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THE SIXTH FERMAT NUMBER AND PALINDROMIC CONTINUED FRACTIONS

by Freeman DYSON

ABSTRACT. An elementary argument is presented, verifying the known factorization of the sixth Fermat number $2^{64}+1$. The verification is made more elegant by using an old theorem of Serret concerning palindromic continued fractions.

It is easy to explain why the fifth Fermat number $2^{32}+1$ is divisible by 641 [Hardy and Wright, 1938]. The prime 641 has the two representations

$$641 = 5 \cdot 2^7 + 1 = 5^4 + 2^4. \tag{1}$$

The congruence

$$2^{32} = 2^4 \cdot 2^{28} \equiv -5^4 \cdot 2^{28} = -(5 \cdot 2^7)^4 \equiv -1 \pmod{641} \tag{2}$$

follows immediately from (1).

The purpose of this note is to explain in a similarly elementary way why the sixth Fermat number $2^{64}+1$ is divisible by 274177. The divisor has the representation

$$q = 274177 = 1 + 2^8 f\,, \qquad f = (2^6-1)(2^4+1)\,, \tag{3}$$

and it is easily verified that

$$2^{24} - 1 = fg\,, \qquad g = (2^6+1)(2^8-2^4+1)\,. \tag{4}$$

We look for a factorization of the form

$$2^{64}+1 = (x^2+y^2)(z^2+w^2)\,, \qquad 2^{32} - i = (x+iy)(z-iw)\,, \tag{5}$$

so that we require integers x, y, z, w satisfying

$$xz + yw = 2^{32}\,, \qquad xw - yz = 1\,, \qquad x^2+y^2 = q\,. \tag{6}$$

When $z = gx$, $w = gy$, the right side of (5), $(x+iy)g(x-iy)$, becomes gq; and $gq = 2^{32}+a$, very close to 2^{32}, with the difference $a = g - 2^8 = 15409$