1 \pmod{3, 7}$ is equivalent to $m \equiv -1 \equiv 20 \pmod{21}$. Also, we know that we must have $m \equiv 0 \pmod{5}$. By the *Chinese Remainder Theorem*, this is equivalent to $m \equiv 20 \pmod{105}$. Hence, the smallest m is $\boxed{20}$.

Problems In Elementary Number Theory Problem Solving

L Darling-Hammond



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