MATHEMATICS OF COMPUTATION, VOLUME 26, NUMBER 118, APRIL 1972

Some Results for $k! \pm 1$ and $2 \cdot 3 \cdot 5 \cdots p \pm 1$

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Abstract. The numbers $k! \pm 1$ for $k = 2(1)100$, and $2 \cdot 3 \cdot 5 \cdots p \pm 1$ for p prime, $2 \leqq p \leqq 307$, were tested for primality. For $k = 2(1)30$, factorizations of $k! \pm 1$ are given.

In this note, we present the results of an investigation of $k! \pm 1$ and $2 \cdot 3 \cdot 5 \cdots p \pm 1$. An IBM 1130 computer was used for all computations.

A number N of one of these forms was first checked for primality by computing $b^{N-1} \pmod N$ for $b = 2$ or $b = 3$. If $b^{N-1} \not\equiv 1 \pmod N$, Fermat's Theorem implies that N is composite. On the other hand, if it was found that $b^{N-1} \equiv 1 \pmod N$, then the primality of N was established using one of the following two theorems, both due to Lehmer [1]. No composite numbers N of these forms were found which passed the above test.

THEOREM 1. *If, for some integer b, $b^{N-1} \equiv 1 \pmod N$, and $b^{(N-1)/q} \not\equiv 1 \pmod N$ holds for all prime factors q of $N - 1$, then N is prime.*

For primes of the forms $k! + 1$ and $2 \cdot 3 \cdot 5 \cdots p + 1$, a value for b satisfying the hypothesis of this theorem is given to aid anyone wishing to check these results.

THEOREM 2. *Given an odd integer N, suppose there is some Q such that the Jacobi symbols (Q/N) and $((1 - 4Q)/N)$ are both negative. Let α and β be the roots of $x^2 - x + Q = 0$, and let $V_n = \alpha^n + \beta^n$. If $V_{(N+1)/2} \equiv 0 \pmod N$, and $V_{2(N+1)/q} \not\equiv 2Q^{(N+1)/q}$ holds for all odd prime factors q of $N + 1$, then N is prime.*

For primes of the forms $k! - 1$ and $2 \cdot 3 \cdot 5 \cdots p - 1$, an appropriate value for Q is given.

Values of k such that $k! + 1$ is prime, $2 \leqq k \leqq 100$

k	b
2	2
3	3
11	26
27	37
37	67
41	43
73	149
77	89

Received June 8, 1971.
AMS 1969 *subject classifications.* Primary 1003; Secondary 1060.
Key words and phrases. Prime, factorial, product of primes, factorizations.

Values of k such that $k! - 1$ is prime, $2 \leqq k \leqq 100$

k	Q
3	2
4	7
6	19
7	26
12	19
14	62
30	122
32	37
33	53
38	61
94	199

Values of p such that $2 \cdot 3 \cdot 5 \cdots p + 1$ is prime, $2 \leqq p \leqq 307$

p	b
2	2
3	3
5	3
7	2
11	3
31	34

Values of p such that $2 \cdot 3 \cdot 5 \cdots p - 1$ is prime, $2 \leqq p \leqq 307$

p	Q
3	2
5	3
11	8
13	3
41	28
89	3

Previous results for primality as given by Sierpiński [2] include all $k \leqq 26$ in the case $k! + 1$, and $k \leqq 22$ and $k = 25$ in the case $k! - 1$. Kraitchik [3] gives factorizations of $k! + 1$ for $k \leqq 22$ and $k! - 1$ for $k \leqq 21$, as well as factorizations of $2 \cdot 3 \cdot 5 \cdots p + 1$ for $p \leqq 53$ and of $2 \cdot 3 \cdot 5 \cdots p - 1$ for $p \leqq 47$. The tables of Sierpiński and Kraitchik are in agreement with those given by the author, with the following exceptions:

(1) In Sierpiński $3! + 1$ is omitted from the list of primes;
(2) Both Sierpiński and Kraitchik erroneously list $20! - 1$ as a prime;
(3) Kraitchik fails to give the factor 5171 of $21! - 1$.

For $N = k! \pm 1$, $2 \leqq k \leqq 30$, N composite, a variety of methods were used to find the prime factors of N. Trial division to 10^8 or so was tried first, and the prime factors discovered by this method were eliminated. The number remaining, say L, was then checked by computing b^{L-1} (mod L), as previously described. If $b^{L-1} \not\equiv 1$ (mod L), then L was factored by expressing it as the difference of two squares [4], or by employing the continued fraction expansion of $\sqrt{L}$ [5]. On the other hand, if $b^{L-1} \equiv 1$ (mod L), then the primality of L was established by completely factoring $L - 1$ and applying Theorem 1. If it proved too difficult to completely factor $L - 1$, $L + 1$ was factored instead and Theorem 2 applied. (For large L, the primality of the largest factor of $L - 1$ had to be established in a similar fashion, and so on for a chain of four or five factorizations.)

Factorizations of $k! + 1$, $k = 2(1)30$

$2! + 1 = 3$ (prime)
$3! + 1 = 7$ (prime)
$4! + 1 = 5^2$
$5! + 1 = 11^2$
$6! + 1 = 7 \cdot 103$
$7! + 1 = 71^2$
$8! + 1 = 61 \cdot 661$
$9! + 1 = 19 \cdot 71 \cdot 269$
$10! + 1 = 11 \cdot 3\ 29891$
$11! + 1 = 399\ 16801$ (prime)
$12! + 1 = 13^2 \cdot 28\ 34329$
$13! + 1 = 83 \cdot 750\ 24347$
$14! + 1 = 23 \cdot 37903\ 60487$
$15! + 1 = 59 \cdot 479 \cdot 462\ 71341$
$16! + 1 = 17 \cdot 61 \cdot 137 \cdot 139 \cdot 10\ 59511$

$17! + 1 = 661 \cdot 5\ 37913 \cdot 10\ 00357$
$18! + 1 = 19 \cdot 23 \cdot 29 \cdot 61 \cdot 67 \cdot 1236\ 10951$
$19! + 1 = 71 \cdot 1\ 71331\ 12733\ 63831$
$20! + 1 = 206\ 39383 \cdot 11\ 78766\ 83047$
$21! + 1 = 43 \cdot 4\ 39429 \cdot 270\ 38758\ 15783$
$22! + 1 = 23 \cdot 521 \cdot 93\ 79961\ 00957\ 69647$
$23! + 1 = 47^2 \cdot 79 \cdot 148\ 13975\ 47368\ 64591$
$24! + 1 = 811 \cdot 7\ 65041\ 18586\ 09610\ 84291$
$25! + 1 = 401 \cdot 386\ 81321\ 80381\ 79201\ 59601$
$26! + 1 = 1697 \cdot 2376\ 49652\ 99151\ 77581\ 52033$
$27! + 1 = 1088\ 88694\ 50418\ 35216\ 07680\ 00001$ (prime)
$28! + 1 = 29 \cdot 1051\ 33911\ 93507\ 37450\ 00518\ 62069$
$29! + 1 = 14557 \cdot 2185\ 68437 \cdot 2778\ 94205\ 75550\ 23489$
$30! + 1 = 31 \cdot 12421 \cdot 82561 \cdot 10\ 80941 \cdot 7\ 71906\ 83199\ 27551$

Factorizations of $k! - 1$, $k = 2(1)30$

$2! - 1 = 1$
$3! - 1 = 5$ (prime)
$4! - 1 = 23$ (prime)
$5! - 1 = 7 \cdot 17$
$6! - 1 = 719$ (prime)
$7! - 1 = 5039$ (prime)
$8! - 1 = 23 \cdot 1753$
$9! - 1 = 11^2 \cdot 2999$
$10! - 1 = 29 \cdot 1\ 25131$
$11! - 1 = 13 \cdot 17 \cdot 23 \cdot 7853$
$12! - 1 = 4790\ 01599$ (prime)
$13! - 1 = 1733 \cdot 35\ 93203$
$14! - 1 = 8\ 71782\ 91199$ (prime)
$15! - 1 = 17 \cdot 31^2 \cdot 53 \cdot 15\ 10259$
$16! - 1 = 3041 \cdot 68802\ 33439$
$17! - 1 = 19 \cdot 73 \cdot 25\ 64437\ 11677$
$18! - 1 = 59 \cdot 2\ 26663 \cdot 4787\ 49547$
$19! - 1 = 653 \cdot 23\ 83907 \cdot 781\ 43369$
$20! - 1 = 1\ 24769 \cdot 1949\ 92506\ 80671$
$21! - 1 = 23 \cdot 89 \cdot 5171 \cdot 482\ 67136\ 12027$
$22! - 1 = 109 \cdot 606\ 56047 \cdot 17\ 00066\ 81813$
$23! - 1 = 51871 \cdot 498\ 39056\ 00216\ 87969$
$24! - 1 = 62\ 57931\ 87653 \cdot 99\ 14591\ 81683$
$25! - 1 = 149 \cdot 907 \cdot 1\ 14776\ 27434\ 14826\ 21993$
$26! - 1 = 20431 \cdot 197\ 39193\ 43774\ 68374\ 32529$
$27! - 1 = 29 \cdot 37\ 54782\ 56910\ 97766\ 07161\ 37931$
$28! - 1 = 239 \cdot 1\ 56967 \cdot 77980\ 78091 \cdot 104\ 21901\ 96053$
$29! - 1 = 31 \cdot 59 \cdot 311 \cdot 261\ 56201 \cdot 594\ 27855\ 62716\ 09021$
$30! - 1 = 265\ 25285\ 98121\ 91058\ 63630\ 84799\ 99999$ (prime)

Acknowledgement. The author gratefully acknowledges the help of Dr. Joseph Roberts and Michael Penk in this study, which was done at Reed College, Portland, Oregon, in connection with an undergraduate thesis.

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