

## 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  $n$

$$n^7 = n \pmod{7}.$$

So for natural numbers  $q$  and  $r$ ,

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

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

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

Thus

$$\begin{aligned} 2222^{5555} + 5555^{2222} &= 3^{5555} + (-3)^{2222} \pmod{7} \\ &= 3^{7 \cdot 793 + 4} + (-3)^{7 \cdot 317 + 3} \pmod{7} \\ &= 3^{13+6} + (-3)^{6+5} \pmod{7} \\ &= 3^{17+0} + (-3)^{7+1} \pmod{7} \\ &= 3^{2+3} + (-3)^{1+1} \pmod{7} \\ &= 3^2(3^2 + 1) \pmod{7} \\ &= 3^2 \cdot 28 \pmod{7} \\ &= 0 \pmod{7}. \end{aligned}$$

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  $n^6 = 1 \pmod{7}$ .

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

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

# Number Theory Problems Solutions

**Rachel S Tattersall**



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