Number Theory II: Problems with Solutions

Greg Gamble

1. Show $7 \mid 2222^{5555} + 5555^{2222}$.

Solution. By Fermat's Little Theorem, for any natural number n

$$n^7 \equiv n \pmod 7.$$

So for natural numbers q and r,

$$
\begin{aligned}
n^{7q+r} &\equiv (n^7)^q . n^r &&\pmod 7 \\
&\equiv n^q . n^r &&\pmod 7 \\
&\equiv n^{q+r} &&\pmod 7.
\end{aligned}
$$

Below we will use this result repeatedly. First though, observe that

$$2222 \equiv 3 \pmod 7 \quad \text{and} \quad 5555 \equiv 4 \equiv -3 \pmod 7.$$

Thus

$$
\begin{aligned}
2222^{5555} + 5555^{2222} &\equiv 3^{5555} + (-3)^{2222} &&\pmod 7 \\
&\equiv 3^{793+4} + (-3)^{317+3} &&\pmod 7 \\
&\equiv 3^{113+6} + (-3)^{65+5} &&\pmod 7 \\
&\equiv 3^{17+0} + (-3)^{7+1} &&\pmod 7 \\
&\equiv 3^{2+3} + (-3)^{1+1} &&\pmod 7 \\
&\equiv 3^2(3^3 + 1) &&\pmod 7 \\
&\equiv 3^2 . 28 &&\pmod 7 \\
&\equiv 0 &&\pmod 7.
\end{aligned}
$$

Hence $7 \mid 2222^{5555} + 5555^{2222}$.

Solution. *(Alternative)* The above solution is not a particularly clever way of using Fermat's Little Theorem. Since $n^7 - n$ factorises as $n(n^6 - 1)$, it follows from Fermat's Little Theorem that:

If n is a natural number and $n \not\equiv 0 \pmod 7$ then $n^6 \equiv 1 \pmod 7$.

So for natural numbers n, q and r, if $n \not\equiv 0 \pmod 7$ then

$$
\begin{aligned}
n^{6q+r} &\equiv (n^6)^q . n^r &&\pmod 7 \\
&\equiv 1^q . n^r &&\pmod 7 \\
&\equiv n^r &&\pmod 7.
\end{aligned}
$$

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   - The Rise of Digital Reading Number Theory Problems Solutions
   - Advantages of eBooks Over Traditional Books
2. Identifying Number Theory Problems Solutions
   - Exploring Different Genres
   - Considering Fiction vs. Non-Fiction
   - Determining Your Reading Goals
3. Choosing the Right eBook Platform
   - Popular eBook Platforms
   - Features to Look for in an Number Theory Problems Solutions
   - User-Friendly Interface

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