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CORRIGENDUM TO "CONGRUENCES FOR CERTAIN BINOMIAL SUMS"

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Abstract. Theorem 1 of J.-J. Lee, Congruences for certain binomial sums. Czech. Math. J. 63 (2013), 65–71, is incorrect as it stands. We correct this here. The final result is changed, but the essential idea of above mentioned paper remains valid.

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The following is a correction of Theorem 1 of [2].

Theorem 1. *Let p be a prime such that $p \geqslant 5$. Let $n = p^r - 1$ or $2p^r - 1$ with $r \geqslant 1$ an integer. Then*

$$\sum_{k=0}^{\lfloor n/2 \rfloor} \binom{2k}{k} \equiv \begin{cases} 1 \pmod p, & \text{if } p \equiv 1 \pmod 3; \\ (-1)^r \pmod p, & \text{if } p \equiv -1 \pmod 3. \end{cases}$$

The error occurs in Lemma 2 of the paper, and the following is a replacement to it.

Lemma 2. *Let $r \geqslant 1$ be a natural number, and p a prime number. Then*

$$\binom{p^r - 1}{k} \equiv (-1)^k \pmod p \quad \text{and} \quad \binom{2p^r - 1}{k} \equiv (-1)^k \pmod p. \tag{1}$$

P r o o f. We will prove the second case, and the first case can be proved similarly.

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Let us write $2p^r - 1$ in base p, that is,

$$2p^r - 1 = p^r + (p-1)p^{r-1} + (p-1)p^{r-2} + \ldots + (p-1).$$

Also, write $k = k_0 + k_1 p + k_2 p + \ldots + k_d p^d$ in base p, where $d \leqslant r$.

Then the Lucas theorem (see [1]) tells us that

$$\binom{2p^r - 1}{k} \equiv \binom{p-1}{k_0} \cdots \binom{p-1}{k_d} \binom{p-1}{0} \cdots \binom{p-1}{0} \binom{1}{0} \pmod{p}. \tag{2}$$

Now, for any integer $m \leqslant p - 1$, observe that

$$\binom{p-1}{m} = \frac{(p-1)!}{m!(p-m-1)!} = \frac{\{(p-1)\ldots(p-m)\}(p-m-1)!}{m!(p-m-1)!} \equiv (-1)^m \pmod{p}.$$

Using this, we can simplify Formula (2) as

$$\binom{2p^r - 1}{k} \equiv (-1)^{k_0} \ldots (-1)^{k_d} = (-1)^{k_0 + \ldots + k_d} = (-1)^k \pmod{p}, \tag{3}$$

where the last equality is because $k_0 + \ldots + k_d \equiv k \pmod{2}$. Notice that since p is an odd prime, $p \equiv 1 \pmod{2}$. This proves the second case.

For the first case, write $p^r - 1$ in base p, that is,

$$p^r - 1 = (p-1)p^{r-1} + (p-1)p^{r-2} + \ldots + (p-1),$$

and the result follows in a similar way. $\square$

Corresponding to this Lemma, we need to replace Formula (3.1) of [2], which is $\binom{rp^2-1}{k} = (-1)^k + p^2 f(k)$, by $\binom{p^r-1}{k} = (-1)^k + pf(k)$ or $\binom{2p^r-1}{k} = (-1)^k + pf(k)$, where $f\colon \mathbb{N} \to \mathbb{N}$ is a function defined on the set of natural numbers $\mathbb{N}$ (including 0).

To prove Theorem 1, we replace $rp^2 - 1$ in [2] by either $p^r - 1$ or $2p^r - 1$. Most of the calculations remain valid without any changes. However, Lemma 6 of [2] needs a slight modification in its statement as follows. It explains why the statement of our main theorem changes as given in Theorem 1.

Lemma 3. *Let p be a prime such that $p \geqslant 5$. Let $n = p^r - 1$ or $2p^r - 1$ with $r \geqslant 1$ an integer. Let*

$$S = (-\mathrm{i})^n \exp\Big(n \cdot \frac{5\pi}{6}\mathrm{i}\Big) \sum_{k=0}^{n} \exp\Big(\frac{4k\pi}{3}\mathrm{i}\Big).$$

Then $S = 1$ if $p \equiv 1 \pmod 3$, and $S = (-1)^r$ if $p \equiv -1 \pmod 3$.

P r o o f. Notice that in Lemma 6 of [2], S was defined as

$$S = (-\mathrm{i})^{rp^2-1} \exp\Big((rp^2 - 1) \cdot \frac{5\pi}{6}\mathrm{i}\Big) \sum_{k=0}^{rp^2-1} \exp\Big(\frac{4k\pi}{3}\mathrm{i}\Big).$$

The proof is also obtained by replacing $rp^2 - 1$ by either $p^r - 1$ or $2p^r - 1$. Only the final statement is changed according to the evaluations of trigonometric functions. In both cases of $n = p^r - 1$ and $2p^r - 1$, it follows that $S = 1$ if $p^r \equiv 1 \pmod 3$, and $S = -1$ if $p^r \equiv -1 \pmod 3$. Equivalently, $S = 1$ if $p \equiv 1 \pmod 3$, and $S = (-1)^r$ if $p \equiv -1 \pmod 3$. $\square$

Now, all the rest of the proofs in [2] are valid and we get the proof of Theorem 1.

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