

# Solutions

## Twentieth International Olympiad, 1978

**1978/1.** Since  $1978^n$  and  $1978^m$  agree in their last three digits, the difference

$$1978^n - 1978^m = 1978^m(1978^{n-m} - 1)$$

is divisible by  $10^3 = 2^3 \cdot 5^3$ ; and since the second factor above is odd,  $2^3$  divides the first. Also

$$1978^m = 2^m \cdot 989^m,$$

so  $m \geq 3$ .

We can write  $m + n = (n - m) + 2m$ ; to minimize this sum, we take  $m = 3$  and seek the smallest value of  $d = n - m$ , such that  $1978^d - 1$  is divisible by  $5^3 = 125$ , i.e.

$$1978^d \equiv 1 \pmod{125}.$$

We shall twice make use of the following

**LEMMA.** *Let  $d$  be the smallest exponent such that  $a^d \equiv 1 \pmod{N}$ . Then any other exponent  $g$  for which  $a^g \equiv 1 \pmod{N}$  is a multiple of  $d$ .*

**PROOF:** If  $d$  does not divide  $g$ , then  $g = qd + r$  with  $0 < r < d$ , and  $a^g \equiv a^{qd}a^r \equiv 1 \pmod{N}$  implies  $a^r \equiv 1 \pmod{N}$  with  $0 < r < d$ , contradicting the minimality of  $d$ . So  $d|g$ .

Fermat's theorem states:† For any prime  $p$  and any integer  $a$  not divisible by  $p$ ,

$$(1) \quad a^{p-1} \equiv 1 \pmod{p}.$$

For example,

$$1978^4 \equiv 1 \pmod{5}.$$

†For a proof, see e.g. p. 126 of S. L. Greitzer, *The International Mathematical Olympiads*, vol. 27 in this NML series.

# Math Olympiad Problems And Solutions

**Emilie Sanchez**



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