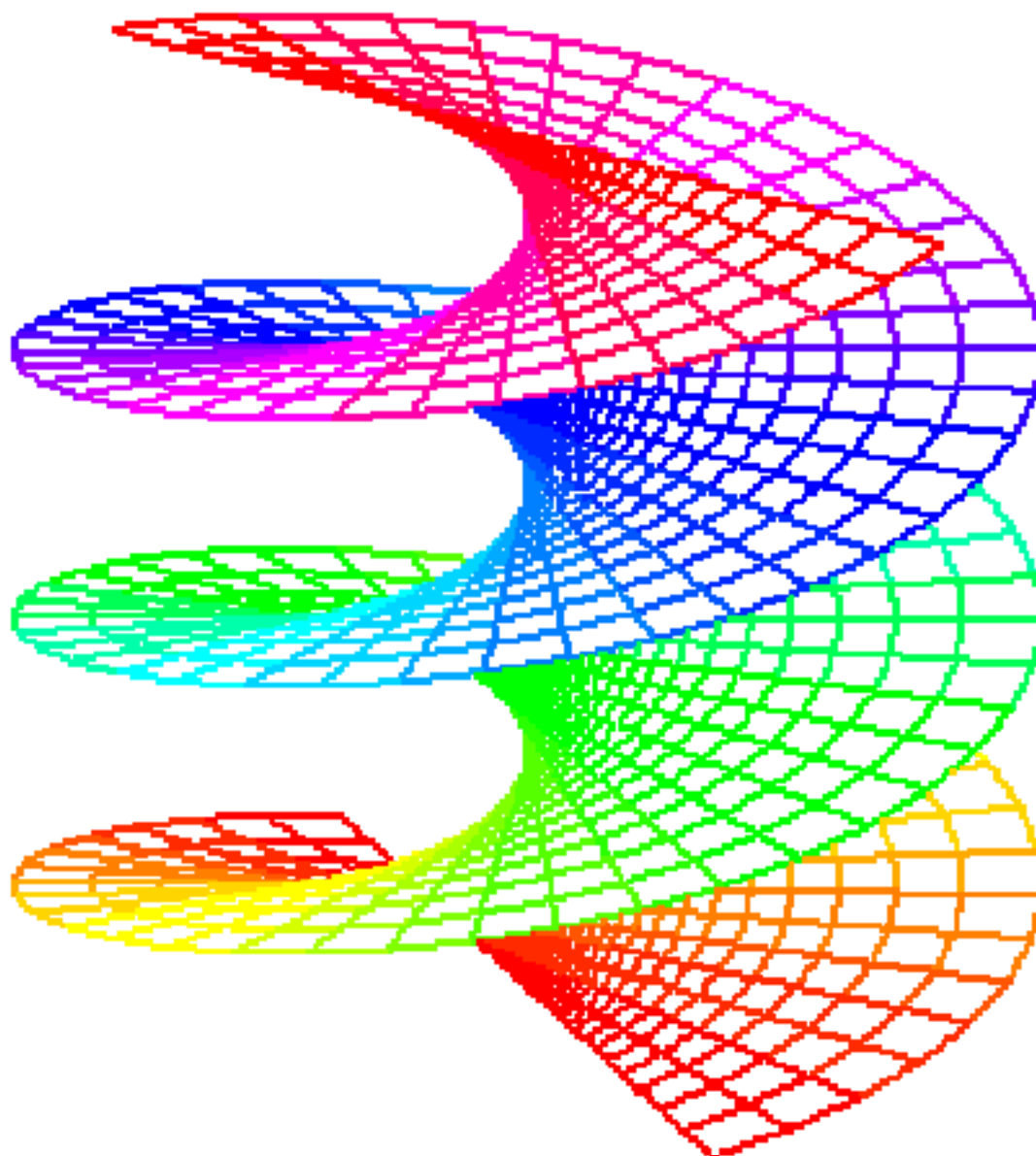


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## Remarks on some of the Smarandache's problem. Part 2

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To Dr. Florentin Smarandache  
for his 50th birthday

**0.** In 1999, the second author of this remarks published a book over 30 of Smarandache's problems in area of elementary number theory (see [1, 2]). After this, we worked over new 20 problems that we collected in our book [28]. These books contain Smarandache's problems, described in [10, 16]. The present paper contains some of the results from [28].

In [16] Florentin Smarandache formulated 105 unsolved problems, while in [10] C.Dumitrescu and V. Seleacu formulated 140 unsolved problems of his. The second book contains almost all the problems from [16], but now each problem has unique number and by this reason in [1, 28] and here the authors use the numeration of the problems from [10].

In the text below the following notations are used.

$\mathcal{N}$  - the set of all natural numbers (i.e., the set of all positive integers);

$[x]$  - "floor function" (or also so called "bracket function") - the greatest integer which is not greater than the real non-negative number  $x$ ;

$\zeta$  - Riemann's Zeta-function;

$\Gamma$  - Euler's Gamma-function;

$\pi$  - the prime counting function, i.e.,  $\pi(n)$  denotes the number of prime  $p$  such that  $p \leq n$ ;

$]x[$  - the largest natural number strongly smaller than the real (positive) number  $x$ ;

$[x]$  - the inferior integer part of  $x$ , i.e, the smallest integer greater than or equal to  $x$ .

For an arbitrary increasing sequence of natural number  $C \equiv \{c_n\}_{n=1}^{\infty}$  we denote by  $\pi_C(n)$  the number of terms of  $C$ , which are not greater than  $n$ . When  $n < c_1$  we put  $\pi_C(n) = 0$ .

**1.** The results in this section are taken from [8].

The second problem from [10] (see also 16-th problem from [16]) is the following:

*Smarandache circular sequence:*

$$\underbrace{1}_1, \underbrace{12, 21}_2, \underbrace{123, 231, 312}_3, \underbrace{1234, 2341, 3412, 4123}_4, \\ \underbrace{12345, 23451, 34512, 45123, 51234}_5,$$



$$\underbrace{123456, 234561, 345612, 456123, 561234, 612345, \dots}_6$$

Let  $f(n)$  be the  $n$ -th member of the above sequence. We shall prove the following **Theorem 1.1.** For each natural number  $n$ :

$$f(n) = \overline{s(s+1) \dots k12 \dots (s-1)},$$

where

$$k \equiv k(n) = \left\lfloor \frac{\sqrt{8n+1} - 1}{2} \right\rfloor$$

and

$$s \equiv s(n) = n - \frac{k(k+1)}{2}.$$

**2.** The results in this section are taken from [25].

The eight problem from [10] (see also 16-th problem from [16]) is the following:

*Smarandache mobile periodicals (I):*

```

...0 0 0 0 0 0 1 0 0 0 0 0 0...
...0 0 0 0 0 1 1 1 0 0 0 0 0...
...0 0 0 0 1 1 0 1 1 0 0 0 0...
...0 0 0 0 0 1 1 1 0 0 0 0 0...
...0 0 0 0 0 0 1 0 0 0 0 0 0...
...0 0 0 0 0 1 1 1 0 0 0 0 0...
...0 0 0 0 1 1 0 1 1 0 0 0 0...
...0 0 0 1 1 0 0 0 1 1 0 0 0...
...0 0 0 0 1 1 0 1 1 0 0 0 0...
...0 0 0 0 0 0 1 0 0 0 0 0 0...
...0 0 0 0 0 1 1 1 0 0 0 0 0...
...0 0 0 0 0 1 1 0 0 0 0 0 0...
...0 0 0 0 1 1 0 1 1 0 0 0 0...
...0 0 0 1 1 0 0 0 1 1 0 0 0...
...0 0 0 1 1 0 0 0 1 1 0 0 0...
...0 0 0 0 1 1 0 1 1 0 0 0 0...
...0 0 0 0 0 1 1 1 0 0 0 0 0...
...0 0 0 0 0 0 1 0 0 0 0 0 0...

```

$$\begin{array}{cccccccccccc}
 \dots & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \dots \\
 \dots & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \dots \\
 \dots & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 \dots \\
 \dots & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \dots \\
 \dots & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \dots \\
 \dots & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \dots \\
 \dots & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \dots \\
 & & & & & & \cdot & & & & \cdot & & \cdot \\
 & & & & & & \cdot & & & & \cdot & & \cdot
 \end{array}$$

This sequence has the form

$$\underbrace{1, 111, 11011, 111, 1, 1, 111, 11011, 1100011, 11011, 111, 1, 1, 111, 11011, 1100011, 11011, 111, 1, 1, 111, 11011, 1100011, 110000011, 1100011, 11011, 111, 1, \dots}_{9}$$

All digits from the above table generate an infinite matrix  $A$ . We described the elements of  $A$ .

Let us take a Cartesian coordinate system  $C$  with origin in the point containing element "1" in the topmost (i.e., the first) row of  $A$ . We assume that this row belongs to the ordinate axis of  $C$  (see Fig. 1) and that the points to the right of the origin have positive ordinates.

The above digits generate an infinite sequence of squares, located in the half-plane (determined by  $C$ ) where the abscissa of the points are nonnegative. Their diameters have the form

$$"110\dots 011".$$

Exactly one of the diameters of each of considered square lies on the abscissa of  $C$ . It can be seen (and proved, e.g., by induction) that the  $s$ -th square, denoted by  $G_s (s = 0, 1, 2, \dots)$  has a diameter with length  $2s + 4$  and the same square has a highest vertex with coordinates  $\langle s^2 + 3s, 0 \rangle$  in  $C$  and a lowest vertex with coordinates  $\langle s^2 + 5s + 4, 0 \rangle$  in  $C$ .

Let us denote by  $a_{k,i}$  an element of  $A$  with coordinates  $\langle k, i \rangle$  in  $C$ .

First, we determine the minimal nonnegative  $s$  for which the inequality

$$s^2 + 5s + 4 \geq k$$

holds. We denote it by  $s(k)$ . Directly it is seen the following

**Lemma 2.1** The number  $s(k)$  admits the explicit representation:

$$s(k) = \begin{cases} 0, & \text{if } 0 \leq k \leq 4 \\ \left[ \frac{\sqrt{4k+9}-5}{2} \right], & \text{if } k \geq 5 \text{ and } 4k+9 \text{ is} \\ & \text{a square of an integer} \\ \left[ \frac{\sqrt{4k+9}-5}{2} \right] + 1, & \text{if } k \geq 5 \text{ and } 4k+9 \text{ is} \\ & \text{not a square of an integer} \end{cases} \tag{2.1}$$

and the inequality

$$(s(k))^2 + 3s(k) \leq k \leq (s(k))^2 + 5s(k) + 4 \quad (2.2)$$

hold.

Second, we introduce the integer  $\delta(k)$  and  $\varepsilon(k)$  by

$$\delta(k) \equiv k - (s(k))^2 - 3s(k), \quad (2.3)$$

$$\varepsilon(k) \equiv (s(k))^2 + 5s(k) + 4 - k. \quad (2.4)$$

From (2.2) we have  $\delta(k) \geq 0$  and  $\varepsilon(k) \geq 0$ . Let  $P_k$  be the infinite strip orthogonal to the abscissa of  $C$  and lying between the straight lines passing through those vertices of the square  $G_{s(k)}$  lying on the abscissa of  $C$ . Then  $\delta(k)$  and  $\varepsilon(k)$  characterize the location of point with coordinate  $\langle k, i \rangle$  in  $C$  in strip  $P_k$ . Namely, the following assertion is true.

**Proposition 2.1.** The elements  $a_{k,i}$  of the infinite matrix  $A$  are described as follows:

if  $k \leq (s(k))^2 + 4s(k) + 2$ , then

$$a_{k,i} = \begin{cases} 0, & \text{if } \delta(k) < |i| \text{ or } \delta(k) \geq |i| + 2, \\ 1, & \text{if } |i| \leq \delta(k) \leq |i| + 1 \end{cases}$$

if  $k \geq (s(k))^2 + 4s(k) + 2$ , then

$$a_{k,i} = \begin{cases} 0, & \text{if } \varepsilon(k) < |i| \text{ or } \varepsilon(k) \geq |i| + 2, \\ 1, & \text{if } |i| \leq \varepsilon(k) \leq |i| + 1 \end{cases}$$

where here and below  $s(k)$  is given by (2.1),  $\delta(k)$  and  $\varepsilon(k)$  are given by (2.3) and (2.4), respectively.

Below, we propose another description of elements of  $A$ , which can be proved (e.g., by induction) using the same considerations.

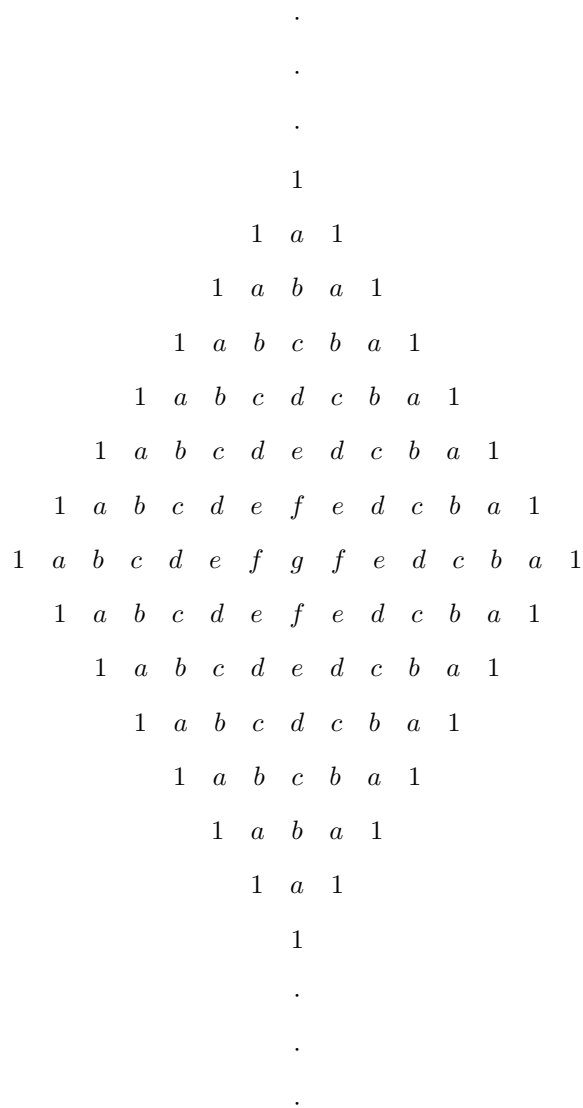
$$a_{k,i} = \begin{cases} 1, & \text{if } \langle k, i \rangle \in \\ & \{ \langle (s(k))^2 + 3s(k), 0 \rangle, \langle (s(k))^2 + 5s(k) + 4, 0 \rangle \} \\ & \cup \{ \langle (s(k))^2 + 3s(k) + j, -j \rangle, \\ & \langle (s(k))^2 + 3s(k) + j, -j + 1 \rangle, \\ & \langle (s(k))^2 + 3s(k) + j, j - 1 \rangle, \\ & \langle (s(k))^2 + 3s(k) + j, j \rangle : 1 \leq j \leq s(k) + 2 \} \\ & \cup \{ \langle (s(k))^2 + 5s(k) + 4 - j, -j \rangle, \\ & \langle (s(k))^2 + 5s(k) + 4 - j, -j + 1 \rangle, \\ & \langle (s(k))^2 + 5s(k) + 4 - j, j - 1 \rangle, \\ & \langle (s(k))^2 + 5s(k) + 4 - j, j \rangle : \\ & 1 \leq j \leq s(k) + 1 \} \\ 0, & \text{otherwise} \end{cases}$$

Similar representations are possible for the ninth, tenth and eleventh problems. In [28] we introduce eight modifications of these problems, giving formulae for their  $(k, i)$ -th members  $a_{k,i}$ .

Essentially more interesting is Problem 103 from [10]:

*Smarandache numerical carpet:*

*has the general form*



*On the border of level 0, the elements are equal to "1";  
 they form a rhomb.  
 Next, on the border of level 1, the elements are equal to "a";  
 where "a" is the sum of all elements of the previous border;  
 the "a"s form a rhomb too inside the previous one.  
 Next again, on the border of level 2, the elements are equal to "b";*



It can be proved by induction that the elements of this square that stay on  $t$ -th place are given by the formula

$$a_t = 4(s + 1) \prod_{i=0}^{t-2} (4s + 1 - 4i).$$

If we would like to generalize the above problem, we can construct, e.g., the following extension:

$$\begin{array}{cccccccc}
 & & & & x & & & \\
 & & & & \cdot & \cdot & \cdot & \\
 & & & & & & & \\
 & & & & x & a_1 & \cdot & \cdot & \cdot & a_1 & x \\
 & & & & x & a_1 & a_2 & \cdot & \cdot & \cdot & a_2 & a_1 & x \\
 x & a_1 & a_2 & a_3 & \cdot & \cdot & \cdot & a_3 & a_2 & a_1 & x \\
 & & & & x & a_1 & a_2 & \cdot & \cdot & \cdot & a_2 & a_1 & x \\
 & & & & x & a_1 & \cdot & \cdot & \cdot & a_1 & x \\
 & & & & \cdot & \cdot & \cdot & & & & & & \\
 & & & & x & & & & & & & & 
 \end{array}$$

where  $x$  is given number. Then we obtain

$$\begin{aligned}
 a_1 &= 4(s + 1)x \\
 a_2 &= 4(s + 1)(4s + 1)x \\
 a_3 &= 4(s + 1)(4s + 1)(4s - 3)x \\
 a_4 &= 4(s + 1)(4s + 1)(4s - 3)(4s - 7)x
 \end{aligned}$$

etc. and for  $t \geq 1$

$$a_t = 4(s + 1) \prod_{i=0}^{t-2} (4s + 1 - 4i)x.$$

where it assumed that

$$\prod_{i=0}^{-1} \cdot = 1.$$

**3.** The results in this section are taken from [21].

The 15-th Smarandache's problem from [10] is the following: "Smarandache's simple numbers":

$$\begin{aligned}
 &2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15, 17, 19, 21, 22, 23, 25, 26, 27, \\
 &29, 31, 33, \dots
 \end{aligned}$$

A number  $n$  is called "Smarandache's simple number" if the product of its proper divisors is less than or equal to  $n$ . Generally speaking,  $n$  has the form  $n = p$ , or  $n = p^2$ , or  $n = p^3$ , or  $n = pq$ , where  $p$  and  $q$  are distinct primes".

Let us denote: by  $S$  - the sequence of all Smarandache's simple numbers and by  $s_n$  - the  $n$ -th term of  $S$ ; by  $\mathcal{P}$  - the sequence of all primes and by  $p_n$  - the  $n$ -th term of  $\mathcal{P}$ ; by  $\mathcal{P}^2$  - the sequence  $\{p_n^2\}_{n=1}^{\infty}$ ; by  $\mathcal{P}^3$  - the sequence  $\{p_n^3\}_{n=1}^{\infty}$ ; by  $\mathcal{P}\mathcal{Q}$  - the sequence  $\{p.q\}_{p,q \in \mathcal{P}}$ , where  $p < q$ .

In the present section we find  $\pi_S(n)$  in an explicit form and using this, we find the  $n$ -th term of  $S$  in explicit form, too.

First, we note that instead of  $\pi_{\mathcal{P}}(n)$  we use the notation  $\pi(n)$ .

Hence

$$\pi_{\mathcal{P}^2}(n) = \pi(\sqrt{n}), \pi_{\mathcal{P}^3}(n) = \pi(\sqrt[3]{n}),$$

Thus, using the definition of  $S$ , we get

$$\pi_S(n) = \pi(n) + \pi(\sqrt{n}) + \pi(\sqrt[3]{n}) + \pi_{\mathcal{P}\mathcal{Q}}(n) \quad (4.1)$$

Our first aim is to express  $\pi_S(n)$  in an explicit form. For  $\pi(n)$  some explicit formulae are proposed in [18]. Other explicit formulae for  $\pi(n)$  are given in [14]. One of them is known as Mináč's formula. It is given below

$$\pi(n) = \sum_{k=2}^n \left[ \frac{(k-1)! + 1}{k} - \left\lfloor \frac{(k-1)!}{k} \right\rfloor \right]. \quad (4.2)$$

Therefore, the problem of finding of explicit formulae for functions  $\pi(n)$ ,  $\pi(\sqrt{n})$ ,  $\pi(\sqrt[3]{n})$  is solved successfully. It remains only to express  $\pi_{\mathcal{P}\mathcal{Q}}(n)$  in an explicit form.

Let  $k \in \{1, 2, \dots, \pi(\sqrt{n})\}$  be fixed. We consider all numbers of the kind  $p_k q$ , which  $p \in \mathcal{P}$ ,  $q > p_k$  for which  $p_k q \leq n$ . The quality of these numbers is  $\pi(\frac{n}{p_k}) - \pi(p_k)$ , or which is the same

$$\pi\left(\frac{n}{p_k}\right) - k. \quad (4.3)$$

When  $k = 1, 2, \dots, \pi(\sqrt{n})$ , the number  $p_k q$ , as defined above, describe all numbers of the kind  $p.q$ , with  $p, q \in \mathcal{P}$ ,  $p < q, p.q < n$ . But the quantity of the last numbers is equal to  $\pi_{\mathcal{P}\mathcal{Q}}(n)$ . Hence

$$\pi_{\mathcal{P}\mathcal{Q}}(n) = \sum_{k=1}^{\pi(\sqrt{n})} (\pi\left(\frac{n}{p_k}\right) - k), \quad (4.4)$$

because of (4.3). The equality (4.4), after a simple computation yields the formula

$$\pi_{\mathcal{P}\mathcal{Q}}(n) = \sum_{k=1}^{\pi(\sqrt{n})} \pi\left(\frac{n}{p_k}\right) - \frac{\pi(\sqrt{n})(\pi(\sqrt{n}) + 1)}{2}. \quad (4.5)$$

In [20] the identity

$$\sum_{k=1}^{\pi(b)} \pi\left(\frac{n}{p_k}\right) = \pi\left(\frac{n}{b}\right) \cdot \pi(b) + \sum_{k=1}^{\pi(\frac{n}{2}) - \pi(\frac{n}{b})} \pi\left(\frac{n}{p_{\pi(\frac{n}{b}) + k}}\right) \quad (4.6)$$

is proved, under the condition  $b > 2$  ( $b$  is a real number). When  $\pi(\frac{n}{2}) = \pi(\frac{n}{b})$ , the right hand-side of (4.6) is reduced to  $\pi(\frac{n}{b}) \cdot \pi(b)$ . In the case  $b = \sqrt{n}$  and  $n \geq 4$  equality (4.6) yields

$$\sum_{k=1}^{\pi(\sqrt{n})} \pi\left(\frac{n}{p_k}\right) = (\pi(\sqrt{n}))^2 + \sum_{k=1}^{\pi(\frac{n}{2}) - \pi(\sqrt{n})} \pi\left(\frac{n}{p_{\pi(\sqrt{n}) + k}}\right). \quad (4.7)$$

If we compare (4.5) with (4.7) we obtain for  $n \geq 4$

$$\pi_{\mathcal{PQ}}(n) = \frac{\pi(\sqrt{n})(\pi(\sqrt{n}) - 1)}{2} + \sum_{k=1}^{\pi(\frac{n}{2}) - \pi(\sqrt{n})} \pi\left(\frac{n}{p_{\pi(\sqrt{n})+k}}\right). \tag{4.8}$$

Thus, we have two different explicit representations for  $\pi_{\mathcal{PQ}}(n)$ . These are formulae (4.5) and (4.8). We note that the right hand side of (4.8) reduces to  $\frac{\pi(\sqrt{n})(\pi(\sqrt{n})-1)}{2}$ , when  $\pi(\frac{n}{2}) = \pi(\sqrt{n})$ .

Finally, we observe that (4.1) gives an explicit representation for  $\pi_S(n)$ , since we may use formula (4.2) for  $\pi(n)$  (or other explicit formulae for  $\pi(n)$ ) and (4.5), or (4.8) for  $\pi_{\mathcal{PQ}}(n)$ .

The following assertion solves the problem for finding of the explicit representation of  $s_n$ .

**Theorem 4.1.** The  $n$ -th term  $s_n$  of  $S$  admits the following three different explicit representations:

$$s_n = \sum_{k=0}^{\theta(n)} \left[ \frac{1}{1 + \lfloor \frac{\pi_S(n)}{n} \rfloor} \right]; \tag{4.9}$$

$$s_n = -2 \sum_{k=0}^{\theta(n)} \zeta\left(-2 \lfloor \frac{\pi_S(n)}{n} \rfloor\right); \tag{4.10}$$

$$s_n = \sum_{k=0}^{\theta(n)} \frac{1}{\Gamma\left(1 - \lfloor \frac{\pi_S(n)}{n} \rfloor\right)}, \tag{4.11}$$

where

$$\theta(n) \equiv \lfloor \frac{n^2 + 3n + 4}{4} \rfloor, \quad n = 1, 2, \dots$$

We note that (4.9)-(4.11) are representations using, respectively, "floor function", Riemann's Zeta-function and Euler's Gamma-function. Also, we note that in (4.9)-(4.11)  $\pi_S(k)$  is given by (4.1),  $\pi(k)$  is given by (4.2) (or by others formulae like (4.2)) and  $\pi_{\mathcal{PQ}}(n)$  is given by (4.5), or by (4.8). Therefore, formulae (4.9)-(4.11) are explicit.

**4.** The results in this section are taken from [6].

The 17-th problem from [10] (see also the 22-nd problem from [16]) is the following:

*Smarandache's digital products:*

$$\underbrace{0, 1, 2, 3, 4, 5, 6, 7, 8, 9}, \underbrace{0, 1, 2, 3, 4, 5, 6, 7, 8, 9},$$

$$\underbrace{0, 2, 4, 6, 8, 10, 12, 14, 16, 18}, \underbrace{0, 3, 6, 9, 12, 15, 18, 21, 24, 27},$$

$$\underbrace{0, 4, 8, 12, 16, 20, 24, 28, 32, 36}, \underbrace{0, 5, 10, 15, 20, 25 \dots}$$

( $d_p(n)$  is the product of digits.)

Let the fixed natural number  $n$  have the form  $n = \overline{a_1 a_2 \dots a_k}$ , where  $a_1, a_2, \dots, a_k \in \{0, 1, \dots, 9\}$  and  $a_1 \geq 1$ . Therefore,

$$n = \sum_{i=1}^k a_i 10^{i-1}.$$



Hence,  $k = \lceil \log_{10} n \rceil + 1$  and

$$\begin{aligned} a_1(n) &\equiv a_1 = \left\lfloor \frac{n}{10^{k-1}} \right\rfloor, \\ a_2(n) &\equiv a_2 = \left\lfloor \frac{n - a_1 10^{k-1}}{10^{k-2}} \right\rfloor, \\ a_3(n) &\equiv a_3 = \left\lfloor \frac{n - a_1 10^{k-1} - a_2 10^{k-2}}{10^{k-3}} \right\rfloor, \\ &\dots \\ a_{\lceil \log_{10}(n) \rceil}(n) &\equiv a_{k-1} = \left\lfloor \frac{n - a_1 10^{k-1} - \dots - a_{k-2} 10^2}{10} \right\rfloor, \\ a_{\lceil \log_{10}(n) \rceil + 1}(n) &\equiv a_k = n - a_1 10^{k-1} - \dots - a_{k-1} 10. \end{aligned}$$

Obviously,  $k, a_1, a_2, \dots, a_k$  are functions only of  $n$ . Therefore,

$$d_p(n) = \prod_{i=1}^{\lceil \log_{10}(n) \rceil + 1} a_i(n).$$

**5.** The results in this section are taken from [4, 27].

The 20-th problem from [10] is the following (see also Problem 25 from [16]):

*Smarandache divisor products:*

$$\begin{aligned} &1, 2, 3, 8, 5, 36, 7, 64, 27, 100, 11, 1728, 13, 196, 225, 1024, 17, 5832, 19, \\ &8000, 441, 484, 23, 331776, 125, 676, 729, 21952, 29, 810000, 31, 32768, \\ &1089, 1156, 1225, 10077696, 37, 1444, 1521, 2560000, 41, \dots \end{aligned}$$

( $P_d(n)$  is the product of all positive divisors of  $n$ .)

The 21-st problem from [10] is the following (see also Problem 26 from [16]):

*Smarandache proper divisor products:*

$$\begin{aligned} &1, 1, 1, 2, 1, 6, 1, 8, 3, 10, 1, 144, 1, 14, 15, 64, 1, 324, 1, 400, 21, 22, 1, \\ &13824, 5, 26, 27, 784, 1, 27000, 1, 1024, 33, 34, 35, 279936, 1, 38, 39, \\ &64000, 1, \dots \end{aligned}$$

( $p_d(n)$  is the product of all positive divisors of  $n$  but  $n$ .)

Let us denote by  $\tau(n)$  the number of all divisors of  $n$ . It is well-known (see, e.g., [13]) that

$$P_d(n) = \sqrt{n^{\tau(n)}} \tag{6.1}$$

and of course, we have

$$p_d(n) = \frac{P_d(n)}{n}. \tag{6.2}$$

But (6.1) is not a good formula for  $P_d(n)$ , because it depends on function  $\tau$  and to express  $\tau(n)$  we need the prime number factorization of  $n$ .

Below, we give other representations of  $P_d(n)$  and  $p_d(n)$ , which do not use the prime number factorization of  $n$ .

**Proposition 6.1.** For  $n \geq 1$  representation

$$P_d(n) = \prod_{k=1}^n k^{\lfloor \frac{n}{k} \rfloor - \lfloor \frac{n-1}{k} \rfloor} \quad (6.3)$$

holds.

Here and further the symbols

$$\prod_{k/n} \cdot \quad \text{and} \quad \sum_{k/n} \cdot$$

mean the product and the sum, respectively, of all divisors of  $n$ .

Let

$$\begin{aligned} \theta(n, k) &\equiv \lfloor \frac{n}{k} \rfloor - \lfloor \frac{n-1}{k} \rfloor \\ &= \begin{cases} 1, & \text{if } k \text{ is a divisor of } n \\ 0, & \text{otherwise} \end{cases} \end{aligned}$$

The following assertion is obtained as a corollary of (6.2) and (6.3).

**Proposition 6.2.** For  $n \geq 1$  representation

$$p_d(n) = \prod_{k=1}^{n-1} k^{\lfloor \frac{n}{k} \rfloor - \lfloor \frac{n-1}{k} \rfloor}$$

holds.

For  $n = 1$  we have

$$p_d(1) = 1.$$

**Proposition 6.3.** For  $n \geq 1$  representation

$$P_d(n) = \prod_{k=1}^n \frac{\lfloor \frac{n}{k} \rfloor!}{\lfloor \frac{n-1}{k} \rfloor!} \quad (6.5)$$

holds, where here and further we assume that  $0! = 1$ .

Now (6.2) and (6.5) yield.

**Proposition 6.4.** For  $n \geq 2$  representation

$$p_d(n) = \prod_{k=2}^n \frac{\lfloor \frac{n}{k} \rfloor!}{\lfloor \frac{n-1}{k} \rfloor!}$$

holds.

Another type of representation of  $p_d(n)$  is the following

**Proposition 6.5.** For  $n \geq 3$  representation

$$p_d(n) = \prod_{k=1}^{n-2} (k!)^{\theta(n,k) - \theta(n,k+1)},$$

where  $\theta(n, k)$  is given by (6.4).

Further, we need the following

**Theorem 6.1.** [22] For  $n \geq 2$  the identity

$$\prod_{k=2}^n \left[\frac{n}{k}\right]! = \prod_{k=1}^{n-1} (k!)^{\left[\frac{n}{k}\right] - \left[\frac{n}{k+1}\right]} \quad (6.6)$$

holds.

Now, we shall deduce some formulae for

$$\prod_{k=1}^n P_d(k) \quad \text{and} \quad \prod_{k=1}^n p_d(k).$$

**Proposition 6.6.** Let  $f$  be an arbitrary arithmetic function. then the identity

$$\prod_{k=1}^n (P_d(k))^{f(k)} = \prod_{k=1}^n k^{\rho(n,k)} \quad (6.7)$$

holds, where

$$\rho(n, k) = \sum_{s=1}^{\left[\frac{n}{k}\right]} f(ks).$$

Now we need the following

**Lemma 6.1.** For  $n \geq 1$  the identity

$$\prod_{k=1}^n \left[\frac{n}{k}\right]! = \prod_{k=1}^n k^{\left[\frac{n}{k}\right]}$$

holds.

**Proposition 6.7.** For  $n \geq 1$  the identity

$$\prod_{k=1}^n P_d(k) = \prod_{k=1}^n \left[\frac{n}{k}\right]! \quad (6.8)$$

holds. As a corollary from (6.2) and (6.8), we also obtain

**Proposition 6.8.** For  $n \geq 2$  the identity

$$\prod_{k=1}^n p_d(k) = \prod_{k=2}^n \left[\frac{n}{k}\right]! \quad (6.9)$$

holds.

From (6.6) and (6.9), we obtain

**Proposition 6.9.** For  $n \geq 2$  the identity

$$\prod_{k=1}^n p_d(k) = \prod_{k=1}^{n-1} (k!)^{\left[\frac{n}{k}\right] - \left[\frac{n}{k+1}\right]} \quad (6.10)$$

holds.

As a corollary from (6.10) we obtain, because of (6.2)

**Proposition 6.10.** For  $n \geq 1$  the identity

$$\prod_{k=1}^n P_d(k) = \prod_{k=1}^n (k!)^{\lfloor \frac{n}{k} \rfloor - \lfloor \frac{n}{k+1} \rfloor} \quad (6.10)$$

holds.

Now, we return to (6.7) and suppose that

$$f(k) > 0 \quad (k = 1, 2, \dots).$$

Then after some simple computations we obtain

**Proposition 6.11.** For  $n \geq 1$  representation

$$P_d(k) = \prod_{k=1}^n k^{\sigma(n,k)} \quad (6.11)$$

holds, where

$$\sigma(n, k) = \frac{\sum_{s=1}^{\lfloor \frac{n}{k} \rfloor} f(ks) - \sum_{s=1}^{\lfloor \frac{n-1}{k} \rfloor} f(ks)}{f(n)}.$$

For  $n \geq 2$  representation

$$p_d(k) = \prod_{k=1}^{n-1} k^{\sigma(n,k)} \quad (6.12)$$

holds.

Note that although  $f$  is an arbitrary arithmetic function, the situation with (6.11) and (6.12) is like the case  $f(x) \equiv 1$ , because

$$\frac{\sum_{s=1}^{\lfloor \frac{n}{k} \rfloor} f(ks) - \sum_{s=1}^{\lfloor \frac{n-1}{k} \rfloor} f(ks)}{f(n)} = \begin{cases} 1, & \text{if } k \text{ is a divisor of } n \\ 0, & \text{otherwise} \end{cases}$$

Finally, we use (6.7) to obtain some new inequalities, involving  $P_d(k)$  and  $p_d(k)$  for  $k = 1, 2, \dots, n$ .

Putting

$$F(n) = \sum_{k=1}^n f(k)$$

we rewrite (6.7) as

$$\prod_{k=1}^n (P_d(k))^{\frac{f(k)}{F(n)}} = \prod_{k=1}^n k^{\frac{\sum_{s=1}^{\lfloor \frac{n}{k} \rfloor} f(ks)}{F(n)}}. \quad (6.13)$$

Then we use the well-known Jensen's inequality

$$\sum_{k=1}^n \alpha_k x_k \geq \prod_{k=1}^n x_k^{\alpha_k},$$

that is valid for arbitrary positive numbers  $x_k$ ,  $\alpha_k$  ( $k = 1, 2, \dots, n$ ) such that

$$\sum_{k=1}^n \alpha_k = 1,$$

for the case:

$$\begin{aligned}x_k &= P_d(k), \\ \alpha_k &= \frac{f(k)}{F(n)}.\end{aligned}$$

Thus we obtain from (6.13) inequality

$$\sum_{k=1}^n f(k) \cdot P_d(k) \geq \left( \sum_{k=1}^n f(k) \right) \cdot \prod_{k=1}^n k^{(\sum_{s=1}^{\lfloor \frac{n}{k} \rfloor} f(ks)) / (\sum_{s=1}^n f(s))}. \quad (6.14)$$

If  $f(x) \equiv 1$ , then (6.14) yields the inequality

$$\frac{1}{n} \sum_{k=1}^n P_d(k) \geq \prod_{k=1}^n (\sqrt[k]{k})^{\lfloor \frac{n}{k} \rfloor}.$$

If we put in (6.14)

$$f(k) = \frac{g(k)}{k}$$

for  $k = 1, 2, \dots, n$ , then we obtain

$$\sum_{k=1}^n g(k) \cdot p_d(k) \geq \left( \sum_{k=1}^n \frac{g(k)}{k} \right) \cdot \prod_{k=1}^n (\sqrt[k]{k})^{(\sum_{s=1}^{\lfloor \frac{n}{k} \rfloor} \frac{g(ks)}{s}) / (\sum_{s=1}^n \frac{g(s)}{s})}. \quad (6.15)$$

because of (6.2).

Let  $g(x) \equiv 1$ . Then (6.15) yields the very interesting inequality

$$\left( \frac{1}{H_n} \sum_{k=1}^n p_d(k) \right)^{H_n} \geq \prod_{k=1}^n (\sqrt[k]{k})^{H_{\lfloor \frac{n}{k} \rfloor}},$$

where  $H_m$  denotes the  $m$ -th partial sum of the harmonic series, i.e.,

$$H_m = \frac{1}{1} + \frac{1}{2} + \dots + \frac{1}{m}.$$

All of the above inequalities become equalities if and only if  $n = 1$ .

## 6. The results in this section are taken from [29].

The 25-th and the 26-th problems from [10] (see also the 30-th and the 31-st problems from [16]) are the following:

*Smarandache's cube free sieve:*

$$\begin{aligned}2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 25, 26, \\ 28, 29, 30, 31, 33, 34, 35, 36, 37, 38, 39, 41, 42, 43, 44, 45, 46, 47, 49, 50, \\ 51, 52, 53, 55, 57, 58, 59, 60, 61, 62, 63, 65, 66, 67, 68, 69, 70, 71, 73, \dots\end{aligned}$$

*Definition: from the set of natural numbers (except 0 and 1):*

- take off all multiples of  $2^3$  (i.e. 8, 16, 24, 32, 40, ...)

- take off all multiples of  $3^3$
- take off all multiples of  $5^3$
- ... and so on (take off all multiples of all cubic primes).

Smarandache's  $m$ -power free sieve:

*Definition:* from the set of natural numbers (except 0 and 1) take off all multiples of  $2^m$ , afterwards all multiples of  $3^m$  ... and so on (take off all multiples of all  $m$ -power primes,  $m \geq 2$ ). (One obtains all  $m$ -power free numbers.)

Here we introduce the solution for both of these problems.

For every natural number  $m$  we denote the increasing sequence  $a_1^{(m)}, a_2^{(m)}, a_3^{(m)}, \dots$  of all  $m$ -power free numbers by  $\overline{m}$ . Then we have

$$\emptyset \equiv \overline{1} \subset \overline{2} \subset \dots \subset \overline{(m-1)} \subset \overline{m} \subset \overline{(m+1)} \subset \dots$$

Also, for  $m \geq 2$  we have

$$\overline{m} = \bigcup_{k=1}^{m-1} (\overline{2})^k$$

where

$$(\overline{2})^k = \{x | (\exists x_1, \dots, x_k \in \overline{2})(x = x_1.x_2 \dots x_k)\}$$

for each natural number  $k \geq 1$ .

Let us consider  $\overline{m}$  as an infinite sequence for  $m = 2, 3, \dots$ . Then  $\overline{2}$  is a subsequence of  $\overline{m}$ . Therefore, the inequality

$$a_n^{(m)} \leq a_n^{(2)}$$

holds for  $n = 1, 2, 3, \dots$ .

Let  $p_1 = 2, p_2 = 3, p_3 = 5, p_4 = 7, \dots$  be the sequence of all primes. It is obvious that this sequence is a subsequence of  $\overline{2}$ . Hence the inequality

$$a_n^{(2)} \leq p_n$$

holds for  $n = 1, 2, 3, \dots$ . But it is well-known that

$$p_n \leq \theta(n) \equiv \left[ \frac{n^2 + 3n + 4}{4} \right]$$

(see [12]). Therefore, for any  $m \geq 2$  and  $n = 1, 2, 3, \dots$  we have

$$a_n^{(m)} \leq a_n^{(2)} \leq \theta(n).$$

Hence, there exists  $\lambda(n)$  such that  $\lambda(n) \leq \theta(n)$  and inequality:

$$a_n^{(m)} \leq a_n^{(2)} \leq \lambda(n).$$

holds. In particular, it is possible to use  $\theta(n)$  instead of  $\lambda(n)$ .

In [28] we find the following explicit formulae for  $a_n^{(m)}$  when  $m \geq 2$  is fixed:

$$a_n^{(m)} = \sum_{k=0}^{\lambda(n)} \left[ \frac{1}{1 + \left[ \frac{\pi_{\overline{m}}(k)}{n} \right]} \right]; \quad (7.1)$$

$$a_n^{(m)} = -2 \sum_{k=0}^{\lambda(n)} \zeta(-2 \lfloor \frac{\pi_{\overline{m}}(k)}{n} \rfloor); \quad (7.2)$$

$$a_n^{(m)} = \sum_{k=0}^{\lambda(n)} \frac{1}{\Gamma(1 - \lfloor \frac{\pi_{\overline{m}}(k)}{n} \rfloor)}. \quad (7.3)$$

Thus, the 26-th Smarandache's problem is solved and for  $m = 3$  the 25-th Smarandache's problem is solved, too.

The following problems are interesting.

**Problem 7.1.** Does there exist a constant  $C > 1$ , such that  $\lambda(n) \leq C.n$ ?

**Problem 7.2.** Is  $C \leq 2$ ?

Below we give the main explicit representation of function  $\pi_{\overline{m}}(n)$ , that takes part in formulae (7.1) - (7.3). In this way we find the main explicit representation for  $a_n^{(m)}$ , that is based on formulae (7.1) - (7.3), too.

**Theorem 7.1.** Function  $\pi_{\overline{m}}(n)$  allows representation

$$\pi_{\overline{m}}(n) = n - 1 + \sum_{s \in \overline{2} \cap \{2, 3, \dots, \lfloor \sqrt[n]{n} \rfloor\}} (-1)^{\omega(s)} \cdot \lfloor \frac{n}{s^m} \rfloor,$$

where  $\omega(s)$  denotes the number of all different prime divisors of  $s$ .

**7.** The results in this section are taken from [24].

The 28-th problem from [10] (see also the 94-th problem from [16]) is the following:

*Smarandache odd sieve:*

$$7, 13, 19, 23, 25, 31, 33, 37, 43, 47, 49, 53, 55, 61, 63, 67, 73, 75, 83, \\ 85, 91, 93, 97, \dots$$

*(All odd numbers that are not equal to the difference of two primes).*

*A sieve is to get this sequence:*

- subtract 2 from all prime numbers and obtain a temporary sequence;
- choose all odd numbers that do not belong to the temporary one.

We find an explicit form of the  $n$ -th term of the above sequence, that will be denoted by  $C = \{C_n\}_{n=1}^{\infty}$  below.

Firstly, we shall note that the above definition of  $C$  can be interpreted to the following equivalent form as follows, having in mind that every odd number is a difference of two prime numbers if and only if it is a difference of a prime number and 2:

*Smarandache's odd sieve contains exactly these odd numbers that cannot be represented as a difference of a prime and 2.*

We rewrite the last definition to the following equivalent form, too:

*Smarandache's odd sieve contains exactly these odd numbers that are represented as a difference of a composite odd number and 2.*

We find an explicit form of the  $n$ -th term of the above sequence, using the third definition of it. Initially, we use the following two assertions.

**Lemma 8.1.** For every natural number  $n \geq 1$ ,  $C_{n+1}$  is exactly one of the numbers:  $u \equiv C_n + 2, v \equiv C_n + 4$  or  $w \equiv C_n + 6$ .

**Corollary 8.1.** For every natural number  $n \geq 1$ :

$$C_{n+1} \leq C_n + 6.$$

**Corollary 8.2.** For every natural number  $n \geq 1$ :

$$C_n \leq 6n + 1. \quad (8.1)$$

Now, we return to the Smarandache's problem.

In [18] the following three universal explicit formulae are introduced, using numbers  $\pi_C(k)$  ( $k = 0, 1, 2, \dots$ ), that can be used to represent numbers  $C_n$ :

$$C_n = \sum_{k=0}^{\infty} \left[ \frac{1}{1 + \left[ \frac{\pi_C(k)}{n} \right]} \right],$$

$$C_n = -2 \sum_{k=0}^{\infty} \zeta \left( -2 \left[ \frac{\pi_C(k)}{n} \right] \right),$$

$$C_n = \sum_{k=0}^{\infty} \frac{1}{\Gamma \left( 1 - \left[ \frac{\pi_C(k)}{n} \right] \right)}.$$

For the present case, having in mind (8.1), we substitute symbol  $\infty$  with  $6n + 1$  in sum  $\sum_{k=0}^{\infty}$  for  $C_n$  and we obtain the following sums:

$$C_n = \sum_{k=0}^{6n+1} \left[ \frac{1}{1 + \left[ \frac{\pi_C(k)}{n} \right]} \right], \quad (8.2)$$

$$C_n = -2 \sum_{k=0}^{6n+1} \zeta \left( -2 \left[ \frac{\pi_C(k)}{n} \right] \right), \quad (8.3)$$

$$C_n = \sum_{k=0}^{6n+1} \frac{1}{\Gamma \left( 1 - \left[ \frac{\pi_C(k)}{n} \right] \right)}. \quad (8.4)$$

We must explain why  $\pi_C(n)$  ( $n = 1, 2, 3, \dots$ ) is represented in an explicit form. It can be directly seen that the number of the odd numbers, that are not bigger than  $n$ , is exactly equal to

$$\alpha(n) = n - \left[ \frac{n}{2} \right], \quad (8.5)$$

because the number of the even numbers that are not greater than  $n$  is exactly equal to  $\left[ \frac{n}{2} \right]$ .

Let us denote by  $\beta(n)$  the number of all odd numbers not bigger than  $n$ , that can be represented as a difference of two primes. According to the second form of the above given definition,  $\beta(n)$  coincides with the number of all odd numbers  $m$  such that  $m \leq n$  and  $m$  has the form  $m = p - 2$ , where  $p$  is an odd prime number. Therefore, we must study all odd prime numbers, because of the inequality  $m \leq n$ . The number of these prime numbers is exactly  $\pi(n + 2) - 1$ . therefore,

$$\beta(n) = \pi(n + 2) - 1. \quad (8.6)$$



Omitting from the number of all odd numbers that are not greater than  $n$  the quantity of those numbers that are a difference of two primes, we find exactly the quantity of these odd numbers that are not greater than  $n$  and that are not a difference of two prime numbers, i.e.,  $\pi_C(n)$ . Therefore, the equality

$$\pi_C(n) = \alpha(n) - \beta(n)$$

holds and from (8.5) and (8.6) we obtain:

$$\pi_C(n) = (n - \lfloor \frac{n}{2} \rfloor) - (\pi(n+2) - 1) = n + 1 - \lfloor \frac{n}{2} \rfloor - \pi(n+2).$$

But  $\pi(n+2)$  can be represented in an explicit form, e.g., by Mináč's formula and therefore, we obtain that the explicit form of  $\pi_C(N)$  is

$$\pi_C(N) = N + 1 - \lfloor \frac{N}{2} \rfloor - \sum_{k=2}^{N+2} \left[ \frac{(k-1)! + 1}{k} - \lfloor \frac{(k-1)!}{k} \rfloor \right], \quad (8.7)$$

where  $N \geq 1$  is a fixed natural number.

It is possible to put  $\lfloor \frac{N+3}{2} \rfloor$  instead of  $N + 1 - \lfloor \frac{N}{2} \rfloor$  into (8.7).

Now, using each of the formulae (8.2) - (8.4), we obtain  $C_n$  in an explicit form, using (8.7).

It can be checked directly that

$$C_1 = 7, C_2 = 13, C_3 = 19, C_4 = 23, C_5 = 25, C_6 = 31,$$

$$C_7 = 33, \dots$$

and

$$\pi_C(0) = \pi_C(1) = \pi_C(2) = \pi_C(3) = \pi_C(4) = \pi_C(5) = \pi_C(6) = 0.$$

Therefore from (8.2) - (8.4) we have the following explicit formulae for  $C_n$

$$\begin{aligned} C_n &= 7 + \sum_{k=7}^{6n+1} \left[ \frac{1}{1 + \lfloor \frac{\pi_C(k)}{n} \rfloor} \right], \\ C_n &= 7 + -2 \sum_{k=7}^{6n+1} \zeta(-2, \lfloor \frac{\pi_C(k)}{n} \rfloor), \\ C_n &= 7 + \sum_{k=7}^{6n+1} \frac{1}{\Gamma(1 - \lfloor \frac{\pi_C(k)}{n} \rfloor)}, \end{aligned}$$

where  $\pi_C(k)$  is given by (8.7).

**8.** The results in this section are taken from [7, 26].

The 46-th Smarandache's problem from [10] is the following:

*Smarandache's prime additive complements;*

$$1, 0, 0, 1, 0, 1, 0, 3, 2, 1, 0, 1, 0, 3, 2, 1, 0, 1, 0, 3, 2, 1, 0, 1, 0, 3, 2, 1, 0, 1, 0, 5, 4, 3, 2, 1,$$

$$0, 1, 0, 5, 4, 3, 2, 1, 0, 3, 2, 1, 0, 5, 4, 3, 2, 1, 0 \dots$$

(For each  $n$  to find the smallest  $k$  such that  $n + k$  is prime.)

*Remarks:* Smarandache asked if it is possible to get as large as we want but finite decreasing  $k, k - 1, k - 2, \dots, 2, 1, 0$  (odd  $k$ ) sequence included in the previous sequence - i.e., for any even integer are there two primes whose difference is equal to it? He conjectured the answer is negative.

Obviously, the members of the above sequence are differences between first prime number that is greater or equal to the current natural number  $n$  and the same  $n$ . It is well-known that the number of primes smaller than or equal to  $n$  is  $\pi(n)$ . Therefore, the prime number smaller than or equal to  $n$  is  $p_{\pi(n)}$ . Hence, the prime number that is greater than or equal to  $n$  is the next prime number, i.e.,  $p_{\pi(n)+1}$ . Finally, the  $n$ -th member of the above sequence will be equal to

$$\begin{cases} p_{\pi(n)+1} - n, & \text{if } n \text{ is not a prime number} \\ 0, & \text{otherwise} \end{cases}$$

We shall note that in [3] the following new formula  $p_n$  for every natural number  $n$  is given:

$$p_n = \sum_{i=0}^{\theta(n)} sg(n - \pi(i)),$$

where  $\theta(n) = \lfloor \frac{n^2+3n+4}{4} \rfloor$  and

$$sg(x) = \begin{cases} 0, & \text{if } x \leq 0, \\ 1, & \text{if } x > 0. \end{cases}$$

Let us denote by  $a_n$  the  $n$ -th term of the above sequence. Next, we propose a way for obtaining an explicit formula for  $a_n$  ( $n = 1, 2, 3, \dots$ ). Extending the below results, we give an answer to the Smarandache's question from his own remark in [10]. At the end, we propose a generalization of Problem 46 and present a proof of an assertion related to Smarandache's conjecture for Problem 46.

**Proposition 9.1.**  $a_n$  admits the representation

$$a_n = p_{\pi(n-1)+1} - n, \tag{9.1}$$

where  $n = 1, 2, 3, \dots$ ,  $\pi$  is the prime counting function and  $p_k$  is the  $k$ -th term of prime number sequence.

It is clear that (9.1) gives an explicit representation for  $a_n$  since several explicit formulae for  $\pi(k)$  and  $p_k$  are known (see, e.g. [14]).

Let us define

$$n(m) = m! + 2.$$

Then all numbers

$$n(m), n(m) + 1, n(m) + 2, \dots, n(m) + m - 2$$

are composite. Hence

$$a_{n(m)} \geq m - 1.$$

This proves the Smarandache's conjecture, since  $m$  may grow up to infinity. Therefore  $\{a_n\}_{n=1}^{\infty}$  is unbounded sequence.

Now, we shall generalize Problem 46.

Let

$$\mathbf{c} \equiv c_1, c_2, c_3, \dots$$

be a strictly increasing sequence of positive integers.

**Definition.** Sequence

$$\mathbf{b} \equiv b_1, b_2, b_3, \dots$$

is called  $c$ -additive complement of  $\mathbf{c}$  if and only if  $b_n$  is the smallest non-negative integer, such that  $n + b_n$  is a term of  $\mathbf{c}$ .

The following assertion generalizes Proposition 1.

**Proposition 9.2.**  $b_n$  admits the representation

$$b_n = c_{\pi_c(n-1)+1} - n,$$

where  $n = 1, 2, 3, \dots$ ,  $\pi_c(n)$  is the counting function of  $\mathbf{c}$ , i.e.,  $\pi_c(n)$  equals to the quantity of  $c_m$ ,  $m = 1, 2, 3, \dots$ , such that  $c_m \leq n$ .

Let

$$d_n \equiv c_{n+1} - c_n \quad (n = 1, 2, 3, \dots).$$

The following assertion is related to the Smarandache's conjecture from Problem 46.

**Proposition 9.3.** If  $\{d_n\}_{n=1}^{\infty}$  is unbounded sequence, then  $\{b_n\}_{n=1}^{\infty}$  is unbounded sequence, too.

**Open Problem.** Formulate necessary conditions for the sequence  $\{b_n\}_{n=1}^{\infty}$  to be unbounded.

**9.** The results in this section are taken from [23].

Solving of the Diophantine equation

$$2x^2 - 3y^2 = 5 \tag{10.1}$$

i.e.,

$$2x^2 - 3y^2 - 5 = 0$$

was put as an open Problem 78 by F. Smarandache in [16]. In [28] this problem is solved completely. Also, we consider here the Diophantine equation

$$l^2 - 6m^2 = -5,$$

i.e.,

$$l^2 - 6m^2 + 5 = 0$$

and the Pellian equation

$$u^2 - 6v^2 = 1,$$

i.e.,

$$u^2 - 6v^2 - 1 = 0.$$

In [28] we introduce a generalization of the Smarandache's problem 78 from [16].

If we consider the Diophantine equation

$$2x^2 - 3y^2 = p, \quad (10.2)$$

where  $p \neq 2$  is a prime number, then using [13], Chapter VII, exercise 2 and the same method as in the case of (10.1), we obtain the following result.

**Theorem 10.1.** (1) The necessary and sufficient condition for solvability of (10.2) is:

$$p \equiv 5 \pmod{24} \text{ or } p \equiv 23 \pmod{24} \quad (10.3)$$

(2) if (10.3) is valid, then there exist exactly one solution  $\langle x, y \rangle \in \mathcal{N}^2$  of (10.2) such that the inequalities

$$x < \sqrt{\frac{3}{2} \cdot p}$$

and

$$y < \sqrt{\frac{3}{2} \cdot p}$$

holds. Every other solution  $\langle x, y \rangle \in \mathcal{N}^2$  of (10.2) has the form:

$$x = l + 3m$$

$$y = l + 2m,$$

where  $\langle l, m \rangle \in \mathcal{N}^2$  is a solution of the Diophantine equation

$$l^2 - 6m^2 = -p.$$

The problem how to solve the Diophantine equation, a special case of which is the above one, is considered in Theorem 110 from [13].

**10.** The results in this section are taken from [9]. In [15, 17] F. Smarandache formulates the following four problems:

**Problem 1.** *Let  $p$  be an integer  $\geq 3$ . Then:*

*$p$  is a prime if and only if*

$$(p-3)! \text{ is congruent to } \frac{p-1}{2} \pmod{p}.$$

**Problem 2.** *Let  $p$  be an integer  $\geq 4$ . Then:*

*$p$  is a prime if and only if*

$$(p-4)! \text{ is congruent to } (-1)^{\lceil \frac{p}{3} \rceil + 1} \lceil \frac{p+1}{6} \rceil \pmod{p}. \quad (11.1)$$

**Problem 3.** *Let  $p$  be an integer  $\geq 5$ . Then:*

*$p$  is a prime if and only if*

$$(p-5)! \text{ is congruent to } rh + \frac{r^2-1}{24} \pmod{p}, \quad (11.2)$$

with  $h = \lceil \frac{p}{24} \rceil$  and  $r = p - 24$ .

**Problem 4.** Let  $p = (k-1)!h + 1$  be a positive integer  $k > 5$ ,  $h$  natural number. Then:

*p is a prime if and only if*

$$(p-k)! \text{ is congruent to } (-1)^t h \pmod{p}. \quad (11.3)$$

with  $t = h + \lceil \frac{p}{h} \rceil + 1$ .

Everywhere above  $\lceil x \rceil$  means the inferior integer part of  $x$ , i.e., the smallest integer greater than or equal to  $x$ .

In [28] we discussed these four problems.

**Problem 1.** Admits the following representation:

Let  $p \geq 3$  be an odd number. Then:

$$p \text{ is a prime if and only if } (p-3)! \equiv \frac{p-1}{2} \pmod{p}.$$

Different than Smarandache's proof of this assertion is given in [28].

**Problem 2.** Is false, because, for example, if  $p = 7$ , then (11.1) obtains the form

$$6 \equiv (-1)^4 2 \pmod{7},$$

where

$$6 = (7-4)!$$

and

$$(-1)^4 2 = (-1)^{\lceil \frac{7}{3} \rceil + 1} \lceil \frac{8}{6} \rceil,$$

i.e.,

$$6 \equiv 2 \pmod{7},$$

which is impossible.

**Problem 3.** Can be modified, having in mind that from  $r = p - 24h$  it follows:

$$\begin{aligned} rh + \frac{r^2-1}{24} &= (p-24h).h + \frac{p^2 - 48ph + 24^2h^2 - 1}{24} \\ &= ph - 24h^2 + \frac{p^2-1}{24} - 2ph + 24h^2 = \frac{p^2-1}{24} - ph, \end{aligned}$$

i.e., (11.2) has the form

*p is a prime if and only if*

$$(p-5)! \text{ is congruent to } \frac{p^2-1}{24} \pmod{p},$$

Different than the Smarandache's proof of this assertion is given in [28].

**Problem 4.** Also can be simplified, because

$$\begin{aligned} t &= h + \left\lceil \frac{p}{h} \right\rceil + 1 \\ &= h + \left\lceil \frac{(k-1)!h + 1}{h} \right\rceil + 1 \\ &= h + (k-1)! + 1 + 1 = h + (k-1)! + 2, \end{aligned}$$

i.e.,

$$(-1)^t = (-1)^h,$$

because for  $k > 2$ :  $(k-1)! + 2$  is an even number. Therefore, (11.3) obtains the form

*p is a prime if and only if*

$$(p-k)! \text{ is congruent to } (-1)^h h \pmod{p},$$

Let us assume that (11.4) is valid. We use again the congruences

$$(p-1) \equiv -1 \pmod{p}$$

$$(p-2) \equiv -2 \pmod{p}$$

...

$$(p-(k-1)) \equiv -(k-1) \pmod{p}$$

and obtain the next form of (11.4)

*p is a prime if and only if*

$$(p-1)! \equiv (-1)^h \cdot (-1)^{k-1} \cdot (k-1)! \cdot h \pmod{p}$$

or

*p is a prime if and only if*

$$(p-1)! \equiv (-1)^{h+k-1} \cdot (p-1) \pmod{p}.$$

But the last congruence is not valid, because, e.g., for  $k=5, h=3, p=73=(5-1)!+1^1$  holds

$$72! \equiv (-1)^9 \cdot 72 \pmod{73},^2$$

i.e.,

$$72! \equiv 1 \pmod{73},$$

<sup>1</sup>In [28] there is a misprint: 3! instead of 3.

<sup>2</sup>In [28] there is a misprint:  $(-1)^9$  instead of  $(-1)^7$ .

while from Wilson's Theorem follows that

$$72! \equiv -1 \pmod{73}.$$

**11.** The results in this section are taken from [5].

In [17] F. Smarandache discussed the following particular cases of the well-known characteristic functions (see, e.g., [11, 30]).

**12.1)** Prime function:  $P : N \rightarrow \{0, 1\}$ , with

$$P(n) = \begin{cases} 0, & \text{if } n \text{ is a prime} \\ 1, & \text{otherwise} \end{cases}$$

More generally:  $P_k : N^k \rightarrow \{0, 1\}$ , where  $k \geq 2$  is an integer, and

$$P_k(n_1, n_2, \dots, n_k) = \begin{cases} 0, & \text{if } n_1, n_2, \dots, n_k \text{ are all prime numbers} \\ 1, & \text{otherwise} \end{cases}$$

**12.2)** Coprime function is defined similarly:  $C_k : N^k \rightarrow \{0, 1\}$ , where  $k \geq 2$  is an integer, and

$$C_k(n_1, n_2, \dots, n_k) = \begin{cases} 0, & \text{if } n_1, n_2, \dots, n_k \text{ are coprime numbers} \\ 1, & \text{otherwise} \end{cases}$$

In [28] we formulate and prove four assertions related to these functions.

**Proposition 12.1.** For each  $k, n_1, n_2, \dots, n_k$  natural numbers:

$$P_k(n_1, n_2, \dots, n_k) = 1 - \prod_{i=1}^k (1 - P(n_i)).$$

**Proposition 12.2.** For each  $k, n_1, n_2, \dots, n_k$  natural numbers:

$$C_k(n_1, n_2, \dots, n_k) = 1 - \prod_{i=1}^k \prod_{j=i+1}^k (1 - C_2(n_i, n_j)).$$

**Proposition 12.3.** For each natural number  $n$ :

$$C_{\pi(n)+P(n)}(p_1, p_2, \dots, p_{\pi(n)+P(n)-1}, n) = P(n).$$

**Proposition 12.4.** For each natural number  $n$ :

$$P(n) = 1 - \prod_{i=1}^{\pi(n)+P(n)-1} (1 - C_2(p_i, n)).$$

**Corollary 12.1.** For each natural number  $k, n_1, n_2, \dots, n_k$ :

$$P_k(n_1, n_2, \dots, n_k) = 1 - \prod_{i=1}^k \prod_{j=1}^{\pi(n_i)+P(n_i)-1} (1 - C_2(p_j, n_i)).$$

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# Smarandache groupoids

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**Abstract**

In this paper, we study the concept of Smarandache groupoids, subgroupoids, ideal of groupoids, semi-normal subgroupoids, Smarandache-Bol groupoids and Strong Bol groupoids and obtain many interesting results about them.

**Keywords** Smarandache groupoid; Smarandache subgroupoid; Smarandache ideal of a Smarandache groupoid; Smarandache semi-normal groupoid; Smarandache normal groupoid; Smarandache semi conjugate subgroupoid; Smarandache Bol groupoid; Smarandache Moufang groupoid.

**Definition [1]:** A groupoid  $(G, *)$  is a non-empty set, closed with respect to an operation  $*$  (in general  $*$  need not to be associative).

**Definition 1:** A *Smarandache groupoid*  $G$  is a groupoid which has a proper subset  $S \subset G$  which is a semigroup under the operation of  $G$ .

Example 1: Let  $(G, *)$  be a groupoid on modulo 6 integers.  $G = \{0, 1, 2, 3, 4, 5\}$  is given by the following table:

*	0	1	2	3	4	5
0	0	3	0	3	0	3
1	1	4	1	4	1	4
2	2	5	2	5	2	5
3	3	0	3	0	3	0
4	4	1	4	1	4	1
5	5	2	5	2	5	2

Clearly  $S_1 = \{0, 3\}$ ,  $S_2 = \{1, 4\}$  and  $S_3 = \{2, 5\}$  are semigroups of  $G$ . So  $(G, *)$  is a Smarandache groupoid.

Example 2: Let  $G = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$  be the set of integers modulo 10. Define an operation  $*$  on  $G$  by choosing a pair  $(1, 5)$  such that  $a * b = 1a + 5b \pmod{10}$  for all  $a, b \in G$ .

The groupoid is given by the following table.

*	0	1	2	3	4	5	6	7	8	9
0	0	5	0	5	0	5	0	5	0	5
1	1	6	1	6	1	6	1	6	1	6
2	2	7	2	7	2	7	2	7	2	7
3	3	8	3	8	3	8	3	8	3	8
4	4	9	4	9	4	9	4	9	4	9
5	5	0	5	0	5	0	5	0	5	0
6	6	1	6	1	6	1	6	1	6	1
7	7	2	7	2	7	2	7	2	7	2
8	8	3	8	3	8	3	8	3	8	3
9	9	4	9	4	9	4	9	4	9	4

Clearly  $S_1 = \{0, 5\}$ ,  $S_2 = \{1, 6\}$ ,  $S_3 = \{2, 7\}$ ,  $S_4 = \{3, 8\}$  and  $S_5 = \{4, 9\}$  are semigroupoids under the operation  $*$ . Thus  $\{G, *, (1, 5)\}$  is a Smarandache groupoid.

**Theorem 2.** Let  $Z_{2p} = \{0, 1, 2, \dots, 2p-1\}$ . Define  $*$  on  $Z_{2p}$  for  $a, b \in Z_{2p}$  by  $a*b = 1a+pb \pmod{2p}$ .  $\{Z_{2p}, *, (1, p)\}$  is a Smarandache groupoid.

**Proof.** Under the operation  $*$  defined on  $Z_{2p}$  we see  $S_1 = \{0, p\}$ ,  $S_2 = \{1, p+1\}$ ,  $S_3 = \{2, p+2\}, \dots, S_p = \{p-1, 2p-1\}$  are semigroup under the operation  $*$ . Hence  $\{Z_{2p}, *, (1, p)\}$  is a Smarandache groupoid.

Example 3: Take  $Z_6 = \{0, 1, 2, 3, 4, 5\}$ .  $(2, 5) = (m, n)$ . For  $a, b \in Z_6$  define  $a * b = ma + nb \pmod{6}$ . The groupoid is given by the following table:

*	0	1	2	3	4	5
0	0	5	4	3	2	1
1	2	1	0	5	4	3
2	4	3	2	1	0	5
3	0	5	4	3	2	1
4	2	1	0	5	4	3
5	4	3	2	1	0	5

Every singleton is an idempotent semigroup of  $Z_6$ .

**Theorem 3.** Let  $Z_{2p} = \{0, 1, 2, \dots, p-1\}$ . Define  $*$  on  $Z_{2p}$  by  $a*b = 2a + (2p-1)b \pmod{2p}$  for  $a, b \in Z_{2p}$ . Then  $\{Z_{2p}, *, (2, 2p-1)\}$  is a Smarandache groupoid.

**Proof.** Under the operation  $*$  defined on  $Z_{2p}$  we see that every element of  $Z_{2p}$  is idempotent, therefore every element forms a singleton semigroup. Hence the claim.

Example 4: Consider  $Z_6 = \{Z_6, *, (4, 5)\}$  given by the following table:

*	0	1	2	3	4	5
0	0	5	4	3	2	1
1	4	3	2	1	0	5
2	2	1	0	5	4	3
3	0	5	4	3	2	1
4	4	3	2	1	0	5
5	2	1	0	5	4	3

$\{3\}$  is a semigroup. Hence  $*$  is a Smarandache groupoid. It is easily verified that  $Z_6$  is a Smarandache groupoid as  $\{Z_6, *, (4, 5)\}$  has an idempotent semigroup  $\{3\}$  under  $*$ .

**Theorem 4.** Let  $Z_{2p} = \{0, 1, 2, \dots, 2p-1\}$  be the set of integers modulo  $2p$ . Define  $*$  on  $a, b \in Z_{2p}$  by  $a(2p-2) + b(2p-1) \pmod{2p}$ . Then  $\{Z_{2p}, *, (2p-2, 2p-1)\}$  is a Smarandache groupoid.

**Proof.**  $Z_{2p} = \{0, 1, 2, \dots, 2p-1\}$ . Take  $(2p-2, 2p-1) = 1$  from  $Z_{2p}$ . For  $a, b \in Z_p$  define  $a*b = a(2p-2) + b(2p-1) \pmod{2p}$ . Clearly for  $a = b = p$  we have  $(2p-2)p + (2p-1)p = p \pmod{2p}$ . Hence  $\{p\}$  is an idempotent semigroup of  $Z_{2p}$ . So  $\{Z_{2p}, *, (2p-2, 2p-1)\}$  is a Smarandache groupoid.

**Definition 5:** Let  $(G, *)$  be a Smarandache groupoid. A non-empty subset  $H$  of  $G$  is said to be a Smarandache groupoid if  $H$  contains a proper subset  $K \subset H$  such that  $K$  is a semigroup under the operation  $*$ .

**Theorem 6.** Not every subgroupoid of a Smarandache groupoid  $S$  is in general a Smarandache subgroupoid of  $S$ .

**Proof.** By an example.

Let  $Z_6 = \{0, 1, 2, 3, 4, 5\} \pmod{6}$ . Take  $(t, u) = (4, 5) = 1$ . For  $a, b \in Z_6$  define  $*$  on  $Z_6$  by  $a*b = at + bu \pmod{6}$  given by the following table:

*	0	1	2	3	4	5
0	0	5	4	3	2	1
1	4	3	2	1	0	5
2	2	1	0	5	4	3
3	0	5	4	3	2	1
4	4	3	2	1	0	5
5	2	1	0	5	4	3

Clearly  $\{Z_6, *, (4, 5)\}$  is a Smarandache groupoid for it contains  $\{0, 3\}$  as a semigroup. But this groupoid has the following subgroupoids:  $A_1 = \{0, 2, 4\}$  and  $A_2 = \{1, 3, 5\}$ .  $A_1$  has no non-trivial semigroup ( $\{0\}$  is a trivial semigroup). But  $A_2$  has a non-trivial semigroup, viz.  $\{3\}$ . Hence the claim.

**Theorem 7.** If a groupoid contains a Smarandache subgroupoid, then the groupoid is a Smarandache groupoid.

**Proof.** Let  $G$  be a groupoid and  $H \subset G$  be a Smarandache subgroupoid, that is  $H$  contains a proper subset  $P \subset H$  such that  $P$  is a semigroup. So  $P \subset G$  and  $P$  is a semigroup. Hence  $G$  is a Smarandache groupoid.

**Definition 8:**

i) A Smarandache Left Ideal  $A$  of the Smarandache Groupoid  $G$  satisfies the following conditions:

1.  $A$  is a Smarandache subgroupoid. 2. For all  $x \in G$ , and  $x \in A$ ,  $xa \in A$ .

ii) Similarly, one defines a Smarandache Right Ideal.

iii) If  $A$  is both a Smarandache right and left ideals then  $A$  is a Smarandache Ideal. We take  $\{0\}$  as a trivial Smarandache ideal.

Example 5: Let  $\{Z_6, *, (4, 5)\}$  be a Smarandache groupoid.  $A = \{1, 3, 5\}$  is a Smarandache subgroupoid and  $A$  is Smarandache left ideal and not a Smarandache right ideal. Easy to verify.

**Theorem 9.** Let  $G$  be a groupoid. An ideal of  $G$  in general is not a Smarandache ideal of  $G$  even if  $G$  is a Smarandache groupoid.

**Proof.** By an example. Consider the groupoid  $G = \{Z_6, *, (2, 4)\}$  given by the following table.

*	0	1	2	3	4	5
0	0	4	2	0	4	2
1	2	0	4	2	0	4
2	4	2	0	4	2	0
3	0	4	2	0	4	2
4	2	0	4	2	0	4
5	4	2	0	4	2	0

Clearly  $G$  is a Smarandache groupoid for  $\{0, 3\}$  is a semigroup of  $G$ . Now,  $\{0, 4, 2\}$  is an ideal of  $G$  but is not a Smarandache ideal as  $\{0, 4, 2\}$  is not a Smarandache subgroupoid.

**Definition 10:** Let  $G$  be a Smarandache groupoid and  $V$  be a Smarandache subgroupoid of  $G$ . We say  $V$  is a Smarandache semi-normal subgroupoid if:

1.  $aV = X$  for all  $a \in G$ ; 2.  $Va = Y$  for all  $a \in G$ , where either  $X$  or  $Y$  is a Smarandache subgroupoid of  $G$  but  $X$  and  $Y$  are both subgroupoids.

Example 6: Consider the groupoid  $G = \{Z_6, *, (4, 5)\}$  given by the table.

*	0	1	2	3	4	5
0	0	5	4	3	2	1
1	4	3	2	1	0	5
2	2	1	0	5	4	3
3	0	5	4	3	2	1
4	4	3	2	1	0	5
5	2	1	0	5	4	3

Clearly  $G$  is a Smarandache groupoid as  $\{3\}$  is a semigroup. Take  $A = \{1, 3, 5\}$ .  $A$  is also a Smarandache subgroupoid. Now  $aA = A$  is a Smarandache groupoid.  $Aa = \{0, 2, 4\}$ .  $\{0, 2, 4\}$  is not a Smarandache subgroupoid of  $G$ . Hence  $A$  is a Smarandache semi-normal subgroupoid.

**Definition 11:** Let  $A$  be a Smarandache groupoid and  $V$  be a Smarandache subgroupoid.  $V$  is said to be *Smarandache normal subgroupoid* if  $aV = X$  and  $Va = Y$  where both  $X$  and  $Y$  are Smarandache subgroupoids of  $G$ .

**Theorem 12.** Every Smarandache normal subgroupoid is a Smarandache semi-normal subgroupoid, and not conversely.

**Proof.** By the definition 10 and 11, we see every Smarandache normal subgroupoid is Smarandache semi-normal subgroupoid. We prove the converse by an example. In example 6 we see  $A$  is a Smarandache semi-normal subgroupoid but not a normal subgroupoid as  $Aa = \{0, 2, 4\}$  is only a subgroupoid and not a Smarandache subgroupoid.

Example 7: Let  $G = \{Z_8, *, (2, 6)\}$  be a groupoid given by the following table:

*	0	1	2	3	4	5	6	7
0	0	6	4	2	0	6	4	2
1	2	0	6	4	2	0	6	4
2	4	2	0	6	4	2	0	6
3	6	4	2	0	6	4	2	0
4	0	6	4	2	0	6	4	2
5	2	0	6	4	2	0	6	4
6	4	2	0	6	4	2	0	6
7	6	4	2	0	6	4	2	0

Clearly  $G$  is a Smarandache groupoid for  $\{0, 4\}$  is a semigroupoid  $G$ .  $A = \{0, 2, 4, 6\}$  is a Smarandache subgroupoid. Clearly  $Aa = A$  for all  $a \in G$ . So  $A$  is a Smarandache normal subgroupoid of  $G$ .

**Definition 13:** Let  $G$  be a Smarandache groupoid  $H$  and  $P$  be subgroupoids of  $G$ , we say  $H$  and  $P$  are Smarandache semi-conjugate subgroupoids of  $G$  if:

1.  $H$  and  $P$  are Smarandache subgroupoids.
2.  $H = xP$  or  $Px$ , for some  $x \in G$ .
3.  $P = xH$  or  $Hx$ , for some  $x \in G$ .

Example 8: Consider the groupoid  $G = \{Z_{12}, *, (1, 3)\}$  which is given by the following table:

*	0	1	2	3	4	5	6	7	8	9	10	11
0	0	3	6	9	0	3	6	9	0	3	6	9
1	1	4	7	10	1	4	7	10	1	4	7	10
2	2	5	8	11	2	5	8	11	2	5	8	11
3	3	6	9	0	3	6	9	0	3	6	9	0
4	4	7	10	1	4	7	10	1	4	7	10	1
5	5	8	11	2	5	8	11	2	5	8	11	2
6	6	9	0	3	6	9	0	3	6	9	0	3
7	7	10	1	4	7	10	1	4	7	10	1	4
8	8	11	2	5	8	11	2	5	8	11	2	5
9	9	0	3	6	9	0	3	6	9	0	3	6
10	10	1	4	7	10	1	4	7	10	1	4	7
11	11	2	5	8	11	2	5	8	11	2	5	8

Clearly  $G$  is a Smarandache groupoid for  $\{0, 6\}$  is a semigroup of  $G$ . Let  $A_1 = \{0, 3, 6, 9\}$  and  $A_2 = \{2, 5, 8, 11\}$  be two subgroupoids. Clearly  $A_1$  and  $A_2$  are Smarandache subgroups of  $G$  as  $\{0, 6\}$  and  $\{2, 8\}$  are semigroups of  $A_1$  and  $A_2$  respectively.

Now:

$$\begin{aligned} A_1 &= 3\{2, 5, 8, 11\} = 3A_2 \\ &= \{0, 3, 6, 9\} \end{aligned}$$

and similarly:

$$A_2 = 2\{0, 3, 6, 9\} = 2A_1.$$

Hence  $A_1$  and  $A_2$  are conjugate Smarandache subgroupoids of  $G$ .

**Definition 15:** Let  $G_1, G_2, G_3, \dots, G_n$  be  $n$  groupoids. We say  $G = G_1 \times G_2 \times \dots \times G_n$  is a *Smarandache direct product of groupoids* if  $G$  has a proper subset  $H$  of  $G$  which is a semigroup under the operations of  $G$ . It is important to note that each  $G_i$  need not be a Smarandache groupoid for in that case  $G$  will be obviously a Smarandache groupoid. Hence we take any set of  $n$  groupoids and find the direct product.

**Definition 16:** Let  $(G, *)$  and  $(G', \circ)$  be any two Smarandache groupoids. A map  $\phi$  from  $(G, *)$  to  $(G', \circ)$  is said to be a *Smarandache groupoid homomorphism* if  $\phi(a * b) = \phi(a) \circ \phi(b)$  for all  $a, b \in A$ .

We say the *Smarandache groupoid homomorphism* is an *isomorphism* if  $\phi$  is an isomorphism.

**Definition 17:** Let  $G$  be a Smarandache groupoid. We say  $G$  is a *Smarandache commutative groupoid* if there is a proper subset  $A$  of  $G$  which is a commutative semigroup under the operation of  $G$ .

**Definition 18:** Let  $G$  be Smarandache groupoid. We say  $G$  is *Smarandache inner commutative groupoid* if every semigroup contained in every Smarandache subgroupoid of  $G$  is commutative.

**Theorem 19.** Every Smarandache inner commutative groupoid  $G$  is a Smarandache commutative groupoid and not conversely.

**Proof.** By the very definition 18 and 19 we see if  $G$  is a Smarandache inner commutative groupoid then  $G$  is Smarandache commutative groupoid.

To prove the converse we prove it by an example. Let  $Z_2 = \{0, 1\}$  be integers modulo 2. Consider set of all  $2 \times 2$  matrices with entries from  $Z_2 = (0, 1)$  denote it by  $M_{2 \times 2}$ .

$$M_{2 \times 2} = \left\{ \begin{array}{l} \left( \begin{array}{cc} 0 & 0 \\ 0 & 0 \end{array} \right), \left( \begin{array}{cc} 0 & 1 \\ 0 & 0 \end{array} \right), \left( \begin{array}{cc} 1 & 0 \\ 0 & 0 \end{array} \right), \left( \begin{array}{cc} 0 & 0 \\ 1 & 0 \end{array} \right) \\ \left( \begin{array}{cc} 0 & 1 \\ 0 & 1 \end{array} \right), \left( \begin{array}{cc} 1 & 0 \\ 0 & 1 \end{array} \right), \left( \begin{array}{cc} 0 & 1 \\ 1 & 0 \end{array} \right), \left( \begin{array}{cc} 1 & 1 \\ 0 & 1 \end{array} \right) \\ \left( \begin{array}{cc} 0 & 0 \\ 0 & 1 \end{array} \right), \left( \begin{array}{cc} 1 & 1 \\ 0 & 0 \end{array} \right), \left( \begin{array}{cc} 0 & 0 \\ 1 & 1 \end{array} \right), \left( \begin{array}{cc} 1 & 0 \\ 1 & 0 \end{array} \right) \\ \left( \begin{array}{cc} 1 & 0 \\ 1 & 1 \end{array} \right), \left( \begin{array}{cc} 1 & 1 \\ 1 & 0 \end{array} \right), \left( \begin{array}{cc} 0 & 1 \\ 1 & 1 \end{array} \right), \left( \begin{array}{cc} 1 & 1 \\ 1 & 1 \end{array} \right) \end{array} \right\}.$$

$M_{2 \times 2}$  is made into a groupoid by for  $A = \begin{pmatrix} a_1 & a_2 \\ a_3 & a_4 \end{pmatrix}$  and  $B = \begin{pmatrix} b_1 & b_2 \\ b_3 & b_4 \end{pmatrix}$  in  $M_{2 \times 2}$ .

$$\begin{aligned} A \circ B &= \begin{pmatrix} a_1 & a_2 \\ a_3 & a_4 \end{pmatrix} \circ \begin{pmatrix} b_1 & b_2 \\ b_3 & b_4 \end{pmatrix} \\ &= \begin{pmatrix} a_1 b_3 + a_2 b_1(\text{mod}2) & a_1 b_4 + a_2 b_2(\text{mod}2) \\ a_3 b_3 + a_4 b_1(\text{mod}2) & a_3 b_4 + a_4 b_2(\text{mod}2) \end{pmatrix} \end{aligned}$$

Clearly  $(M_{2 \times 2}, \circ)$  is a Smarandache groupoid for  $\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \circ \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$ .

So  $\left\{ \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \circ \right\}$  is a semigroup.

Now consider  $A_1 = \left\{ \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}, \begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix}, \circ \right\}$  is a Smarandache groupoid but  $A_1$  is non-commutative Smarandache groupoid for  $A_1$  contains a non-commutative semigroupoid  $S$ .  $S = \left\{ \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}, \begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix}, \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}, \circ \right\}$  such that  $\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \circ$



$\begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$  and  $\begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix} \circ \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$ . So  $(M_{2 \times 2}, \circ)$  is a Smarandache commutative groupoid but not Smarandache inner commutative groupoid.

**Definition 20:** A groupoid  $G$  is said to be a *Moufang groupoid* if for every  $x, y, z$  in  $G$  we have  $(xy)(zx) = (x(yz))x$ .

**Definition 21:** A Smarandache groupoid  $(G, *)$  is said to be *Smarandache Moufang groupoid* if there exists  $H \subset G$  such that  $H$  is a Smarandache groupoid satisfying the Moufang identity:  $(xy)(zx) = (x(yz))x$  for all  $x, y, z$  in  $H$ .

**Definition 22:** Let  $S$  be a Smarandache groupoid. If every Smarandache subgroupoid  $H$  of  $S$  satisfies the Moufang identity for all  $x, y, z$  in  $H$  then  $S$  is a *Smarandache Strong Moufang groupoid*.

**Theorem 23.** Every Smarandache Strong Moufang groupoid is a Smarandache Moufang groupoid and not conversely.

**Proof.** Every Strong Smarandache Moufang groupoid is a Smarandache Moufang groupoid. The proof of the converse can be proved by constructing examples.

**Definition 24:** A groupoid  $G$  is said to be a *Bol groupoid* if  $((xy)z)y = x((yz))y$  for all  $x, y, z \in G$ .

**Definition 25:** Let  $G$  be a groupoid.  $G$  is said to be *Smarandache – Bol groupoid* if  $G$  has a subgroupoid  $H$  of  $G$  such that  $H$  is a Smarandache subgroupoid and satisfies the identity  $((xy)z)y = x((yz))y$  for all  $x, y, z$  in  $H$ .

**Definition 26:** Let  $G$  be a groupoid. We say  $G$  is *Smarandache Strong Bol groupoid* if every Smarandache subgroupoid of  $G$  is a Bol groupoid.

**Theorem 27.** Every Smarandache Strong Bol groupoid is a Smarandache Bol groupoid and the converse is not true.

**Proof.** Obvious.

**Theorem 28.** Let  $Z_n = \{0, 1, 2, \dots, n-1\}$  be the set of integers modulo  $n$ . Let  $G = \{Z_n, *, (t, u)\}$  be a Smarandache groupoid.  $G$  is a Smarandache Bol groupoid if  $t^3 = t \pmod{n}$  and  $u^2 = u \pmod{n}$ .

**Proof.** Easy to verify.

Example 9: Let  $G = \{Z_6, *, (2, 3)\}$  defined by the following table:

*	0	1	2	3	4	5
0	0	3	0	3	0	3
1	2	5	2	5	2	5
2	4	1	4	1	4	1
3	0	3	0	3	0	3
4	2	5	2	5	2	5
5	4	1	4	1	4	1

$\{0, 3\}$  is a Smarandache subgroupoid and since  $2^3 = 2 \pmod{6}$  and  $3^2 = 3 \pmod{6}$  we see  $G$  is a Smarandache Bol groupoid.

**Problem 2:** Let  $\{0, 1, 2, \dots, n-1\}$  be the ring of integers modulo  $n$ .  $G = \{Z_n, *, (t, u)\}$  be a groupoid. Find conditions on  $n, t$  and  $u$  so that  $G$ :

1. is a Smarandache groupoid.
2. has Smarandache semi-normal subgroupoids.
3. has Smarandache normal subgroupoids.
4. is Smarandache commutative.
5. is Smarandache inner commutative.
6. is a Smarandache-Bol groupoid.
7. is a Smarandache Strong Bol groupoid.
8. is a Smarandache-Moufang groupoid.
9. is a Smarandache-Strong-Moufang groupoid.
10. has always a pair of Smarandache conjugate subgroupoid.

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# On the primitive numbers of power $P$ and its mean value properties<sup>1</sup>

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**Abstract** Let  $p$  be a prime,  $n$  be any fixed positive integer.  $S_p(n)$  denotes the smallest positive integer such that  $S_p(n)!$  is divisible by  $p^n$ . In this paper, we study the mean value properties of  $S_p(n)$  for  $p$ , and give a sharp asymptotic formula for it.

**Keywords** Primitive numbers; Mean value; Asymptotic formula.

## §1. Introduction

Let  $p$  be a prime,  $n$  be any fixed positive integer,  $S_p(n)$  denotes the smallest positive integer such that  $S_p(n)!$  is divisible by  $p^n$ . For example,  $S_3(1) = 3$ ,  $S_3(2) = 6$ ,  $S_3(3) = 9$ ,  $S_3(4) = 9$ ,  $S_3(5) = 12$ ,  $\dots$ . In problem 49 of book [1], Professor F. Smarandache asks us to study the properties of the sequence  $S_p(n)$ . About this problem, some asymptotic properties of this sequence have been studied by Zhang Wenpeng and Liu Duansen [2], they proved that

$$S_p(n) = (p-1)n + O\left(\frac{p}{\log p} \log n\right).$$

The problem is interesting because it can help us to calculate the Smarandache function. In this paper, we use the elementary methods to study the mean value properties of  $S_p(n)$  for  $p$ , and give a sharp asymptotic formula for it. That is, we shall prove the following:

**Theorem** Let  $x \geq 2$ , for any fixed positive integer  $n$ , we have the asymptotic formula

$$\sum_{p \leq x} S_p(n) = \frac{nx^2}{2 \log x} + \sum_{m=1}^{k-1} \frac{na_m x^2}{\log^{m+1} x} + O\left(\frac{nx^2}{\log^{k+1} x}\right),$$

where  $a_m (m = 1, 2, \dots, k-1)$  are computable constants.

## §2. Some Lemmas

To complete the proof of the theorem, we need the following:

**Lemma** Let  $p$  be a prime,  $n$  be any fixed positive integer. Then we have the estimate

$$(p-1)n \leq S_p(n) \leq np.$$

---

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**Proof.** Let  $S_p(n) = k = a_1p^{\alpha_1} + a_2p^{\alpha_2} + \cdots + a_s p^{\alpha_s}$  with  $\alpha_s > \alpha_{s-1} > \cdots > \alpha_1 \geq 0$  under the base  $p$ . Then from the definition of  $S_p(n)$  we know that  $p \mid S_p(n)!$  and the  $S_p(n)$  denotes the smallest integer satisfy the condition. However, let

$$(np)! = 1 \cdot 2 \cdot 3 \cdots p \cdot (p+1) \cdots 2p \cdot (2p+1) \cdots np = up^l.$$

where  $l \geq n$ ,  $p \nmid u$ .

So combining this and  $p \mid S_p(n)!$  we can easily obtain

$$S_p(n) \leq np. \quad (1)$$

On the other hand, from the definition of  $S_p(n)$  we know that  $p \mid S_p(n)!$  and  $p^{n \dagger} (S_p(n) - 1)!$ , so that  $\alpha_1 \geq 1$ , note that the factorization of  $S_p(n)!$  into prime power is

$$k! = \prod_{q \leq k} q^{\alpha_q(k)}.$$

where  $\prod_{q \leq k}$  denotes the product over all prime  $q$ , and

$$\alpha_q(k) = \sum_{i=1}^{\infty} \left[ \frac{k}{q^i} \right]$$

because  $p \mid S_p(n)!$ , so we have

$$n \leq \alpha_p(k) = \sum_{i=1}^{\infty} \left[ \frac{k}{p^i} \right] = \frac{k}{p-1}$$

or

$$(p-1)n \leq k \quad (2)$$

combining (1) and (2) we immediately get the estimate

$$(p-1)n \leq S_p(n) \leq np.$$

This completes the proof of the lemma.

### §3. Proof of the theorem

In this section, we complete the proof of Theorem. Based on the result of lemma

$$(p-1)n \leq S_p(n) \leq np$$

we can easily get

$$\sum_{p \leq x} (p-1)n \leq \sum_{p \leq x} S_p(n) \leq \sum_{p \leq x} np.$$

Let

$$a(n) = \begin{cases} 1, & \text{if } n \text{ is prime;} \\ 0, & \text{otherwise,} \end{cases}$$

Then from [3] we know that for any positive integer  $k$ ,

$$\sum_{n \leq x} a(n) = \pi(x) = \frac{x}{\log x} \left( 1 + \sum_{m=1}^{k-1} \frac{m!}{\log^m x} \right) + O\left(\frac{x}{\log^{k+1} x}\right).$$

By Abel's identity we have

$$\begin{aligned} \sum_{p \leq x} p &= \sum_{m \leq x} a(m)m \\ &= \pi(x)x - \int_2^x \pi(t)dt \\ &= \frac{x^2}{\log x} + \frac{x^2}{\log x} \sum_{m=1}^{k-1} \frac{m!}{\log^m x} - \int_2^x \frac{t}{\log t} \left( 1 + \sum_{m=1}^{k-1} \frac{m!}{\log^m t} \right) dt + O\left(\frac{x^2}{\log^{k+1} x}\right) \\ &= \frac{x^2}{2 \log x} + \sum_{m=1}^{k-1} \frac{a_m x^2}{\log^{(m+1)} x} + O\left(\frac{x^2}{\log^{k+1} x}\right) \end{aligned}$$

where  $a_m (m = 1, 2, \dots, k-1)$  are computable constants. From above we have

$$\sum_{p \leq x} (p-1) = \sum_{p \leq x} p - \pi(x) = \frac{x^2}{2 \log x} + \sum_{m=1}^{k-1} \frac{a_m x^2}{\log^{(m+1)} x} + O\left(\frac{x^2}{\log^{k+1} x}\right).$$

Therefore

$$\sum_{p \leq x} S_p(n) = \sum_{p \leq x} k = \frac{x^2}{2 \log x} + \sum_{m=1}^{k-1} \frac{a_m x^2}{\log^{(m+1)} x} + O\left(\frac{x^2}{\log^{k+1} x}\right).$$

This completes the proof of the theorem.

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# Consecutive, reversed, mirror, and symmetric Smarandache sequence of triangular numbers

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**Abstract** We use the Maple system to check the investigations of S.S.Gupta regarding the Smarandache consecutive and the reversed Smarandache sequence of triangular numbers [Smarandache Notions Journal,Vol. 14, 2004, pp.366-368]. Furthermore, we extend previous investigations to the mirror and symmetric Smarandache sequences of triangular numbers.

The  $n$ th triangular number  $t_n, n \in N$ , is defined by  $t_n = \sum_{i=1}^n i = n(n+1)/2$ . These numbers were first studied by the Pythagoreans.

The first  $k$  terms of the triangular sequence  $\{t_n\}_{n=1}^{\infty}$  are easily obtained in Maple:

```
> t:=n ->n*(n+1)/2:
```

```
> first :=k -> seq(t(n), n=1,...,k):
```

For example:

```
> first(20);
```

1, 3, 6, 10, 15, 21, 28, 36, 45, 55, 66, 78, 91, 105, 120, 136, 153, 171, 190, 210

In this short note we are interested in studying Smarandache sequences of triangular numbers with the help of the Maple system. To define the Smarandache sequences, it is convenient to introduce first the concatenation operation. Given two positive integer numbers  $n$  and  $m$ , the concatenation operation `conc` is defined in Maple by the following function:

```
> conc :=(n, m) -> n*10length(m)+m:
```

For example,

```
> conc(12, 345);
```

12345

Given a positive integer sequence  $\{u_n\}_{n=1}^{\infty}$ , we define the corresponding Smarandache Consecutive Sequence  $\{scs_n\}_{n=1}^{\infty}$  recursively:

$$scs_1 = u_1,$$

$$scs_n = conc(scs_{n-1}, u_n).$$

In Maple we define:

> `scs_n := (u, n) -> if n = 1 then u(1) else conc(scs_n(u, n-1), u(n)) fi:`

> `scs := (u, n) -> seq(scs_n(u, i), i=1..n):`

The standard Smarandache consecutive sequence, introduced by the Romanian mathematician Florentin Smarandache, is obtained when one chooses  $u_n = n, \forall n \in \mathbb{N}$ . The first 10 terms are: > `scs(n->n,10);`

1, 12, 123, 1234, 12345, 123456, 1234567, 12345678, 123456789, 12345678910

Another example of a Smarandache consecutive sequence is the Smarandache consecutive sequence of triangular numbers. With our Maple definitions, the first 10 terms of such sequence are obtained with the following command:

> `scs(t, 10);`

1, 13, 136, 13610, 1361015, 136101521, 13610152128,

1361015212836, 136101521283645, 13610152128364555,

Sometimes, it is preferred to display Smarandache sequence in "triangular form".

> `show := L -> map(i -> print(i), L):`

> `show([scs(t, 10)]):`

1

13

136

13610

1361015

136101521

13610152128

1361015212836

136101521283645

13610152128364555

The Reversed Smarandache Sequence (rss) associated with a given sequence  $\{u_n\}_{n=1}^{\infty}$ , is defined recursively by

$$rss_1 = u_1$$

$$rss_n = conc(u_n, rss_{n-1}).$$

In Maple we propose the following definitions:

> `rss_n := (u, n) -> if n = 1 then u(1) else conc(u(n), res_n(u, n-1)) fi:`

> `rss := (u, n) -> seq(rss_n(u, i), i=1..n):`

The first terms of the reversed Smarandache sequence of triangular numbers are now easily obtained:

```
> rss(t, 10);
```

```
1, 31, 631, 10631, 1510631, 211510631, 28211510631,
3628211510631, 453628211510631, 55453628211510631,
```

We define the Smarandache Mirror Sequence (sms) as follows:

$$sms_1 = u_1,$$

$$sms_n = conc(conc(u_n, sms_{n-1}), u_n)$$

```
> sms_n :=(u, n) - > if n = 1 then
```

```
  >          u(1)
```

```
>          else
```

```
>          conc(conc(u(n), sms_n(u, n-1)), u(n))
```

```
> sms :=(u, n) - > seq(sms_n(u, i), i=1..n):
```

The first 10 terms of the Smarandache mirror sequence introduced by Smarandache are:

```
> sms(n - >, 10);
```

```
1, 212, 32123, 4321234, 543212345, 65432123456, 7654321234567,
876543212345678, 98765432123456789, 109876543212345678910
```

We are interested in the Smarandache mirror sequence of triangular numbers. The first 10 terms are:

```
> sms(t, 10);
```

```
1, 313, 63136, 106313610, 1510631361015, 21151063136101521,
282115106313610152128, 3628211510631361015212836,
45362821151063136101521283645, 554536282115106313610152128364555,
```

Finally, we define the Smarandache Symmetric Sequence (sss). For that we introduce the function "But Last Digit" (bld):

```
> bld :=n - > iquo(n,10):
```

```
> bld(123);
```

12

If the integer number is a one-digit number, then function bld returns zero:

```
> bld(3);
```

0

This is important: with our conc function, the concatenation of zero with a positive integer  $n$  gives  $n$ .

```
> conc(bld(1), 3);
```

3



The Smarandache Symmetric Sequence (sss) is now easily defined, appealing to the Smarandache consecutive, and reversed Smarandache sequences:

$$sss_{2n-1} = \text{conc}(\text{bld}(\text{scs}_{2n-1}), \text{rss}_{2n-1}),$$

$$sss_{2n} = \text{conc}(\text{scs}_{2n}, \text{rss}_{2n}),$$

$n \in \mathbb{N}$ . In Maple, we give the following definitions:

```
> sss_n :=(u, n) - > if type(n, odd) then
>         conc(bld(scs_n(u, (n+1)/2), rss_(u, (n+1)/2))
>         else
>         conc(scs_n(u, n/2), rss_n(u, n/2))
>         fi:
> sss :=(u, n) - > seq(sss_n(u, i), i=1..n):
The first terms of Smarandache's symmetric sequence are
> sss(n - > n, 10);
```

1, 11, 121, 1221, 12321, 123321, 1234321, 12344321, 123454321, 1234554321

while the first 10 terms of the Smarandache symmetric sequence of triangular numbers are

```
> sss(t, 10);
```

1, 11, 131, 1331, 13631, 136631, 136110631, 1361010631, 1361011510631, 13610151510631,

One interesting question is to find prime numbers in the above defined Smarandache sequences of triangular numbers. We will restrict our search to the first 1000 terms of each sequence. All computations were done with Maple 9 running on a 2.00Ghz Pentium 4 with 256Mb RAM. We begin by collecting four lists with the first 1000 terms of the consecutive, reversed, mirror, and symmetric Smarandache sequences of triangular numbers:

```
> st:=time(): Lscs1000:=[scs(t, 1000)]: print("%a seconds", round(time()-st));
20 seconds
> st:=time(): Lrss1000:=[rss(t, 1000)]: print("%a seconds", round(time()-st));
75 seconds
> st:=time(): Lsms1000:=[sms(t, 1000)]: print("%a seconds", round(time()-st));
212 seconds
> st:=time(): Lsss1000:=[sss(t, 1000)]: print("%a seconds", round(time()-st));
26 seconds
We note that scs1000 and rss1000 are positive integer numbers with 5354 digits;
> length(Lscs1000[1000]), length(Lrss1000[1000]);
```

5354, 5354

while sms<sub>1000</sub> and sss<sub>1000</sub> have, respectively, 10707 and 4708 digits.

```
> length(Lsms1000[1000]), length(Lsss1000[1000]);
```

10707, 4708

There exist two primes (13 and 136101521) among the first 1000 terms of the Smarandache consecutive sequence of triangular numbers;

```
> st := time()
> select(isprime, Lscs1000);
> printf("%a minutes", round((time()-st)/60));
```

[13, 136101521]

9 minutes

six primes among the first 1000 terms of the reversed Smarandache sequence of triangular numbers;

```
> st := time()
> select(isprime, Lrss1000);
> printf("%a minutes", round((time()-st)/60));
```

[31, 631, 10631, 55453628211510631, 786655453628211510631, 10591786655453628211510631]

31 minutes

only one prime (313) among the first 600 terms of the Smarandache mirror sequence of triangular numbers;

```
> length(Lsms1000[600]); # sms_{600} is a number with 5907 digits
```

5907

```
> st := time()
> select(isprime, Lsms1000[1..600]);
> printf("%a minutes", round((time()-st)/60));
```

[313]

3 minutes

and five primes among the first 1000 terms of the Smarandache symmetric sequence of triangular numbers (the fifth prime is an integer with 336 digits).

```
> st := time()
> select(isprime, Lsss1000);
> printf("%a minutes", round((time()-st)/60));
```

[11,131,136110631,1361015212836455566789110512012010591786655453628211510631,  
1361015212836455566789110512013615317119021023125327630032535137840643546549652856159  
5630666703741780820861903946990103510811128117612251275132613781431148515401596165316  
5315961540148514311378132612751225117611281081103599094690386182078074170366663059556  
152849646543540637835132530027625323121019017115313612010591786655453628211510631]

19 minutes

```
> length(%[5]);
```

336

How many primes are there in the above defined Smarandache sequences of triangular numbers? This seems to be an open question. Another interesting question is to find triangular

numbers in the Smarandache sequences of triangular numbers. We begin by defining in Maple the boolean function `istriangular`.

```
> istriangular := n -> evalb(nops(select(i -> evalb(whattype(i)=integer), [solve(t(k)=n)])) > 0)
```

There exist two triangular numbers (1 and 136) among the first 1000 terms of the Smarandache consecutive sequence of triangular numbers;

```
> st := time()
> select(istriangular, Lscs1000);
> printf("%a seconds", round(time()-st));
```

[1, 136]

6 seconds

while the other Smarandache sequences of triangular numbers only show, among the first 1000 terms, the trivial triangular number 1:

```
> st := time()
> select(istriangular, Lrss1000);
> printf("%a seconds", round(time()-st));
```

[1]

6 seconds

```
> st := time()
> select(istriangular, Lsms1000);
> printf("%a seconds", round(time()-st));
```

[1]

10 seconds

```
> st := time()
> select(istriangular, Lsss1000);
> printf("%a seconds", round(time()-st));
```

[1]

6 seconds

Does exist more triangular numbers in the Smarandache sequences of triangular numbers? This is, to the best of our knowledge, an open question needing further investigations. Since checking if a number is triangular is much faster than to check if a number if prime, we invite the readers to continue our research of triangular numbers for besides the 1000th term of the Smarandache sequences of triangular numbers. We look forward to readers discoveries.

## References

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# On the square-free number sequence

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**Abstract** The main purpose of this paper is to study the number of the square-free number sequence, and give two interesting asymptotic formulas for it. At last, give another asymptotic formula and a corollary.

**Keywords** Square-free number sequence; Asymptotic formula.

## §1. Introduction

A number is called a square-free number if its digits don't contain the numbers: 0, 1, 4, 9. Let  $\mathcal{A}$  denote the set of all square-free numbers. In reference [1], Professor F. Smarandache asked us to study the properties of the square-free number sequence. About this problem, it seems that none had studied it, at least we have not seen such a paper before. In this paper, we use the elementary method to study the number of the square-free number sequence, and obtain two interesting asymptotic formulas for it. That is, let  $S(x) = \sum_{n \leq x, n \in \mathcal{A}} 1$ , we shall prove

the followings:

**Theorem 1.** For any real number  $x \geq 1$ , we have the asymptotic formula

$$\ln S(x) = \frac{\ln 6}{\ln 10} \times \ln x + O(1).$$

**Theorem 2.** For any real number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{n \leq x, n \in \mathcal{B}} 1 = x + O\left(x^{\frac{2 \ln 2}{\ln 10}}\right),$$

where  $\mathcal{B}$  denote the complementary set of those numbers whose all digits are square numbers.

Let  $\mathcal{B}'$  denote the set of those numbers whose all digits are square numbers. Then we have the following:

**Theorem 3.** For any real number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{n \leq x, n \in \mathcal{B}'} \frac{1}{n} = \ln x + \gamma - C + O\left(x^{-\frac{\ln 3}{\ln 10}}\right),$$

where  $C$  is a computable constant,  $\gamma$  denotes the Euler's constant.

Let  $\mathcal{A}'$  denote the complementary set of  $\mathcal{A}$ , we have following:

**Corollary.** For any real number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{n \leq x, n \in \mathcal{A}'} \frac{1}{n} = \ln x + \gamma - D + O\left(x^{-\frac{\ln \frac{5}{3}}{\ln 10}}\right),$$

where  $D$  is a computable constant.

## §2. Proof of Theorems

In this section, we shall complete the proof of Theorems. First we need the following one simple lemma.

**Lemma.** For any real number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{n \leq x, n \in \mathcal{B}'} \frac{1}{n} = C + O\left(x^{-\frac{\ln \frac{5}{2}}{\ln 10}}\right).$$

**Proof.** In the interval  $[10^{r-1}, 10^r)$ , ( $r \geq 2$ ), there are  $3 \times 4^{r-1}$  numbers belong to  $\mathcal{B}'$ , and every number's reciprocal isn't greater than  $\frac{1}{10^{r-1}}$ ; when  $r = 1$ , there are 4 numbers belong to  $\mathcal{B}'$  and their reciprocals aren't greater than 1. Then we have

$$\sum_{n \in \mathcal{B}'} \frac{1}{n} < 3 + \sum_{r=1}^{\infty} 3 \times \frac{4^r}{10^r},$$

then  $\sum_{n \in \mathcal{B}'} 1$  is convergent to a constant  $C$ . So

$$\sum_{n \leq x, n \in \mathcal{B}'} \frac{1}{n} = \sum_{n \in \mathcal{B}'} \frac{1}{n} - \sum_{n > x, n \in \mathcal{B}'} \frac{1}{n} = C + O\left(\sum_{r=k}^{\infty} \frac{3 \times 4^r}{10^r}\right) = C + O\left(x^{-\frac{\ln \frac{5}{2}}{\ln 10}}\right).$$

Now we come to prove Theorem 1. First for any real number  $x \geq 1$ , there exists a non-negative integer  $k$ , such that  $10^k \leq x < 10^{k+1}$  ( $k \geq 1$ ) therefore  $k \leq \log x < k + 1$ . If a number belongs to  $\mathcal{A}$ , then its digits only contain these six numbers: 2, 3, 5, 6, 7, 8.

So in the interval  $[10^{r-1}, 10^r)$  ( $r \geq 1$ ), there are  $6^r$  numbers belong to  $\mathcal{A}$ . Then we have

$$\sum_{n \leq x, n \in \mathcal{A}} 1 \leq \sum_{r=1}^{k+1} 6^r = \frac{6}{5} \times (6^{k+1} - 1) < \frac{6^{k+2}}{5} < \frac{6^2}{5} \times x^{\frac{\ln 6}{\ln 10}},$$

and

$$\sum_{n \leq x, n \in \mathcal{A}} 1 \geq \sum_{r=1}^k 6^r = \frac{6}{5} \times (6^k - 1) \geq 6^k > \frac{1}{6} \times x^{\frac{\ln 6}{\ln 10}}.$$

So we have

$$\frac{1}{6} \times x^{\frac{\ln 6}{\ln 10}} < \sum_{n \leq x, n \in \mathcal{A}} 1 < \frac{6^2}{5} \times x^{\frac{\ln 6}{\ln 10}}.$$

Taking the logarithm computation on both sides of the above, we get

$$\ln(x^{\frac{\ln 6}{\ln 10}}) + (-\ln 6) < \sum_{n \leq x, n \in \mathcal{A}} 1 < \ln(x^{\frac{\ln 6}{\ln 10}}) + (2 \times \ln 6 - \ln 5).$$

So

$$\ln S(x) = \ln \left( \sum_{n \leq x, n \in \mathcal{A}} 1 \right) = \ln(x^{\frac{\ln 6}{\ln 10}}) + O(1) = \frac{\ln 6}{\ln 10} \times \ln x + O(1).$$

This proves the Theorem 1.

Now we prove Theorem 2. It is clear that if a number doesn't belong to  $\mathcal{B}$ , then all of its digits are square numbers. So in the interval  $[10^{r-1}, 10^r)$ , ( $r \geq 2$ ), there are  $3 \times 4^{r-1}$  numbers don't belong to  $\mathcal{B}$ ; when  $r = 1$ , there are 4 numbers don't belong to  $\mathcal{B}$ . Then we have

$$\begin{aligned} \sum_{n \leq x, n \in \mathcal{B}} 1 &= \sum_{n \leq x} 1 - \sum_{n \leq x, n \in \mathcal{B}'} 1 \\ &= x + O(4 + 3 \times 4 + 3 \times 4^2 + \cdots + 3 \times 4^k) \\ &= x + O(4^{k+1}) = x + O\left(x^{\frac{2 \times \ln 2}{\ln 10}}\right). \end{aligned}$$

This completes the proof of the Theorem 2. Now we prove the Theorem 3. In reference [2], we know the asymptotic formula:

$$\sum_{n \leq x} \frac{1}{n} = \ln x + \gamma + O\left(\frac{1}{x}\right),$$

where  $\gamma$  is the Euler's constant.

Then from this asymptotic formula and the above Lemma, we have

$$\begin{aligned} \sum_{n \leq x, n \in \mathcal{B}} \frac{1}{n} &= \sum_{n \leq x} \frac{1}{n} - \sum_{n \leq x, n \in \mathcal{B}'} \frac{1}{n} \\ &= \ln x + \gamma + O\left(\frac{1}{x}\right) - C + O\left(x^{-\frac{\ln \frac{5}{2}}{\ln 10}}\right) \\ &= \ln x + \gamma - C + O\left(x^{-\frac{\ln \frac{5}{2}}{\ln 10}}\right). \end{aligned}$$

This completes the proof of the Theorem 3. Now the Corollary immediately follows from the Lemma and Theorem 3.

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## On finite Smarandache near-rings

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**Abstract** In this paper we study the Finite Smarandache-2-algebraic structure of Finite-near-ring, namely, Finite-Smarandache-near-ring, written as Finite-S-near-ring. We define Finite Smarandache near-ring with examples. We introduce some equivalent conditions for Finite S-near-ring and obtain some of its properties.

**Keywords** Finite-S-near-ring; Finite-Smarandache-near-ring.

### §1. Introduction

In this paper, we studied Finite-Smarandache 2-algebraic structure of Finite-near-rings, namely, Finite-Smarandache-near-ring, written as Finite-S-near-ring. A Finite-Smarandache 2-algebraic structure on a Finite-set  $N$  means a weak algebraic structure  $A_0$  on  $N$  such that there exist a proper subset  $M$  of  $N$ , which is embedded with a stronger algebraic structure  $A_1$ , stronger algebraic structure means satisfying more axioms, by proper subset means a subset different from the empty set, from the unit element if any, from the whole set [5]. By a Finite-near-ring  $N$ , we mean a zero-symmetric Finite- right-near-ring. For basic concept of near-ring we refer to Gunter Pilz [2].

**Definition 1.** A Finite-near-ring  $N$  is said to be Finite-Smarandache-near-ring. If a proper subset  $M$  of  $N$  is a Finite-near-field under the same induced operations in  $N$ .

**Example 1 [2].** Let  $N = \{0, n_1, n_2, n_3\}$  be the Finite-near-ring defined by:

Let  $M = \{0, n_1\} \subset N$  be a Finite-near-field. Defined by

Now  $(N, +, \cdot)$  is a Finite-S-near-ring .

**Example 2 [4].** Let  $N = \{0, 6, 12, 18, 24, 30, 36, 42, 48, 54\} \pmod{60}$  be the Finite-near-ring since every ring is a near-ring. Now  $N$  is a Finite-near-ring, Whose proper subset  $M = \{0, 12, 24, 36, 48\} \pmod{60}$  is a Finite-field. Since every field is a near-field, then  $M$  is a Finite-near-field. Therefore  $N$  is a Finite-S-near-ring.

**Theorem 1.** Let  $N$  be a Finite-near-ring.  $N$  is a Finite-S-near-ring if and only if there exist a proper subset  $M$  of  $N$ , either  $M \cong M_c(z_2)$  or  $Z_p$ , integers modulo  $p$ , a prime number.

**Proof. Part-I:** We assume that  $N$  is a Finite-S-near-ring. By definition, there exist a proper subset  $M$  of  $N$  is a Finite-near-field. By Gunter Pilz Theorem (8.1)[2], either  $M \cong$



$M_c(z_2)$  or zero-symmetric. Since  $Z_p^S$  is zero-symmetric and Finite-fields implies  $Z_p, S$  are zero-symmetric and Finite-near-fields because every field is a near-field. Therefore in particular  $M$  is  $Z_p$ .

**Part-II:** We assume that a proper subset  $M$  of  $N$ , either  $M \cong M_c(z_2)$  or  $Z_p$ . Since  $M_c(z_2)$  and  $Z_p$  are Finite-near-fields. Then  $M$  is a Finite-near-field. By definition,  $N$  is a Finite-S-near-ring.

**Theorem.** Let  $N$  be a Finite-near-ring.  $N$  is a Finite-S-near-ring if and only if there exist a proper subset  $M$  of  $N$  such that every element in  $M$  satisfying the polynomial  $x^{p^m} - x$ .

**Proof. Part-I:** We assume that  $N$  is a Finite-S-near-ring. By definition, there exist a proper subset  $M$  of  $N$  is a Finite-near-field. By Gunter Pilz, Theorem (8.13)[2]. If  $M$  is a Finite-near-field, then there exist  $p \in P, \exists m \in M$  such that  $|M| = p^m$ . According to I.N.Herstein[3]. If the Finite-near-field  $M$  has  $p^m$  element, then every  $a \in M$  satisfies  $a^{p^m} = a$ , since every field is a near-field. Now  $M$  is a Finite-near-field having  $p^m$  element, every element  $a$  in  $M$  satisfies  $a^{p^m} = a$ . Therefore every element in  $M$  satisfying the polynomial  $x^{p^m} - x$ .

**Part-II:** We assume that there exist a proper subset  $M$  of  $N$  such that every element in  $M$  satisfying the polynomial  $x^{p^m} - x$ , which implies  $M$  has  $p^m$  element. According to I.N.Herstein[3], For every prime number  $p$  and every positive integer  $m$ , there is a unique field having  $p^m$  element. Hence  $M$  is a Finite-field implies  $M$  is a Finite-near-field. By definition,  $N$  is a Finite-S-near-ring.

**Theorem 3.** Let  $N$  be a Finite-near-ring.  $N$  is a Finite-S-near-ring if and only if  $M$  has no proper left ideals and  $M_0 \neq M$ . Where  $M$  is a proper sub near-ring of  $N$ , in which idempotent commute and for each  $x \in M$ , there exist  $y \in M$  such that  $yx \neq 0$ .

**Proof. Part-I :** We assume that  $N$  is a Finite-S-near-ring. By definition A proper subset  $M$  of  $N$  is a Finite-near-field. In [1] Theorem (4), it is zero-symmetric and hence every left-ideal is a M-subgroup. Let  $M_1 \neq 0$  be a M-subgroup and  $m_1 \neq 0 \in M_1$ . Then  $m_1^{-1}m_1 = 1 \in M_1$ . therefore  $M = M_1$ . Hence  $M$  has no proper M-subgroup, which implies  $M$  has no proper left ideal.

**Part-II:** We assume that a proper sub-near-ring  $M$  of  $N$  has no proper left ideals and  $M_0 \neq M$ , in which idempotent commute and for each  $x \in M$  there exist  $y \in M$  such that  $yx \neq 0$ . Let  $x \neq 0$  in  $M$ . Let  $F(x) = \{m \in M \mid mx = 0\}$ . Clearly  $F(x)$  is a left ideal. Since there exist  $y \in M$  such that  $yx \neq 0$ . Then  $y \notin F(x)$ . Hence  $F(x) = 0$ . Let  $\phi : (M, +) \rightarrow (Mx, +)$  given by  $\phi(m) = mx$ . Then  $\phi$  is an isomorphism. Since  $M$  is finite then  $Mx = M$ . Now by a theorem(2) in [1],  $M$  is a Finite-near-field. Therefore, by definition  $N$  is a Finite-S-near-ring.

We summarize what has been studied in

**Theorem 4.** Let  $N$  be a Finite-near-ring. Then the following conditions are equivalent.

1. A proper subset  $M$  of  $N$ , either  $M \cong M_c(z_2)$  or  $Z_p$ , integers modulo  $p$ , a prime number.
2. A proper subset  $M$  of  $N$  such that every element in  $M$  satisfying the polynomial  $x^{p^m} - x$ .
3.  $M$  has no proper left ideals and  $M_0 \neq M$ . Where  $M$  is a proper sub near-ring of  $N$ , in which idempotent commute and for each  $x \in M$ , there exist  $y \in M$  such that  $yx \neq 0$ .

**Theorem 5.** Let  $N$  be a Finite-near-ring. If a proper subset  $M$ , sub near-ring of  $N$ , in which  $M$  has left identity and  $M$  is 0-primitive on  $M^M$ . Then  $N$  is a Finite-S-near-ring.

**Proof.** By Theorem(8.3)[2], the following conditions are equivalent:

- (1)  $M$  is a Finite-near-field;
- (2)  $M$  has left identity and  $M$  is 0-primitive on  $M^M$ .

Now Theorem is immediate.

**Theorem 6.** Let  $N$  be a Finite-near-ring. If a proper subset  $M$ , sub near-ring of  $N$ , in which  $M$  has left identity and  $M$  is simple. Then  $N$  is a Finite-S-near-ring.

**Proof.** By Theorem(8.3)[2], the following conditions are equivalent:

- (1)  $M$  is a Finite-near-field;
- (2)  $M$  has left identity and  $M$  is simple. Now the Theorem is immediate.

**Theorem 7.** Let  $N$  be a Finite-near-ring. If a proper subset  $M$ , sub near-ring of  $N$  is a Finite-near-domain, then  $N$  is a Finite-S-near-ring.

**Proof.** By Theorem(8.43)[2], a Finite-near-domain is a Finite-near-field. Therefore  $M$  is a Finite-near-field. By definition  $N$  is a Finite-S-near-ring.

**Theorem 8.** Let  $N$  be a Finite-near-ring. If a proper subset  $M$  of  $N$  is a Finite-Integer-domain. Then  $N$  is a Finite-S-near-ring.

**Proof.** By I.N.Herstein[3], every Finite-Integer-domain is a field, since every field is a near-field. Now  $M$  is a Finite-near-field. By definition  $N$  is a Finite-S-near-ring.

**Theorem 9.** Let  $N$  be a Finite-near-ring. If a proper subset  $M$  of  $N$  is a Finite-division-ring. Then  $N$  is a Finite-S-near-ring.

**Proof.** By Wedderburn's Theorem(7.2.1)[3], a Finite-division-ring is a necessarily commutative field, which gives  $M$  is a field, implies  $M$  is a Finite-near-field. By definition  $N$  is a Finite-S-near-ring.

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# Some interesting properties of the Smarandache function

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**Abstract** The main purpose of this paper is using the elementary method to study the property of the Smarandache function, and give an interesting result.

**Keywords** Smarandache function; Additive property; Greatest prime divisor.

## §1. Introduction and results

Let  $n$  be an positive integer, the famous Smarandache function  $S(n)$  is defined as following:

$$S(n) = \min\{m : m \in N, n|m!\}.$$

About this function and many other Smarandache type function, many scholars have studied its properties, see [1], [2], [3] and [4]. Let  $p(n)$  denotes the greatest prime divisor of  $n$ , it is clear that  $S(n) \geq p(n)$ . In fact,  $S(n) = p(n)$  for almost all  $n$ , as noted by Erdős [5]. This means that the number of  $n \leq x$  for which  $S(n) \neq p(n)$ , denoted by  $N(x)$ , is  $o(x)$ . It is easily to show that  $S(p) = p$  and  $S(n) < n$  except for the case  $n = 4, n = p$ . So there have a closely relationship between  $S(n)$  and  $\pi(x)$ :

$$\pi(x) = -1 + \sum_{n=2}^{[x]} \left[ \frac{S(n)}{n} \right],$$

where  $\pi(x)$  denotes the number of primes up to  $x$ , and  $[x]$  denotes the greatest integer less than or equal to  $x$ . For two integer  $m$  and  $n$ , can you say  $S(mn) = S(m) + S(n)$  is true or false? It is difficult to say. For some  $m$  an  $n$ , it is true, but for some other numbers it is false.

About this problem, J.Sandor [7] proved an very important conclusion. That is, for any positive integer  $k$  and any positive integers  $m_1, m_2, \dots, m_k$ , we have the inequality

$$S\left(\prod_{i=1}^k m_i\right) \leq \sum_{i=1}^k S(m_i).$$

This paper as a note of [7], we shall prove the following two conclusions:

**Theorem 1.** For any integer  $k \geq 2$  and positive integers  $m_1, m_2, \dots, m_k$ , we have the inequality

$$S\left(\prod_{i=1}^k m_i\right) \leq \prod_{i=1}^k S(m_i).$$

**Theorem 2.** For any integer  $k \geq 2$ , we can find infinite group numbers  $m_1, m_2, \dots, m_k$  such that:

$$S\left(\prod_{i=1}^k m_i\right) = \sum_{i=1}^k S(m_i).$$

## §2. Proof of the theorems

In this section, we will complete the proof of the Theorems. First we prove a special case of Theorem 1. That is, for any positive integers  $m$  and  $n$ , we have

$$S(m)S(n) \geq S(mn).$$

If  $m = 1$  ( or  $n = 1$ ), then it is clear that  $S(m)S(n) \geq S(mn)$ . Now we suppose  $m \geq 2$  and  $n \geq 2$ , so that  $S(m) \geq 2$ ,  $S(n) \geq 2$ ,  $mn \geq m + n$  and  $S(m)S(n) \geq S(m) + S(n)$ . Note that  $m|S(m)!$ ,  $n|S(n)!$ , we have  $mn|S(m)!S(n)!|(S(m) + S(n))!$ . Because  $S(m)S(n) \geq S(m) + S(n)$ , we have  $(S(m) + S(n))!|(S(m)S(n))!$ . That is,  $mn|S(m)!S(n)!|(S(m) + S(n))!|(S(m)S(n))!$ . From the definition of  $S(n)$  we may immediately deduce that

$$S(mn) \leq S(m)S(n).$$

Now the theorem 1 follows from  $S(mn) \leq S(m)S(n)$  and the mathematical induction.

Proof of Theorem 2. For any integer  $n$  and prime  $p$ , if  $p^\alpha || n!$ , then we have

$$\alpha = \sum_{j=1}^{\infty} \left[ \frac{n}{p^j} \right].$$

Let  $n_i$  are positive integers such that  $n_i \neq n_j$ , if  $i \neq j$ , where  $1 \leq i, j \leq k$ ,  $k \geq 2$  is any positive integer. Since

$$\sum_{r=1}^{\infty} \left[ \frac{p^{n_i}}{p^r} \right] = p^{n_i-1} + p^{n_i-2} + \dots + 1 = \frac{p^{n_i} - 1}{p - 1}.$$

For convenient, we let  $u_i = \frac{p^{n_i} - 1}{p - 1}$ . So we have

$$S(p^{u_i}) = p^{n_i}, \quad i = 1, 2, \dots, k. \quad (1)$$

In general, we also have

$$\sum_{r=1}^{\infty} \left[ \frac{\sum_{i=1}^k p^{n_i}}{p^r} \right] = \sum_{i=1}^k \frac{p^{n_i} - 1}{p - 1} = \sum_{i=1}^k u_i.$$

So

$$S(p^{u_1+u_2+\dots+u_k}) = \sum_{i=1}^k p^{n_i}. \quad (2)$$

Combining (1) and (2) we may immediately obtain

$$S\left(\prod_{i=1}^k p^{u_i}\right) = \sum_{i=1}^k S(p^{u_i}).$$

Let  $m_i = p^{u_i}$ , noting that there are infinity primes  $p$  and  $n_i$ , we can easily get Theorem 2.

This completes the proof of the theorems.

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# On automorphism groups of maps, surfaces and Smarandache geometries <sup>1</sup>

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**Abstract** A combinatorial map is a connected topological graph cellularly embedded in a surface. This report concentrates on the automorphism group of a map, which is related to the automorphism groups of a Klein surface and a Smarandache manifold, also applied to the enumeration of unrooted maps on orientable and non-orientable surfaces. A number of results for the automorphism groups of maps, Klein surfaces and Smarandache manifolds and the enumeration of unrooted maps underlying a graph on orientable and non-orientable surfaces are discovered. An classification for the closed  $s$ -manifolds by maps is found. Open problems related the combinatorial maps with the differential geometry, Riemann geometry and Smarandache geometries are also presented in this report for the further applications of the combinatorial maps to the classical mathematics.

**Keywords** Automorphism group; Surface; Map; Smarandache geometries; Map geometries; Classification.

## Part I. Terminology and Notations

### §1.1 Klein Surfaces

A *Klein surface* is a Hausdorff, connected, topological space  $S$  with a family  $\Sigma = \{(U_i, \phi_i) | i \in I\}$  such that the chart  $\{U_i | i \in I\}$  is an open covering of  $S$ , each map  $\phi_i : U_i \rightarrow A_i$  is a homeomorphism onto an open subset  $A_i$  of  $\mathcal{C}$  or  $\mathcal{C}^+ = \{z \in \mathcal{C} : \text{Im}z \geq 0\}$  and the transition functions

$$\phi_{ij} = \phi_i \phi_j^{-1} : \phi_j(U_i \cap U_j) \rightarrow \phi_i(U_i \cap U_j).$$

are dianalytic, where a mapping  $f : A \rightarrow \mathcal{C}$  is said dianalytic if  $\frac{\partial f}{\partial \bar{z}} = 0$  (*Cauchy-Riemann equation*) or  $\frac{\partial f}{\partial z} = 0$ .

### §1.2 {Riemann Surfaces} $\subset$ {Klein surfaces}

### §1.3 Embedding and Combinatorial Maps

#### Embedding of a graph:

For any connected graph  $\Gamma = (V(\Gamma), E(\Gamma))$  and a surface  $S$ , an *embedding* of the graph  $\Gamma$  in the surface  $S$  is geometrical defined to be a continuous 1-1 mapping  $\tau : \Gamma \rightarrow S$ . The image

<sup>1</sup>Reported at the Academy of Mathematics and Systems of Chinese Academy of Sciences.

$\tau(\Gamma)$  is contained in the 1-skeleton of a triangulation of the surface  $S$ . If each component in  $S - \tau(\Gamma)$  homeomorphic to an open disk, then the embedding is an embedding.

**Map:**

A combinatorial map is a connected topological graph cellularly embedded in a surface.

**The Algebraic Definition of Maps:**

A combinatorial map  $M = (\mathcal{X}_{\alpha,\beta}, \mathcal{P})$  is defined to be a basic permutation  $\mathcal{P}$ , i.e, for any  $x \in \mathcal{X}_{\alpha,\beta}$ , no integer  $k$  exists such that  $\mathcal{P}^k x = \alpha x$ , acting on  $\mathcal{X}_{\alpha,\beta}$ , the disjoint union of quadricells  $Kx$  of  $x \in X$  (the base set), where  $K = \{1, \alpha, \beta, \alpha\beta\}$  is the Klein group, satisfying the following two conditions:

- (Ci)  $\alpha\mathcal{P} = \mathcal{P}^{-1}\alpha$ ;
- (Cii) the group  $\Psi_J = \langle \alpha, \beta, \mathcal{P} \rangle$  is transitive on  $\mathcal{X}_{\alpha,\beta}$ .

**§1.4 Orientation**

If the group  $\Psi_I = \langle \alpha, \beta, \mathcal{P} \rangle$  is transitive on  $\mathcal{X}_{\alpha,\beta}$ , then  $M$  is non-orientable. Otherwise, orientable.

**§1.5 An Example of Maps  $K_4$  on the torus.**

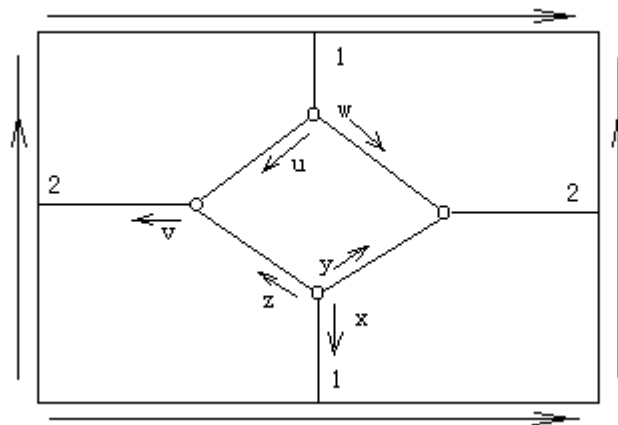


Fig.1

$(\mathcal{X}_{\alpha,\beta}, \mathcal{P})$ :

$$\begin{aligned} \mathcal{X}_{\alpha,\beta} = \{ & x, y, z, u, v, w, \alpha x, \alpha y, \alpha z, \alpha u, \alpha v, \\ & \alpha w, \beta x, \beta y, \beta z, \beta u, \beta v, \beta w, \alpha\beta x, \alpha\beta y, \\ & \alpha\beta z, \alpha\beta u, \alpha\beta v, \alpha\beta w \} \end{aligned}$$

$$\begin{aligned}
\mathcal{P} &= (x, y, z)(\alpha\beta x, u, w)(\alpha\beta z, \alpha\beta u, v) \\
&\times (\alpha\beta y, \alpha\beta v, \alpha\beta w)(\alpha x, \alpha z, \alpha y)(\beta x, \alpha w, \alpha u) \\
&\times (\beta z, \alpha v, \beta u)(\beta y, \beta w, \beta v)
\end{aligned}$$

**Vertices:**

$$\begin{aligned}
v_1 &= \{(x, y, z), (\alpha x, \alpha z, \alpha y)\} \\
v_2 &= \{(\alpha\beta x, u, w), (\beta x, \alpha w, \alpha u)\} \\
v_3 &= \{(\alpha\beta z, \alpha\beta u, v), (\beta z, \alpha v, \beta u)\} \\
v_4 &= \{(\alpha\beta y, \alpha\beta v, \alpha\beta w), (\beta y, \beta w, \beta v)\}
\end{aligned}$$

**Edges:**

$$\{e, \alpha e, \beta e, \alpha\beta e\}, e \in \{x, y, z, u, v, w\}$$

**Faces:**

$$\begin{aligned}
f_1 &= \{(x, u, v, \alpha\beta w, \alpha\beta x, y, \alpha\beta v, \alpha\beta z), (\beta x, \alpha z, \alpha v, \beta y, \alpha x, \alpha w, \beta v, \beta u)\} \\
f_2 &= \{(z, \alpha\beta u, w, \alpha\beta y), (\beta z, \alpha y, \beta w, \alpha u)\}
\end{aligned}$$

### §1.6 Isomorphism of Maps

Two maps  $M_1 = (\mathcal{X}_{\alpha,\beta}^1, \mathcal{P}_1)$  and  $M_2 = (\mathcal{X}_{\alpha,\beta}^2, \mathcal{P}_2)$  are said to be *isomorphic* if there exists a bijection  $\xi$

$$\xi : \mathcal{X}_{\alpha,\beta}^1 \longrightarrow \mathcal{X}_{\alpha,\beta}^2$$

such that for  $\forall x \in \mathcal{X}_{\alpha,\beta}^1$ ,

$$\xi\alpha(x) = \alpha\xi(x), \xi\beta(x) = \beta\xi(x), \xi\mathcal{P}_1(x) = \mathcal{P}_2\xi(x).$$

### §1.7 Equivalence

Two maps  $M_1, M_2$  underlying graph  $\Gamma$  are equivalent if there exists an isomorphism  $\zeta$  between them induced by an element  $\xi, \xi \in \text{Aut}\Gamma$ . Call  $\zeta$  an equivalence between  $M_1, M_2$ . Certainly, on an orientable surface, an equivalence preserve the orientation on this surface.

**Theorem 1.1.** Let  $M = (\mathcal{X}_{\alpha,\beta}, \mathcal{P})$  be a map with an underlying graph  $\Gamma, \forall g \in \text{Aut}\Gamma$ . Then the extend action of  $g$  on  $\mathcal{X}_{\alpha,\beta}$  with  $X = E(\Gamma)$  is an automorphism of map  $M$  iff  $\forall v \in V(M)$ ,  $g$  preserves the cyclic order of  $v$ .

### §1.8 Covering of Maps

For two maps  $\widetilde{M} = (\widetilde{\mathcal{X}}_{\alpha,\beta}, \widetilde{\mathcal{P}})$  and  $M = (\mathcal{X}_{\alpha,\beta}, \mathcal{P})$ , call the map  $\widetilde{M}$  covering the map  $M$  if there is a mapping  $\pi : \widetilde{\mathcal{X}}_{\alpha,\beta} \rightarrow \mathcal{X}_{\alpha,\beta}$  such that  $\forall x \in \widetilde{\mathcal{X}}_{\alpha,\beta}$ ,

$$\alpha\pi(x) = \pi\alpha(x), \beta\pi(x) = \pi\beta(x), \pi\widetilde{\mathcal{P}}(x) = \mathcal{P}\pi(x).$$

**Theorem 1.2.** Let  $\pi : \widetilde{\mathcal{X}}_{\alpha,\beta} \rightarrow \mathcal{X}_{\alpha,\beta}$  be a covering mapping. Then  $\pi$  is an isomorphism iff  $\pi$  is an 1 – 1 mapping.

### §1.9 Voltage Map



Let  $M = (\mathcal{X}_{\alpha,\beta}, \mathcal{P})$  be a map and  $G$  a finite group. Call a pair  $(M, \vartheta)$  a voltage map with group  $G$  if  $\vartheta : \mathcal{X}_{\alpha,\beta} \rightarrow G$ , satisfying the following condition:

- (i)  $\forall x \in \mathcal{X}_{\alpha,\beta}, \vartheta(\alpha x) = \vartheta(x), \vartheta(\alpha\beta x) = \vartheta(\beta x) = \vartheta^{-1}(x)$ ;
- (ii)  $\forall F = (x, y, \dots, z)(\beta z, \dots, \beta y, \beta x) \in F(M)$ , the face set of  $M$ ,  $\vartheta(F) = \vartheta(x)\vartheta(y)\dots\vartheta(z)$  and  $\langle \vartheta(F) | F \in F(u), u \in V(M) \rangle = G$ , where,  $F(u)$  denotes all the faces incident with the vertex  $u$ .

### §1.10 Lifting of a Voltage Map

For a voltage map  $(M, \vartheta)$  with group  $G$ , the map  $M^\vartheta = (\mathcal{X}_{\alpha,\beta}^\vartheta, \mathcal{P}^\vartheta)$  is called its lifting map.

**Theorem 1.3.** An finite group  $G$  is a fixed-free automorphism group of a map  $M = (\mathcal{X}_{\alpha,\beta}, \mathcal{P})$  on  $V(M)$  iff there is a voltage map  $(M/G, G)$  with an assignment  $\vartheta : \mathcal{X}_{\alpha,\beta}/G \rightarrow G$  such that  $M \cong (M/G)^\vartheta$ .

( A permutation group  $G$  action on  $\Omega$  is called *fixed-free* if  $G_x = \mathbf{1}_G$  for  $\forall x \in \Omega$ .)

### §1.11 Semi-Arcs of a Graph

An edge  $e = uv \in E(\Gamma)$  can be divided into two semi-arcs  $e_u, e_v$ .

$X_{\frac{1}{2}}(\Gamma)$ — the set of semi-arcs.

#### Incidence of Semi-Arcs:

Call  $u$  the root vertex in the semi-arc  $e_u$ . Two semi-arc  $e_u, f_v$  are said  $v$ -incident or  $e$ -incident if  $u = v$  or  $e = f$ .

### §1.12 A Semi-Arc Automorphism

An 1 – 1 mapping  $\xi$  on  $X_{\frac{1}{2}}(\Gamma)$  such that  $\forall e_u, f_v \in X_{\frac{1}{2}}(\Gamma)$ ,  $\xi(e_u)$  and  $\xi(f_v)$  are  $v$ -incident or  $e$ -incident if  $e_u$  and  $f_v$  are  $v$ -incident or  $e$ -incident, is called a semi-arc automorphism of the graph  $\Gamma$ .

$\text{Aut}_{\frac{1}{2}}\Gamma$ — the semi-arc automorphism group of  $\Gamma$

For  $\forall g \in \text{Aut}\Gamma$ , there is also an induced action  $g|_{\frac{1}{2}}$  on  $X_{\frac{1}{2}}(\Gamma)$ ,  $g : X_{\frac{1}{2}}(\Gamma) \rightarrow X_{\frac{1}{2}}(\Gamma)$ , as follows:

$$\forall e_u \in X_{\frac{1}{2}}(\Gamma), g(e_u) = (g(e))_{g(u)}.$$

All induced action of the elements in  $\text{Aut}\Gamma$  on  $X_{\frac{1}{2}}(\Gamma)$  is denoted by  $\text{Aut}\Gamma|_{\frac{1}{2}}$ . Notice that

$$\text{Aut}\Gamma \cong \text{Aut}\Gamma|_{\frac{1}{2}}.$$

**Theorem 1.4.** For a graph  $\Gamma$  without loops,

$$\text{Aut}_{\frac{1}{2}}\Gamma = \text{Aut}\Gamma|_{\frac{1}{2}}.$$

**Theorem 1.5.** For two maps  $M_1 = (\mathcal{X}_{\alpha,\beta}, \mathcal{P}_1)$  and  $M_2 = (\mathcal{X}_{\alpha,\beta}, \mathcal{P}_2)$  underlying a graph  $\Gamma$ , then

- (i)  $M_1, M_2$  are equivalent iff  $M_1, M_2$  are in one orbits of  $\text{Aut}_{\frac{1}{2}}\Gamma$  action on  $X_{\frac{1}{2}}(\Gamma)$ ;
- (ii)  $M_1, M_2$  are isomorphic iff  $M_1, M_2$  are in one orbits of  $\text{Aut}_{\frac{1}{2}}\Gamma \times \langle \alpha \rangle$  action on  $\mathcal{X}_{\alpha,\beta}$ .

## Part II Automorphisms of Maps and Klein Surfaces

### §2.1 Relation of Maps with Klein Surfaces

#### Angles incident with a Quadricell:

For a map  $M = (\mathcal{X}_{\alpha,\beta}, \mathcal{P})$ ,  $x \in \mathcal{X}_{\alpha,\beta}$ , the permutation pair  $\{(x, \mathcal{P}x), (\alpha x, \mathcal{P}^{-1}\alpha x)\}$  is called an *angle* incident with  $x$ .

**Theorem 2.1.** Any automorphism of a map  $M = (\mathcal{X}_{\alpha,\beta}, \mathcal{P})$  is conformal.

**Theorem 2.2.** If  $M$  is a locally orientable map of genus  $q$ , then  $\text{Aut}M$  is isomorphic to a group of conformal transformations of a compact Klein surface of genus  $q$ .

(For Riemann surfaces, the same result gotten by Jones and Singerman in 1978.)

### §2.2 The Euler Characteristic of Lifting Map

**Theorem 2.3.** The Euler characteristic  $\chi(M^\theta)$  of the lifting map  $M^\theta$  of the voltage map  $(M, G)$  is

$$\chi(M^\theta) = |G|(\chi(M) + \sum_{m \in \mathcal{O}(F(M))} (-1 + \frac{1}{m})),$$

where  $\mathcal{O}(F(M))$  denotes the order  $o(F)$  set of the faces in  $M$ .

### §2.3 A Group Being That of a Map

**Theorem 2.4** If a group  $G, G \preceq \text{Aut}M$ , is fixed-free on  $V(M)$ , then

$$|G|(\chi(M/G) + \sum_{m \in \mathcal{O}(F(M/G))} (-1 + \frac{1}{m})) = \chi(M).$$

**Corollary 2.1.** If  $M$  is an orientable map of genus  $p$ ,  $G \preceq \text{Aut}M$  is fixed-free on  $V(M)$  and the quotient map  $M/G$  with genus  $\gamma$ , then

$$|G| = \frac{2p - 2}{2\gamma - 2 + \sum_{m \in \mathcal{O}(F(M/G))} (1 - \frac{1}{m})}.$$

Particularly, if  $M/G$  is planar, then

$$|G| = \frac{2p - 2}{-2 + \sum_{m \in \mathcal{O}(F(M/G))} (1 - \frac{1}{m})}.$$

**Corollary 2.2.** If  $M$  is a non-orientable map of genus  $q$ ,  $G \preceq \text{Aut}M$  is fixed-free on  $V(M)$  and the quotient map  $M/G$  with genus  $\delta$ , then

$$|G| = \frac{q - 2}{\delta - 2 + \sum_{m \in \mathcal{O}(F(M/G))} (1 - \frac{1}{m})}.$$

Particularly, if  $M/G$  is projective planar, then

$$|G| = \frac{q - 2}{-1 + \sum_{m \in \mathcal{O}(F(M/G))} (1 - \frac{1}{m})}.$$

**Theorem 2.5.** If a group  $G, G \preceq \text{Aut}M$ , then

$$\chi(M) + \sum_{g \in G, g \neq 1_G} (|\Phi_v(g)| + |\Phi_f(g)|) = |G|\chi(M/G),$$

where,  $\Phi_v(g) = \{v|v \in V(M), v^g = v\}$  and  $\Phi_f(g) = \{f|f \in F(M), f^g = f\}$ , and if  $G$  is fixed-free on  $V(M)$ , then

$$\chi(M) + \sum_{g \in G, g \neq 1_G} |\Phi_f(g)| = |G|\chi(M/G).$$

**Corollary 2.3.** If a finite group  $G, G \preceq \text{Aut}M$  is fixed-free on  $V(M)$  and transitive on  $F(M)$ , for example,  $M$  is regular and  $G = \text{Aut}M$ , then  $M/G$  is an one face map and

$$\chi(M) = |G|(\chi(M/G) - 1) + \phi(M)$$

**Corollary 2.4.** For an one face map  $M$ , if  $G, G \preceq \text{Aut}M$  is fixed-free on  $V(M)$ , then

$$\chi(M) - 1 = |G|(\chi(M/G) - 1),$$

and  $|G|$ , especially,  $|\text{Aut}M|$  is an integer factor of  $\chi(M) - 1$ .

**Remark 2.1.** For an one face planar map, i.e., the plane tree, the only fixed-free automorphism group on its vertices is the trivial group by the Corollary 2.4.

#### §2.4 The Non-Euclid Area of a Map

For a given voltage map  $(M, G)$ , its *non-Euclid area*  $\mu(M, G)$  is

$$\mu(M, G) = 2\pi(-\chi(M) + \sum_{m \in \mathcal{O}(F(M))} (-1 + \frac{1}{m})).$$

Particularly, since any map  $M$  can be viewed as a voltage map  $(M, \mathbf{1}_G)$ , we get the non-Euclid area of a map  $M$

$$\mu(M) = \mu(M, \mathbf{1}_G) = -2\pi\chi(M).$$

**Theorem 2.6.** ( Riemann-Hurwitz formula) If  $G \preceq \text{Aut}M$  is fixed-free on  $V(M)$ , then

$$|G| = \frac{\mu(M)}{\mu(M/G, \vartheta)}.$$

**Theorem 2.7.** The non-Euclid area  $\mu(\Delta)$  of a triangle  $\Delta$  on a surface  $\mathcal{S}$  with internal angles  $\eta, \theta, \sigma$  is

$$\mu(\Delta) = \eta + \theta + \sigma - \pi.$$

#### §2.5 A Combinatorial Refinement of Huriwitz Theorem

**Graphical property  $P$ :**

Define a *graphical property  $P$*  to be a kind of subgraphs of a graph  $\Gamma$ , such as, regular subgraphs, circuits, trees, stars, wheels,  $\dots$ .

Call a subset  $A$  of  $\mathcal{X}_{\alpha, \beta}$  of  $M = (\mathcal{X}_{\alpha, \beta}, \mathcal{P})$  has the graphical property  $P$  if the underlying graph of  $A$  has property  $P$ .

$\mathcal{A}(P, M)$ — the set of all the  $A$  subset with property  $P$  in the map  $M$ .

**Theorem 2.8.** Let  $M = (\mathcal{X}_{\alpha, \beta}, \mathcal{P})$  be a map. Then for  $\forall G \preceq \text{Aut}M$ ,

$$[|v^G| | v \in V(M)] \mid |G|$$

$$|G| \mid |A| |\mathcal{A}(P, M)|,$$

where  $[a, b, \dots]$  denotes least common multiple of  $a, b, \dots$ .

**Corollary 2.5.** Let  $\mathcal{T}r_2$  be the set of tours with each edge appearing 2 times. Then for  $\forall G \preceq \text{Aut}M$ ,

$$|G| \mid (l|\mathcal{T}r_2|, l = |T| = \frac{|T|}{2} \geq 1, T \in \mathcal{T}r_2,).$$

Let  $\mathcal{T}r_1$  be the set of tours without repeat edges. Then

$$|G| \mid (2l|\mathcal{T}r_1|, l = |T| = \frac{|T|}{2} \geq 1, T \in \mathcal{T}r_1,).$$

Particularly, denote by  $\phi(i, j)$  the number of faces in  $M$  with facial length  $i$  and singular edges  $j$ , then

$$|G| \mid ((2i - j)\phi(i, j), i, j \geq 1),$$

where,  $(a, b, \dots)$  denotes the greatest common divisor of  $a, b, \dots$ .

**Corollary 2.6.** Let  $\mathcal{T}$  be the set of trees in the map  $M$ . Then for  $\forall G \preceq \text{Aut}M$ ,

$$|G| \mid (2lt_l, l \geq 1),$$

where  $t_l$  denotes the number of trees with  $l$  edges.

**Corollary 2.7.** Let  $v_i$  be the number of vertices with valence  $i$ . Then for  $\forall G \preceq \text{Aut}M$ ,

$$|G| \mid (2iv_i, i \geq 1).$$

**Theorem 2.9.** Let  $M$  be an orientable map of genus  $g(M) \geq 2$ . Then for  $\forall G \preceq \text{Aut}^+M$ ,

$$|G| \leq 84(g(M) - 1)$$

and for  $\forall G \preceq \text{Aut}M$ ,

$$|G| \leq 168(g(M) - 1).$$

**Corollary 2.8.** For any Riemann surface  $\mathcal{S}$  of genus  $g \geq 2$ ,

$$4g(\mathcal{S}) + 2 \leq |\text{Aut}^+\mathcal{S}| \leq 84(g(\mathcal{S}) - 1)$$

$$8g(\mathcal{S}) + 4 \leq |\text{Aut}\mathcal{S}| \leq 168(g(\mathcal{S}) - 1).$$

**Theorem 2.10.** Let  $M$  be a non-orientable map of genus  $g'(M) \geq 3$ . Then for  $\forall G \preceq \text{Aut}^+M$ ,

$$|G| \leq 42(g'(M) - 2)$$

and for  $\forall G \preceq \text{Aut}M$ ,

$$|G| \leq 84(g'(M) - 2),$$

with the equality hold iff  $M$  is a regular map with vertex valence 3 and face valence 7 or vice via.

**Corollary 2.9.** For any Klein surface  $\mathcal{K}$  underlying a non-orientable surface of genus  $q \geq 3$ ,

$$|\text{Aut}^+\mathcal{K}| \leq 42(q - 2) \quad \text{and} \quad |\text{Aut}\mathcal{K}| \leq 84(q - 2).$$

### §2.6 The Cyclic Group of a Klein Surface

**Theorem 2.11.** Let  $M = (\mathcal{X}_{\alpha,\beta}, \mathcal{P})$  be a map and  $N = p_1^{r_1} \cdots p_k^{r_k}$ ,  $p_1 < p_2 < \cdots < p_k$ , be the arithmetic decomposition of the integer  $N$ . Then for any voltage assignment  $\vartheta : \mathcal{X}_{\alpha,\beta} \rightarrow Z_N$ ,

(i) if  $M$  is orientable, the minimum genus  $g_{min}$  of the lifting map  $M^\vartheta$  which admits an automorphism of order  $N$ , fixed-free on  $V(M^\vartheta)$ , is

$$g_{min} = 1 + N\{g(M) - 1 + (1 - \sum_{m \in \mathcal{O}(F(M))} \frac{1}{p_1}) \lfloor \frac{\phi(M)}{2} \rfloor\}.$$

(ii) if  $M$  is non-orientable, the minimum genus  $g'_{min}$  of the lifting map  $M^\vartheta$  which admits an automorphism of order  $N$ , fixed-free on  $V(M^\vartheta)$ , is

$$g'_{min} = 2 + N\{g(M) - 2 + 2(1 - \frac{1}{p_1}) \lfloor \frac{\phi(M)}{2} \rfloor\}. \quad \spadesuit$$

**Theorem 2.12.** The maximum order  $N_{max}$  of an automorphism  $g$  of an orientable map  $M$  of genus  $\geq 2$  is

$$N_{max} \leq 2g(M) + 1$$

and the maximum order  $N'_{max}$  of an automorphism  $g$  of a non-orientable map of genus  $\geq 3$  is

$$N'_{max} \leq g(M) + 1,$$

where  $g(M)$  is the genus of the map  $M$ .

**Corollary 2.10.** The maximum order of an automorphism of a Riemann surface of genus  $\geq 2$  is  $2g(M) + 1$ , and the maximum order of an automorphism of a non-orientable Klein surface of genus  $\geq 3$  without boundary is  $g(M) + 1$ .

### §2.7 The Subgroup of a Graph Being That of Maps

**Theorem 2.13.** Let  $\Gamma$  be a connected graph. If  $G \preceq \text{Aut}\Gamma$ , then  $G$  is an automorphism group of a map underlying the graph  $\Gamma$  iff for  $\forall v \in V(\Gamma)$ , the stabler  $G_v \preceq \langle v \rangle \times \langle \alpha \rangle$ .

**Theorem 2.14.** Let  $\Gamma$  be a connected graph. If  $G \preceq \text{Aut}\Gamma$ , then  $G$  is an orientation-preserving automorphism group of a map underlying the graph  $\Gamma$  iff for  $\forall v \in V(\Gamma)$ , the stabler  $G_v \preceq \langle v \rangle$  is a cyclic group.

**Theorem 2.15.** Let  $M$  be a map underlying the graph  $G$  and  $o_{max}(M, g), o_{max}(G, g)$  be the maximum order of orientation-preserving automorphism in  $\text{Aut}M$  and in  $\text{Aut}_{\frac{1}{2}}G$ . Then

$$o_{max}(M, g) \leq o_{max}(G, g),$$

and the equality hold for at least one map underlying the graph  $G$ .

**Corollary 2.11.** For any positive integer  $n$ , there exists a vertex transitive map  $M$  underlying a circulant such that  $Z_n$  is an orientation-preserving automorphism group of the map  $M$ .

**Corollary 2.12.** The maximum order of an orientation - preserving automorphism of a complete map  $\mathcal{K}_n, n \geq 3$ , is at most  $n$ .

## Part III The representation of Automorphisms of a Map

### §3.1 Complete Maps

A map underlying a complete graph  $K_n$  is called a complete map. Let  $K_n$  be a complete graph of order  $n$ . Label its vertices by integers  $1, 2, \dots, n$ . Then its edge set is  $\{ij | 1 \leq i, j \leq n, i \neq j\}$ , and

$$\begin{aligned} \mathcal{X}_{\alpha, \beta}(K_n) &= \{i^{j+} : 1 \leq i, j \leq n, i \neq j\} \\ &\cup \{i^{j-} : 1 \leq i, j \leq n, i \neq j\} \end{aligned}$$

$$\alpha = \prod_{1 \leq i, j \leq n, i \neq j} (i^{j+}, i^{j-}),$$

$$\beta = \prod_{1 \leq i, j \leq n, i \neq j} (i^{j+}, i^{j+})(i^{j-}, i^{j-}).$$

**Theorem 3.1.** All orientation-preserving automorphisms of non-orientable complete maps of order  $\geq 4$  are extended actions of elements in

$$\mathcal{E}_{[s \frac{n}{s}]}, \quad \mathcal{E}_{[1, s \frac{n-1}{s}]},$$

and all orientation-reversing automorphisms of non-orientable complete maps of order  $\geq 4$  are extended actions of elements in

$$\alpha \mathcal{E}_{[(2s) \frac{n}{2s}]}, \quad \alpha \mathcal{E}_{[(2s) \frac{4}{2s}]}, \quad \alpha \mathcal{E}_{[1, 1, 2]},$$

where,  $\mathcal{E}_\theta$  denotes the conjugacy class containing element  $\theta$  in the symmetry group  $S_n$ .

**Theorem 3.2.** All orientation-preserving automorphisms of orientable complete maps of order  $\geq 4$  are extended actions of elements in

$$\mathcal{E}_{[s \frac{n}{s}]}, \quad \mathcal{E}_{[1, s \frac{n-1}{s}]}$$

and all orientation-reversing automorphisms of orientable complete maps of order  $\geq 4$  are extended actions of elements in

$$\alpha \mathcal{E}_{[(2s) \frac{n}{2s}]}, \quad \alpha \mathcal{E}_{[(2s) \frac{4}{2s}]}, \quad \alpha \mathcal{E}_{[1, 1, 2]},$$

where,  $\mathcal{E}_\theta$  denotes the conjugatcy class containing  $\theta$  in  $S_n$ .

### §3.2 Semi-Regular Maps

A graph is *semi-regular* if it is simple and its automorphism group action on its ordered pair of adjacent vertices is fixed-free and a map is semi-regular if it underlying a semi-regular graph.

**Theorem 3.3.** Let  $\Gamma$  be a semi-regular graph. Then all the automorphisms of orientable maps underlying the graph  $\Gamma$  are

$$g|_{\mathcal{X}_{\alpha,\beta}} \text{ and } \alpha h|_{\mathcal{X}_{\alpha,\beta}}, g, h \in \text{Aut}\Gamma \text{ with } h \equiv 0(\text{mod}2).$$

and all the automorphisms of non-orientable maps underlying the graph  $\Gamma$  are also

$$g|_{\mathcal{X}_{\alpha,\beta}} \text{ and } \alpha h|_{\mathcal{X}_{\alpha,\beta}}, g, h \in \text{Aut}\Gamma \text{ with } h \equiv 0(\text{mod}2).$$

### §3.3 One Face Maps

**Theorem 3.4.** Let  $B_n$  be a bouquet with  $n$  edges  $1, 2, \dots, n$ . Then the automorphisms  $(g; h_1, h_2, \dots, h_n)$  of orientable maps underlying a  $B_n, n \geq 1$ , are respective

$$(O1) \quad g \in \mathcal{E}_{[k \frac{n}{k}]}, h_i = 1, i = 1, 2, \dots, n;$$

$$(O2) \quad g \in \mathcal{E}_{[k \frac{n}{k}]} \text{ and if}$$

$$g = \prod_{i=1}^{n/k} (i_1, i_2, \dots, i_k),$$

where  $i_j \in \{1, 2, \dots, n\}, n/k \equiv 0(\text{mod}2)$ , then  $h_{i_1} = (1, \alpha\beta), i = 1, 2, \dots, \frac{n}{k}$  and  $h_{i_j} = 1$  for  $j \geq 2$ ;

$$(O3) \quad g \in \mathcal{E}_{[k^{2s}, (2k) \frac{n-2ks}{2k}]} \text{ and if}$$

$$g = \prod_{i=1}^{2s} (i_1, i_2, \dots, i_k) \prod_{j=1}^{(n-2ks)/2k} (e_{j_1}, e_{j_2}, \dots, e_{j_{2k}}),$$

where  $i_j, e_{j_t} \in \{1, 2, \dots, n\}$ , then  $h_{i_1} = (1, \alpha\beta), i = 1, 2, \dots, s, h_{i_l} = 1$  for  $l \geq 2$  and  $h_{j_t} = 1$  for  $t = 1, 2, \dots, 2k$  and the automorphisms  $(g; h_1, h_2, \dots, h_n)$  of non-orientable maps underlying a  $B_n, n \geq 1$ , are respective

$$(N1) \quad g \in \mathcal{E}_{[k \frac{n}{k}]}, h_i = 1, i = 1, 2, \dots, n;$$

$$(N2) \quad g \in \mathcal{E}_{[k \frac{n}{k}]} \text{ and if}$$

$$g = \prod_{i=1}^{n/k} (i_1, i_2, \dots, i_k),$$

where  $i_j \in \{1, 2, \dots, n\}, n/k \equiv 0(\text{mod}2)$ , then  $h_{i_1} = (1, \alpha\beta), (1, \beta)$  with at least one  $h_{i_{01}}(1, \beta), i = 1, 2, \dots, \frac{n}{k}$  and  $h_{i_j} = 1$  for  $j \geq 2$ ;

$$(N3) \quad g \in \mathcal{E}_{[k^{2s}, (2k) \frac{n-2ks}{2k}]} \text{ and if}$$

$$g = \prod_{i=1}^{2s} (i_1, i_2, \dots, i_k) \prod_{j=1}^{(n-2ks)/2k} (e_{j_1}, e_{j_2}, \dots, e_{j_{2k}}),$$

where  $i_j, e_{j_t} \in \{1, 2, \dots, n\}$ , then  $h_{i_1} = (1, \alpha\beta), (1, \beta)$  with at least one  $h_{i_{0_1}} = (1, \beta), i = 1, 2, \dots, s, h_{i_l} = 1$  for  $l \geq 2$  and  $h_{j_t} = 1$  for  $t = 1, 2, \dots, 2k$ .

## Part IV The Enumeration of Unrooted Maps

### §4.1 A Scheme for Enumeration

**Theorem 4.1.** For a given graph  $\Gamma$ , let  $\mathcal{E} \subset \mathcal{E}^L(\Gamma)$ , then the numbers  $n(\mathcal{E}, \Gamma)$  and  $\eta(\mathcal{E}, \Gamma)$  of non-isomorphic unrooted maps and non-equivalent embeddings in  $\mathcal{E}$  are respective

$$n(\mathcal{E}, \Gamma) = \frac{1}{2|\text{Aut}_{\frac{1}{2}}\Gamma|} \sum_{g \in \text{Aut}_{\frac{1}{2}}\Gamma} |\Phi_1(g)|,$$

where,  $\Phi_1(g) = \{\mathcal{P} | \mathcal{P} \in \mathcal{E} \text{ and } \mathcal{P}^g = \mathcal{P} \text{ or } \mathcal{P}^{g\alpha} = \mathcal{P}\}$  and

$$\eta(\mathcal{E}, \Gamma) = \frac{1}{|\text{Aut}_{\frac{1}{2}}\Gamma|} \sum_{g \in \text{Aut}_{\frac{1}{2}}\Gamma} |\Phi_2(g)|,$$

where,  $\Phi_2(g) = \{\mathcal{P} | \mathcal{P} \in \mathcal{E} \text{ and } \mathcal{P}^g = \mathcal{P}\}$ .

**Corollary 4.1.** The numbers  $n^O(\Gamma), n^N(\Gamma)$  and  $n^L(\Gamma)$  of non-isomorphic unrooted orientable maps, non-orientable maps and locally orientable maps underlying a graph  $\Gamma$  are respective

$$n^O(\Gamma) = \frac{1}{2|\text{Aut}_{\frac{1}{2}}\Gamma|} \sum_{g \in \text{Aut}_{\frac{1}{2}}\Gamma} |\Phi_1^O(g)|;$$

$$n^N(\Gamma) = \frac{1}{2|\text{Aut}_{\frac{1}{2}}\Gamma|} \sum_{g \in \text{Aut}_{\frac{1}{2}}\Gamma} |\Phi_1^N(g)|;$$

$$n^L(\Gamma) = \frac{1}{2|\text{Aut}_{\frac{1}{2}}\Gamma|} \sum_{g \in \text{Aut}_{\frac{1}{2}}\Gamma} |\Phi_1^L(g)|,$$

where,  $\Phi_1^O(g) = \{\mathcal{P} | \mathcal{P} \in \mathcal{E}^O(\Gamma) \text{ and } \mathcal{P}^g = \mathcal{P} \text{ or } \mathcal{P}^{g\alpha} = \mathcal{P}\}$ ,  $\Phi_1^N(g) = \{\mathcal{P} | \mathcal{P} \in \mathcal{E}^N(\Gamma) \text{ and } \mathcal{P}^g = \mathcal{P} \text{ or } \mathcal{P}^{g\alpha} = \mathcal{P}\}$ ,  $\Phi_1^L(g) = \{\mathcal{P} | \mathcal{P} \in \mathcal{E}^L(\Gamma) \text{ and } \mathcal{P}^g = \mathcal{P} \text{ or } \mathcal{P}^{g\alpha} = \mathcal{P}\}$ .

### §4.2 The Number of Complete Maps

**Theorem 4.2.** The number  $n^L(K_n)$  of complete maps of order  $n \geq 5$  on surfaces is

$$n^L(K_n) = \frac{1}{2} \left( \sum_{k|n} + \sum_{k|n, k \equiv 0 \pmod{2}} \right) \frac{2^{\alpha(n,k)} (n-2)! \frac{n}{k}}{k^{\frac{n}{k}} \left(\frac{n}{k}\right)!} + \sum_{k|(n-1), k \neq 1} \frac{\phi(k) 2^{\beta(n,k)} (n-2)! \frac{n-1}{k}}{n-1},$$

where,

$$\alpha(n, k) = \begin{cases} \frac{n(n-3)}{2k}, & \text{if } k \equiv 1 \pmod{2}; \\ \frac{n(n-2)}{2k}, & \text{if } k \equiv 0 \pmod{2}, \end{cases}$$

and



$$\beta(n, k) = \begin{cases} \frac{(n-1)(n-2)}{2k}, & \text{if } k \equiv 1(\text{mod}2); \\ \frac{(n-1)(n-3)}{2k}, & \text{if } k \equiv 0(\text{mod}2). \end{cases}$$

and  $n^L(K_4) = 11$ .

**Theorem 4.3.** The number  $n^O((K_n))$  of complete maps of order  $n \geq 5$  on orientable surfaces is

$$n^O(K_n) = \frac{1}{2} \left( \sum_{k|n} + \sum_{k|n, k \equiv 0(\text{mod}2)} \right) \frac{(n-2)!^{\frac{n}{k}}}{k^{\frac{n}{k}} \left(\frac{n}{k}\right)!} + \sum_{k|(n-1), k \neq 1} \frac{\phi(k)(n-2)!^{\frac{n-1}{k}}}{n-1}.$$

and  $n(K_4) = 3$ . For  $K_4$  on the surfaces, see the Fig.2

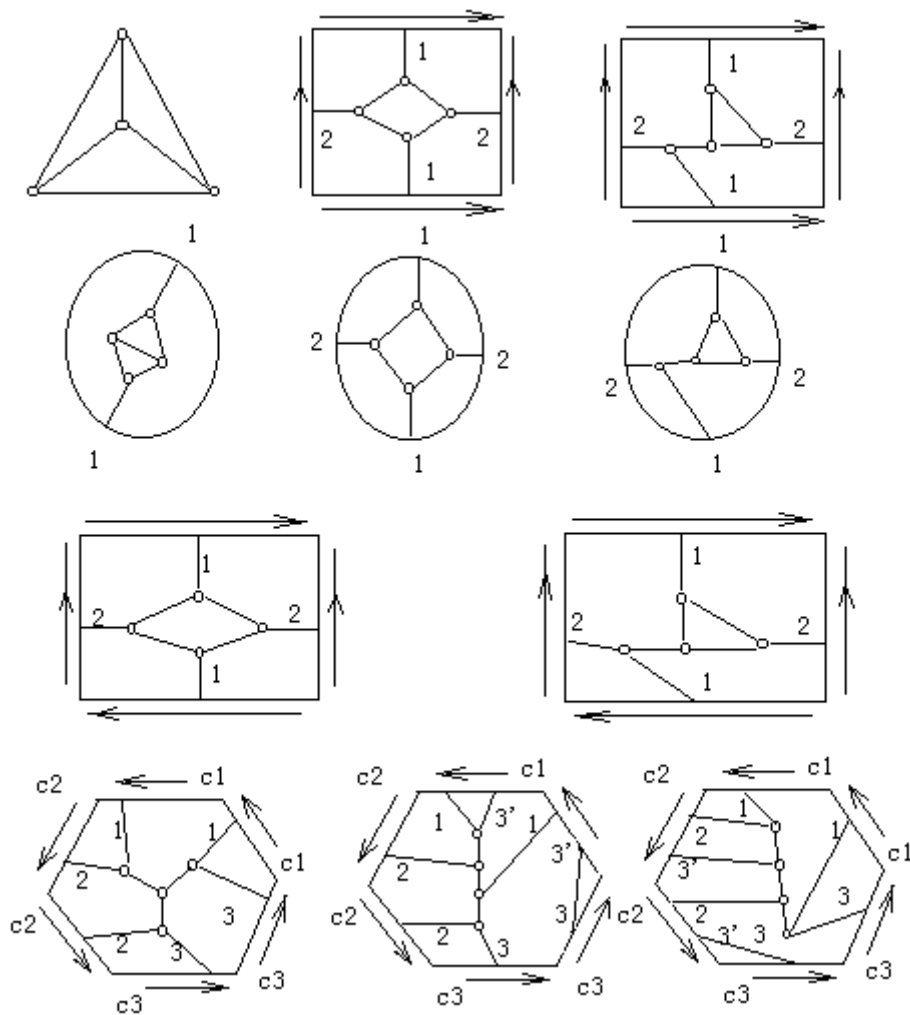


Fig.2

§4.3 The Number of Semi-Regular Maps

**Theorem 4.4.** Let  $\Gamma$  be a semi-regular graph. Then the numbers of unrooted maps on orientable and non-orientable surfaces underlying the graph  $\Gamma$  are

$$n^O(\Gamma) = \frac{1}{|\text{Aut}\Gamma|} \left( \sum_{\xi \in \text{Aut}\Gamma} \lambda(\xi) \prod_{x \in T_\xi^V} \left( \frac{d(x)}{o(\xi|_{N_\Gamma(x)})} - 1 \right)! \right)$$

and

$$n^N(\Gamma) = \frac{1}{|\text{Aut}\Gamma|} \times \sum_{\xi \in \text{Aut}\Gamma} (2^{|T_\xi^E| - |T_\xi^V|} - 1) \lambda(\xi) \prod_{x \in T_\xi^V} \left( \frac{d(x)}{o(\xi|_{N_\Gamma(x)})} - 1 \right)!,$$

where  $\lambda(\xi) = 1$  if  $o(\xi) \equiv 0 \pmod{2}$  and  $\frac{1}{2}$ , otherwise.

**Corollary 4.2.** Let  $\Gamma = \text{Cay}(Z_p : S)$  be connected graph of prime order  $p$  with  $(p-1, |S|) = 2$ . Then

$$n^O(\Gamma, \mathcal{M}) = \frac{(|S| - 1)!^p + 2p(|S| - 1)!^{\frac{p+1}{2}}}{4p} + \frac{(p-1)(|S| - 1)!}{4p}$$

and

$$\begin{aligned} n^N(\Gamma, \mathcal{M}) &= \frac{(2^{\frac{p|S|}{2} - p} - 1)(|S| - 1)!^p}{2p} + \frac{2(2^{\frac{p|S| - 2p - 2}{4}} - 1)p(|S| - 1)!^{\frac{p+1}{2}}}{2p} \\ &+ \frac{(2^{\frac{|S| - 2}{2}} - 1)(p-1)(|S| - 1)!}{4p}. \end{aligned}$$

#### §4.4 The Number of One Vertex Maps

**Theorem 4.5.** The number  $n^O(B_n)$  of non -isomorphic maps on orientable surfaces underlying a graph  $B_n$  is

$$\begin{aligned} n^O(B_n) &= \sum_{k|2n, k \neq 2n} k^{\frac{2n}{k} - 1} \left( \frac{2n}{k} - 1 \right)! \frac{1}{\left( \frac{2n}{k} \right)!} \frac{\partial^{\frac{2n}{k}} (Z(S_n[S_2]))}{\partial s_k^{\frac{2n}{k}}} \Big|_{s_k=0} \\ &+ \phi(2n) \frac{\partial (Z(S_n[S_2]))}{\partial s_{2n}} \Big|_{s_{2n}=0} \end{aligned}$$

**Theorem 4.6.** he number  $n^N(B_n)$  of non -isomorphic maps on the non-orientable surfaces with an underlying graph  $B_n$  is

$$\begin{aligned} n^N(B_n) &= \frac{(2n-1)!}{n!} + \sum_{k|2n, 3 \leq k < 2n} (2k)^{\frac{2n}{k} - 1} \left( \frac{2n}{k} - 1 \right)! \frac{\partial^{\frac{2n}{k}} (Z(S_n[S_2]))}{\partial s_k^{\frac{2n}{k}}} \Big|_{s_k=0} \\ &+ \frac{1}{2^n n!} \left( \sum_{s \geq 1} \frac{n!}{(n-2s)! s!} + 4^n (n-1)! \left( \frac{\partial^n (Z(S_n[S_2]))}{\partial s_2^n} \Big|_{s_2=0} - \lfloor \frac{n}{2} \rfloor \right) \right). \end{aligned}$$

For  $B_2$  on the surfaces, see the Fig.3.

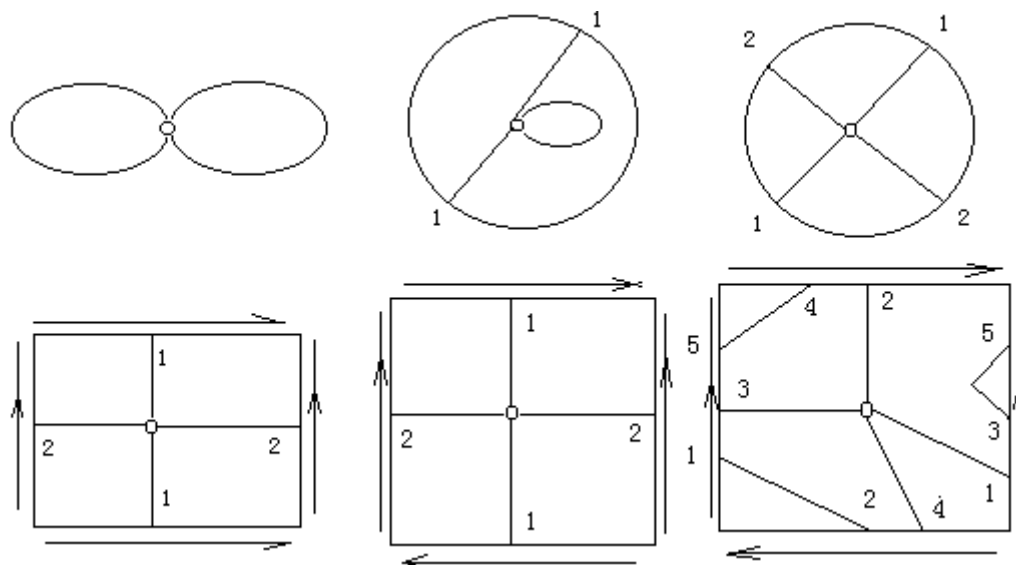


Fig.3

## Part V Map Geometry

### §5.1 What are the Contribution of Maps to Mathematics

#### Klein Erlanger Program:

Any geometry is finding invariant properties under the transformation group of this geometry (This is essentially the group action idea.)

The following problems are applications of the Klein Erlanger Program in maps:

- (i) determine isomorphism maps or rooted maps;
- (ii) determine equivalent embeddings of a graph;
- (iii) determine an embedding whether exists;
- (iv) enumerate maps or rooted maps on a surface;
- (v) enumerate embeddings of a graph on a surface;
- (vi)  $\dots$ , etc.

**What are their importance to classical mathematics?**

**What are their contributions to science?**

### §5.2 Smarandache Geometries

#### Classical geometries:

The axiom system of *Euclid geometry* is the following:

- (A1) there is a straight line between any two points.
- (A2) a finite straight line can produce a infinite straight line continuously.

(A3) any point and a distance can describe a circle.

(A4) all right angles are equal to one another.

(A5) if a straight line falling on two straight lines make the interior angles on the same side less than two right angles, then the two straight lines, if produced indefinitely, meet on that side on which are the angles less than the two right angles.

The axiom (A5) can be also replaced by:

(A5') given a line and a point exterior this line, there is one line parallel to this line.

The *Lobachevshy-Bolyai-Gauss geometry*, also called hyperbolic geometry, is a geometry with axioms (A1) – (A4) and the following axiom (L5):

(L5) there are infinitely many line parallels to a given line passing through an exterior point.

The *Riemann geometry* is a geometry with axioms (A1) – (A4) and the following axiom (R5):

there is no parallel to a given line passing through an exterior point.

Smarandache introduced the *paradoxist geometry, non-geometry, counter-projective geometry* and *anti-geometry* by contradicts the axioms (A1) – (A5) in Euclid geometry, generalize the classical geometries. For example, the axioms of a Paradoxist geometry are (A1) – (A4) and with one of the following as the axiom (P5):

(i) there are at least a straight line and a point exterior to it in this space for which any line that passes through the point intersect the initial line.

(ii) there are at least a straight line and a point exterior to it in this space for which only one line passes through the point and does not intersect the initial line.

(iii) there are at least a straight line and a point exterior to it in this space for which only a finite number of lines  $l_1, l_2, \dots, l_k, k \geq 2$  pass through the point and do not intersect the initial line.

(iv) there are at least a straight line and a point exterior to it in this space for which an infinite number of lines pass through the point (but not all of them) and do not intersect the initial line.

(v) there are at least a straight line and a point exterior to it in this space for which any line that passes through the point and does not intersect the initial line.

F. Smarandache, Mixed noneuclidean geometries, *eprint arXiv: math/0010119*, 10/2000.

The Smarandache geometries are defined as follows.

**Definition 5.1.** An axiom is said Smarandachely denied if the axiom behaves in at least two different ways within the same space, i.e., validated and invalidated, or only invalidated but in multiple distinct ways.

A Smarandache geometry is a geometry which has at least one Smarandachely denied axiom (1969).

A nice model for the Smarandache geometries, called *s-manifolds*, is found by Isier, which is defined by Mao using maps as follows:

An *s-manifold* is any collection  $\mathcal{C}(T, n)$  of these equilateral triangular disks  $T_i, 1 \leq i \leq n$  satisfying the following conditions:

(i) Each edge  $e$  is the identification of at most two edges  $e_i, e_j$  in two distinct triangular disks  $T_i, T_j, 1 \leq i, j \leq n$  and  $i \neq j$ ;

(ii) Each vertex  $v$  is the identification of one vertex in each of five, six or seven distinct triangular disks.

H.Iseri, *Smarandache manifolds*, American Research Press, Rehoboth, NM,2002.

L.F.Mao, *Automorphism groups of maps, surfaces and Smarandache geometries*, American Research Press, Rehoboth, NM,2005.

### §5.3 A Classification of Smarandache Manifolds

#### Classical Type:

- (1)  $\Delta_1 = \{5 - \text{regular triangular maps}\}$  (elliptic);
- (2)  $\Delta_2 = \{6 - \text{regular triangular maps}\}$  (euclidean);
- (3)  $\Delta_3 = \{7 - \text{regular triangular maps}\}$  (hyperbolic).

#### Smarandache Type:

- (4)  $\Delta_4 = \{\text{triangular maps with vertex valency 5 and 6}\}$  (euclid-elliptic);
- (5)  $\Delta_5 = \{\text{triangular maps with vertex valency 5 and 7}\}$  (elliptic-hyperbolic);
- (6)  $\Delta_6 = \{\text{triangular maps with vertex valency 6 and 7}\}$  (euclid-hyperbolic);
- (7)  $\Delta_7 = \{\text{triangular maps with vertex valency 5, 6 and 7}\}$  (mixed).

**Theorem 5.1.**  $|\Delta_1| = 2$ ,  $|\Delta_5| \geq 2$  and  $|\Delta_i|, i = 2, 3, 4, 6, 7$  are infinite.

Iseri proposed a question: *Do the other closed 2-manifolds correspond to s-manifolds with only hyperbolic vertices?* Since  $|\Delta_3|$  is infinite, the answer is affirmative for this question.

### §5.4 Map Geometry

**Definition 5.2.** For a combinatorial map  $M$  with each vertex valency  $\geq 3$ , associates a real number  $\mu(u), 0 < \mu(u) < \pi$ , to each vertex  $u, u \in V(M)$ . Call  $(M, \mu)$  the fundamental map space,  $\mu(u)$  the angle factor of the vertex  $u$  and to be orientable or non-orientable if the map  $M$  is orientable or not.

**Definition 5.3.** A point  $u$  in a map space  $(M, \mu)$  is called elliptic, euclidean or hyperbolic if  $\rho(u)\mu(u) < 2\pi$ ,  $\rho(u)\mu(u) = 2\pi$  or  $\rho(u)\mu(u) > 2\pi$ .

**Definition 5.4.** Let  $(M, \mu)$  be a map space. An  $m$ -line in  $(M, \mu)$  is a curve with a constant curvature. Points in  $(M, \mu)$  are called  $m$ -points.

We have the following result for map geometries.

**Theorem 5.2.** For any planar map  $M$  with order  $\geq 3$  and vertex valency  $\geq 3$ , there is an angle factor  $\mu$  such that  $(M, \mu)$  is a Smarandache geometry by denial the axiom (A5) with the axioms (A5), (L5) and (R5).

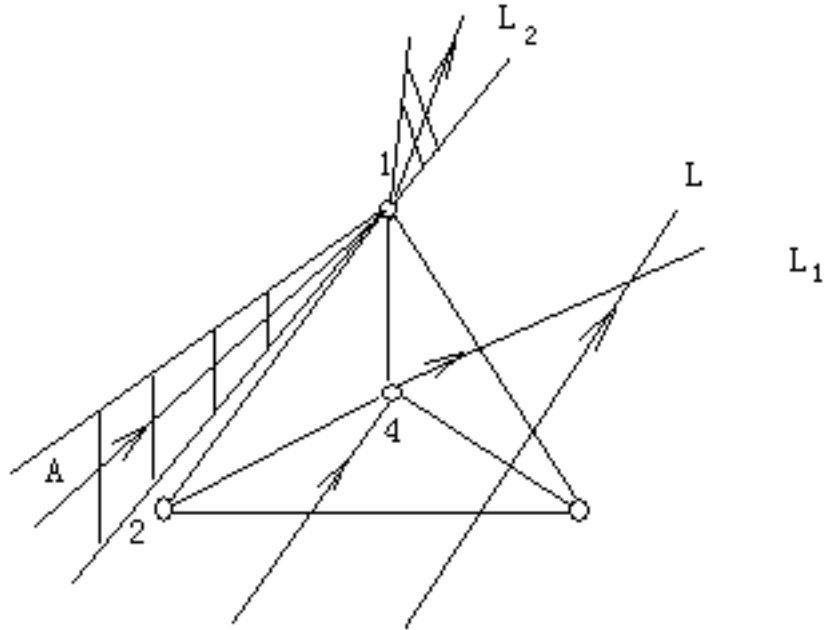


Fig.4

**Theorem 5.3.** For any map  $M$  on an orientable surface with order  $\geq 3$  and vertex valency  $\geq 3$ , there is an angle factor  $\mu$  such that  $(M, \mu)$  is a Smarandache geometry by denial the axiom (A5) with the axioms (A5), (L5) and (R5).

**Theorem 5.4.** Let  $P$  be a  $k$ -polygon in a map space with each line segment passes through at most one elliptic or hyperbolic point. If  $H$  is the set of elliptic points and hyperbolic points on the line segment of  $P$ , then the sum of the internal angles in  $P$  is

$$(k + |H| - 2)\pi - \frac{1}{2} \sum_{u \in H} \rho(u)\mu(u).$$

**Corollary 5.1.** Let  $\Delta$  be a triangle in a map space. Then

- (i) if  $\Delta$  is euclidean, then then the sum of its internal angles is equal to  $\pi$ ;
- (ii) if  $\Delta$  is elliptic, then the sum of its internal angles is less than  $\pi$ ;
- (iii) if  $\Delta$  is hyperbolic, then the sum of its internal angles is more than  $\pi$ .

**Theorem 5.5.** The number  $n^O(\Gamma, g)$  of non -equivalent orientable map geometries underlying a simple graph  $\Gamma$  by denial the axiom (A5) by (A5), (L5) or (R5) is

$$\frac{3^{|\Gamma|} \prod_{v \in V(\Gamma)} (\rho(v) - 1)!}{2|\text{Aut}\Gamma|},$$

where  $\rho(v)$  is the valency of the vertex  $v$  in the graph  $G$ .

## Part VI Open Problems for Combinatorial Maps

### §6.1 The Uniformization Theorem for Simple Connected Riemann Surfaces

The *uniformization theorem* for simple connected Riemann surfaces is one of those beautiful results in the Riemann surface theory, which is stated as follows:

If  $\mathcal{S}$  is a simple connected Riemann surface, then  $\mathcal{S}$  is conformally equivalent to one and only one of the following three:

- (a)  $\mathcal{C} \cup \infty$ ;
- (b)  $\mathcal{C}$ ;
- (c)  $\Delta = \{z \in \mathcal{C} \mid |z| < 1\}$ .

**How can we define the conformal equivalence for maps enabling us to get the uniformization theorem of maps?**

**What is the correspondence class maps with the three type (a) – (c) Riemann surfaces?**

### §6.2 Combinatorial Construction of an Algebraic Curve of Genus

A complex plane algebraic curve  $\mathcal{C}_l$  is a homogeneous equation  $f(x, y, z) = 0$  in  $P_2\mathcal{C} = (\mathcal{C}^2 \setminus (0, 0, 0)) / \sim$ , where  $f(x, y, z)$  is a polynomial in  $x, y$  and  $z$  with coefficients in  $\mathcal{C}$ . The degree of  $f(x, y, z)$  is said the *degree of the curve*  $\mathcal{C}_l$ . For a Riemann surface  $S$ , a well-known result is ([2]) there is a holomorphic mapping  $\varphi : S \rightarrow P_2\mathcal{C}$  such that  $\varphi(S)$  is a complex plane algebraic curve and

$$g(S) = \frac{(d(\varphi(S)) - 1)(d(\varphi(S)) - 2)}{2}.$$

By map theory, we know a combinatorial map also is on a surface with genus. Then

**whether we can get an algebraic curve by all edges in a map or by make operations on the vertices or edges of the map to get plane algebraic curve with given  $k$ -multiple points?**

**how do we find the equation  $f(x, y, z) = 0$ ?**

### §6.3 Classification of $s$ -Manifolds by Maps

We present an elementary classification for the closed  $s$ -manifolds in the Part V. For the general  $s$ -manifolds, their correspondence combinatorial model is the maps on surfaces with boundary, founded by Bryant and Singerman in 1985 (R.P.Bryant and D.Singerman, Foundations of the theory of maps on surfaces with boundary, *Quart.J.Math.Oxford*(2),36(1985), 17-41.). The later is also related to the modular groups of spaces and need to investigate further itself. The questions are

(i) **how can we combinatorially classify the general  $s$ -manifolds by maps with boundary?**

(ii) **how can we find the automorphism group of an  $s$ -manifold?**

(iii) **how can we know the numbers of non-isomorphic  $s$ -manifolds, with or without root?**

(iv) find rulers for drawing an  $s$ -manifold on a surface, such as, the torus, the projective plane or Klein bottle, not the plane.

#### §6.4 Map Geometries

(i) For a given graph, determine properties of the map geometries underlying this graph.

(ii) For a given locally orientable surface, determine the properties of map geometries on this surface.

(iii) Classify map geometries on a locally orientable surface.

(iv) Enumerate non-equivalent map geometries underlying a graph or on a locally orientable surface.

(v) Establish the surface geometry by map geometries.

(vi) Applying map geometries to classical mathematics or other sciences.

#### §6.5 Gauss Mapping Among Surfaces

In the classical differential geometry, a *Gauss mapping* among surfaces is defined as follows:

Let  $\mathcal{S} \subset R^3$  be a surface with an orientation  $\mathbf{N}$ . The mapping  $N : \mathcal{S} \rightarrow R^3$  takes its value in the unit sphere

$$S^2 = \{(x, y, z) \in R^3 | x^2 + y^2 + z^2 = 1\}$$

along the orientation  $\mathbf{N}$ . The map  $N : \mathcal{S} \rightarrow S^2$ , thus defined, is called the Gauss mapping.

we know that for a point  $P \in \mathcal{S}$  such that the Gaussian curvature  $K(P) \neq 0$  and  $V$  a connected neighborhood of  $P$  with  $K$  does not change sign,

$$K(P) = \lim_{A \rightarrow 0} \frac{N(A)}{A},$$

where  $A$  is the area of a region  $B \subset V$  and  $N(A)$  is the area of the image of  $B$  by the Gauss mapping  $N : \mathcal{S} \rightarrow S^2$ . The questions are

(i) what is its combinatorial meaning of the Gauss mapping? How to realizes it by maps?

(ii) how we can define various curvatures for maps and rebuilt the results in the classical differential geometry?

#### §6.6 The Gauss-Bonnet Theorem

Let  $\mathcal{S}$  be a compact orientable surface. Then

$$\int \int_{\mathcal{S}} K d\sigma = 2\pi\chi(\mathcal{S}),$$

where  $K$  is Gaussian curvature on  $\mathcal{S}$ .

This is the famous Gauss-Bonnet theorem for compact surface. The questions are

(i) what is its combinatorial mean of the Gauss curvature?

(ii) how can we define the angle, area, volume, curvature,  $\dots$ , of a map?

(iii) can we rebuilt the Gauss-Bonnet theorem by maps? or can we get a generalization of the classical Gauss-Bonnet theorem by maps?



# On the mean value of Smarandache ceil function<sup>1</sup>

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**Abstract** For any fixed positive integer  $n$ , the Smarandache ceil function of order  $k$  is denoted by  $N^* \rightarrow N$  and has the following definition:

$$S_k(n) = \min\{x \in N \mid n \mid x^k\} (\forall n \in N^*).$$

In this paper, we study the mean value properties of the Smarandache ceil function, and give a sharp asymptotic formula for it.

**Keywords** Smarandache ceil function; Mean value; Asymptotic formula.

## §1. Introduction

For any fixed positive integer  $n$ , the Smarandache ceil function of order  $k$  is denoted by  $N^* \rightarrow N$  and has the following definition:

$$S_k(n) = \min\{x \in N \mid n \mid x^k\} (\forall n \in N^*).$$

For example,  $S_2(1) = 1, S_2(2) = 2, S_2(3) = 3, S_2(4) = 2, S_2(5) = 5, S_2(6) = 6, S_2(7) = 7, S_2(8) = 4, S_2(9) = 3, \dots$ . This was introduced by Smarandache who proposed many problems in [1]. There are many papers on the Smarandache ceil function. For example, Ibstedt [2] and [3] studied this function both theoretically and computationally, and got the following conclusions:

$$(\forall a, b \in N^*)(a, b) = 1 \Rightarrow S_k(ab) = S_k(a)S_k(b),$$

$$S_k(p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_r^{\alpha_r}) = S_k(p_1^{\alpha_1}) \cdots S_k(p_r^{\alpha_r}).$$

In this paper, we study the mean value properties of the Smarandache ceil function, and give a sharp asymptotic formula for it. That is, we shall prove the following:

**Theorem.** Let  $x \geq 2$ , for any fixed positive integer  $k$ , we have the asymptotic formula

$$\sum_{n \leq x} S_k(n) = \frac{x^2}{2} \zeta(2k-1) \prod_p \left[ 1 - \frac{1}{p(p+1)} \left( 1 + \frac{1}{p^{2k-3}} \right) \right] + O\left(x^{\frac{3}{2}+\epsilon}\right).$$

where  $\zeta(s)$  is the Riemann zeta function,  $\prod_p$  denotes the product over all prime  $p$ , and  $\epsilon$  be any fixed positive number.

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This solved a conjecture of [4].

From this theorem we may immediately deduce the following:

**Corollary 1.** For any real number  $x \geq 2$ , we have the asymptotic formula:

$$\sum_{n \leq x} S_2(n) = \frac{3x^2}{\pi^2} \zeta(3) + O\left(x^{\frac{3}{2}+\epsilon}\right).$$

**Corollary 2.** Let  $x \geq 1$  and  $Sc(n)$  denotes the smallest cube greater than or equal to  $n$ , then we have

$$\sum_{n \leq x} (Sc(n) - n) = \frac{9}{10} x^{\frac{5}{3}} + O\left(x^{\frac{4}{3}}\right).$$

## §2. A Lemma

To complete the proof of the theorem, we need the following famous Perron formula [5]:

**Lemma.** Suppose that the Dirichlet series  $f(s) = \sum_{n=1}^{\infty} a(n)n^{-s}$ , with  $s = \sigma + it$  is convergent absolutely for  $\sigma > \beta$ , and that there exist a positive  $\lambda$  and a positive increasing function  $A(s)$  such that

$$\sum_{n=1}^{\infty} |a(n)| n^{-\sigma} \ll (\sigma - \beta)^{-1}, \sigma \rightarrow \beta + 0$$

and

$$a(n) \ll A(n), n = 1, 2, \dots$$

Then for any  $b > 0$ ,  $b + \sigma > \beta$ , and  $x$  not to be an integer, we have

$$\begin{aligned} \sum_{n \leq x} a(n)n^{-s_0} &= \frac{1}{2\pi i} \int_{b-iT}^{b+iT} f(s_0 + \omega) \frac{x^\omega}{\omega} d\omega + O\left(\frac{x^b}{T(b + \sigma - \beta)^\lambda}\right) \\ &+ O\left(\frac{A(2x)x^{1-\sigma} \log x}{T \|x\|}\right), \end{aligned}$$

where  $\|x\|$  is the nearest integer to  $x$ .

## §3. Proof of the theorem

In this section, we shall complete the proof of Theorem. Let

$$f(s) = \sum_{n=1}^{\infty} \frac{S_k(n)}{n^s},$$

where  $\operatorname{Re}(s) > 3$ .

By Euler product formula [6], we have

$$\begin{aligned}
 f(s) &= \prod_p \left( 1 + \frac{S_k(p)}{p^s} + \frac{S_k(p^2)}{p^{2s}} + \cdots + \frac{S_k(p^k)}{p^{ks}} + \cdots \right) \\
 &= \prod_p \left( 1 + \frac{p}{p^s} + \frac{p}{p^{2s}} + \cdots + \frac{p}{p^{ks}} + \frac{p^2}{p^{(k+1)s}} + \cdots + \frac{p^2}{p^{2ks}} + \cdots \right) \\
 &= \prod_p \left( 1 + \frac{1}{p^{s-1}} \frac{1 - \frac{1}{p^{ks}}}{1 - \frac{1}{p^s}} + \frac{p^2}{p^{(k+1)s}} \frac{1 - \frac{1}{p^{ks}}}{1 - \frac{1}{p^s}} + \cdots \right) \\
 &= \prod_p \left( 1 + \frac{1 - \frac{1}{p^{ks}}}{1 - \frac{1}{p^s}} \frac{\frac{1}{p^{s-1}}}{1 - \frac{1}{p^{ks-1}}} \right) \\
 &= \frac{\zeta(s)\zeta(s-1)\zeta(ks-1)}{\zeta(2s-2)} \prod_p \left( 1 - \frac{1}{1 + \frac{1}{p^{s-1}}} \left( \frac{1}{p^{ks-1}} + \frac{1}{p^s} \right) \right)
 \end{aligned}$$

where  $\zeta(s)$  is the Riemann zeta function.

Taking  $s_0 = 0$ ,  $b = 3$ ,  $T = x^{\frac{3}{2}}$  in the Lemma, we have

$$\sum_{n \leq x} S_k(n) = \frac{1}{2i\pi} \int_{3-iT}^{3+iT} \frac{\zeta(s)\zeta(s-1)\zeta(ks-1)}{\zeta(2s-2)} R(s) \frac{x^s}{s} ds + O(x^{\frac{3}{2}+\varepsilon}),$$

where

$$R(s) = \prod_p \left( 1 - \frac{1}{1 + \frac{1}{p^{s-1}}} \left( \frac{1}{p^{ks-1}} + \frac{1}{p^s} \right) \right).$$

To estimate the main term

$$\frac{1}{2i\pi} \int_{3-iT}^{3+iT} \frac{\zeta(s)\zeta(s-1)\zeta(ks-1)}{\zeta(2s-2)} R(s) \frac{x^s}{s} ds,$$

we move the integral line from  $s = 3 \pm iT$  to  $s = \frac{3}{2} \pm iT$ . This time, the function

$$f(s) = \frac{\zeta(s)\zeta(s-1)\zeta(ks-1)x^s}{\zeta(2s-2)s} R(s)$$

has a simple pole point at  $s = 2$  with residue  $\frac{x^2}{2}\zeta(2k-1)R(2)$ . So we have

$$\begin{aligned}
 &\frac{1}{2i\pi} \left( \int_{3-iT}^{3+iT} + \int_{3+iT}^{\frac{3}{2}+iT} + \int_{\frac{3}{2}+iT}^{\frac{3}{2}-iT} + \int_{\frac{3}{2}-iT}^{3-iT} \right) \frac{\zeta(s)\zeta(s-1)\zeta(ks-1)x^s}{\zeta(2s-2)s} R(s) ds \\
 &= \frac{x^2}{2} \zeta(2k-1) \prod_p \left[ 1 - \frac{1}{p(p+1)} \left( 1 + \frac{1}{p^{2k-3}} \right) \right].
 \end{aligned}$$

Note that

$$\frac{1}{2i\pi} \left( \int_{3+iT}^{\frac{3}{2}+iT} + \int_{\frac{3}{2}+iT}^{\frac{3}{2}-iT} + \int_{\frac{3}{2}-iT}^{3-iT} \right) \frac{\zeta(s)\zeta(s-1)\zeta(ks-1)x^s}{\zeta(2s-2)s} R(s) ds \ll x^{\frac{3}{2}+\varepsilon}$$

From the above, we may immediately get the asymptotic formula:

$$\sum_{n \leq x} S_k(n) = \frac{x^2}{2} \zeta(2k-1) \prod_p \left[ 1 - \frac{1}{p(p+1)} \left( 1 + \frac{1}{p^{2k-3}} \right) \right] + O(x^{\frac{3}{2}+\varepsilon}).$$

This completes the proof of Theorem.

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# An equation concerning the Smarandache function<sup>1</sup>

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**Abstract** In this paper, we solve an open question concerning the Smarandache function.

**Keywords** Smarandache function; Euler totient function; Diophantine equation.

For any positive integer  $n$ , let  $S(n)$  and  $\varphi(n)$  denote the Smarandache function and the Euler totient function respectively. In [1], Bencze asked that solve the equation

$$S\left(\sum_{k=1}^n n^k\right) = \varphi(n) \prod_{k=1}^n S(k) \quad (1)$$

in positive integers  $n$ . In this paper we solve this question as follows.

**Theorem.** The equation (1) has only positive integer solution  $n = 1$ .

The proof of our Theorem depends on the following lemmas.

**Lemma 1([3]).** If  $a$  is a positive integer with  $a > 1$ , then  $S(a) > 1$ .

**Lemma 2([3]).** If  $a$  and  $b$  are coprime positive integers, then we have  $S(ab) = \max(S(a), S(b))$ .

**Lemma 3([2]).** If  $p$  is a prime and  $\alpha$  is a positive integer, then we have  $S(p^\alpha) \leq p\alpha$  and  $p|S(p^\alpha)$ .

**Proof of Theorem.** It is easy to see that (1) has only solution  $n = 1$  with  $n \leq 5$ . We now suppose that  $n$  is a positive integer solution of (1) with  $n > 5$ . Since  $\gcd(n, 1 + n + \cdots + n^{n-1})^\delta = 1$ , by Lemma 2, we get

$$\begin{aligned} S\left(\sum_{k=1}^n n^k\right) &= S(n(1 + n + \cdots + n^{n-1})) \\ &= \max(S(n), S(1 + n + \cdots + n^{n-1})). \end{aligned} \quad (2)$$

If  $S(n) \geq S(1 + n + \cdots + n^{n-1})$ , then from (1) and (2) we obtain

$$1 = \varphi(n) \prod_{k=1}^{n-1} S(k). \quad (3)$$

Since  $n \geq 5$ , by Lemma 1, we get  $S(n-1) > 1$  and (3) is impossible. So we have  $S(n) < S(1 + n + \cdots + n^{n-1})$ .

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Then, by (1) and (2), we get

$$S(1 + n + \cdots + n^{n-1}) = \varphi(n) \prod_{k=1}^n S(k). \quad (4)$$

Let

$$1 + n + \cdots + n^{n-1} = p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_r^{\alpha_r} \quad (5)$$

be the factorization of  $1 + n + \cdots + n^{n-1}$ . By Lemma 2, we have

$$S(1 + n + \cdots + n^{n-1}) = \max(S(p_1^{\alpha_1}), S(p_2^{\alpha_2}), \dots, S(p_r^{\alpha_r})). \quad (6)$$

It implies that

$$S(1 + n + \cdots + n^{n-1}) = S(p^\alpha), \quad (7)$$

where

$$p^\alpha = p_j^{\alpha_j}, \quad 1 \leq j \leq r. \quad (8)$$

Hence, by (1) and (7), we get

$$S(p^\alpha) = \varphi(n) \prod_{k=1}^n S(k). \quad (9)$$

Since  $p$  is a prime, we find from (9) that  $p|S(p^\alpha)$  and

$$p|\varphi(n) \quad \text{or} \quad p|S(k), \quad 1 \leq k \leq n. \quad (10)$$

On the other hand, by Lemma 3, we have  $S(p^\alpha) \leq \alpha p$ . Therefore, we get from (9) that

$$\alpha p \geq \varphi(n) \prod_{k=1}^n S(k). \quad (11)$$

Since  $n \geq 5$ , we have  $\varphi(n) > 1$  and  $S(k) > 1$  for  $k = 2, \dots, n$ . hence, by (10) and (11), we get

$$\alpha \geq \frac{1}{p} \varphi(n) \prod_{k=1}^n S(k) > 2^{n-1}. \quad (12)$$

However, since  $1 + n + \cdots + n^{n-1}$  is odd, we see from (5) and (8) that  $p^\alpha < n^n$  and

$$\alpha < \frac{n \log n}{\log p} < \frac{n \log n}{\log 3} < n \log n. \quad (13)$$

The combination of (12) and (13) yields

$$n \log n > 2^{n-1}, \quad n > 5, \quad (14)$$

a contradiction. Thus, (1) has only solution  $n = 1$ . The theorem is proved.

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# An extension of ABC-theorem<sup>1</sup>

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**Abstract** In this paper we generalize the abc-theorem for  $n$ -polynomials over  $\mathbb{F}[x]$  in which  $\mathbb{F}$  is an algebraically closed field of characteristic zero. This generalization is obtained by considering the Wronskian of functions over  $\mathbb{F}[x]$ . We also show that the Diophantine equation (The generalized Fermat-Catalan equation)

$$a_1^{m_1} + a_2^{m_2} + \cdots + a_{n-1}^{m_{n-1}} = a_n^{m_n},$$

where  $a_1, a_2, \dots, a_n \in \mathbb{F}[x]$  such that at most one of  $a_i$ 's is constant, and  $m_1, m_2, \dots, m_n \in \mathbb{N}$ , has no solution for which  $a_i (i = 1, \dots, n)$  are relatively prime by pairs provided that  $n(n-2) \leq \min_{1 \leq i \leq n} \{m_i\}$ .

**Keywords** abc-theorem; abc-conjecture; algebraically closed field; Wronskian; Diophantine equations.

## §1. Introduction

Although the arithmetic abc-conjecture is a great mystery, its algebraic counterpart is a rather easy theorem (abc-theorem). It looks like it was first noticed by W.W. Stothers [1]. Later on it was generalized and rediscovered independently by several people, including R.C. Mason [2] and J.H. Silverman [3].

Discovering the abc-theorem, opened a new way for investigating the Fermat's last theorem over the polynomials with coefficients in an algebraically closed field of characteristic zero. This theorem presented a very elementary proof of the Fermat's last theorem for polynomials. This led mathematician to give a variant of this theorem over the ring of integer numbers. Of course, this result has been stated as a conjecture and this conjecture has not been proved yet. Today this conjecture is known as the abc-conjecture. Let us state the original abc-theorem [1-4,8,9]. To do this, we need to introduce some notations. We denote the set of all polynomials of one variable  $x$  over  $\mathbb{F}$  by  $\mathbb{F}[x]$ , where  $\mathbb{F}$  is an algebraically closed field of characteristic zero. We also consider the non-zero elements of  $\mathbb{F}[x]$ , as follows

$$f(x) = c \prod_{i=1}^r (x - \alpha_i)^{m_i},$$

where  $\alpha_1, \alpha_2, \dots, \alpha_r$  are the distinct roots of  $f$ ,  $c \neq 0$  is a constant, and the positive integers  $m_i (i = 1, 2, \dots, r)$  are the multiplicities of the roots. The degree of the polynomial  $f$  is

$$\deg f = m_1 + m_2 + \cdots + m_r.$$

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The number of distinct roots of  $f$  will be denoted by  $n_0(f)$ . Thus, we have  $n_0(f) = r$ . If  $f, g$  are two nonzero polynomials, then in general

$$n_0(fg) \leq n_0(f) + n_0(g),$$

and the equality holds whenever  $f, g$  are relatively prime. Now, we state the abc-theorem.

**The abc-Theorem (Stothers, Mason, Silverman).** *Let  $a, b, c \in \mathbb{F}[x]$  be non-constant relatively prime polynomials satisfying  $a + b = c$ . Then*

$$\max\{\deg a, \deg b, \deg c\} \leq n_0(abc) - 1.$$

The similar result for the ring of integers is well-known as the abc-conjecture. This conjecture has been stated by Oesterle and Masser [5,6] in 1986.

**The abc-Conjecture (Oesterle, Masser).** *Given  $\varepsilon > 0$ , there exists a constant  $C(\varepsilon)$  such that for all  $a, b, c \in \mathbb{Z}$  with  $a + b = c$ , we have the inequality*

$$\max\{|a|, |b|, |c|\} \leq C(\varepsilon)(N_0(abc))^{1+\varepsilon},$$

in which  $N_0(abc)$  denotes the radical of  $abc$ . By radical function we mean

$$N_0(n) = \prod_{p|n} p \quad (p \text{ is prime and } n \in \mathbb{N}).$$

Note that Stewart and Tijdeman gave some lower bounds for  $C(\varepsilon)$  (cf [7]).

## §2. Generalizing ABC-Theorem

Now, we generalized the abc-theorem for  $n$ -functions. To do this, we need the following lemmas:

**Lemma 1.** *Suppose  $f$  is a nonzero polynomial in  $\mathbb{F}[x]$ . Then, we have*

$$\deg f - m.n_0(f) \leq \deg(f, f', \dots, f^{(m)}), \quad (1)$$

where  $(f, f', \dots, f^{(m)})$  is the greatest common divisor of  $f, f', \dots, f^{(m)}$ .

Needless to say that the derivative is considered as a purely algebraic operator over the elements of  $\mathbb{F}[x]$ . However, all known rules for derivatives in calculus text book can be easily proved by means of simple algebraic tools.

**Proof of Lemma 1.** Suppose  $f(x) = c \prod_{i=1}^r (x - \alpha_i)^{m_i}$ , in which  $\alpha_1, \alpha_2, \dots, \alpha_r$  are the distinct roots of  $f$  with multiplicities  $m_1, m_2, \dots, m_r$  respectively.

**Case I.** Suppose for any  $i(1 \leq i \leq r)$  we have  $m_i \leq m$ . Then we get

$$\deg f = \sum_{i=1}^r m_i \leq mr = m.n_0(f) \leq m.n_0(f) + \deg(f, f', \dots, f^{(m)}).$$

**Case II.** Now, we suppose that there exists an  $i$  such that  $m_i > m$ . Therefore, we have

$$(x - \alpha_i)^{m_i - m} \mid f^{(j)} \quad (j = 0, 1, \dots, m),$$

and consequently,

$$(x - \alpha_i)^{m_i - m} \mid (f, f', \dots, f^{(m)}).$$

It is clear to see that,

$$\prod_{\substack{0 < m_i - m \\ 1 \leq i \leq r}} (x - \alpha_i)^{m_i - m} \mid (f, f', \dots, f^{(m)}).$$

Considering the degrees of the both sides of the above result, we obtain

$$\sum_{\substack{0 < m_i - m \\ 1 \leq i \leq r}} (m_i - m) \leq \deg(f, f', \dots, f^{(m)}).$$

Since

$$\sum_{i=1}^r (m_i - m) \leq \sum_{\substack{0 < m_i - m \\ 1 \leq i \leq r}} (m_i - m),$$

we get

$$\sum_{i=1}^r (m_i - m) \leq \deg(f, f', \dots, f^{(m)}),$$

or equivalently

$$\deg f - m.n_0(f) \leq \deg(f, f', \dots, f^{(m)}),$$

and this completes our proof.

**Remark 1.** If  $\text{char}(\mathbb{F}) = 0$ , then we conclude that

$$\deg f - m.n_0(f) \leq \deg(f, f^{(m)}) = \sum_{\substack{0 < m_i - m \\ 1 \leq i \leq r}} (m_i - m).$$

**Definition 1.** Let  $f_1, f_2, \dots, f_n$  be functions over the ring  $\mathbb{F}[x]$ . The Wronskian of these functions is defined by,

$$W[f_1, f_2, \dots, f_n] = \det \left| f_j^{(i-1)} \right|_{1 \leq i, j \leq n}.$$

**Lemma 2.** If  $\text{char}(\mathbb{F}) = 0$  and  $f_1, f_2, \dots, f_n$  be linearly independent functions over  $\mathbb{F}$  in  $\mathbb{F}[x]$ , then there exists an element  $x$  in  $\mathbb{F}$ , such that  $W[f_1, f_2, \dots, f_n](x) \neq 0$  ( i.e.  $W[f_1, f_2, \dots, f_n](x)$  is a nonzero polynomial ).

**Proof.** Suppose for every  $x \in \mathbb{F}$ , we have

$$W[f_1, f_2, \dots, f_n](x) = 0.$$

Therefore, there are constant numbers  $c_i (i = 1, 2, \dots, n)$  in  $\mathbb{F}$ , such that at least one of these  $c_i$  is nonzero and

$$c_1 \begin{pmatrix} f_1(x) \\ f_1'(x) \\ \vdots \\ f_1^{(n-1)}(x) \end{pmatrix} + \dots + c_n \begin{pmatrix} f_n(x) \\ f_n'(x) \\ \vdots \\ f_n^{(n-1)}(x) \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{pmatrix},$$

or

$$c_1 f_1(x) + \cdots + c_n f_n(x) = 0,$$

which is a contradiction with the linearly independence of  $f_1, f_2, \dots, f_n$ .

**Lemma 3.** *Suppose  $\text{char}(\mathbb{F}) = 0$  and  $f_1, f_2, \dots, f_n$  are nonzero functions in  $\mathbb{F}[x]$ . Then, for  $W[f_1, f_2, \dots, f_n] \neq 0$ , we have*

$$\deg W[f_1, f_2, \dots, f_n] \leq \deg(f_1 f_2 \cdots f_n) - \frac{n(n-1)}{2}. \quad (2)$$

Whenever  $\deg f_1 = \cdots = \deg f_n$ , we get

$$\deg W[f_1, f_2, \dots, f_n] \leq \deg(f_1 f_2 \cdots f_n) - \frac{n(n-1)}{2} - 1. \quad (3)$$

**Proof.** We proceed it by mathematical induction on  $n$ . The initialization step  $n = 1$ , is clear. Suppose it holds for  $n - 1$  nonzero functions. By expanding the Wronskian determinant  $W[f_1, f_2, \dots, f_n]$  with respect to the first row, we obtain

$$W[f_1, f_2, \dots, f_n] = \sum_{i=1}^n (-1)^{i+1} f_i \cdot W[f'_1, \dots, f'_{i-1}, f'_{i+1}, \dots, f'_n]. \quad (4)$$

We have the following inequality for degrees

$$\deg W[f_1, f_2, \dots, f_n] \leq \max_{1 \leq i \leq n} \{\deg f_i + \deg W[f'_1, \dots, f'_{i-1}, f'_{i+1}, \dots, f'_n]\},$$

and since  $W[f_1, f_2, \dots, f_n] \neq 0$ , there exists an  $i$  such that the right-hand side has the greatest degree, namely

$$\deg W[f_1, f_2, \dots, f_n] \leq \deg f_i + \deg W[f'_1, \dots, f'_{i-1}, f'_{i+1}, \dots, f'_n]. \quad (5)$$

Now, considering the induction hypothesis for the set of  $(n - 1)$ -functions

$$f'_1, \dots, f'_{i-1}, f'_{i+1}, \dots, f'_n,$$

we get

$$\begin{aligned} \deg W[f'_1, \dots, f'_{i-1}, f'_{i+1}, \dots, f'_n] &\leq \deg(f'_1 \cdots f'_{i-1} f'_{i+1} \cdots f'_n) - \frac{(n-1)(n-2)}{2} \\ &\leq \deg(f_1 \cdots f_{i-1} f_{i+1} \cdots f_n) - \frac{n(n-1)}{2}. \end{aligned} \quad (6)$$

Finally, by (5) and (6), we have

$$\deg W[f_1, f_2, \dots, f_n] \leq \deg(f_1 f_2 \cdots f_n) - \frac{n(n-1)}{2}.$$

For proving (3), it is necessary to show that after expanding the determinant of  $W[f_1, f_2, \dots, f_n]$ , the term with the highest degree is vanished. We prove this by induction on  $n$ , with  $n \geq 2$ . First we investigate the case  $n = 2$ . Since  $\deg f_1 = \deg f_2$ , we have  $f_1(x) = a_k x^k + P(x)$  and

$f_2(x) = b_k x^k + Q(x)$ , where  $P(x)$  and  $Q(x)$  are two polynomials of degree at most  $(k-1)$ . So, we have

$$\begin{aligned} W[f_1, f_2] &= \begin{vmatrix} a_k x^k + P(x) & b_k x^k + Q(x) \\ k a_k x^{k-1} + P'(x) & k b_k x^{k-1} + Q'(x) \end{vmatrix} \\ &= a_k x^k Q'(x) + k b_k x^{k-1} P(x) - b_k x^k P'(x) - k a_k x^{k-1} Q(x). \end{aligned}$$

Now, assume its validity for any arbitrary  $(n-1)$ -functions. Then the proof is straight forward considering the relation (4). Now, we are ready to state our main result

**Theorem 1.** *Let  $f_n = f_1 + f_2 + \cdots + f_{n-1}$ , in which  $f_i$ 's are relatively prime by pairs in  $\mathbb{F}[x]$  with  $\text{char}(\mathbb{F}) = 0$  and at most one of them is constant. Then, we have*

$$\max_{1 \leq i \leq n} \deg f_i \leq (n-2)n_0(f_1 f_2 \cdots f_n) - \frac{(n-1)(n-2)}{2}, \quad (7)$$

and also

$$\min_{1 \leq i \leq n} \deg f_i \leq (n-2)n_0(f_1 f_2 \cdots f_n) - \frac{(n-1)(n-2)}{2} - 1. \quad (8)$$

**Proof.** For proving the first inequality, we distinguish between two cases. The proof of Case I, is analogous with [9, Theorem 1.2].

**Case I.** Let  $f_1, f_2, \dots, f_{n-1}$  be linearly dependent over  $\mathbb{F}$ . Now, the proof proceeds by induction on  $n$ . For  $n = 3$ , it is true; considering the results in [1-4]. Assume that the theorem is true for all cases  $n', 3 \leq n' < n$ , and consider  $n$  polynomials. In equality  $f_n = f_1 + f_2 + \cdots + f_{n-1}$ , assume that  $f_i (i = 1, 2, \dots, n-1)$ , are linearly dependent over  $\mathbb{F}$ . Note that, at most one of the  $f_i (i = 1, 2, \dots, n-1)$ , is constant. Let  $\{f_{i_1}, \dots, f_{i_q}\}$ ,  $q < n-1$ , be a maximal linearly independent subset of the  $f_i (i = 1, 2, \dots, n-1)$ . Since  $n-1 \geq 2$ , and  $f_j$ 's are relatively prime by pairs, it follows that  $q \geq 2$ . So each  $f_j, 1 \leq j \leq n-1$ ;  $j$  not one of the  $i_k$ , is a linear combination of the  $f_{i_k}$ , of the form

$$f_j = \lambda_1 f_{i_1} + \cdots + \lambda_q f_{i_q}, \quad (9)$$

where the  $\lambda_k \in \mathbb{F}$ , and at least two of these  $\lambda_k$  are not zero. Using our inductive hypothesis we apply the theorem to (9). This yields that if  $\lambda_k \neq 0$ , then

$$\deg f_{i_k} \leq (q-1)n_0(f_j \prod_{k=1}^q f_{i_k}) - \frac{q(q-1)}{2},$$

and so that

$$\deg f_{i_k} \leq (q-1)n_0(\prod_{i=1}^n f_i) - \frac{q(q-1)}{2}. \quad (10)$$

Now, since at most one of  $f_i$  is a constant, i.e.  $n-1 \leq n_0(\prod_{i=1}^n f_i)$ , we yield that

$$(q-1)n_0(\prod_{i=1}^n f_i) - \frac{q(q-1)}{2} \leq (n-2)n_0(\prod_{i=1}^n f_i) - \frac{(n-1)(n-2)}{2}. \quad (11)$$

Now, using (10) and (11), we have

$$\deg f_{i_k} \leq (n-2)n_0 \left( \prod_{i=1}^n f_i \right) - \frac{(n-1)(n-2)}{2}. \quad (12)$$

From (9) the same estimate as in (12) follows for  $\deg f_j$ . Thus the theorem is proved for such  $f_j$  and  $f_{i_k}$ . Inserting all the relations of the from (9) into the right side of equality  $f_n = f_1 + f_2 + \cdots + f_{n-1}$ , yields an equation of the form

$$f_r = \kappa_1 f_{i_1} + \cdots + \kappa_q f_{i_q}, \quad (13)$$

where the  $\kappa_j \in \mathbb{F}$ . Moreover, if one of these  $\kappa_\nu = 0$ , then the corresponding  $f_{i_\nu}$  must be appeared in one of the equations (9) with a nonzero  $\lambda_\nu$ . Hence, (12) is established for this  $f_{i_\nu}$ . Finally, for those  $\kappa_\nu \neq 0$ , we treat (13) exactly as we did (9), (note that  $q+1 < n$ ), and obtain the estimate (12) for  $\deg f_{i_\nu}$ , and  $\deg f_n$ . This completes the induction in this case.

**Case II.**  $f_1, f_2, \dots, f_{n-1}$  are linearly independent over  $\mathbb{F}$ . By using Lemma 2, we have  $W[f_1, f_2, \dots, f_{n-1}] \neq 0$ . Without lost of generality, we suppose that  $f_n$  has the greatest degree, and therefore it is necessary to prove that

$$\deg f_n \leq (n-2)n_0(f_1 f_2 \cdots f_n) - \frac{(n-1)(n-2)}{2}.$$

Considering the equality  $f_n = f_1 + f_2 + \cdots + f_{n-1}$ , we have

$$W[f_1, \dots, f_{n-2}, f_{n-1}] = W[f_1, \dots, f_{n-2}, f_n].$$

It can be easily seen for any  $i$  ( $i = 1, \dots, n$ ),

$$(f_i, f'_i, \dots, f_i^{(n-2)}) \Big| W[f_1, \dots, f_{n-2}, f_{n-1}].$$

Since  $f_i$ 's are relatively prime by pairs, we conclude that  $(f_i, f'_i, \dots, f_i^{(n-2)})$ 's are relatively prime. So, we get

$$\prod_{i=1}^n (f_i, f'_i, \dots, f_i^{(n-2)}) \Big| W[f_1, \dots, f_{n-2}, f_{n-1}].$$

Now since  $W[f_1, \dots, f_{n-2}, f_{n-1}] \neq 0$ , we conclude that

$$\sum_{i=1}^n \deg(f_i, f'_i, \dots, f_i^{(n-2)}) \leq \deg W[f_1, \dots, f_{n-2}, f_{n-1}].$$

Using the relations (1) and (2), we obtain

$$\sum_{i=1}^n (\deg f_i - (n-2)n_0(f_i)) \leq \deg(f_1 f_2 \cdots f_{n-1}) - \frac{(n-1)(n-2)}{2}$$

or equivalently,

$$\deg f_n \leq (n-2)n_0(f_1 f_2 \cdots f_n) - \frac{(n-1)(n-2)}{2}.$$

For proving (8), it is necessary to consider the case  $\deg f_1 = \cdots = \deg f_n$ . Now the proof is clear using the relation (3).

**Remark 2.** In the case where the number of constant polynomials are more than one, the inequality (7) is not valid in general case. For example if  $f_1 = \dots = f_5 = 1, f_6 = x$  and  $f_7 = x + 5$ , then it is not true. Indeed, finding similar inequality for the case that constant polynomials are more than one is an open question yet.

As an immediate result of the relation (7), we have:

**Corollary 1.** *With the assumption of the Theorem 1, we have*

$$\deg(f_1 f_2 \cdots f_n) \leq n(n-2)n_0(f_1 f_2 \cdots f_n) - \frac{n(n-1)(n-2)}{2}.$$

**Corollary 2.** *For  $n \geq 3$ , suppose  $f_1, f_2, \dots, f_n$  are non-constant and relatively prime by pairs. Then we obtain*

$$\frac{1}{n-2} < \frac{n_0(f_1)}{\deg f_1} + \frac{n_0(f_2)}{\deg f_2} + \cdots + \frac{n_0(f_n)}{\deg f_n}.$$

**Proof.** Without loss of generality, we suppose that  $\deg f_1 \leq \dots \leq \deg f_n$ . Applying Theorem 1, yields

$$\deg f_n < (n-2)(n_0(f_1) + \cdots + n_0(f_n)).$$

Dividing the both sides of the above inequality by  $(n-2) \deg f_n$ , completes the proof.

### §3. Application to the generalized Fermat-Catalan Equation

Now, we deal with the generalized Fermat-Catalan equation [8].

**Theorem 2.** *Consider the generalized Fermat-Catalan equation as follows*

$$a_1^{m_1} + a_2^{m_2} + \cdots + a_{n-1}^{m_{n-1}} = a_n^{m_n}, \quad (14)$$

in which  $a_1, a_2, \dots, a_n$  are elements of  $\mathbb{F}[x]$  with  $\text{char}(\mathbb{F}) = 0$ , such that they are relatively prime by pairs and at most one of  $a_i$ 's is constant. Then the equation (14) with condition  $n(n-2) \leq m = \min_{1 \leq i \leq n} \{m_i\}$  has no solution in  $\mathbb{F}[x]$ .

**Proof.** Suppose  $f_1 = a_1^{m_1}, f_2 = a_2^{m_2}, \dots, f_n = a_n^{m_n}$ . These functions satisfy the conditions of Theorem 1. Thus we have

$$\deg(a_1^{m_1} a_2^{m_2} \cdots a_n^{m_n}) \leq n(n-2)n_0(a_1^{m_1} \cdots a_n^{m_n}) - \frac{n(n-1)(n-2)}{2}. \quad (15)$$

We also have,

$$m \deg(a_1 a_2 \cdots a_n) \leq \deg(a_1^{m_1} a_2^{m_2} \cdots a_n^{m_n}), \quad (16)$$

and

$$n_0(a_1^{m_1} a_2^{m_2} \cdots a_n^{m_n}) = n_0(a_1 a_2 \cdots a_n) \leq \deg(a_1 a_2 \cdots a_n). \quad (17)$$

Now considering the both relations (15)-(17), we get

$$m \deg(a_1 a_2 \cdots a_n) \leq n(n-2) \deg(a_1 a_2 \cdots a_n) - \frac{n(n-1)(n-2)}{2}, \quad (18)$$

or equivalently,

$$(m - n(n - 2)) \deg(a_1 a_2 \cdots a_n) \leq -\frac{n(n - 1)(n - 2)}{2}. \quad (19)$$

The last inequality result in  $m - n(n - 2) < 0$ , which is in contradiction with our theorem's hypothesis. Therefore, we conclude that the Diophantine equation (14) has no solution in  $\mathbb{F}[x]$ .

Of course, there is in [10] a natural extension of the above result for several variables using the generalized Wronskian.

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# An equation involving the Smarandache function

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**Abstract** For any positive integer  $n$ , let  $S(n)$  denotes the Smarandache function, and  $\phi(n)$  is the Euler function. The main purpose of this paper is using the elementary method to study the solutions of the equation  $S(n) = \phi(n)$ , and give all solutions for it.

**Keywords** Smrandache function; Equation; Solutions.

## §1. Introduction

For any positive integer  $n$ , the Smarandache function  $S(n)$  is defined as the smallest integer  $m$  such that  $n|m!$ . From the definition and the properties of  $S(n)$ , one can easily deduce that if  $n = p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_k^{\alpha_k}$  is the prime powers factorization of  $n$ , then

$$S(n) = \max_{1 \leq i \leq k} \{S(p_i^{\alpha_i})\}.$$

About the arithmetical properties of  $S(n)$ , many people had studied it before, see references [3], [4] and [5].

If  $n \geq 1$ , the Euler function  $\phi(n)$  is defined to be the number of all positive integers not exceeding  $n$ , which are relatively prime to  $n$ . It is clear that  $\phi(n)$  is a multiplicative function.

In this paper, we shall use the elementary method to study the solutions of the equation  $S(n) = \phi(n)$ , and give all solutions for it. That is, we shall prove the following:

**Theorem.** The equation  $S(n) = \phi(n)$  have only 4 solutions, namely,

$$n = 1, 8, 9, 12.$$

## §2. Proof of the theorem

In this section, we shall complete the proof of the theorem. Let  $n = p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_k^{\alpha_k}$  denotes the factorization of  $n$  into prime powers, and let

$$S(n) = \max_{1 \leq i \leq k} \{S(p_i^{\alpha_i})\} = S(p^\alpha).$$

Then from the definitions of  $S(n)$  and  $\phi(n)$  we have

$$\begin{aligned} \phi(n) &= p_1^{\alpha_1-1}(p_1-1)p_2^{\alpha_2-1}(p_2-1)\cdots p_k^{\alpha_k-1}(p_k-1) \\ &= \phi(p^\alpha)\phi(n_1) = p^{\alpha-1}(p-1)\phi(n_1) = S(p^\alpha). \end{aligned}$$



It is clear that  $n = 1$  is a solution of the equation  $S(n) = \phi(n)$ . If  $n > 1$ , then we will discuss the problem in three cases:

(I) If  $\alpha = 1$  and  $n = p$ , then  $S(n) = p \neq p - 1 = \phi(n)$ . That is, there is no any prime satisfied the equation. If  $\alpha = 1$  and  $n = n_1 p$ , then  $S(n) = p \neq (p - 1)\phi(n_1) = \phi(n_1 p)$ . So the equation has also no solution.

(II) If  $\alpha = 2$ , then  $S(p^2) = 2p$  and  $\phi(p^2 n_1) = p(p - 1)\phi(n_1)$ . So in this case  $S(n) = \phi(n)$  if and only if

$$(p - 1)\phi(n_1) = 2.$$

This time, there are two cases:  $p - 1 = 1$ ,  $\phi(n_1) = 2$ ;  $p - 1 = 2$ ,  $\phi(n_1) = 1$ . That is,  $p = 2$ ,  $n_1 = 3$ ;  $p = 3$ ,  $n_1 = 1$ . So in this case, the equation has two solutions:  $n = 12, 9$ .

(III) If  $\alpha = 3$ , it is clear that  $S(2^3) = \phi(2^3) = 4$ , so  $n = 8$  satisfied the equation.

If  $\alpha \geq 3$  and  $p > 2$ , noting that

$$p^{\alpha-2} > 2^{\alpha-2} = (1 + 1)^{\alpha-2} = 1 + \alpha - 2 + \cdots + 1 > \alpha.$$

That is,

$$p^{\alpha-1} > \alpha p \Rightarrow p^{\alpha-1}(p - 1)\phi(n_1) > \alpha p,$$

but

$$S(p^\alpha) \leq \alpha p.$$

So this time, the equation has no solution.

Now combining the above three cases, we may immediately get all 4 solutions of equation  $S(n) = \phi(n)$ , namely

$$n = 1, 8, 9, 12.$$

This completes the proof of Theorem.

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# Inequalities for the polygamma functions with application<sup>1</sup>

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**Abstract** We present some inequalities for the polygamma functions. As an application, we give the upper and lower bounds for the expression  $\sum_{k=1}^n \frac{1}{k} - \ln n - \gamma$ , where  $\gamma = 0.57721 \dots$  is the Euler's constant.

**Keywords** Inequality; Polygamma function; Harmonic sequence; Euler's constant.

## §1. Inequalities for the Polygamma Function

The gamma function is usually defined for  $\text{Re}z > 0$  by

$$\Gamma(z) = \int_0^\infty t^{z-1} e^{-t} dt.$$

The psi or digamma function, the logarithmic derivative of the gamma function and the polygamma functions can be expressed as

$$\psi(z) = \frac{\Gamma'(z)}{\Gamma(z)} = -\gamma + \sum_{k=0}^{\infty} \left( \frac{1}{1+k} - \frac{1}{z+k} \right),$$

$$\psi^n(z) = (-1)^{n+1} n! \sum_{k=0}^{\infty} \frac{1}{(z+k)^{n+1}}$$

for  $\text{Re}z > 0$  and  $n = 1, 2, \dots$ , where  $\gamma = 0.57721 \dots$  is the Euler's constant.

M. Merkle [2] established the inequality

$$\frac{1}{x} + \frac{1}{2x^2} + \sum_{k=1}^{2N} \frac{B_{2k}}{x^{2k+1}} < \sum_{k=0}^{\infty} \frac{1}{(x+k)^2} < \frac{1}{x} + \sum_{k=1}^{2N+1} \frac{B_{2k}}{x^{2k+1}}$$

for all real  $x > 0$  and all integers  $N \geq 1$ , where  $B_k$  denotes Bernoulli numbers, defined by

$$\frac{t}{e^t - 1} = \sum_{j=0}^{\infty} \frac{B_j}{j!} t^j.$$

The first five Bernoulli numbers with even indices are

$$B_2 = \frac{1}{6}, B_4 = -\frac{1}{30}, B_6 = \frac{1}{42}, B_8 = -\frac{1}{30}, B_{10} = \frac{5}{66}.$$

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The following theorem 1 establishes a more general result.

**Theorem 1.** Let  $m \geq 0$  and  $n \geq 1$  be integers, then we have for  $x > 0$ ,

$$\ln x - \frac{1}{2x} - \sum_{j=1}^{2m+1} \frac{B_{2j}}{2j} \frac{1}{x^{2j}} < \psi(x) < \ln x - \frac{1}{2x} - \sum_{j=1}^{2m} \frac{B_{2j}}{2j} \frac{1}{x^{2j}} \quad (1)$$

and

$$\begin{aligned} & \frac{(n-1)!}{x^n} + \frac{n!}{2x^{n+1}} + \sum_{j=1}^{2m} \frac{B_{2j}}{(2j)!} \frac{\Gamma(n+2j)}{x^{n+2j}} \\ & < (-1)^{n+1} \psi^{(n)}(x) < \frac{(n-1)!}{x^n} + \frac{n!}{2x^{n+1}} + \sum_{j=1}^{2m+1} \frac{B_{2j}}{(2j)!} \frac{\Gamma(n+2j)}{x^{n+2j}}. \end{aligned} \quad (2)$$

**Proof.** From Binet's formula [6, p. 103]

$$\ln \Gamma(x) = \left(x - \frac{1}{2}\right) \ln x - x + \ln \sqrt{2\pi} + \int_0^\infty \left(\frac{t}{e^t - 1} - 1 + \frac{t}{2}\right) \frac{e^{-xt}}{t^2} dt,$$

we conclude that

$$\psi(x) = \ln x - \frac{1}{2x} - \int_0^\infty \left(\frac{t}{e^t - 1} - 1 + \frac{t}{2}\right) \frac{e^{-xt}}{t} dt \quad (3)$$

and therefore

$$(-1)^{n+1} \psi^{(n)}(n) = \frac{(n-1)!}{x^n} + \frac{n!}{2x^{n+1}} + \int_0^\infty \left(\frac{t}{e^t - 1} - 1 + \frac{t}{2}\right) t^{n-1} e^{-xt} dt. \quad (4)$$

It follows from Problem 154 in Part I, Chapter 4, of [3] that

$$\sum_{j=1}^{2m} \frac{B_{2j}}{(2j)!} t^{2j} < \frac{t}{e^t - 1} - 1 + \frac{t}{2} < \sum_{j=1}^{2m+1} \frac{B_{2j}}{(2j)!} t^{2j} \quad (5)$$

for all integers  $m > 0$ . The inequality (5) can be also found in [4].

From (3) and (5) we conclude (1), and we obtain (2) from (4) and (5). This completes the proof of the theorem 1.

Note that  $\psi(x+1) = \psi(x) + \frac{1}{x}$  (see [1, p. 258]), (1) can be written as

$$\frac{1}{2x} - \sum_{j=1}^{2m+1} \frac{B_{2j}}{2j} \frac{1}{x^{2j}} < \psi(x+1) - \ln x < \frac{1}{2x} - \sum_{j=1}^{2m} \frac{B_{2j}}{2j} \frac{1}{x^{2j}} \quad (6)$$

and (2) can be written as

$$\begin{aligned} & \frac{(n-1)!}{x^n} - \frac{n!}{2x^{n+1}} + \sum_{j=1}^{2m} \frac{B_{2j}}{(2j)!} \frac{\Gamma(n+2j)}{x^{n+2j}} \\ & < (-1)^{n+1} \psi^{(n)}(x) < \frac{(n-1)!}{x^n} - \frac{n!}{2x^{n+1}} + \sum_{j=1}^{2m+1} \frac{B_{2j}}{(2j)!} \frac{\Gamma(n+2j)}{x^{n+2j}}. \end{aligned} \quad (7)$$

In particular, taking in (6)  $m = 0$  we obtain for  $x > 0$ ,

$$\frac{1}{2x} - \frac{1}{12x^2} < \psi(x+1) - \ln x < \frac{1}{2x} \quad (8)$$

and taking in (7)  $m = 1$  and  $n = 1$ , we obtain for  $x > 0$

$$\frac{1}{2x^2} - \frac{1}{6x^3} + \frac{1}{30x^5} - \frac{1}{42x^7} < \frac{1}{x} - \psi'(x+1) < \frac{1}{2x^2} - \frac{1}{6x^3} + \frac{1}{30x^5} \quad (9)$$

The inequalities (8) and (9) play an important role in the proof of the theorem 2 in Section 2.

## §2. Inequalities for Euler's Constant

Euler's constant  $\gamma = 0.57721 \dots$  is defined by

$$\gamma = \lim_{n \rightarrow \infty} \left( 1 + \frac{1}{2} + \frac{1}{3} + \dots + \frac{1}{n} - \ln n \right).$$

It is of interest to investigate the bounds for the expression  $\sum_{k=1}^n \frac{1}{k} - \ln n - \gamma$ . The inequality

$$\frac{1}{2n} - \frac{1}{8n^2} < \sum_{k=1}^n \frac{1}{k} - \ln n - \gamma < \frac{1}{2n}$$

is called in literature Franel's inequality [3, Ex. 18].

It is given in [1, p. 258] that  $\psi(n) = \sum_{k=1}^{n-1} \frac{1}{k} - \gamma$ , and then we have get

$$\sum_{k=1}^n \frac{1}{k} - \ln n - \gamma = \psi(n+1) - \ln n. \quad (10)$$

Taking in (6)  $x = n$  we obtain that

$$\frac{1}{2n} - \sum_{j=1}^{2m+1} \frac{B_{2j}}{2j} \frac{1}{n^{2j}} < \sum_{k=1}^n \frac{1}{k} - \ln n - \gamma < \frac{1}{2n} - \sum_{j=1}^{2m} \frac{B_{2j}}{2j} \frac{1}{n^{2j}}. \quad (11)$$

The inequality (11) provides closer bounds for  $\sum_{k=1}^n \frac{1}{k} - \ln n - \gamma$ .

L.Tóth [5, p. 264] proposed the following problems:

(i) Prove that for every positive integer  $n$  we have

$$\frac{1}{2n + \frac{2}{5}} < \sum_{k=1}^n \frac{1}{k} - \ln n - \gamma < \frac{1}{2n + \frac{1}{3}}.$$

(ii) Show that  $\frac{2}{5}$  can be replaced by a slightly smaller number, but that  $\frac{1}{3}$  can not be replaced by a slightly larger number.

The following Theorem 2 answers the problem due to L.Tóth.

**Theorem 2.** For every positive integer  $n$ ,

$$\frac{1}{2n + a} < \sum_{i=1}^n \frac{1}{i} - \ln n - \gamma < \frac{1}{2n + b}, \quad (12)$$

with the best possible constants

$$a = \frac{1}{1-\gamma} - 2 \quad \text{and} \quad b = \frac{1}{3}$$

**Proof.** By (10), the inequality (12) can be rearranged as

$$b < \frac{1}{\psi(n+1) - \ln n} - 2n \leq a.$$

Define for  $x > 0$

$$\phi(x) = \frac{1}{\psi(x+1) - \ln x} - 2x.$$

Differentiating  $\phi$  and utilizing (8) and (9) reveals that for  $x > \frac{12}{5}$

$$\begin{aligned} (\psi(x+1) - \ln x)^2 \phi'(x) &= \frac{1}{x} - \psi'(x+1) - 2(\psi(x+1) - \ln x)^2 \\ &< \frac{1}{2x^2} - \frac{1}{6x^3} + \frac{1}{30x^5} - 2 \left( \frac{1}{2x} - \frac{1}{12x^2} \right)^2 = \frac{12-5x}{360x^5} < 0, \end{aligned}$$

and then the function  $\phi$  strictly decreases with  $x > \frac{12}{5}$ .

Straightforward calculation produces

$$\begin{aligned} \phi(1) &= \frac{1}{1-\gamma} - 2 = 0.36527211862544155 \dots, \\ \phi(2) &= \frac{1}{\frac{3}{2} - \gamma - \ln 2} - 4 = 0.35469600731465752 \dots, \\ \phi(3) &= \frac{1}{\frac{11}{6} - \gamma - \ln 3} - 6 = 0.34898948531361115 \dots. \end{aligned}$$

Therefore, the sequence

$$\phi(n) = \frac{1}{\psi(n+1) - \ln n} - 2n, \quad n \in N$$

is strictly decreasing. This leads to

$$\lim_{n \rightarrow \infty} \phi(n) < \phi(n) \leq \phi(1) = \frac{1}{1-\gamma} - 2.$$

Making use of asymptotic formula of  $\psi$  (see [1, p. 259])

$$\psi(x) = \ln x - \frac{1}{2x} - \frac{1}{12x^2} + O(x^{-4}) \quad (x \rightarrow \infty),$$

we conclude that

$$\lim_{n \rightarrow \infty} \phi(n) = \lim_{x \rightarrow \infty} \phi(x) = \lim_{x \rightarrow \infty} \frac{\frac{1}{3} + O(x^{-2})}{1 + O(x^{-1})} = \frac{1}{3}.$$

This completes the proof of the theorem 2.

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# On the number of Smarandache zero-divisors and Smarandache weak zero-divisors in loop rings

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**Abstract** In this paper we find the number of smarandache zero divisors (S-zero divisors) and smarandache weak zero divisors (S-weak zero divisors) for the loop rings  $Z_2L_n(m)$  of the loops  $L_n(m)$  over  $Z_2$ . We obtain the exact number of S-zero divisors and S-weak zero divisors when  $n = p^2$  or  $p^3$  or  $pq$  where  $p, q$  are odd primes. We also prove  $ZL_n(m)$  has infinitely many S-zero divisors and S-weak zero divisors, where  $Z$  is the ring of integers. For any loop  $L$  we give conditions on  $L$  so that the loop ring  $Z_2L$  has S-zero divisors and S-weak zero divisors.

## §0 . Introduction

This paper has four sections. In the first section, we just recall the definitions of S-zero divisors and S-weak zero divisors and some of the properties of the new class of loops  $L_n(m)$ . In section two, we obtain the number of S-zero divisors of the loop rings  $Z_2L_n(m)$

and show when  $n = p^2$ , where  $p$  is an odd prime,  $Z_2L_n(m)$  has  $p(1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r)$  S-zero divisors. Also when  $n = p^3$ ,  $p$  an odd prime,  $Z_2L_n(m)$  has  $p(1 + \sum_{r=2, r \text{ even}}^{p^2-1} p^{+1}C_r) + p^2(1 +$

$\sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r)$  S-zero divisors. Again when  $n = pq$ , where  $p, q$  are odd primes,  $Z_2L_n(m)$  has

$p + q + p(\sum_{r=2, r \text{ even}}^{q-1} q^{+1}C_r) + q(\sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r)$  S-zero divisors. Further we prove  $ZL_n(m)$  has

infinitely many S-zero divisors. In section three, we find the number of S-weak zero divisors for the loop ring  $Z_2L_n(m)$  and prove that when  $n = p^2$ , where  $p$  is an odd prime,  $Z_2L_n(m)$

has  $2p(1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r)$  S-weak zero divisors. Also when  $n = p^3$ , where  $p$  is an odd prime,

$Z_2L_n(m)$  has  $2p(\sum_{r=2, r \text{ even}}^{p^2-1} p^{+1}C_r) + 2p^2(\sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r)$  S-weak zero divisors. Again when

$n = pq$ , where  $p, q$  are odd primes,  $Z_2L_n(m)$  has  $2[p(\sum_{r=2, r \text{ even}}^{q-1} q^{+1}C_r) + q(\sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r)]$

S-weak zero divisors. We prove  $ZL_n(m)$  has infinitely many S-weak zero divisors. The final section gives some unsolved problems and some conclusions based on our study.

### §1. Basic Results

Here we just recollect some basic results to make this paper a self contained one.

**Definition 1.1[4].** Let  $R$  be a ring. An element  $a \in R \setminus \{0\}$  is said to be a S-zero divisor if  $a.b = 0$  for some  $b \neq 0$  in  $R$  and there exists  $x, y \in R \setminus \{0, a, b\}$  such that

- i.  $a.x = 0$  or  $x.a = 0$
- ii.  $b.y = 0$  or  $y.b = 0$
- iii.  $x.y \neq 0$  or  $y.x \neq 0$

**Definition 1.2[4].** Let  $R$  be a ring. An element  $a \in R \setminus \{0\}$  is a S-weak zero divisor if there exists  $b \in R \setminus \{0, a\}$  such that  $a.b = 0$  satisfying the following conditions: There exists  $x, y \in R \setminus \{0, a, b\}$  such that

- i.  $a.x = 0$  or  $x.a = 0$
- ii.  $b.y = 0$  or  $y.b = 0$
- iii.  $x.y = 0$  or  $y.x = 0$

**Definition 1.3[3].** Let  $L_n(m) = \{e, 1, 2, 3 \dots, n\}$  be a set where  $n > 3$ ,  $n$  is odd and  $m$  is a positive integer such that  $(m, n) = 1$  and  $(m - 1, n) = 1$  with  $m < n$ . Define on  $L_n(m)$ , a binary operation  $'.'$  as follows:

- i.  $e.i = i.e$  for all  $i \in L_n(m) \setminus \{e\}$
- ii.  $i^2 = e$  for all  $i \in L_n(m)$
- iii.  $i.j = t$ , where  $t \equiv (mj - (m-1)i) \pmod n$  for all  $i, j \in L_n(m)$ ,  $i \neq e$  and  $j \neq e$ .

Then  $L_n(m)$  is a loop. This loop is always of even order; further for varying  $m$ , we get a class of loops of order  $n + 1$  which we denote by  $L_n$ .

**Example 1.1[3].** Consider  $L_5(2) = \{e, 1, 2, 3, 4, 5\}$ . The composition table for  $L_5(2)$  is given below:

.	e	1	2	3	4	5
e	e	1	2	3	4	5
1	1	e	3	5	2	4
2	2	5	e	4	1	3
3	3	4	1	e	5	2
4	4	3	5	2	e	1
5	5	2	4	1	3	e

This loop is non-commutative and non-associative and of order 6.

**Theorem 1.1[3].** Let  $L_n(m) \in L_n$ . For every  $t|n$  there exists  $t$  subloops of order  $k + 1$ , where  $k = n/t$ .



**Theorem 1.2[3].** Let  $L_n(m) \in L_n$ . If  $H$  is a subloop of  $L_n(m)$  of order  $t + 1$ , then  $t|n$ .

**Remark 1.2[3].** Lagrange's theorem is not satisfied by all subloops of the loop  $L_n(m)$ , i.e there always exists a subloop  $H$  of  $L_n(m)$  which does not satisfy the Lagrange's theorem, i.e  $o(H) \nmid o(L_n(m))$ .

## §2. Definition of the number of S-zero divisors in $Z_2L_n(m)$ and $ZL_n(m)$

In this section, we give the number of S-zero divisors in  $Z_2L_n(m)$ . We prove  $ZL_n(m)$  (where  $n = p^2$  or  $pq$ ,  $p$  and  $q$  are odd primes), has infinitely many S-zero divisors. Further we show any loop  $L$  of odd (or even) order if it has a proper subloop of even (or odd) order then the loop ring  $Z_2L_n(m)$  over the field  $Z_2$  has S-zero divisors. We first show if  $L$  is a loop of odd order and  $L$  has a proper subloop of even order, then  $Z_2L_n(m)$  has S-zero divisors.

**Theorem 2.1.** Let  $L$  be a finite loop of odd order.  $Z_2 = \{0, 1\}$ , the prime field of characteristic 2. Suppose  $H$  is a subloop of  $L$  of even order, then  $Z_2L$  has S-zero divisors.

**Proof.** Let  $|L| = n$ ; where  $n$  is odd.  $Z_2L$  be the loop ring of  $L$  over  $Z_2$ .  $H$  be the subloop of  $L$  of order  $m$ , where  $m$  is even. Let  $X = \sum_{i=1}^n g_i$  and  $Y = \sum_{i=1}^m h_i$ , then

$$X.Y = 0.$$

Now

$$(1 + g_t)X = 0, \quad g_t \in L \setminus H.$$

also

$$(1 + h_i + h_j + h_k)Y = 0, \quad h_i, h_j, h_k \in H.$$

so that

$$(1 + g_t)(1 + h_i + h_j + h_k) \neq 0.$$

Hence the claim.

**Corollary 2.1.** If  $L$  is a finite loop of even order  $n$  and  $H$  is a subloop of odd order  $m$ , then the loop ring  $Z_2L$  has S-zero divisors.

It is important here to mention that  $Z_2L$  may have other types of S-zero divisors. This theorem only gives one of the basic conditions for  $Z_2L$  to have S-zero divisors.

**Example 2.1.** Let  $Z_2L_{25}(m)$  be the loop ring of the loop  $L_{25}(m)$  over  $Z_2$ , where  $(m, 25) = 1$  and  $(m - 1, 25) = 1$ . As  $5|25$ , so  $L_{25}(m)$  has 5 proper subloops each of order 6. Let  $H$  be one of the proper subloops of  $L_{25}(m)$ .

Now take

$$X = \sum_{i=1}^{26} g_i, \quad Y = \sum_{i=1}^6 h_i, \quad g_i \in L_{25}(m), \quad h_i \in H,$$

then

$$(1 + g_i)X = 0, \quad g_i \in L_{25}(m) \setminus H$$

$$(1 + h_i)Y = 0, \quad h_i \in H$$

but

$$(1 + g_i)(1 + h_i) \neq 0.$$

so  $X$  and  $Y$  are S-zero divisors in  $Z_2L_{25}(m)$ .

**Theorem 2.2.** Let  $L_n(m)$  be a loop of order  $n+1$  ( $n$  an odd number,  $n > 3$ ) with  $n = p^2$ ,  $p$  an odd prime.  $Z_2$  be the prime field of characteristic 2. The loop ring  $Z_2L_n(m)$  has exactly

$$p \left( 1 + \sum_{r=2, r \text{ even}}^{p-1} {}^{p+1}C_r \right)$$

S-zero divisors.

**Proof.** Given  $L_n(m)$  is a loop of order  $n+1$ , where  $n = p^2$  ( $p$  an odd prime). Let  $Z_2L_n(m)$  be the loop ring of the loop  $L_n(m)$  over  $Z_2$ . Now clearly the loop  $L_n(m)$  has exactly  $p$  subloops of order  $p+1$ . The number of S-zero divisors in  $Z_2L_n(m)$  for  $n = p^2$  can be enumerated in the following way: Let

$$X = \sum_{i=1}^{n+1} g_i \quad \text{and} \quad Y = \sum_{i=1}^{p+1} h_i$$

where  $g_i \in L_n(m)$  and  $h_i \in H_j$ . For this

$$X.Y = 0$$

choose

$$\begin{aligned} a &= (1 + g), \quad g \in L_n(m) \setminus H_j \\ b &= (h_i + h_j), \quad h_i, h_j \in H_j \end{aligned}$$

then

$$a.X = 0 \quad \text{and} \quad b.Y = 0$$

but

$$a.b \neq 0.$$

So  $X$  and  $Y$  are S-zero divisors. There are  $p$  such S-zero divisors, as we have  $p$  subloops  $H_j$  ( $j = 1, 2, \dots, p$ ) of  $L_n(m)$ .

Next consider, S-zero divisors of the form

$$(h_1 + h_2) \sum_{i=1}^{n+1} g_i = 0, \quad \text{where} \quad h_1, h_2 \in H_j, \quad g_i \in L_n(m)$$

put

$$X = (h_1 + h_2), \quad Y = \sum_{i=1}^{n+1} g_i$$

we have  ${}^{p+1}C_2$  such S-zero divisors. This is true for each of the subloops. Hence there exists  ${}^{p+1}C_2 \times p$  such S-zero divisors. Taking four elements  $h_1, h_2, h_3, h_4$  from  $H_j$  at a time, we get

$$(h_1 + h_2 + h_3 + h_4) \sum_{i=1}^{n+1} g_i = 0$$

so we get  $p^{+1}C_4 \times p$  such S-zero divisors. Continue in this way, we get

$$(h_1 + h_2 + \cdots + h_{p-1}) \sum_{i=1}^{n+1} g_i = 0, \quad \text{where } h_1, h_2, \cdots, h_{p-1} \in H_j$$

So we get  $p^{+1}C_{p-1} \times p$  such S-zero divisors. Adding all these S-zero divisors, we get

$$p \left( 1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

number of S-zero divisors in the loop ring  $Z_2L_n(m)$ . Hence the claim.

**Example 2.2.** Let  $Z_2L_{49}(m)$  be the loop ring of the loop  $L_{49}(m)$  over  $Z_2$ , where  $(m, 49) = 1$  and  $(m-1, 49) = 1$ . Here  $p = 7$ , so from Theorem 2.2,  $Z_2L_{49}(m)$  has

$$7 \left( 1 + \sum_{r=2, r \text{ even}}^6 7^{+1}C_r \right)$$

S-zero divisors i.e  $7(1 + \sum_{r=2, r \text{ even}}^6 8C_r) = 889$  S-zero divisors.

**Theorem 2.3.** Let  $L_n(m)$  be a loop of order  $n+1$  ( $n$  an odd number,  $n > 3$ ) with  $n = p^3$ ,  $p$  an odd prime.  $Z_2$  be the prime field of characteristic 2. The loop ring  $Z_2L_n(m)$  has exactly

$$p \left( 1 + \sum_{r=2, r \text{ even}}^{p^2-1} p^{2+1}C_r \right) + p^2 \left( 1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

S-zero divisors.

**Proof.** We enumerate all the S-zero divisors of  $Z_2L_n(m)$  in the following way:

Case I: As  $p|p^3$ ,  $L_n(m)$  has  $p$  proper subloops  $H_j$  each of order  $p^2+1$ . In this case I, we have  $p^2-1$  types of S-zero divisors. We just index them by type  $I_1$ , type  $I_2$ ,  $\cdots$ , type  $I_{p^2-1}$ .

Type  $I_1$ : Here

$$\sum_{i=1}^{n+1} g_i \sum_{i=1}^{p^2+1} h_i = 0, \quad g_i \in L_n(m), \quad h_i \in H_j, (j = 1, 2, \cdots, p)$$

So we will get  $p$  S-zero divisors of this type.

Type  $I_2$ :

$$(h_1 + h_2) \sum_{i=1}^{n+1} g_i = 0, \quad h_1, h_2 \in H_j (j = 1, 2, \cdots, p).$$

As in the Theorem 2.2, we will get  $p^{2+1}C_2 \times p$  S-zero divisors of this type.

Type  $I_3$ :

$$(h_1 + h_2 + h_3 + h_4) \sum_{i=1}^{n+1} g_i = 0, \quad h_1, h_2, h_3, h_4 \in H_j (j = 1, 2, \cdots, p).$$

We will get  $p^{2+1}C_4 \times p$  S-zero divisors of this type.

Continue this way,

Type  $I_{p^2-1}$ :

$$(h_1 + h_2 + \dots + h_{p^2-1}) \sum_{i=1}^{n+1} g_i = 0, \quad h_i \in H_j$$

We will get  $p^{2+1}C_{p^2-1} \times p$  S-zero divisors of this type. Hence adding all this types of S-zero divisors we will get

$$p \left( 1 + \sum_{r=2, r \text{ even}}^{p^2-1} p^{2+1}C_r \right)$$

S-zero divisors for case I.

Case II: Again  $p^2|p^3$ , so there are  $p^2$  subloops  $H_j$  each of order  $p + 1$ . Now we can enumerate all the S-zero divisors in this case exactly as in case I above. So there are

$$p^2 \left( 1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

S-zero divisors. Hence the total number of S-zero divisors in  $Z_2L_n(m)$  is

$$p \left( 1 + \sum_{r=2, r \text{ even}}^{p^2-1} p^{2+1}C_r \right) + p^2 \left( 1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

Hence the claim.

**Example 2.3.** Let  $Z_2L_{27}(m)$  be the loop ring of the loop  $L_{27}(m)$  over  $Z_2$ , where  $(m, 27) = 1$  and  $(m - 1, 27) = 1$ . Here  $p = 3$ , so from Theorem 2.3,  $Z_2L_{27}(m)$  has

$$3 \left( 1 + \sum_{r=2, r \text{ even}}^8 3^{2+1}C_r \right) + 3^2 \left( 1 + \sum_{r=2, r \text{ even}}^2 4C_r \right)$$

S-zero divisors i.e  $3 \left( 1 + \sum_{r=2, r \text{ even}}^8 10C_r \right) + 9 \left( 1 + \sum_{r=2, r \text{ even}}^2 4C_r \right) = 1533$  S-zero divisors.

**Theorem 2.4.** Let  $L_n(m)$  be a loop of order  $n + 1$  ( $n$  an odd number,  $n > 3$ ) with  $n = pq$ , where  $p, q$  are odd primes.  $Z_2$  be the prime field of characteristic 2. The loop ring  $Z_2L_n(m)$  has exactly

$$p + q + p \left( 1 + \sum_{r=2, r \text{ even}}^{q-1} q^{+1}C_r \right) + q \left( 1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

S-zero divisors.

**Proof.** We will enumerate all the S-zero divisors in the following way:

Case I: As  $p|pq$ ,  $L_n(m)$  has  $p$  subloops  $H_j$  each of order  $q + 1$ . Proceeding exactly in the same way as in the Theorem 2.3, we will get  $p + p \left( 1 + \sum_{r=2, r \text{ even}}^{q-1} q^{+1}C_r \right)$  S-zero divisors for case I.

Case II: Again  $q|pq$ , so  $L_n(m)$  has  $q$  subloops  $H_j$  each of order  $p + 1$ . Now as above we will get  $q + q \left( 1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$  S-zero divisors for case II. Hence adding all the S-zero

divisors in case I and case II, we get

$$p + q + p \left( 1 + \sum_{r=2, r \text{ even}}^{q-1} q^{+1} C_r \right) + q \left( 1 + \sum_{r=2, r \text{ even}}^{p-1} p^{+1} C_r \right)$$

S-zero divisors in  $Z_2L_n(m)$ .

Hence the claim.

Now we prove for the loop ring  $ZL_n(m)$  when  $n = p^2$  or  $p^3$  or  $pq$ , where  $p, q$  are odd primes,  $ZL_n(m)$  has infinitely many S-zero divisors.

**Theorem 2.5.** Let  $ZL_n(m)$  be the loop ring of the loop  $L_n(m)$  over  $Z$ , where  $n = p^2$  or  $p^3$  or  $pq$  ( $p, q$  are odd primes), then  $ZL_n(m)$  has infinitely many S-zero divisors.

**Proof.** Let  $L_n(m)$  be a loop ring such that  $n = p^2$ .  $L_n(M)$  has  $p$  subloops (say  $H_j$ ) each of order  $p + 1$ .

Now the loop ring  $ZL_n(m)$  has the following types of S-zero divisors:

$$X = a - bh_1 + bh_2 - ah_3 \quad \text{and} \quad Y = \sum_{i=1}^{n+1} g_i$$

where  $a, b \in Z$  and  $h_i \in H_i$ ,  $g_i \in L_n(m)$  such that

$$(a - bh_1 + bh_2 - ah_3) \sum_{i=1}^{n+1} g_i = 0$$

Again

$$(1 - g_k)Y = 0, \quad g_k \in L_n(m) \setminus H_j$$

also

$$(a - bh_1 + bh_2 - ah_3) \sum h_i = 0, \quad h_i \in H_j$$

clearly

$$(1 - g_k) \left( \sum_{h_i \in H_j} h_i \right) \neq 0.$$

So  $X, Y$  are S-zero divisors in  $ZL_n(m)$ . Now we see there are infinitely many S-zero divisors of this type for  $a$  and  $b$  can take infinite number of values in  $Z$ . For  $n = p^2$  or  $p^3$  or  $pq$  we can prove the results in a similar way. Hence the claim.

### §3. Determination of the number of S-weak zero divisors in $Z_2L_n(m)$ and $ZL_n(m)$

In this section, we give the number of S-weak zero divisors in the loop ring  $Z_2L_n(m)$  when  $n$  is of the form  $p^2, p^3$  or  $pq$  where  $p$  and  $q$  are odd primes. Before that we prove the existence of S-weak zero divisors in the loop ring  $Z_2L$  whenever  $L$  has a proper subloop.

**Theorem 3.1.** Let  $n$  be a finite loop of odd order. Suppose  $H$  is a subloop of  $L$  of even order, then  $Z_2L$  has S-weak zero divisors.

**Proof.** Let  $|L| = n$ ;  $n$  odd.  $Z_2L$  be the loop ring.  $H$  be the subloop of  $L$  of order  $m$ , where  $m$  is even. Let  $X = \sum_{i=1}^n g_i$  and  $Y = 1 + h_t, g_i \in L, h_t \in H$ , then

$$X.Y = 0$$

Now

$$Y. \sum_{i=1}^m h_i = 0, \quad h_i \in H$$

also

$$X(1 + g_t) = 0, \quad g_t (\neq h_t) \in H$$

so that

$$(1 + g_t) \sum_{i=1}^m h_i = 0.$$

Hence the claim.

**Example 3.1.** Let  $Z_2L_{25}(m)$  be the loop ring of the loop  $L_{25}(m)$  over  $Z_2$ , where  $(m, 25) = 1$  and  $(m - 1, 25) = 1$ . As  $5|25$ , so  $L_{25}(m)$  has 5 proper subloops each of order 6.

Take

$$X = \sum_{i=1}^{26} g_i, \quad Y = 1 + h_t, \quad g_i \in L_{25}(m), \quad h_t \in H$$

then

$$X.Y = 0$$

again

$$X(1 + g_t) = 0, \quad g_t (\neq h_t) \in H$$

$$Y \sum_{i=1}^6 h_i = 0, \quad h_i \in H$$

also

$$(1 + g_t) \sum_{i=1}^6 h_i = 0,$$

So  $X$  and  $Y$  are S-weak zero divisors in  $Z_2L_{25}(m)$ .

**Example 3.2.** Let  $Z_2L_{21}(m)$  be the loop ring of the loop  $L_{21}(m)$  over  $Z_2$ , where where  $(m, 21) = 1$  and  $(m - 1, 21) = 1$ . As  $3|21$ , so  $L_{21}(m)$  has 3 proper subloops each of order 8.

Take

$$X = \sum_{i=1}^8 h_i, \quad Y = 1 + h_t, \quad h_i, h_t \in H$$

then

$$X.Y = 0$$

again

$$X(1 + g_t) = 0, \quad g_t (\neq h_t) \in H$$

$$Y \sum_{i=1}^{22} g_i = 0, \quad g_i \in L_{21}(m)$$

also

$$(1 + gt) \sum_{i=1}^{22} g_i = 0,$$

So  $X$  and  $Y$  are S-weak zero divisors in  $Z_2L_{21}(m)$ .

**Theorem 3.2.** Let  $L_n(m)$  be a loop of order  $n + 1$  ( $n$  an odd number,  $n > 3$ ) with  $n = p^2$ ,  $p$  an odd prime.  $Z_2$  be the prime field of characteristic 2. The loop ring  $Z_2L_n(m)$  has exactly

$$2p \left( \sum_{r=2, r \text{ even}}^{p-1} {}^{p+1}C_r \right)$$

S-weak zero divisors.

**Proof.** Clearly the loop  $L_n(m)$  has  $p$  subloops  $H_j$  each of order  $p + 1$ . As in case of Theorem 2.3, we index the  $p - 1$  types of S-weak zero divisors by  $I_1, I_2, \dots, I_{p-1}$ . Now the number of S-weak zero divisors in  $Z_2L_n(m)$  for  $n = p^2$  can be enumerated in the following way:

Type  $I_1$ . Let

$$X = h_1 + h_2, \quad Y = \sum_{i=1}^{n+1} g_i$$

where  $h_1, h_2 \in H_j$  and  $g_i \in L_n(m)$  then

$$XY = 0$$

take

$$a = \sum_{i=1}^{p+1} h_i, \quad \text{and} \quad b = h_3 + h_4 \quad \text{where} \quad h_i \in H_j, \quad (j = 1, 2, \dots, p)$$

then

$$aX = 0, \quad bY = 0$$

also

$$ab = 0$$

So for each proper subloop we will get  ${}^{p+1}C_2$  S-weak zero divisors and as there are  $p$  proper subloops we will get  ${}^{p+1}C_2 \times p$  such S-weak zero divisors.

Type  $I_2$ . Again let

$$X = h_1 + h_2, \quad Y = \sum_{i=1}^{p+1} h_i, \quad h_i \in H_j$$

then

$$XY = 0$$

take

$$a = \sum_{i=1}^{n+1} g_i, \quad g_i \in L_n(m), \quad b = h_1 + h_2, \quad h_1, h_2 \in H_j,$$

then

$$aX = 0, \quad bY = 0$$

also

$$ab = 0$$

Here also we will get  $p^{+1}C_2 \times p$  such S-weak zero divisors of this type.

Type  $I_3$ .

$$(h_1 + h_2 + h_3 + h_4) \sum_{i=1}^{n+1} g_i, \quad g_i \in L_n(m), \quad h_i \in H_j.$$

As above we can say there are  $p^{+1}C_4 \times p$  such S-weak zero divisors.

Type  $I_4$ .

$$(h_1 + h_2 + h_3 + h_4) \sum_{i=1}^{p+1} h_i, \quad h_i \in H_j.$$

There are  $p^{+1}C_4 \times p$  such S-weak zero divisors.

Continue this way,

Type  $I_{p-2}$ .

$$(h_1 + h_2 + \cdots + h_{p-1}) \sum_{i=1}^{n+1} g_i, \quad g_i \in L_n(m), \quad h_i \in H_j.$$

there are  $p^{+1}C_{p-1} \times p$  such S-weak zero divisors.

Type  $I_{p-1}$ .

$$(h_1 + h_2 + \cdots + h_{p-1}) \sum_{i=1}^n h_i, \quad h_i \in H_j.$$

Again there are  $p^{+1}C_{p-1} \times p$  such S-weak zero divisors of this type. Adding all these S-weak zero divisors we will get the total number of S-weak zero divisors in  $Z_2L_n(m)$  as

$$2p \left( \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

Hence the claim.

**Theorem 3.3.** Let  $L_n(m)$  be a loop of order  $n + 1$  ( $n$  an odd number,  $n > 3$ ) with  $n = p^3$ ,  $p$  an odd prime.  $Z_2$  be the prime field of characteristic 2. The loop ring  $Z_2L_n(m)$  has exactly

$$2p \left( \sum_{r=2, r \text{ even}}^{p^2-1} p^{+1}C_r \right) + 2p^2 \left( \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

S-weak zero divisors.

**Proof.** We enumerate all the S-weak zero divisors of  $Z_2L_n(m)$  in the following way:

Case I: As  $p|p^3$ ,  $L_n(m)$  has  $p$  proper subloops  $H_j$  each of order  $p^2 + 1$ . Now as in the Theorem 3.2.

Type  $I_1$ :

$$(h_1 + h_2) \sum_{i=1}^{n+1} g_i = 0, \quad g_i \in L_n(m), \quad h_i \in H_j.$$

So we will get  $p^{+1}C_2 \times p$  S-weak zero divisors of type  $I_1$ .



Type  $I_2$ :

$$(h_1 + h_2) \sum_{i=1}^{p^2+1} h_i = 0, \quad h_i \in H_j.$$

So we will get  $p^{2+1}C_2 \times p$  S-weak zero divisors of type  $I_2$ .

Continue in this way

Type  $I_{p^2-2}$ :

$$(h_1 + h_2 + \dots + h_{p^2-1}) \sum_{i=1}^{n+1} g_i = 0,$$

So we will get  $p^{2+1}C_{p^2-1} \times p$  S-weak zero divisors of this type.

Type  $I_{p^2-1}$ :

$$(h_1 + h_2 + \dots + h_{p^2-1}) \sum_{i=1}^{p^2+1} h_i = 0,$$

So we will get  $p^{2+1}C_{p^2-1} \times p$  S-weak zero divisors of type  $I_{p^2-1}$ .

Adding all this S-weak zero divisors, we will get the total number of S-weak zero divisors

(in case I) in  $Z_2L_n(m)$  as  $2p \left( \sum_{r=2, r \text{ even}}^{p^2-1} p^{2+1}C_r \right)$ .

Case II: Again  $p^2|p^3$ , so there are  $p^2$  proper subloops  $H_j$  each of order  $p + 1$ . Now we can enumerate all the S-weak zero divisors in this case exactly as in case I above. So there are

$$2p^2 \left( \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

S-weak zero divisors in case II.

Hence the total number of S-weak zero divisors in  $Z_2L_n(m)$  is

$$2p \left( \sum_{r=2, r \text{ even}}^{p^2-1} p^{2+1}C_r \right) + 2p^2 \left( \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right)$$

Hence the claim.

**Theorem 3.4.** Let  $L_n(m)$  be a loop of order  $n + 1$  ( $n$  an odd number,  $n > 3$ ) with  $n = pq$ ,  $p, q$  are odd primes.  $Z_2$  be the prime field of characteristic 2. The loop ring  $Z_2L_n(m)$  has exactly

$$2 \left[ p \left( \sum_{r=2, r \text{ even}}^{q-1} q^{+1}C_r \right) + q \left( \sum_{r=2, r \text{ even}}^{p-1} p^{+1}C_r \right) \right]$$

S-weak zero divisors.

**Proof.** We will enumerate all the S-weak zero divisors in the following way:

Case I: As  $p|pq$ ,  $L_n(m)$  has  $p$  proper subloops  $H_j$  each of order  $q + 1$ . Proceeding exactly same way as in Theorem 3.3, we will get

$$2p \left( \sum_{r=2, r \text{ even}}^{q-1} q^{+1}C_r \right)$$

S-weak zero divisors in case I.

Case II: Again as  $q|pq$ ,  $L_n(m)$  has  $q$  proper subloops  $H_j$  each of order  $p+1$ . So as above we will get

$$2q \left( \sum_{r=2, r \text{ even}}^{p-1} {}^{p+1}C_r \right)$$

S-weak zero divisors in case II.

Hence adding all the S-weak zero divisors in case I and case II, we get

$$2 \left[ p \left( \sum_{r=2, r \text{ even}}^{q-1} {}^{q+1}C_r \right) + q \left( \sum_{r=2, r^4 \text{ even}}^{p-1} {}^{p+1}C_r \right) \right]$$

S-weak zero divisors in  $Z_2L_n(m)$ .

Hence the claim.

Now we prove for the loop ring  $ZL_n(m)$  where  $n = p^2$  or  $p^3$  or  $pq$ , ( $p, q$  are odd primes),  $ZL_n(m)$  has infinitely many S-weak zero divisors.

**Theorem 3.5.** Let  $ZL_n(m)$  be the loop ring of the loop  $L_n(m)$  over  $Z$ , where  $n = p^2$  or  $p^3$  or  $pq$  ( $p, q$  are odd primes), then  $ZL_n(m)$  has infinitely many S-weak zero divisors.

Proof. Let  $L_n(m)$  be a loop ring such that  $n = p^2$ .  $L_n(M)$  has  $p$  subloops (say  $H_j$ ) each of order  $p+1$ . Now the loop ring  $ZL_n(m)$  has the following types of S-weak zero divisors:

$$X = a - bh_1 + bh_2 - ah_3 \quad \text{and} \quad Y = \sum_{i=1}^{n+1} g_i$$

where  $a, b \in Z, g_i \in L_n(m)$  and  $h_1, h_2, h_3 \in H_j$  are such that

$$XY = 0.$$

Again

$$X \sum_{i=1}^{p+1} h_i = 0, \quad h_i \in H_j$$

also

$$(1 - g_t)Y = 0, \quad g_t (\neq h_t) \in H_j$$

clearly

$$(1 - g_t) \left( \sum_{i=1}^{p+1} h_i \right) = 0.$$

So  $X, Y$  are S-weak zero divisors in  $ZL_n(m)$ . Now we see there are infinitely many S-weak zero divisors of this type for  $a$  and  $b$  can take infinite number of values in  $Z$ .

For  $n = p^2$  or  $p^3$  or  $pq$  we can prove the results in a similar way.

Hence the claim.

## §4. Conclusions:

In this paper we find the exact number of S-zero divisors and S-weak zero divisors for the loop rings  $Z_2L_n(m)$  in case of the special type of loops  $L_n(m) \in L_n$  over  $Z_2$ , when  $n = p^2$  or  $p^3$  or  $pq$  ( $p, q$  are odd primes). We also prove for the loop ring  $ZL_n(m)$  has infinite number of S-zero divisors and S-weak zero divisors. We obtain conditions for any loop  $L$  to have S-zero divisors and S-weak zero divisors. We suggest it would be possible to enumerate in the similar way the number of S-zero divisors and S-weak zero divisors for the loop ring  $Z_2L_n(m)$  when  $n = p^s, s > 3$ ;  $p$  a prime or when  $n = p_1p_2 \cdots p_t$  where  $p_1, p_2, \cdots, p_t$  are odd primes. However we find it difficult when we take  $Z_p$  instead of  $Z_2$ , where  $p$  can be odd prime or a composite number such that  $(p, n+1 = 1)$  or  $(p, n+1 = p)$  and  $n$  is of the form  $n = p_1^{t_1} p_2^{t_2} \cdots p_r^{t_r}, t_i > 1, n$  is odd and  $p_1, p_2, \cdots, p_r$  are odd primes.

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## The function equation $S(n) = Z(n)$ <sup>1</sup>

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**Abstract** For any positive integer  $n$ , let  $S(n)$  and  $Z(n)$  denote the Smarandache function and the pseudo Smarandache function respectively. In this paper we prove that the equation  $S(n) = Z(n)$  has infinitely many positive integer solutions  $n$ .

**Keywords** Smarandache function; Pseudo Smarandache function; Diophantine equation.

For any positive integers  $n$ , let  $S(n)$  and  $Z(n)$  denote the Smarandache function and pseudo Smarandache function respectively. In [1], Ashbacher proposed two problems concerning the equation

$$S(n) = Z(n) \tag{1}$$

as follows.

**Problem 1.** Prove that if  $n$  is an even perfect number, then  $n$  satisfies (1).

**Problem 2.** Prove that (1) has infinitely many positive integer solutions  $n$ .

In this paper we completely solve these problems as follows.

**Theorem 1.** If  $n$  is an even perfect number, then (1) holds.

**Theorem 2.** (1) has infinitely many positive integer solutions  $n$ .

**Proof of Theorem 1.** By [2, Theorem 277], if  $n$  is an even perfect number, then

$$n = 2^{p-1}(2^p - 1), \tag{2}$$

where  $p$  is a prime. By [3] and [4], we have

$$S(n) = 2^p - 1. \tag{3}$$

On the other hand, since

$$\frac{1}{2}(2^p - 1)((2^p - 1) + 1) = n, \tag{4}$$

by (2), we get

$$Z(n) = 2^p - 1 \tag{5}$$

immediately. The combination of (3) and (5) yields (1). Thus, the theorem is proved.

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**Proof of Theorem 2.** Let  $p$  be an odd prime with  $p \equiv 3 \pmod{4}$ . Since  $S(2) = 2$  and  $S(p) = p$ , we have

$$S(2p) = \max(S(2), S(p)) = \max(2, p) = p. \quad (6)$$

Let  $t = Z(2p)$ , By the define of  $Z(n)$ , we have

$$\frac{1}{2}t(t+1) \equiv 0 \pmod{2p}. \quad (7)$$

It implies that either  $t \equiv 0 \pmod{p}$  or  $t+1 \equiv 0 \pmod{p}$ . Hence, we get  $t \geq p-1$ . If  $t = p-1$ , then from (7) we obtain

$$\frac{1}{2}(p-1)p \equiv 0 \pmod{2p}. \quad (8)$$

whence we get

$$\frac{1}{2}(p-1)p \equiv 0 \pmod{2}. \quad (9)$$

But, since  $p \equiv 3 \pmod{4}$ , (9) is impossible. So we have

$$t \geq p. \quad (10)$$

Since  $p+1 \equiv 0 \pmod{4}$ , we get

$$\frac{1}{2}p(p+1) \equiv 0 \pmod{2p} \quad (11)$$

and  $t = p$  by (10). Therefore, by (6),  $n = 2p$  is a solution of (1). Notice that there exist infinitely many primes  $p$  with  $p \equiv 3 \pmod{4}$ . It implies that (1) has infinitely many positive integer solutions  $n$ . The theorem is proved.

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# On the Smarandache Pseudo-number Sequences

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**Abstract** The main purpose of this paper is using elementary method to study the main value of the  $m$ -th power mean of the sum of all digits in the Smarandache pseudo-number sequence, and give some interesting asymptotic formulae for them.

**Keywords** Smarandache Pseudo-multiple of 5, pseudo-even, pseudo-odd sequence number; Sum of digits; Asymptotic formulae.

## §1. Introduction

A number is called Smarandache pseudo-multiple of 5 if some permutation of the digits is a multiple of 5, including the identity permutation. For example: 51, 52, 53, 54, 56, 57, 58, 59, 101, 102, 103, 104, 106... are Smarandache pseudo-multiple of 5 numbers. Similarly we can define the Smarandache pseudo-even numbers and the Smarandache pseudo-odd numbers. In reference [1], Professor F.Smarandache asked us to study the properties of the pseudo-multiple of 5, pseudo-even, pseudo-odd sequence. Let  $A$  denote the set of all Smarandache Pseudo-multiple of 5 numbers; Let  $B$  denote the set of all Smarandache Pseudo-even numbers and Let  $C$  denote the set of all Smarandache Pseudo-odd numbers. For convenience, denoted by  $A(n)$ , the sum of all the digits of the base 10 digits of  $n$ . That is

$$A(n) = \sum_{i=0}^k a_i$$

if  $n = a_k 10^k + a_{k-1} 10^{k-1} + \dots + a_1 10 + a_0$ . In this paper, we shall use the element method to study the mean value of the  $m$ -power of the sum of all digits in the pseudo-number sequence, and give some interesting formulae for them. That is, we shall prove the following results:

**Theorem 1.** For any integer number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{\substack{n \in A \\ n \leq x}} A^m(n) = x \left( \frac{9}{2} \log x \right)^m + O(x(\log x)^{m-1}).$$

**Theorem 2** For any integer number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{\substack{n \in B \\ n \leq x}} A^m(n) = x \left( \frac{9}{2} \log x \right)^m + O(x(\log x)^{m-1}).$$

**Theorem 3** For any integer number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{\substack{n \in C \\ n \leq x}} A^m(n) = x \left( \frac{9}{2} \log x \right)^m + O(x(\log x)^{m-1}).$$

## §2. Some lemmas

To complete the proof of the theorem, we need the following lemmas.

**Lemma 1.** For any integer number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{n \leq x} A^m(n) = x \left( \frac{9}{2} \log x \right)^m + O(x(\log x)^{m-1}).$$

**Proof.** See reference [1].

**Lemma 2.** For any integer number  $x \geq 1$ . Let  $D$  denotes the complementary set of  $A$ , then we have the asymptotic formula

$$\sum_{\substack{n \in D \\ n \leq x}} A^m(n) = O\left(x \frac{(\log x)^m}{\left(\frac{5}{4}\right)^{\log x}}\right).$$

**Proof.** From the definition of the set  $D$ , we know that the base 10 digits of the numbers in  $D$  are 1, 2, 3, 4, 6, 7, 8, 9, not including 0, 5. So, there are  $8^m$   $m$ -digit number in  $D$ . Hence, for any integer  $n$ , there is a  $k$  such that  $10^{k-1} \leq x < 10^k$ . Then we have

$$\sum_{\substack{n \in D \\ n \leq x}} A^m(n) \leq \sum_{t=1}^k \sum_{\substack{10^{t-1} \leq n < 10^t \\ n \in D}} A^m(n)$$

Noting that

$$\sum_{\substack{10^{t-1} \leq n < 10^t \\ n \in D}} A^m(n) < (9t)^m \times 8^t,$$

we can write

$$\sum_{t=1}^k \sum_{\substack{10^{t-1} \leq n < 10^t \\ n \in D}} A^m(n) < \sum_{t=1}^k (9t)^m \times 8^t < 9^m \times k^m \times 8^{k+1}.$$

Since  $k \leq (\log x) + 1 < k + 1$ , we have

$$\sum_{\substack{n \in D \\ n \leq x}} A^m(n) = O((\log x)^m \times 8^{\log x}) = O\left(x \frac{(\log x)^m}{\left(\frac{5}{4}\right)^{\log x}}\right).$$

This proves Lemma 2.

**Lemma 3.** For any integer number  $x \geq 1$ . Let  $E$  denote the complementary set of  $B$ , then we have the asymptotic formula

$$\sum_{\substack{n \in E \\ n \leq x}} A^m(n) = O\left(x \frac{(\log x)^m}{2^{\log x}}\right).$$

**Proof.** By use the same method of proving Lemma 2, we can also get this Lemma.

### §3. Proof of the theorems

Now we complete the proof of the theorems. First we prove Theorem 1. From the definition of Smarandache pseudo-multiple of 5 numbers, Lemma 1 and Lemma 2, we can get

$$\begin{aligned} \sum_{\substack{n \in A \\ n \leq x}} A^m(n) &= \sum_{n \leq x} A^m(n) - \sum_{\substack{n \in D \\ n \leq x}} A^m(n) \\ &= x \left( \frac{9}{2} \log x \right)^m + O(x(\log x)^{m-1}) - O\left(x \frac{(\log x)^m}{\left(\frac{5}{4}\right)^{\log x}}\right) \\ &= x \left( \frac{9}{2} \log x \right)^m + O(x(\log x)^{m-1}). \end{aligned}$$

This completes the proof of Theorem 1. Using the same method of proving Theorem 1, we can also deduce the other Theorems.

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# The classical Smarandache function and a formula for twin primes

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**Abstract** This short paper presents an exact formula for counting twin prime pairs less than or equal to  $x$  in terms of the classical Smarandache Function. An extension of the formula to count prime pairs  $(p, p + 2n), n > 1$  and a positive interger is also given.

## §1. Introduction

The most known Smarandache function which has become a classical Smarandache function in number theory is defined as follows:

**Definition.** The classical Smarandache function,  $S$ , is a function

$S : N \rightarrow N, N$ , the set of natural numbers such that  $S(1) = 1$ , and  $S(n)$ =The smallest integer such that  $n/S(n)!$ .

This function has been extensively studied and many interesting properties of it have been discovered [1]. Subsequently many Smarandache type functions have been defined and their interesting properties have been achieved. Ruiz and Perez have discussed some properties of several Smarandache type functions that are involved in many proposed, solved and unsolved problems [2].

An exact formula for counting primes less than or equal to given  $x$  in terms of classical Smarandache function has been discovered by L.Seagull[3]. Ruiz and Perez have quoted this result along with a proof while discussing some properties of the classical Smrandache function (Property 2.4) [2].

## §2. A formula for twin prime pairs

We now proceed to obtain an exact formula for counting twin prime pairs less than or equal to given  $x$  in terms of the classical Smarandache function.

We denote by  $T_2(x)$  the exact number of twin prime pairs less than or equal to  $x$ . Also  $[m]$  denotes the integral part of  $m$ .

**Theorem.**

$$T_2(x) = -1 + \sum_{1 \leq j \leq x-2} \left[ \frac{S(j) \cdot S(j+2)}{(j) \cdot (j+2)} \right],$$

where  $S(k)$  denotes the value of classical Smarandache function evaluated at  $k$ .

**Proof.** It is well known that (1)  $S(p) = p$  iff  $p$  is prime  $> 4$ , (2)  $S(p) < p$  when  $p$  is not prime and  $p \neq 4$ , (3)  $S(4) = 4$ .

In the light of the above properties,

$$(1) \left[ \frac{S(2) \cdot S(4)}{(2) \cdot (4)} \right] = 1,$$

therefore (2, 4) will be counted as a twin prime pair in the sum given in the above formula.

The term " - 1" is added in the formula to eliminate this additional count. Also,

$$(2) \left[ \frac{S(j) \cdot S(j+2)}{(j) \cdot (j+2)} \right] = 1$$

only when  $(j, j + 2)$  will be a twin prime pair and in all other cases

$$\left[ \frac{S(j) \cdot S(j+2)}{(j) \cdot (j+2)} \right] = 0.$$

Hence the theorem is obvious.

Let us denote by  $T_{2n}(x)$  the exact number of prime pairs  $(p, p + 2n)$ ,  $n$  is a positive integer and  $n > 1$ .

**Corollary.**

$$T_{2n}(x) = \sum_{1 \leq j \leq x-2n} \left[ \frac{S(j) \cdot S(j+2n)}{(j) \cdot (j+2n)} \right].$$

**Proof.** Since  $n > 1$ , the illegal appearance of the pair (2, 4) as a prime pair is automatically prohibited, and the proof follows by proceeding on the similar lines.

### §3. Conclusion

Like formula for counting primes up to given  $x$ , [3], one can obtain a similar formula for counting twin prime pairs as well as prime pairs in which the primes are separated by  $2n$  in terms of the Classical Smarandache Functions by proceeding along the same lines.

### Acknowledgements

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## On completely $f$ -perfect numbers

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**1.** Let  $f : \mathbf{N}^* \rightarrow \mathbf{N}$  be a given arithmetic function. Recently, J.L.Pe[3] has called a number  $n$  to be  **$f$ -perfect**, if

$$\sum_{i|n, i < n} f(i) = n, \tag{1}$$

where the sum is taken for all proper divisors  $i$  of  $n$  (i.e.  $i|n, i < n$ ). Clearly for  $f = I$  (where  $I(n) = n$  for all  $n \geq 1$ )(1) given  $\sigma(n) = 2n$ , i.e. one reobtains the classical perfect numbers.

Let  $S, Z$  be the **Smarandache**, resp. **Pseudo-Smarandache functions**, defined by

$$S(n) = \min\{k \in \mathbf{N} : n|n!\}, Z(n) = \min\{k \in \mathbf{N} : n | \frac{k(k+1)}{2}\} \tag{2}$$

Since  $0! = 1$ , we may assume  $S(1) = 0$ . With this assumption, recently Ch. Ashbacher [1] showed that for  $n \leq 10^6$  the only  $S$ -perfect number is  $n = 12$ , while the  $Z$ -perfect numbers in this range are  $n = 4, 6, 471544$ .

**2.** In what follows, we shall call a number  $n$  **completely  $f$ -perfect**, if

$$\sum_{i|n} f(i) = n, \tag{3}$$

where the sum is over **all** divisors of  $n$ . We note that this notion generalizes again the classical notion of a perfect number, since for  $f = I - \varphi$  (where  $\varphi$  is Euler's totient), clearly  $f(n) = n - \varphi \geq 0$  for all  $n$ , and by Gauss' relation  $\sum_{i|n} \varphi(i) = n$ , (3) implies  $\sigma(n) = 2n$ . Thus, the completely  $I - \varphi$ -perfect numbers are the perfect numbers.

**3.** By assuming  $S(1) = 0$ , P.Gronas [2] has shown that for  $f = S$ , all solutions of equation (3) are the following:  $n = p$  (prime), and  $n = 9, 16, 24$ . Thus:

**Theorem 1.** All completely  $S$ -perfect numbers are the primes, and the numbers 9,16,24.

**Remark.** It is important to note, that if one defines  $S(n)$  by  $S(n) = \min\{k \in \mathbf{N}^* : n|k!\}$ , then clearly  $S(1) = 1$ , and Theorem 1 above, as well as Aschbacher's result, are no more valid. Indeed, when  $S(1) = 0$ , then for  $f = S$ , (1) has the form

$$\sum_{i|n, 1 < i < n} S(i) = n, \tag{4}$$

while if  $S(1) = 1$ , then (1) becomes

$$\sum_{i|n, 1 < i < n} f(i) = n - 1. \quad (5)$$

Thus we have two distinct equations, namely (4) at one part, and (5) at another part. On the other hand, from (3) we can deduce the two distinct equations (the first one solved by Theorem 1):

$$\sum_{i|n, 1 < i < n} f(i) = n - S(n), \quad (6)$$

and

$$\sum_{i|n, 1 < i < n} f(i) = n - S(n) - 1. \quad (7)$$

Then, since  $S(2) = 2$ ,  $S(3) = 3$  and 2, 3 are the only proper divisors of 6,  $n = 6$  is a solution to (5), but not (4). Therefore one can have **two distinct notions** of "S-perfect" (as well as "completely S-perfect") numbers. Let us call  $n$  to be S-perfect in the case 1, if (4) holds, and S-perfect in the sense 2, if (5) holds. The following little result is true:

**Theorem 2.** Let  $p, q$  be distinct primes. Then the only S-perfect number  $n$  of the form  $n = pq$  in the sense 2 is  $n = 6$ . There are no S-perfect numbers of this form in sense 1. The only S-perfect numbers of this form in sense 2.

**Proof.** Let  $n = pq$  in (5), and assume  $p < q$ . Then since  $S(p) = p$ ,  $S(q) = q$ , one obtains the equation  $p + q = pq - 1$  i.e.  $(p - 1)(q - 1) = 2$ , giving  $p - 1 = 1, q - 1 = 2$ , i.e.  $p = 2$ ,  $q = 3$ , implying  $n = 6$ . The equation (4) gives  $p + q = pq$ , which cannot have a solution. Let now  $n = p^2q$ . The proper divisors are  $p, q, p^2, pq$ , and since  $S(p^2) = 2p$ ,  $S(pq) = q$ , (4) implies the equation

$$3p + 2q = p^2q.$$

Since  $p|2q$ , clearly  $p|2$ , so  $p = 2$ . This implies  $q = 3$ , so  $n = 2^2 \cdot 3 = 12$ . The equation

$$3p + 2q = p^2q - 1$$

can not have solution, since for  $p = 2$  this gives  $7 = 2q$  (impossible); while for  $p, q$  odd,  $p^2q - 1 = \text{even}$ ,  $3p + 2q = \text{odd}$ .

In the similar way, one can prove:

**Theorem 3.** There are no completely S-perfect numbers of the form  $n = pq$  in both sense. There are no completely S-perfect numbers of the form  $n = p^2q$  in sense 1. The only completely S-perfect number of this form in sense 2, is  $n = 28$ .

**Proof.** Let  $n = pq$  ( $p > q$  primes) in (6), resp. (7). Then one gets  $p + q = pq - q$ , resp.  $p + q = pq - q - 1$ . The first equation, i.e.  $p + 2q = pq$  forces  $q|p$ , impossible; while the second one, i.e.  $p + 2q + 1 = pq$  for  $p = 2$  gives  $3 = 0$ , while for  $p, q \geq 3$  left side = even, right side  $n$  odd.

Now let  $n = p^2q$ . Since  $S(p^2) = 2p$ ,  $S(pq) = q$  and  $S(p^2q) = \max\{S(p^2), S(q)\} = \max\{2p, q\}$ , one can deduce the following equations:

- i)  $3p + 2q = p^2q - \max\{2p, q\}$ ;  
 ii)  $3p + 2q = p^2q - \max\{2p, q\} - 1$ .  
 i) a)  $2p > q \Rightarrow 5p + 2q = p^2q$ . Since  $p|2q$ , this gives  $p = 2$ , when  $2q = 10$ , impossible.  
 b)  $2p < q \Rightarrow 3p + 3q = p^2q$ , giving  $p|3q$ , so  $p = 3$  and  $9 = 6p$ , impossible again.  
 ii)a)  $\Rightarrow 5p + 2q = p^2q - 1$ . For  $p = 2$  one has  $q = -5$ , impossible, while for  $p, q \geq 3$  left side = odd, right side = even.  
 b)  $\Rightarrow 3p + 3q = p^2q - 1$ . Remark that  $p = 2, q = 7$  is a solution of this equation and this satisfies condition  $2p < q$  since  $4 < 7$ . Now, for  $p, q \geq 3$  write the equation in the form

$$q(pq - 3) = 3p + 1$$

and remark that by  $q > p \geq 3$  one has  $q \geq 5$  so  $q(pq - 3) \geq 5(5p - 3) > 3p + 1$ , i.e.  $22p > 16$ , which is true. Thus, there are no other solutions.

4. The solutions  $n = 6$  of (5) and  $n = 28$  of (7) are ordinary perfect numbers. Having in view to determine all these solutions, we first prove the following result:

**Theorem 4.** Let  $n = 2^k p$ , where  $p$  is an odd prime,  $k \geq 1$  and  $p \geq 2k$ . Then  $n$  cannot be a solution to equation (4) or (6). The number  $n$  is a solution of (5) iff  $n = 6$ . The only solution of this type of equation (7) is  $n = 28$ .

**Proof.** We first calculate  $S = \sum_{i|n, 1 < i < n} S(n)$ . Since the proper divisors of  $n = 2^k p$  are  $2, 2^2, \dots, 2^k, p, 2p, 2^2 p, \dots, 2^{k-1} p$ , one has

$$S(n) = S(2) + S(2^2) + \dots + S(2^k) + S(1 \cdot p) + S(2 \cdot p) + \dots + S(2^{k-1} \cdot p)$$

Now

$$S(2^l p) = \max\{S(2^l), S(p)\} = \max\{S(2^l), p\}$$

and since it is well-known that  $S(2^l) \leq 2l$ , by  $2l \leq 2(k-1) < 2k < p$  we get

$$S \leq 2 + 2 \cdot 2 + \dots + 2 \cdot k + kp = \frac{2(k+1)k}{2} + kp = k(k+1) + kp,$$

so

$$S \leq k(k+1) + kp \tag{8}$$

Therefore, by (4), (5), (6), (7) we have to solve the equations

$$S(2) + S(2^2) + \dots + S(2^k) + kp = \begin{cases} 2^k p & (4') \\ 2^k p - 1 & (5') \\ 2^k p - p & (6') \\ 2^k p - p - 1 & (7') \end{cases}$$

a) For (4') remark that by (8) we must have  $2^k p \leq kp + k(k+1)$ , so  $p(2^k - k) \leq k(k+1)$ . Since  $p > 2k$ , on the other hand we have  $p(2^k - k) > 2k(2^k - 2) \geq k(k+1)$  by the inequality  $2(2^k - k) \geq k+1$ , i.e.

$$2^{k+1} \geq 3k + 1, k \geq 1 \tag{9}$$

It is easy to verify by induction that (9) holds true for all  $k \geq 1$ . Therefore, equation (4') is impossible.

**Remark.** The solution  $n = 12 = 2^2 \cdot 3$  with  $p = 3$ ,  $k = 2$  doesn't satisfy  $p > 2k$ .

b) Similarly, for (5'), by (8) we should have satisfied the inequality  $2^k p - 1 \leq kp + k(k+1)$ . Now, by  $p > 2k$  we get

$$p(2^k - k) < 2k(2^k - k) > k(k+1) + 1 \Leftrightarrow k(2^{k+1} - 3k - 1) \geq 2.$$

Now, the inequality

$$2^{k+1} \geq 3k + 2, k \geq 2 \tag{10}$$

holds true. Thus for  $k \geq 2$  we cannot have a solution. For  $k = 1$ , however, by Theorem 2 we get the solution  $n = 2^1 \cdot 3$  when  $p = 3 > 2 \cdot 1 = 2$ .

c) For (6') remark, that similarly we must have  $2^k p - p \leq k(k+1) + kp$ , or  $p(2^k - k - 1) \leq k(k+1)$ . Now, by  $p > 2k$ , and the inequality

$$2^{k+1} > 3k + 3, k \geq 3 \tag{11}$$

it follows that  $p(2^k - k - 1) > 2k(2^k - k - 1) > k(k+1)$ . Thus we could have eventually  $k = 1$  or  $k = 2$ . By Theorem 3 we cannot have solutions.

d) The equation (7'), by (8) implies  $2^k p - p - 1 \leq k(k+1) + kp$  so  $p(2^k - k - 1) - 1 \leq k(k+1)$ . Now, by  $p > 2k$ , and  $2k(2^k - k - 1) > k(k+1) + 1 \Leftrightarrow k(2^{k+1} - 3k - 3) > 1$ , this is true by

$$2^{k+1} \geq 3k + 4, k \geq 3, \tag{12}$$

so we could have eventually  $k = 1$  or  $k = 2$ , i.e.  $n = 2p$  or  $n = 2^2 p$ . By Theorem 3 this is possible only when  $p = 7$ , when  $p > 2k$ , i.e.  $7 > 4$  is satisfied.

**Corollary.** There are no ordinary even perfect numbers which are  $S$ -perfect or completely  $S$ -perfect in sense 1. The only even perfect number which is  $S$ -perfect in sense 2 is  $n = 6$ . The only even perfect number which is completely  $S$ -perfect in sense 2 is  $n = 28$ .

**Proof.** Let  $n$  be an even perfect number. Then, by Euclid-Euler's theorem,  $n$  can be written as  $n = 2^k p$ , where  $p$  is a prime of the form  $p = 2^{k+1} - 1$ . Now,  $p > 2k$  is true, since  $2^{k+1} > 2k + 1$ ,  $k \geq 1$ . This follows e.g. by induction, and we omit the details. Theorem 4 implies the corollary.

4. Finally, note that in paper [4] we have proved that the only completely  $d$ -perfect numbers are  $n = 1, 3, 18$  and  $36$  (here  $d(n)$  is the number of distinct divisors of  $n$ ).

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# Parallel bundles in planar map geometries

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**Abstract** Parallel lines are very important objects in Euclid plane geometry and its behaviors can be gotten by one's intuition. But in a planar map geometry, a kind of the Smarandache geometries, the situation is complex since it may contains elliptic or hyperbolic points. This paper concentrates on the behaviors of parallel bundles in planar map geometries, a generalization of parallel lines in plane geometry and obtains characteristics for parallel bundles.

**Keywords** Parallel bundle; Planar map; Smarandache geometry; Map geometry; Classification.

## §1. Introduction

A *map* is a connected topological graph cellularly embedded in a surface. On the past century, many works are concentrated on to find the combinatorial properties of maps, such as to determine whether exists a particularly embedding on a surface ([7], [11]) or to enumerate a family of maps ([6]). All these works are on the side of algebra, not the object itself, i.e., geometry. For the later, more attentions are given to its element's behaviors, such as, the line, angle, area, curvature,  $\dots$ , see also [12] and [14]. For returning to its original face, the conception of map geometries is introduced in [10]. It is proved in [10] that the map geometries are nice model of the Smarandache geometries. They are also a new kind of intrinsic geometry of surfaces ([1]). The main purpose of this paper is to determine the behaviors of parallel bundles in planar geometries, a generalization of parallel lines in the Euclid plane geometry.

An axiom is said *Smarandachely denied* if the axiom behaves in at least two different ways within the same space, i.e., validated and invalidated, or only invalidated but in multiple distinct ways.

A *Smarandache geometry* is a geometry which has at least one Smarandachely denied axiom(1969)([5], [13]).

In [3] and [4], Iseri presented a nice model of the Smarandache geometries, called *s*-manifolds by using equilateral triangles, which is defined as follows([3], [5] and [9]):

*An s-manifold is any collection  $\mathcal{C}(T, n)$  of these equilateral triangular disks  $T_i, 1 \leq i \leq n$  satisfying the following conditions:*

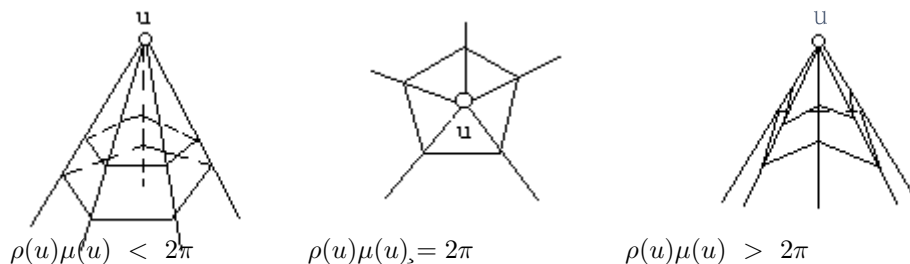
(i) *Each edge  $e$  is the identification of at most two edges  $e_i, e_j$  in two distinct triangular disks  $T_i, T_j, 1 \leq i, j \leq n$  and  $i \neq j$ ;*

(ii) *Each vertex  $v$  is the identification of one vertex in each of five, six or seven distinct triangular disks.*

The conception of map geometries without boundary is defined as follows ([10]).

**Definition 1.1** For a given combinatorial map  $M$ , associates a real number  $\mu(u), 0 < \mu(u) < \pi$ , to each vertex  $u, u \in V(M)$ . Call  $(M, \mu)$  a map geometry without boundary,  $\mu(u)$  the angle factor of the vertex  $u$  and to be orientable or non-orientable if  $M$  is orientable or not.

In [10], it has proved that map geometries are the Smarandache geometries. The realization of each vertex  $u, u \in V(M)$  in  $R^3$  space is shown in the Fig.1 for each case of  $\rho(u)\mu(u) > 2\pi$ ,  $= 2\pi$  or  $< 2\pi$ , call *elliptic point*, *euclidean point* and *hyperbolic point*, respectively.

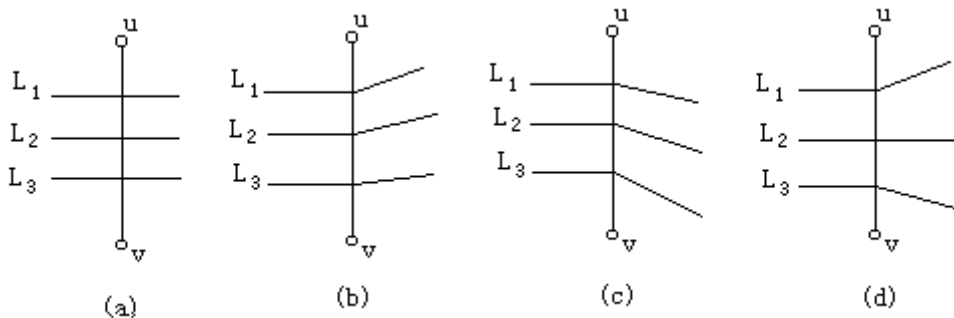


**Fig.1**

Therefore, a line passes through an elliptic vertex, an euclidean vertex or a hyperbolic vertex  $u$  has angle  $\frac{\rho(u)\mu(u)}{2}$  at the vertex  $u$ . It is not  $180^\circ$  if the vertex  $u$  is elliptic or hyperbolic. Then what is the angle of a line passes through a point on an edge of a map? It is  $180^\circ$ ? Since we wish the change of angles on an edge is smooth, the answer is not. For the Smarandache geometries, the parallel lines in them are need to be given more attention. We have the following definition.

**Definition 1.2** A family  $\mathcal{L}$  of infinite lines not intersecting each other in a planar geometry is called a parallel bundle.

In the Fig.2, we present all cases of parallel bundles passing through an edge in planar geometries, where, (a) is the case of points  $u, v$  are same type with  $\rho(u)\mu(u) = \rho(v)\mu(v)$ , (b) and (c) the cases of same types with  $\rho(u)\mu(u) > \rho(v)\mu(v)$  and (d) the case of  $u$  is elliptic and  $v$  hyperbolic.



**Fig.2**

Here, we assume the angle at the intersection point is in clockwise, that is, a line passing



through an elliptic point will bend up and a hyperbolic point will bend down, such as the cases (b),(c) in the Fig.2. For a vector  $\vec{O}$  on the Euclid plane, call it an *orientation*. We classify parallel bundles in planar map geometries along an orientation  $\vec{O}$ .

## §2. A condition for parallel bundles

We investigate the behaviors of parallel bundles in the planar map geometries. For this object, we define a function  $f(x)$  of angles on an edge of a planar map as follows.

**Definition 2.1** Denote by  $f(x)$  the angle function of a line  $L$  passing through an edge  $uv$  at the point of distance  $x$  to  $u$  on the edge  $uv$ .

Then we get the following result.

**Proposition 2.1** A family  $\mathcal{L}$  of parallel lines passing through an edge  $uv$  is a parallel bundle iff

$$\left. \frac{df}{dx} \right|_+ \geq 0.$$

**Proof.** If  $\mathcal{L}$  is a parallel bundle, then any two lines  $L_1, L_2$  will not intersect after them passing through the edge  $uv$ . Therefore, if  $\theta_1, \theta_2$  are the angles of  $L_1, L_2$  at the intersect points of  $L_1, L_2$  with  $uv$  and  $L_2$  is far from  $u$  than  $L_1$ , then we know that  $\theta_2 \geq \theta_1$ . Whence, for any point with  $x$  distance from  $u$  and  $\Delta x > 0$ , we have that

$$f(x + \Delta x) - f(x) \geq 0.$$

Therefore, we get that

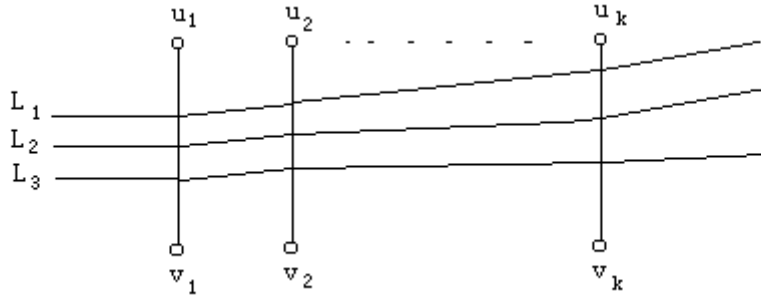
$$\left. \frac{df}{dx} \right|_+ = \lim_{\Delta x \rightarrow +0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \geq 0.$$

As the cases in the Fig.1.

Now if  $\left. \frac{df}{dx} \right|_+ \geq 0$ , then  $f(y) \geq f(x)$  if  $y \geq x$ . Since  $\mathcal{L}$  is a family of parallel lines before meeting  $uv$ , whence, any two lines in  $\mathcal{L}$  will not intersect each other after them passing through  $uv$ . Therefore,  $\mathcal{L}$  is a parallel bundle.  $\square$

A general condition for a family of parallel lines passing through a cut of a planar map being a parallel bundle is the following.

**Proposition 2.2** Let  $(M, \mu)$  be a planar map geometry,  $C = \{u_1v_1, u_2v_2, \dots, u_lv_l\}$  a cut of the map  $M$  with order  $u_1v_1, u_2v_2, \dots, u_lv_l$  from the left to the right,  $l \geq 1$  and the angle functions on them are  $f_1, f_2, \dots, f_l$ , respectively, also see the Fig.3.

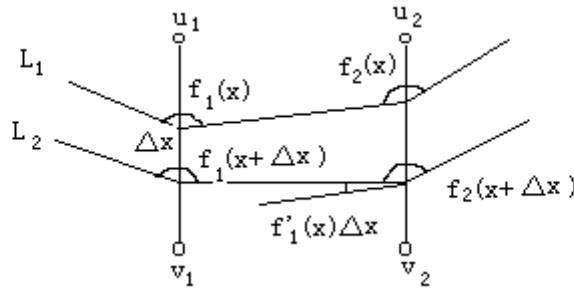


**Fig.3**

Then a family  $\mathcal{L}$  of parallel lines passing through  $C$  is a parallel bundle iff for any  $x, x \geq 0$ ,

$$\begin{aligned}
 f'_1(x) &\geq 0 \\
 f'_{1+}(x) + f'_{2+}(x) &\geq 0 \\
 f'_{1+}(x) + f'_{2+}(x) + f'_{3+}(x) &\geq 0 \\
 &\dots\dots\dots \\
 f'_{1+}(x) + f'_{2+}(x) + \dots + f'_{l+}(x) &\geq 0.
 \end{aligned}$$

**Proof.** According to the Proposition 2.1, see the following Fig.4,



**Fig.4**

we know that any lines will not intersect after them passing through  $u_1v_1$  and  $u_2v_2$  iff for  $\forall \Delta x > 0$  and  $x \geq 0$ ,

$$f_2(x + \Delta x) + f'_{1+}(x)\Delta x \geq f_2(x).$$

That is,

$$f'_{1+}(x) + f'_{2+}(x) \geq 0.$$

Similarly, any lines will not intersect after them passing through  $u_1v_1, u_2v_2$  and  $u_3v_3$  iff for  $\forall \Delta x > 0$  and  $x \geq 0$ ,

$$f_3(x + \Delta x) + f'_{2+}(x)\Delta x + f'_{1+}(x)\Delta x \geq f_3(x).$$

That is,

$$f'_{1+}(x) + f'_{2+}(x) + f'_{3+}(x) \geq 0.$$

Generally, any lines will not intersect after them passing through  $u_1v_1, u_2v_2, \dots, u_{l-1}v_{l-1}$  and  $u_lv_l$  iff for  $\forall \Delta x > 0$  and  $x \geq 0$ ,

$$f_l(x + \Delta x) + f'_{l-1+}(x)\Delta x + \dots + f'_{1+}(x)\Delta x \geq f_l(x).$$

Whence, we get that

$$f'_{1+}(x) + f'_{2+}(x) + \dots + f'_{l+}(x) \geq 0.$$

Therefore, a family  $\mathcal{L}$  of parallel lines passing through  $C$  is a parallel bundle iff for any  $x, x \geq 0$ , we have that

$$\begin{aligned} f'_1(x) &\geq 0 \\ f'_{1+}(x) + f'_{2+}(x) &\geq 0 \\ f'_{1+}(x) + f'_{2+}(x) + f'_{3+}(x) &\geq 0 \\ &\dots\dots\dots \\ f'_{1+}(x) + f'_{2+}(x) + \dots + f'_{l+}(x) &\geq 0. \end{aligned}$$

This completes the proof.  $\square$

**Corollary 2.1** *Let  $(M, \mu)$  be a planar map geometry,  $C = \{u_1v_1, u_2v_2, \dots, u_lv_l\}$  a cut of the map  $M$  with order  $u_1v_1, u_2v_2, \dots, u_lv_l$  from the left to the right,  $l \geq 1$  and the angle functions on them are  $f_1, f_2, \dots, f_l$ . Then a family  $\mathcal{L}$  of parallel lines passing through  $C$  is still parallel lines after them leaving  $C$  iff for any  $x, x \geq 0$ ,*

$$\begin{aligned} f'_1(x) &\geq 0 \\ f'_{1+}(x) + f'_{2+}(x) &\geq 0 \\ f'_{1+}(x) + f'_{2+}(x) + f'_{3+}(x) &\geq 0 \\ &\dots\dots\dots \\ f'_{1+}(x) + f'_{2+}(x) + \dots + f'_{l-1+}(x) &\geq 0 \\ f'_{1+}(x) + f'_{2+}(x) + \dots + f'_{l+}(x) &= 0. \end{aligned}$$

**Proof.** According to the Proposition 2.2, we know the condition is a necessary and sufficient condition for  $\mathcal{L}$  being a parallel bundle. Now since lines in  $\mathcal{L}$  are parallel lines after them leaving  $C$  iff for any  $x \geq 0$  and  $\Delta x \geq 0$ , there must be that

$$f_l(x + \Delta x) + f'_{l-1+}(x)\Delta x + \dots + f'_{1+}(x)\Delta x = f_l(x).$$

Therefore, we get that

$$f'_{1+}(x) + f'_{2+}(x) + \dots + f'_{l+}(x) = 0 \quad \spadesuit$$

When do the parallel lines parallel the initial parallel lines after them passing through a cut  $C$  in a planar map geometry? The answer is in the following result.

**Proposition 2.3** *Let  $(M, \mu)$  be a planar map geometry,  $C = \{u_1v_1, u_2v_2, \dots, u_lv_l\}$  a cut of the map  $M$  with order  $u_1v_1, u_2v_2, \dots, u_lv_l$  from the left to the right,  $l \geq 1$  and the angle functions on them are  $f_1, f_2, \dots, f_l$ . Then the parallel lines parallel the initial parallel lines after them passing through  $C$  iff for  $\forall x \geq 0$ ,*

$$\begin{aligned} f'_1(x) &\geq 0 \\ f'_{1+}(x) + f'_{2+}(x) &\geq 0 \\ f'_{1+}(x) + f'_{2+}(x) + f'_{3+}(x) &\geq 0 \\ &\dots\dots\dots \\ f'_{1+}(x) + f'_{2+}(x) + \dots + f'_{l-1+}(x) &\geq 0 \end{aligned}$$

and

$$f_1(x) + f_2(x) + \dots + f_l(x) = l\pi.$$

**Proof.** According to the Proposition 2.2 and Corollary 2.1, we know the parallel lines passing through  $C$  is a parallel bundle.

We calculate the angle  $\alpha(i, x)$  of a line  $L$  passing through an edge  $u_iv_i, 1 \leq i \leq l$  with the line before it meeting  $C$  at the intersection of  $L$  with the edge  $u_iv_i$ , where  $x$  is the distance of the intersection point to  $u_1$  on  $u_1v_1$ , see also the Fig.4. By the definition, we know the angle  $\alpha(1, x) = f(x)$  and  $\alpha(2, x) = f_2(x) - (\pi - f_1(x)) = f_1(x) + f_2(x) - \pi$ .

Now if  $\alpha(i, x) = f_1(x) + f_2(x) + \dots + f_i(x) - (i - 1)\pi$ , then similar to the case  $i = 2$ , we know that  $\alpha(i + 1, x) = f_{i+1}(x) - (\pi - \alpha(i, x)) = f_{i+1}(x) + \alpha(i, x) - \pi$ . Whence, we get that

$$\alpha(i + 1, x) = f_1(x) + f_2(x) + \dots + f_{i+1}(x) - i\pi.$$

Notice that a line  $L$  parallel the initial parallel line after it passing through  $C$  iff  $\alpha(l, x) = \pi$ , i.e.,

$$f_1(x) + f_2(x) + \dots + f_l(x) = l\pi.$$

This completes the proof.  $\spadesuit$

### §3. Linear condition and combinatorial realization for parallel bundles

For the simplicity, we can assume the function  $f(x)$  is linear and denoted it by  $f_i(x)$ . We can calculate  $f_i(x)$  as follows.

**Proposition 3.1** *The angle function  $f_l(x)$  of a line  $L$  passing through an edge  $uv$  at the point with distance  $x$  to  $u$  is*

$$f_l(x) = \left(1 - \frac{x}{d(uv)}\right) \frac{\rho(u)\mu(v)}{2} + \frac{x}{d(uv)} \frac{\rho(v)\mu(v)}{2},$$

where,  $d(uv)$  is the length of the edge  $uv$ .

**Proof.** Since  $f_l(x)$  is linear, we know that  $f_l(x)$  satisfies the following equation.

$$\frac{f_l(x) - \frac{\rho(u)\mu(u)}{2}}{\frac{\rho(v)\mu(v)}{2} - \frac{\rho(u)\mu(u)}{2}} = \frac{x}{d(uv)},$$

Calculation shows that

$$f_l(x) = \left(1 - \frac{x}{d(uv)}\right) \frac{\rho(u)\mu(v)}{2} + \frac{x}{d(uv)} \frac{\rho(v)\mu(v)}{2}. \quad \spadesuit$$

**Corollary 3.1** *Under the linear assumption, a family  $\mathcal{L}$  of parallel lines passing through an edge  $uv$  is a parallel bundle iff*

$$\frac{\rho(u)}{\rho(v)} \leq \frac{\mu(v)}{\mu(u)}.$$

**Proof.** According to the Proposition 2.1, a family of parallel lines passing through an edge  $uv$  is a parallel bundle iff for  $\forall x, x \geq 0, f'(x) \geq 0$ , i.e.,

$$\frac{\rho(v)\mu(v)}{2d(uv)} - \frac{\rho(u)\mu(u)}{2d(uv)} \geq 0.$$

Therefore, a family  $\mathcal{L}$  of parallel lines passing through an edge  $uv$  is a parallel bundle iff

$$\rho(v)\mu(v) \geq \rho(u)\mu(u).$$

Whence,

$$\frac{\rho(u)}{\rho(v)} \leq \frac{\mu(v)}{\mu(u)}. \quad \spadesuit$$

For a family of parallel lines pass through a cut, we have the following condition for it being a parallel bundle.

**Proposition 3.2** *Let  $(M, \mu)$  be a planar map geometry,  $C = \{u_1v_1, u_2v_2, \dots, u_lv_l\}$  a cut of the map  $M$  with order  $u_1v_1, u_2v_2, \dots, u_lv_l$  from the left to the right,  $l \geq 1$ . Then under the linear assumption, a family  $L$  of parallel lines passing through  $C$  is a parallel bundle iff the angle factor  $\mu$  satisfies the following linear inequality system*

$$\begin{aligned} &\rho(v_1)\mu(v_1) \geq \rho(u_1)\mu(u_1) \\ &\frac{\rho(v_1)\mu(v_1)}{d(u_1v_1)} + \frac{\rho(v_2)\mu(v_2)}{d(u_2v_2)} \geq \frac{\rho(u_1)\mu(u_1)}{d(u_1v_1)} + \frac{\rho(u_2)\mu(u_2)}{d(u_2v_2)} \\ &\dots\dots\dots \end{aligned}$$

$$\begin{aligned} \frac{\rho(v_1)\mu(v_1)}{d(u_1v_1)} + \frac{\rho(v_2)\mu(v_2)}{d(u_2v_2)} + \dots + \frac{\rho(v_l)\mu(v_l)}{d(u_lv_l)} \\ \geq \frac{\rho(u_1)\mu(u_1)}{d(u_1, v_1)} + \frac{\rho(u_2)\mu(u_2)}{d(u_2, v_2)} + \dots + \frac{\rho(u_l)\mu(u_l)}{d(u_l, v_l)}. \end{aligned}$$

**Proof.** Under the linear assumption, for any integer  $i, i \geq 1$ , we know that

$$f'_{i+}(x) = \frac{\rho(v_i)\mu(v_i) - \rho(u_i)\mu(u_i)}{2d(u_iv_i)}$$

by the Proposition 3.1. Whence, according to the Proposition 2.2, we get that a family  $L$  of parallel lines passing through  $C$  is a parallel bundle iff the angle factor  $\mu$  satisfies the following linear inequality system

$$\rho(v_1)\mu(v_1) \geq \rho(u_1)\mu(u_1)$$

$$\frac{\rho(v_1)\mu(v_1)}{d(u_1v_1)} + \frac{\rho(v_2)\mu(v_2)}{d(u_2v_2)} \geq \frac{\rho(u_1)\mu(u_1)}{d(u_1v_1)} + \frac{\rho(u_2)\mu(u_2)}{d(u_2v_2)}$$

.....

$$\begin{aligned} \frac{\rho(v_1)\mu(v_1)}{d(u_1v_1)} + \frac{\rho(v_2)\mu(v_2)}{d(u_2v_2)} + \dots + \frac{\rho(v_l)\mu(v_l)}{d(u_lv_l)} \\ \geq \frac{\rho(u_1)\mu(u_1)}{d(u_1, v_1)} + \frac{\rho(u_2)\mu(u_2)}{d(u_2, v_2)} + \dots + \frac{\rho(u_l)\mu(u_l)}{d(u_l, v_l)}. \end{aligned}$$

This completes the proof.  $\spadesuit$

For planar maps underlying a regular graph, we have the following interesting results for parallel bundles.

**Corollary 3.2** *Let  $(M, \mu)$  be a planar map geometry with  $M$  underlying a regular graph,  $C = \{u_1v_1, u_2v_2, \dots, u_lv_l\}$  a cut of the map  $M$  with order  $u_1v_1, u_2v_2, \dots, u_lv_l$  from the left to the right,  $l \geq 1$ . Then under the linear assumption, a family  $L$  of parallel lines passing through  $C$  is a parallel bundle iff the angle factor  $\mu$  satisfies the following linear inequality system*

$$\mu(v_1) \geq \mu(u_1)$$

$$\frac{\mu(v_1)}{d(u_1v_1)} + \frac{\mu(v_2)}{d(u_2v_2)} \geq \frac{\mu(u_1)}{d(u_1v_1)} + \frac{\mu(u_2)}{d(u_2v_2)}$$

.....

$$\frac{\mu(v_1)}{d(u_1v_1)} + \frac{\mu(v_2)}{d(u_2v_2)} + \dots + \frac{\mu(v_l)}{d(u_lv_l)} \geq \frac{\mu(u_1)}{d(u_1v_1)} + \frac{\mu(u_2)}{d(u_2v_2)} + \dots + \frac{\mu(u_l)}{d(u_lv_l)}$$

and particularly, if assume that all the lengths of edges in  $C$  are the same, then

$$\begin{aligned}
 \mu(v_1) &\geq \mu(u_1) \\
 \mu(v_1) + \mu(v_2) &\geq \mu(u_1) + \mu(u_2) \\
 &\dots\dots\dots \\
 \mu(v_1) + \mu(v_2) + \dots + \mu(v_l) &\geq \mu(u_1) + \mu(u_2) + \dots + \mu(u_l).
 \end{aligned}$$

Certainly, by choosing different angle factors, we can also get combinatorial conditions for existing parallel bundles under the linear assumption.

**Proposition 3.3** *Let  $(M, \mu)$  be a planar map geometry,  $C = \{u_1v_1, u_2v_2, \dots, u_lv_l\}$  a cut of the map  $M$  with order  $u_1v_1, u_2v_2, \dots, u_lv_l$  from the left to the right,  $l \geq 1$ . If for any integer  $i, i \geq 1$ ,*

$$\frac{\rho(u_i)}{\rho(v_i)} \leq \frac{\mu(v_i)}{\mu(u_i)},$$

then under the linear assumption, a family  $L$  of parallel lines passing through  $C$  is a parallel bundle.

**Proof.** Notice that under the linear assumption, for any integer  $i, i \geq 1$ , we know that

$$f'_{i+}(x) = \frac{\rho(v_i)\mu(v_i) - \rho(u_i)\mu(u_i)}{2d(u_iv_i)}$$

by the Proposition 3.1. Whence,  $f'_{i+}(x) \geq 0$  for  $i = 1, 2, \dots, l$ . Therefore, we get that

$$\begin{aligned}
 f'_1(x) &\geq 0 \\
 f'_{1+}(x) + f'_{2+}(x) &\geq 0 \\
 f'_{1+}(x) + f'_{2+}(x) + f'_{3+}(x) &\geq 0 \\
 &\dots\dots\dots \\
 f'_{1+}(x) + f'_{2+}(x) + \dots + f'_{l+}(x) &\geq 0.
 \end{aligned}$$

By the Proposition 2.2, we know that a family  $L$  of parallel lines passing through  $C$  is a parallel bundle. ‡

### §4. Classification of parallel bundles

For a cut  $C$  in a planar map geometry and  $e \in C$ , denote by  $f_e(x)$  the angle function on the edge  $e$ ,  $f(C, x) = \sum_{e \in C} f_e(x)$ . If  $f(C, x)$  is independent on  $x$ , then we abbreviate it to  $f(C)$ . According to the results in the Section 2 and 3, we can classify the parallel bundles with a given orientation  $\vec{O}$  in planar map geometries into the following 15 classes, where, each class is labelled by a 4-tuple 0, 1 code.

**Classification of parallel bundles**

- (1)  $\mathcal{C}_{1000}$ : for any cut  $C$  along  $\vec{O}$ ,  $f(C) = |C|\pi$ ;

- (2)  $\mathcal{C}_{0100}$ : for any cut  $C$  along  $\vec{O}$ ,  $f(C) < |C|\pi$ ;
- (3)  $\mathcal{C}_{0010}$ : for any cut  $C$  along  $\vec{O}$ ,  $f(C) > |C|\pi$ ;
- (4)  $\mathcal{C}_{0001}$ : for any cut  $C$  along  $\vec{O}$ ,  $f'_+(C, x) > 0$  for  $\forall x, x \geq 0$ ;
- (5)  $\mathcal{C}_{1100}$ : There exist cuts  $C_1, C_2$  along  $\vec{O}$ , such that  $f(C_1) = |C_1|\pi$  and  $f(C_2) = c < |C_2|\pi$ ;
- (6)  $\mathcal{C}_{1010}$ : there exist cuts  $C_1, C_2$  along  $\vec{O}$ , such that  $f(C_1) = |C_1|\pi$  and  $f(C_2) > |C_2|\pi$ ;
- (7)  $\mathcal{C}_{1001}$ : there exist cuts  $C_1, C_2$  along  $\vec{O}$ , such that  $f(C_1) = |C_1|\pi$  and  $f'_+(C_2, x) > 0$  for  $\forall x, x \geq 0$ ;
- (8)  $\mathcal{C}_{0110}$ : there exist cuts  $C_1, C_2$  along  $\vec{O}$ , such that  $f(C_1) < |C_1|\pi$  and  $f(C_2) > |C_2|\pi$ ;
- (9)  $\mathcal{C}_{0101}$ : there exist cuts  $C_1, C_2$  along  $\vec{O}$ , such that  $f(C_1) < |C_1|\pi$  and  $f'_+(C_2, x) > 0$  for  $\forall x, x \geq 0$ ;
- (10)  $\mathcal{C}_{0011}$ : there exist cuts  $C_1, C_2$  along  $\vec{O}$ , such that  $f(C_1) > |C_1|\pi$  and  $f'_+(C_2, x) > 0$  for  $\forall x, x \geq 0$ ;
- (11)  $\mathcal{C}_{1110}$ : there exist cuts  $C_1, C_2$  and  $C_3$  along  $\vec{O}$ , such that  $f(C_1) = |C_1|\pi$ ,  $f(C_2) < |C_2|\pi$  and  $f(C_3) > |C_3|\pi$ ;
- (12)  $\mathcal{C}_{1101}$ : there exist cuts  $C_1, C_2$  and  $C_3$  along  $\vec{O}$ , such that  $f(C_1) = |C_1|\pi$ ,  $f(C_2) < |C_2|\pi$  and  $f'_+(C_3, x) > 0$  for  $\forall x, x \geq 0$ ;
- (13)  $\mathcal{C}_{1011}$ : there exist cuts  $C_1, C_2$  and  $C_3$  along  $\vec{O}$ , such that  $f(C_1) = |C_1|\pi$ ,  $f(C_2) > |C_2|\pi$  and  $f'_+(C_1, x) > 0$  for  $\forall x, x \geq 0$ ;
- (14)  $\mathcal{C}_{0111}$ : there exist cuts  $C_1, C_2$  and  $C_3$  along  $\vec{O}$ , such that  $f(C_1) < |C_1|\pi$ ,  $f(C_2) > |C_2|\pi$  and  $f'_+(C_1, x) > 0$  for  $\forall x, x \geq 0$ ;
- (15)  $\mathcal{C}_{1111}$ : there exist cuts  $C_1, C_2, C_3$  and  $C_4$  along  $\vec{O}$ , such that  $f(C_1) = |C_1|\pi$ ,  $f(C_2) < |C_2|\pi$ ,  $f(C_3) > |C_3|\pi$  and  $f'_+(C_4, x) > 0$  for  $\forall x, x \geq 0$ .

Notice that only the first three classes may be parallel lines after them passing through the cut  $C$ . All of the other classes are only parallel bundles, not parallel lines in the usual meaning.

**Proposition 4.1** For an orientation  $\vec{O}$ , the 15 classes  $\mathcal{C}_{1000} \sim \mathcal{C}_{1111}$  are all the parallel bundles in planar map geometries.

**Proof.** Not loss of generality, we assume  $C_1, C_2, \dots, C_m, m \geq 1$ , are all the cuts along  $\vec{O}$  in a planar map geometry  $(M, \mu)$  from the upon side of  $\vec{O}$  to its down side. We find their structural characters for each case in the following discussion.

$\mathcal{C}_{1000}$ : By the Proposition 2.3, a family  $\mathcal{L}$  of parallel lines parallel their initial lines before meeting  $M$  after the passing through  $M$ .

$\mathcal{C}_{0100}$ : By the definition, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if

$$f(C_1) \leq f(C_2) \leq \dots \leq f(C_m) < \pi.$$

Otherwise, some lines in  $\mathcal{L}$  will intersect. According to the Corollary 2.1, they parallel each other after they passing through  $M$  only if

$$f(C_1) = f(C_2) = \dots = f(C_m) < \pi.$$

$\mathcal{C}_{0010}$ : Similar to the case  $\mathcal{C}_{0100}$ , a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if



$$\pi < f(C_1) \leq f(C_2) \leq \cdots \leq f(C_m)$$

and parallel each other after they passing through  $M$  only if

$$\pi < f(C_1) = f(C_2) = \cdots = f(C_m).$$

$\mathcal{C}_{0001}$ : Notice that by the proof of the Proposition 2.3, a line has angle  $f(C, x) - (|C| - 1)\pi$  after it passing through  $C$  with the initial line before meeting  $C$ . In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if for  $\forall x_i, x_i \geq 0, 1 \leq i \leq m$ ,

$$f(C_1, x_1) \leq f(C_2, x_2) \leq \cdots \leq f(C_m, x_m).$$

Otherwise, they will intersect.

$\mathcal{C}_{1100}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is an integer  $k, 2 \leq k \leq m$ , such that

$$f(C_1) \leq f(C_2) \leq \cdots \leq f(C_{k-1}) < f(C_k) = f(C_{k+1}) = \cdots = f(C_m) = \pi.$$

Otherwise, they will intersect.

$\mathcal{C}_{1010}$ : Similar to the case  $\mathcal{C}_{1100}$ , in this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is an integer  $k, 2 \leq k \leq m$ , such that

$$\pi = f(C_1) = f(C_2) = \cdots = f(C_k) < f(C_{k+1}) \leq \cdots \leq f(C_m).$$

Otherwise, they will intersect.

$\mathcal{C}_{1001}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is an integer  $k, l, 1 \leq k < l \leq m$ , such that for  $\forall x_i, x_i \geq 0, 1 \leq i \leq k$  or  $l \leq i \leq m$ ,

$$\begin{aligned} f(C_1, x_1) &\leq f(C_2, x_2) \leq \cdots \leq f(C_k, x_k) < f(C_{k+1}) \\ &= f(C_{k+2}) = \cdots = f(C_{l-1}) = \pi < f(C_l, x_l) \leq \cdots \leq f(C_m, x_m). \end{aligned}$$

Otherwise, they will intersect.

$\mathcal{C}_{0110}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is integers  $k, 1 \leq k < m$ , such that

$$f(C_1) \leq f(C_2) \leq \cdots \leq f(C_k) < \pi < f(C_{k+1}) \leq \cdots \leq f(C_m).$$

Otherwise, they will intersect.

$\mathcal{C}_{0101}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is integers  $k, 1 \leq k \leq m$ , such that for  $\forall x_i, x_i \geq 0, 1 \leq i \leq m$ ,

$$f(C_1, x_1) \leq f(C_2, x_2) \leq \cdots \leq f(C_k, x_k) < \pi \leq f(C_{k+1}, x_{k+1}) \leq \cdots \leq f(C_m, x_m),$$

and there must be a constant in  $f(C_1, x_1), f(C_2, x_2), \cdots, f(C_k, x_k)$ .

$\mathcal{C}_{0011}$ : In this case, the situation is similar to the case  $\mathcal{C}_{0101}$  and there must be a constant in  $f(C_{k+1}, x_{k+1}), f(C_{k+2}, x_{k+2}), \dots, f(C_m, x_m)$ .

$\mathcal{C}_{1110}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is an integer  $k, l, 1 \leq k < l \leq m$ , such that

$$\begin{aligned} f(C_1) &\leq f(C_2) \leq \dots \leq f(C_k) < f(C_{k+1}) \\ &= \dots = f(C_{l-1}) = \pi < f(C_l) \leq \dots \leq f(C_m). \end{aligned}$$

Otherwise, they will intersect.

$\mathcal{C}_{1101}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is an integer  $k, l, 1 \leq k < l \leq m$ , such that for  $\forall x_i, x_i \geq 0, 1 \leq i \leq k$  or  $l \leq i \leq m$ ,

$$\begin{aligned} f(C_1, x_1) &\leq f(C_2, x_2) \leq \dots \leq f(C_k, x_k) < f(C_{k+1}) \\ &= \dots = f(C_{l-1}) = \pi < f(C_l, x_l) \leq \dots \leq f(C_m, x_m) \end{aligned}$$

and there must be a constant in  $f(C_1, x_1), f(C_2, x_2), \dots, f(C_k, x_k)$ . Otherwise, they will intersect.

$\mathcal{C}_{1011}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is an integer  $k, l, 1 \leq k < l \leq m$ , such that for  $\forall x_i, x_i \geq 0, 1 \leq i \leq k$  or  $l \leq i \leq m$ ,

$$\begin{aligned} f(C_1, x_1) &\leq f(C_2, x_2) \leq \dots \leq f(C_k, x_k) < f(C_{k+1}) \\ &= \dots = f(C_{l-1}) = \pi < f(C_l, x_l) \leq \dots \leq f(C_m, x_m) \end{aligned}$$

and there must be a constant in  $f(C_l, x_l), f(C_{l+1}, x_{l+1}), \dots, f(C_m, x_m)$ . Otherwise, they will intersect.

$\mathcal{C}_{0111}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is an integer  $k, 1 \leq k \leq m$ , such that for  $\forall x_i, x_i \geq 0$ ,

$$f(C_1, x_1) \leq f(C_2, x_2) \leq \dots \leq f(C_k, x_k) < \pi < f(C_l, x_l) \leq \dots \leq f(C_m, x_m)$$

and there must be a constant in  $f(C_1, x_1), f(C_2, x_2), \dots, f(C_k, x_k)$  and a constant in  $f(C_l, x_l), f(C_{l+1}, x_{l+1}), \dots, f(C_m, x_m)$ . Otherwise, they will intersect.

$\mathcal{C}_{1111}$ : In this case, a family  $\mathcal{L}$  of parallel lines is a parallel bundle along  $\vec{O}$  only if there is an integer  $k, l, 1 \leq k < l \leq m$ , such that for  $\forall x_i, x_i \geq 0, 1 \leq i \leq k$  or  $l \leq i \leq m$ ,

$$\begin{aligned} f(C_1, x_1) &\leq f(C_2, x_2) \leq \dots \leq f(C_k, x_k) < f(C_{k+1}) \\ &= \dots = f(C_{l-1}) = \pi < f(C_l, x_l) \leq \dots \leq f(C_m, x_m) \end{aligned}$$

and there must be a constant in  $f(C_1, x_1), f(C_2, x_2), \dots, f(C_k, x_k)$  and a constant in  $f(C_l, x_l), f(C_{l+1}, x_{l+1}), \dots, f(C_m, x_m)$ . Otherwise, they will intersect.

Following the structural characters of the classes  $\mathcal{C}_{1000} \sim \mathcal{C}_{1111}$ , by the Proposition 2.2, 2.3 and Proposition 3.1, we know that any parallel bundle is in one of the classes  $\mathcal{C}_{1000} \sim \mathcal{C}_{1111}$  and each class in  $\mathcal{C}_{1000} \sim \mathcal{C}_{1111}$  is non-empty. This completes the proof.  $\square$

A example of parallel bundle in a planar map geometry is shown in the Fig.5, in where the number on a vertex  $u$  denotes the number  $\rho(u)\mu(u)$ .

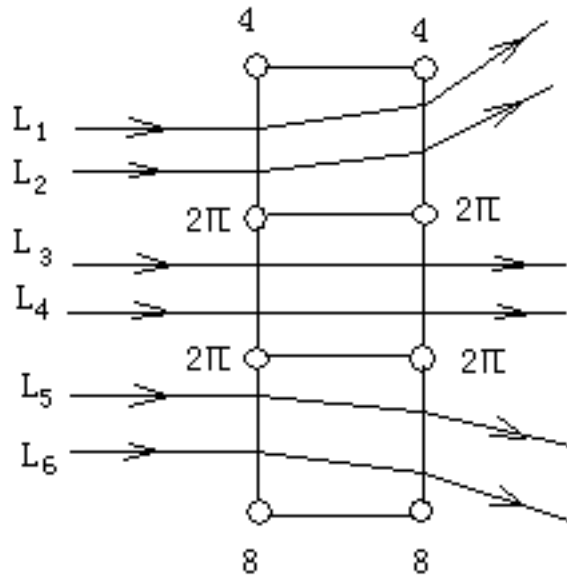


Fig.5

### §5. Generalization

All the planar map geometries considered in this paper are without boundary. For planar map geometries with boundary, i.e., some faces are deleted ([10]), which are correspondence with the maps with boundary ([2]). We know that they are the Smarandache *non-geometries*, satisfying one or more of the following conditions:

- (A1<sup>-</sup>) *It is not always possible to draw a line from an arbitrary point to another arbitrary point.*
- (A2<sup>-</sup>) *It is not always possible to extend by continuity a finite line to an infinite line.*
- (A3<sup>-</sup>) *It is not always possible to draw a circle from an arbitrary point and of an arbitrary interval.*
- (A4<sup>-</sup>) *Not all the right angles are congruent.*
- (A5<sup>-</sup>) *If a line, cutting two other lines, forms the interior angles of the same side of it strictly less than two right angle, then not always the two lines extended towards infinite cut each other in the side where the angles are strictly less than two right angle.*

Notice that for an one face planar map geometry  $(M, \mu)^{-1}$  with boundary, if we choose all points being euclidean, then  $(M, \mu)^{-1}$  is just the Poincaré's model for the hyperbolic geometry.

Using the neutrosophic logic idea, we can also define the conception of *neutrosophic surface* as follow, comparing also with the surfaces in [8] and [14].

**Definition 5.1** *A neutrosophic surface is a Hausdorff, connected, topological space  $S$  such that every point  $v$  is elliptic, euclidean, or hyperbolic.*

For this kind of surface, we present the following problem for the further researching.

**Problem 5.1** *To determine the behaviors of elements, such as, the line, angle, area,  $\dots$ , in neutrosophic surfaces.*

Notice that results in this paper are just the behaviors of line bundles in a neutrosophic plane.

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# On the asymptotic properties of odd sieve sequence

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**Abstract** The main purpose of this paper is using elementary method and an analytic method to study the asymptotic properties of the odd sieve sequence, and give two interesting asymptotic formulae.

**Keywords** Odd sieve sequence; Mean value; Asymptotic formula.

## §1. Introduction And Results

According to reference [1], the definition of the odd sieve is: subtract 2 from all prime numbers and obtain a temporary sequence, and choose all odd number that do not belong to the temporary one. For example: 7, 13, 19, 23, 25, 31, 33, 37, 43, 47, 49, 53, 55, 61, 63, 67, 73, 75, 79, 83, 85, 91, 93, 97, ... are all belong to odd sieve sequence. Let  $A$  denote the set of all odd sieve. In reference [1], Professor F.Smarandache asked us to study the properties of the odd sieve sequence. About this problem, it seems that none had studied it, at least we have not seen related paper before. In this paper, we use elementary method and analytic method to study the asymptotic properties of odd sieve sequence, and obtain two interesting asymptotic formulae. That is, we shall prove the following:

**Theorem 1.** For any real number  $x \geq 3$ , we have the asymptotic formula

$$\sum_{\substack{a \in A \\ a \leq x}} a = x^2 - \frac{x^2}{2 \log x} - \frac{x^2}{4 \log^2 x} + O(x).$$

**Theorem 2.** For any real number  $x \geq 3$ , we have the asymptotic formula

$$\sum_{\substack{a \in A \\ a \leq x}} d(a) = \frac{1}{2} x \log x + Bx + O\left(x^{\frac{1}{2}} \log^2 x\right),$$

where  $B = 4C - \frac{1}{2} + \frac{3}{2} \log 2 - \frac{315\zeta(3)}{6\pi^4}$ ,  $C$  is Euler constant,  $d(n)$  be the Dirichlet divisor function.

## §2. Several Lemmas

To complete the proof of the theorems, we need the following several simple lemmas. Firstly, we have

**Lemma 1.** For any real number  $x \geq 1$ , we have

$$\sum_{n \leq x} n^\alpha = \frac{x^{\alpha+1}}{\alpha+1} + O(x^\alpha). \quad (\alpha \geq 1)$$

**Proof.** (See reference [2]).

Taking  $\alpha = 0, 1$  in the lemma 1, we may immediately obtain the following:

**Corollary.** For any real number  $x \geq 1$ , then we have

$$\sum_{n \leq x} 1 = x + O(1)$$

and

$$\sum_{n \leq x} n = \frac{1}{2}x^2 + O(x).$$

**Lemma 2.** For any fixed real number  $x$ , let  $\pi(x)$  denote the number of all primes not exceeding  $x$ , then we have

$$\pi(x) = \frac{x}{\log x} + \frac{x}{\log^2 x} + O\left(\frac{x}{\log^3 x}\right).$$

**Proof.** (See reference [3]).

**Lemma 3.** For any real number  $x \geq 3$ , let  $p$  be a prime, then we have

$$\sum_{p \leq x} p = \frac{x^2}{2 \log x} + \frac{x^2}{4 \log^2 x} + O\left(\frac{x^2}{\log^3 x}\right).$$

**Proof.** From Lemma 2 and by Abel's identity, we can easily deduce that

$$\begin{aligned} \sum_{p \leq x} p &= \pi(x)x - \int_1^x \pi(t)dt \\ &= \frac{x^2}{\log x} + \frac{x^2}{\log^2 x} + O\left(\frac{x^2}{\log^3 x}\right) \\ &\quad - \int_2^x \frac{t}{\log t} dt - \int_2^x \frac{t}{\log^2 t} dt + O\left(\int_2^x \frac{t}{\log^3 t} dt\right) \\ &= \frac{x^2}{2 \log x} + \frac{x^2}{4 \log^2 x} + O\left(\frac{x^2}{\log^3 x}\right). \end{aligned}$$

This completes the proof of Lemma 3.

**Lemma 4.** For any real number  $x \geq 1$ , we have

$$\sum_{n \leq x} d(n) = x \log x + (2C - 1)x + O(\sqrt{x}),$$

where  $C$  is Euler constant, and  $d(n)$  be the Dirichlet divisor function.

**Proof.** This result may be immediately got from [2].

**Lemma 5.** For any real number  $x \geq 1$ , we have

$$\sum_{n \leq x} d(2n) = \frac{3}{2}x \log x + \left(\frac{\log 2}{2} - \frac{3}{2}\right)x + O\left(x^{\frac{1}{2}} \log^2 x\right).$$

**Proof.** Let  $s = \sigma + it$  be a complex number and  $h(s) = \sum_{n=1}^{\infty} \frac{d(2n)}{n^s}$ . Note that  $d(2n) \ll n^\epsilon$ , so it is clear that  $h(s)$  is a Dirichlet series absolutely convergent for  $\text{Re}(s) > 1$ , by the Euler Product formula [2] and the definition of  $d(n)$  we get

$$\begin{aligned}
 h(s) &= \prod_p \sum_{m=0}^{\infty} \frac{d(2p^m)}{p^{ms}} \\
 &= \sum_{m=0}^{\infty} \frac{d(2^{m+1})}{2^{ms}} \cdot \prod_{p>2} \sum_{m=0}^{\infty} \frac{d(2p^m)}{p^{ms}} \\
 &= 2\zeta^2(s) \cdot \frac{(\prod_{p>2} \sum_{m=0}^{\infty} \frac{d(p^m)}{p^{ms}}) \cdot (\sum_{m=0}^{\infty} \frac{d(2^{m+1})}{2^{ms}})}{\prod_p \sum_{m=0}^{\infty} \frac{d(p^m)}{p^{ms}}} \\
 &= 2\zeta^2(s) \cdot \frac{\sum_{m=0}^{\infty} \frac{d(2^{m+1})}{2^{ms}}}{\sum_{m=0}^{\infty} \frac{d(2^m)}{2^{ms}}} \\
 &= \zeta^2(s) (2 - \frac{1}{2^s}), \tag{1}
 \end{aligned}$$

where  $\zeta(s)$  is the Riemann Zeta-function and  $\prod_p$  denotes the product over all primes.

From (1) and Perron's formula [4], for  $b = 1 + \epsilon, T \geq 1$  and  $x \geq 1$  we have

$$\sum_{n \leq x} d(2n) = \frac{1}{2\pi i} \int_{b-iT}^{b+iT} h(s) \frac{x^s}{s} ds + O\left(\frac{x^b}{T}\right) + O\left(\frac{xH(2x) \log x}{T}\right). \tag{2}$$

Taking  $a = \frac{1}{2} + \epsilon$ , we move the integral line in (2). Then

$$\begin{aligned}
 \sum_{n \leq x} d(2n) &= \text{Res}_{s=1} \zeta^2(s) (2 - \frac{1}{2^s}) \frac{x^s}{s} \\
 &+ \frac{1}{2\pi i} \left| \int_{b-iT}^{a-iT} + \int_{a-iT}^{a+iT} + \int_{a+iT}^{b+iT} \right| \zeta^2(s) (2 - \frac{1}{2^s}) \frac{x^s}{s} ds \\
 &+ O\left(\frac{x^b}{T}\right) + O\left(\frac{xH(2x) \log x}{T}\right),
 \end{aligned}$$

where

$$\begin{aligned}
 &\left| \int_{b-iT}^{a-iT} + \int_{a+iT}^{b+iT} \right| \zeta^2(s) (2 - \frac{1}{2^s}) \frac{x^s}{s} ds \ll \frac{x}{T} \\
 &\int_{a-iT}^{a+iT} \zeta^2(s) (2 - \frac{1}{2^s}) \frac{x^s}{s} ds \ll x^{\frac{1}{2}} \log^2 T.
 \end{aligned}$$

Hence, we have

$$\begin{aligned}
\sum_{n \leq x} d(2n) &= \operatorname{Res}_{s=1} \zeta^2(s) \left(2 - \frac{1}{2^s}\right) \frac{x^s}{s} + O\left|\frac{x}{T}\right| \\
&\quad + O\left(x^{\frac{1}{2}} \log^2 T\right) + O\left|\frac{x^b}{T}\right| + O\left|xH(2x) \frac{\log x}{T}\right| \\
&= \operatorname{Res}_{s=1} \zeta^2(s) \left(2 - \frac{1}{2^s}\right) \frac{x^s}{s} + O\left|\frac{x}{T}\right| \\
&\quad + O\left(x^{\frac{1}{2}} \log^2 T\right) + O\left|x^{1+\varepsilon} \frac{\log x}{T}\right|. \tag{3}
\end{aligned}$$

Taking  $T = x^{\frac{1}{2}+\varepsilon}$  in (3), then

$$\begin{aligned}
\sum_{n \leq x} d(2n) &= \operatorname{Res}_{s=1} \zeta^2(s) \left(2 - \frac{1}{2^s}\right) \frac{x^s}{s} + O\left(x^{\frac{1}{2}-\varepsilon}\right) + O\left(x^{\frac{1}{2}} \log^2 x\right) \\
&= \operatorname{Res}_{s=1} \zeta^2(s) \left(2 - \frac{1}{2^s}\right) \frac{x^s}{s} + O\left(x^{\frac{1}{2}} \log^2 x\right). \tag{4}
\end{aligned}$$

Now we can easily get the residue of the function  $\zeta^2(s) \left(2 - \frac{1}{2^s}\right) \cdot \frac{x^s}{s}$  at second order pole point  $s = 1$

$$\operatorname{Res}_{s=1} \zeta^2(s) \left(2 - \frac{1}{2^s}\right) \frac{x^s}{s} = \frac{3}{2}x \log x + \left(\frac{\log 2}{2} - \frac{3}{2}\right)x. \tag{5}$$

Combining (4) and (5), we immediately get

$$\sum_{n \leq x} d(2n) = \frac{3}{2}x \log x + \left(\frac{\log 2}{2} - \frac{3}{2}\right)x + O\left(x^{\frac{1}{2}} \log^2 x\right).$$

This completes the proof of Lemma 5.

**Lemma 6.** *For any  $x > 0$ , let  $a$  be any fixed positive integer, then we have*

$$\sum_{0 < p-a \leq x} d(p-a) = \frac{315\zeta(3)}{2\pi^4} \prod_{p|a} \frac{(p-1)^2}{p^2-p+1} x + O\left(x(\log x)^{-1+\varepsilon}\right),$$

where  $\varepsilon$  is any positive integer.

**Proof.** This result may be immediately got from [5].

### §3. Proof of the Theorem

In this section, we will complete the proof of Theorem. First, we have

$$\begin{aligned}
\sum_{\substack{a \in A \\ a \leq x}} a &= \sum_{n \leq x} (2n-1) - \sum_{p \leq x} (p-2) \\
&= 2 \sum_{n \leq x} n - \sum_{n \leq x} 1 - \sum_{p \leq x} p + 2\pi(x).
\end{aligned}$$



From Lemma 1, Lemma 2 and Lemma 3, we have

$$\begin{aligned} \sum_{\substack{a \in A \\ a \leq x}} a &= 2 \left( \frac{x^2}{2} + O(x) \right) - (x + O(1)) \\ &\quad - \left( \frac{x^2}{2 \log x} + \frac{x^2}{4 \log^2 x} + O \left( \frac{x^2}{\log^3 x} \right) \right) \\ &\quad + 2 \left( \frac{x}{\log x} + \frac{x}{\log^2 x} + O \left( \frac{x}{\log^3 x} \right) \right) \\ &= x^2 - \frac{x^2}{2 \log x} - \frac{x^2}{4 \log^2 x} + O(x). \end{aligned}$$

This completes the proof of Theorem 1.

Now we will give the proof of Theorem 2.

From Lemma 4, Lemma 5 and Lemma 6, we can easily obtain

$$\begin{aligned} \sum_{\substack{a \in A \\ a \leq x}} d(a) &= \sum_{n \leq x} d(2n-1) - \sum_{p \leq x} d(p-2) \\ &= \sum_{n \leq 2x} d(n) - \sum_{n \leq x} d(2n) - \sum_{p \leq x} d(p-2) \\ &= 2x \log x + 2(2C-1 + \log 2)x + O(\sqrt{x}) \\ &\quad - \frac{3}{2}x \log x + \left( \frac{\log 2}{2} - \frac{3}{2} \right)x + O(x^{\frac{1}{2}} \log^2 x) \\ &\quad - \frac{315\zeta(3)}{6\pi^4}x + O(x(\log x)^{-1+\varepsilon}) \\ &= \frac{1}{2}x \log x + Bx + O(x^{\frac{1}{2}} \log^2 x), \end{aligned}$$

where  $B = 4C - \frac{1}{2} + \frac{3}{2} \log 2 - \frac{315\zeta(3)}{6\pi^4}$ ,  $C$  is Euler constant.

This completes the proof of Theorem 2.

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# Smarandache quasigroup rings

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**Abstract** In this paper, we have introduced Smarandache quasigroups which are Smarandache non-associative structures. W.B.Kandasamy [2] has studied groupoid ring and loop ring. We have defined Smarandache quasigroup rings which are again non-associative structures having two binary operations. Substructures of quasigroup rings are also studied.

**Keywords** Non-associative rings; Smarandache non-associative rings; Quasigroups; Smarandache quasigroups; Smarandache quasigroup rings.

## §1. Introduction

In the paper [2] W.B.Kandasamy has introduced a new concept of groupoid rings. This structure provides number of examples of SNA-rings (Smarandache non-associative rings). SNA-rings are non-associative structure on which are defined two binary operations one associative and other being non-associative and addition distributes over multiplication both from right and left. We are introducing a new concept of quasigroup rings. These are non-associative structures. In our view groupoid rings and quasigroup rings are the rich source of non-associative SNA-rings without unit since all other rings happen to be either associative or non-associative rings with unit. To make this paper self contained we recollect some definitions and results which we will use subsequently.

## §2. Preliminaries

**Definition 2.1.** A groupoid  $S$  such that for all  $a, b \in S$  there exist unique  $x, y \in S$  such that  $ax = b$  and  $ya = b$  is called a quasigroup.

Thus a quasigroup does not have an identity element and it is also non-associative. Here is a quasigroup that is not a loop.

*	1	2	3	4	5
1	3	1	4	2	5
2	5	2	3	1	4
3	1	4	2	5	3
4	4	5	1	3	2
5	2	3	5	4	1

We note that the definition of quasigroup  $Q$  forces it to have a property that every element of  $Q$  appears exactly once in every row and column of its operation table. Such a table is called a LATIN SQUARE. Thus, quasigroup is precisely a groupoid whose multiplication table is a LATIN SQUARE.

**Definition 2.2.** If a quasigroup  $(Q, *)$  contains a group  $(G, *)$  properly then the quasigroup is said to be Smarandache quasigroup.

**Example 2.1.** Let  $Q$  be a quasigroup defined by the following table:

*	$a_0$	$a_1$	$a_2$	$a_3$	$a_4$
$a_0$	$a_0$	$a_1$	$a_3$	$a_4$	$a_2$
$a_1$	$a_1$	$a_0$	$a_2$	$a_3$	$a_4$
$a_2$	$a_3$	$a_4$	$a_1$	$a_2$	$a_0$
$a_3$	$a_4$	$a_2$	$a_0$	$a_1$	$a_3$
$a_4$	$a_2$	$a_3$	$a_4$	$a_0$	$a_1$

Clearly,  $A = \{a_0, a_1\}$  is a group w.r.t.  $*$  which is a proper subset of  $Q$ . Therefore  $Q$  is a Smarandache quasigroup.

**Definition 2.3.** A quasigroup  $Q$  is idempotent if every element  $x$  in  $Q$  satisfies  $x * x = x$ .

**Definition 2.4.** A ring  $(R, +, *)$  is said to be a non-associative ring if  $(R, +)$  is an additive abelian group,  $(R, *)$  is a non-associative semigroup (i.e. binary operation  $*$  is non-associative) such that the distributive laws

$a * (b + c) = a * b + a * c$  and  $(a + b) * c = a * c + b * c$  for all  $a, b, c$  in  $R$ .

**Definition 2.5.** Let  $R$  be a commutative ring with one.  $G$  be any group ( $S$  any semigroup with unit)  $RG$  ( $RS$  the semigroup ring of the semigroup  $S$  over the ring  $R$ ) the group ring of the group  $G$  over the ring  $R$  consists of finite formal sums of the form  $\sum_{i=1}^n \alpha_i g_i$ , ( $n < \infty$ ) i.e.  $i$  runs over a finite number where  $\alpha_i \in R$  and  $g_i \in G$  ( $g_i \in S$ ) satisfying the following conditions:

- $\sum_{i=1}^n \alpha_i m_i = \sum_{i=1}^n \beta_i m_i \Leftrightarrow \alpha_i = \beta_i$ , for  $i = 1, 2, \dots, n$
- $\sum_{i=1}^n \alpha_i m_i + \sum_{i=1}^n \beta_i m_i \Leftrightarrow \sum_{i=1}^n (\alpha_i + \beta_i) m_i$
- $(\sum_{i=1}^n \alpha_i m_i)(\sum_{i=1}^n \beta_i m_i) = \sum_{i=1}^n \gamma_k m_k$ ,  $m_k = m_i m_j$ , where  $\gamma_k = \sum \alpha_i \beta_j$
- $r_i m_i = m_i r_i$  for all  $r_i \in R$  and  $m_i \in G$  ( $m_i \in S$ ).
- $r \sum_{i=1}^n r_i m_i = \sum_{i=1}^n r r_i m_i$  for all  $r \in R$  and  $\sum_{i=1}^n r_i m_i \in RG$ .  $RG$  is an associative ring with  $0 \in R$  acts as its additive identity. Since  $I \in R$  we have  $G = IG \subseteq RG$  and  $R.e = R \subseteq RG$  where  $e$  is the identity element of  $G$ .

If we replace the group  $G$  in the above definition by a quasigroup  $Q$  we get  $RQ$  the quasigroup ring which will satisfy all the five conditions 1 to 5 given in the definition. But  $RQ$

will only be a non-associative ring without identity. As  $I \in R$  we have  $Q \subseteq RQ$ . Thus we define quasigroup rings as follows:

**Definition 2.6.** For any quasigroup  $Q$  the quasigroup ring  $RQ$  is the quasigroup  $Q$  over the ring  $R$  consisting of all finite formal sums of the form  $\sum_{i=1}^n r_i q_i$ , ( $n < \infty$ ) i.e.  $i$  runs over a finite number where  $r_i \in R$  and  $q_i \in Q$  satisfying conditions 1 to 5 given in the definition of group rings above.

Note that only when  $Q$  is a quasigroup with identity (i.e. then  $Q$  is a Loop) that the quasigroup ring  $RQ$  will be a non-associative ring with unit. Here we give examples of non-associative quasigroup rings.

**Example 2.2.** Let  $Z$  be the ring of integers and  $(Q, *)$  be the quasigroup given by the following table:

*	1	2	3	4	5
1	3	1	4	2	5
2	5	2	3	1	4
3	1	4	2	5	3
4	4	5	1	3	2
5	2	3	5	4	1

Clearly  $(Q, *)$  is a quasigroup and does not possess an identity element. The quasigroup ring  $ZQ$  is a non-associative ring without unit element.

**Example 2.3.** Let  $R$  be the ring of reals and  $(Q, *)$  be the quasigroup defined by the following table:

*	1	2	3	4
1	1	3	4	2
2	4	2	1	3
3	2	4	3	1
4	3	1	2	4

$(Q, *)$  is an idempotent quasigroup. Again  $RQ$  is a non-associative quasigroup ring without unit. Note that  $R\langle 1 \rangle$ ,  $R\langle 2 \rangle$ ,  $R\langle 3 \rangle$ ,  $R\langle 4 \rangle$  are the subrings of  $RQ$  which are associative.

Result: All quasigroup rings  $RQ$  of a quasigroup  $Q$  over the ring  $R$  are non-associative rings without unit.

The smallest non-associative ring without unit is quasigroup ring given by the following example. This example was quoted by W.B.Kandasamy [2] as a groupoid ring.

**Example 2.4.** Let  $Z_2 = \{0, 1\}$  be the prime field of characteristic 2.  $(Q, *)$  be a quasigroup of order 3 given by the following table:

*	$q_1$	$q_2$	$q_3$
$q_1$	$q_1$	$q_2$	$q_3$
$q_2$	$q_3$	$q_1$	$q_2$
$q_3$	$q_2$	$q_3$	$q_1$

$Z_2Q$  is a quasigroup ring having only eight elements given by  $\{0, q_1, q_2, q_3, q_1 + q_2, q_2 + q_3, q_1 + q_3, q_1 + q_2 + q_3\}$ . Clearly,  $Z_2Q$  is a non-associative ring without unit. This happens to be the smallest non-associative ring without unit known to us.

### §3. SNA-Quasigroup rings

We introduce Smarandache non-associative quasigroup rings. It is true that quasigroup rings are always non-associative. We write “Smarandache non-associative quasigroup ring” only to emphasize the fact that they are non-associative.

**Definition 3.1.** Let  $S$  be a quasigroup ring.  $S$  is said to be SNA-quasigroup ring (Smarandache non-associative quasigroup ring) if  $S$  contains a proper subset  $P$  such that  $P$  is an associative ring under the operations of  $S$ .

**Example 3.1.** Let  $Z$  be the ring of integers and  $Q$  be a quasigroup defined by the following table;

*	$a_0$	$a_1$	$a_2$	$a_3$	$a_4$
$a_0$	$a_0$	$a_1$	$a_3$	$a_4$	$a_2$
$a_1$	$a_1$	$a_0$	$a_2$	$a_3$	$a_4$
$a_2$	$a_3$	$a_4$	$a_1$	$a_2$	$a_0$
$a_3$	$a_4$	$a_2$	$a_0$	$a_1$	$a_3$
$a_4$	$a_2$	$a_3$	$a_4$	$a_0$	$a_1$

Clearly,  $A = \{a_0, a_1\}$  is group and  $ZQ \supset ZA$ . Thus the quasigroup ring  $ZQ$  contains an associative ring properly. Hence  $ZQ$  is an SNA-quasigroup ring. Note that  $Q$  is a Smarandache quasigroup.

**Example 3.2.** Let  $R$  be the reals,  $(Q, *)$  be the quasigroup defined by the following table;

*	0	1	2	3
0	0	1	3	2
1	1	0	2	3
2	3	2	1	0
3	2	3	0	1

Then clearly  $RQ$  is an SNA-quasigroup ring as  $RQ \supset R\langle 0, 1 \rangle$  and  $R\langle 0, 1 \rangle$  is an associative ring.

**Theorem 3.1.** *Let  $Q$  be a quasigroup and  $R$  be any ring. Then the quasigroup ring  $RQ$  is not always an SNA-quasigroup ring.*

**Proof.** Since  $Q$  does not have an identity element, there is no guarantee that  $R$  is contained in  $RQ$ .

**Example 3.3.** Let  $R$  be an arbitrary ring and  $Q$  be a quasigroup defined by the table;

*	1	2	3	4	5
1	3	1	4	2	5
2	5	2	3	1	4
3	1	4	2	5	3
4	4	5	1	3	2
5	2	3	5	4	1

Then clearly,  $RQ$  is not an SNA-quasigroup ring as the quasigroup ring  $RQ$  does not contain an associative ring.

**Theorem 3.2.** *If  $Q$  is a quasigroup with identity, then quasigroup ring  $RQ$  is SNA-quasigroup ring.*

**Proof.** Quasigroup with identity is a Loop. So,  $RI \subseteq RQ$  and  $R$  serves as the associative ring in  $RQ$ . Thus  $RQ$  is an SNA-quasigroup ring.

**Theorem 3.3.** *Let  $R$  be a ring. If  $Q$  is a Smarandache quasigroup, then quasigroup ring  $RQ$  is an SNA-quasigroup ring.*

**Proof.** Obviously  $RQ$  is a non-associative ring. As  $Q$  is a Smarandache quasigroup  $Q$  contains a group  $G$  properly. So  $RQ \supset RG$  and  $RG$  is an associative ring contained in  $RQ$ . Therefore  $RQ$  is an SNA-quasigroup ring.

## §4. Substructure of SNA-quasigroup rings

**Definition 4.1.** Let  $R$  be a SNA-quasigroup ring. Let  $S$  be a non-empty subset of  $R$ . Then  $S$  is said to be S-quasigroup subring of  $R$  if  $S$  itself is a ring and contains a proper subset  $P$  such that  $P$  is an associative ring under the operation of  $R$ .

**Example 4.1.** Let  $Z$  be the ring of integers. Let  $Q$  be the quasigroup defined by the following table:

*	1	2	3	4	5	6	7	8
1	1	2	3	4	6	5	8	7
2	2	1	4	3	5	6	7	8
3	3	4	1	2	7	8	6	5
4	4	3	2	1	8	7	5	6
5	6	5	7	8	1	2	3	4
6	5	6	8	7	2	3	4	1
7	8	7	6	5	3	4	1	2
8	7	8	5	6	4	1	2	3

Clearly the quasigroup ring  $ZQ$  is a non-associative ring. Consider the subset  $S = \{1, 2, 3, 4\}$  then  $S$  is a group and hence  $ZS$  is a group ring and hence also a quasigroup ring. Let  $P = \{1, 2\}$ . Note that  $ZS$  also contains  $ZP$  where  $P = \{1, 2\}$ . So,  $ZS$  is an S-quasigroup subring of SNA-quasigroup ring  $ZQ$ .

We have not yet been able to find a Smarandache non associative quasigroup subring for a given quasigroup ring. We think that it is not possible to obtain a subquasigroup for any quasigroup because for a quasigroup its composition table is a LATIN SQUARE.

**Theorem 4.1.** *Let  $R$  be a quasigroup ring, if  $R$  has a SNA-quasigroup subring  $S$ , then  $R$  itself is SNA-quasigroup ring.*

**Proof.** As  $S$  is an SNA-quasigroup subring  $S$  contains an associative ring. As a result  $R$  contains an associative ring. Thus  $R$  is an SNA-quasigroup ring.

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# Two asymptotic formulae on the $k + 1$ -power free numbers

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**Abstract** The main purpose of this paper is to study the distributive properties of  $k + 1$ -power free numbers, and give two interesting asymptotic formulae.

**Keywords**  $k + 1$ -power free numbers; Asymptotic formula.

## §1. Introduction

A natural number  $n$  is called a  $k + 1$ -power free number if it can not be divided by any  $p^{k+1}$ , where  $p$  is a prime number. One can obtain all  $k + 1$ -power free numbers by the following method:

From the set of natural numbers (except 0 and 1)

-take off all multiples of  $2^{k+1}$  (i.e.  $2^{k+1}, 2^{k+2}, \dots$ ).

-take off all multiples of  $3^{k+1}$ .

-take off all multiples of  $5^{k+1}$ .

$\dots$  and so on (take off all multiples of all  $k + 1$ -power primes).

In reference [1], Professor F. Smarandache asked us to study the properties of the  $k + 1$ -power free numbers sequence. Yet we still know very little about it.

Now we define two new number-theoretic functions  $U(n)$  and  $V(n)$  as following,

$$U(1) = 1, \quad U(n) = \prod_{p|n} p,$$

$$V(1) = 1, \quad V(n) = V(p_1^{\alpha_1}) \cdots U(p_r^{\alpha_r}) = (p^{\alpha_1} - 1) \cdots (p^{\alpha_r} - 1),$$

where  $n$  is any natural number with the form  $n = p_1^{\alpha_1} \cdots p_r^{\alpha_r}$ . Obviously they are both multiplicative functions. In this paper, we shall use the analytic method to study the distribution properties of this sequence, and obtain two interesting asymptotic formulae. That is, we have the following two theorems:

**Theorem 1.** *Let  $\mathcal{A}$  denote the set of all  $k + 1$ -power free numbers, then for any real number  $x \geq 1$ , we have the asymptotic formula*

$$\sum_{\substack{n \in \mathcal{A} \\ n \leq x}} U(n) = \frac{3x^2}{\pi^2} \prod_p \left( 1 + \frac{p^{2k-2} - 1}{p^{2k+1} + p^{2k} - p^{2k-1} - p^{2k-2}} \right) + O\left(x^{\frac{3}{2} + \varepsilon}\right),$$



where  $\varepsilon$  denotes any fixed positive number and  $\prod_p$  denotes the product of all the prime numbers.

**Theorem 2.** For any real number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{\substack{n \in \mathcal{A} \\ n \leq x}} V(n) = \frac{x^2}{2} \prod_p \left( 1 - \frac{1}{p^{k+1}} - \frac{p^{2k+1} + p^{2k} - p - 1}{p^{2k+3} + p^{2k+1}} \right) + O\left(x^{\frac{3}{2} + \varepsilon}\right).$$

## §2. Proof of Theorems

In this section, we shall complete the proof of Theorems. First we prove Theorem 1, let

$$f(s) = 1 + \sum_{\substack{n \in \mathcal{A} \\ n \leq x}} \frac{U(n)}{n^s}.$$

From the Euler product formula [2] and the definition of  $U(n)$ , we may have

$$\begin{aligned} f(s) &= \prod_p \left( 1 + \frac{U(p)}{p^s} + \frac{U(p^2)}{p^{2s}} + \cdots + \frac{U(p^k)}{p^{ks}} \right) \\ &= \prod_p \left( 1 + \frac{1}{p^{s-1}} + \frac{1}{p^{2s-1}} + \cdots + \frac{1}{p^{ks-1}} \right) \\ &= \prod_p \left( 1 + \frac{1}{p^{s-1}} + \frac{p^{(k-1)s} - 1}{p^{2s-1}(p^{(k-1)s} - p^{(k-2)s})} \right) \\ &= \frac{\zeta(s-1)}{\zeta(2(s-1))} \prod_p \left( 1 + \frac{p^{(k-1)s} - 1}{(p^{2s-1} + p^s)(p^{(k-1)s} - p^{(k-2)s})} \right), \end{aligned}$$

where  $\zeta(s)$  is the Riemann-zeta function. Obviously, we have the following two inequalities

$$|U(n)| \leq n, \quad \left| \sum_{n=1}^{\infty} \frac{U(n)}{n^\sigma} \right| < \frac{1}{\sigma - 2},$$

where  $\sigma > 2$  is the real part of  $s$ . So by Perron formula [3]

$$\begin{aligned} \sum_{n \leq x} \frac{U(n)}{n^{s_0}} &= \frac{1}{2i\pi} \int_{b-iT}^{b+iT} f(s+s_0) \frac{x^s}{s} ds + O\left(\frac{x^b B(b+\sigma_0)}{T}\right) \\ &\quad + O\left(x^{1-\sigma_0} H(2x) \min\left(1, \frac{\log x}{T}\right)\right) + O\left(x^{-\sigma_0} H(N) \min\left(1, \frac{x}{\|x\|}\right)\right), \end{aligned}$$

where  $N$  is the nearest integer to  $x$ ,  $\|x\| = |x - N|$ . Taking  $s_0 = 0$ ,  $b = 3$ ,  $T = x^{\frac{3}{2}}$ ,  $H(x) = x$ ,  $B(\sigma) = \frac{1}{\sigma-2}$ , we have

$$\sum_{n \leq x} U(n) = \frac{1}{2i\pi} \int_{3-iT}^{3+iT} \frac{\zeta(s-1)}{\zeta(2(s-1))} R(s) \frac{x^s}{s} ds + O(x^{\frac{3}{2} + \varepsilon}),$$

where

$$R(s) = \prod_p \left( 1 + \frac{p^{2k-2} - 1}{p^{2k+1} + p^{2k} - p^{2k-1} - p^{2k-2}} \right).$$

To estimate the main term

$$\frac{1}{2i\pi} \int_{3-iT}^{3+iT} \frac{\zeta(s-1)}{\zeta(2(s-1))} R(s) \frac{x^s}{s} ds,$$

we move the integral line from  $s = 3 \pm iT$  to  $s = \frac{3}{2} \pm iT$ . This time, the function

$$f(s) = \frac{\zeta(s-1)x^s}{\zeta(2(s-1))s} R(s)$$

has a simple pole point at  $s = 2$  with residue  $\frac{x^2}{2\zeta(2)} R(2)$ . So we have

$$\begin{aligned} & \frac{1}{2i\pi} \left( \int_{3-iT}^{3+iT} + \int_{3+iT}^{\frac{3}{2}+iT} + \int_{\frac{3}{2}+iT}^{\frac{3}{2}-iT} + \int_{\frac{3}{2}-iT}^{3-iT} \right) \frac{\zeta(s-1)x^s}{\zeta(2(s-1))s} R(s) ds \\ &= \frac{x^2}{2\zeta(2)} \prod_p \left( 1 + \frac{p^{2k-2} - 1}{p^{2k+1} + p^{2k} - p^{2k-1} - p^{2k-2}} \right). \end{aligned}$$

We can easily get the estimates

$$\begin{aligned} & \left| \frac{1}{2\pi i} \left( \int_{3+iT}^{\frac{3}{2}+iT} + \int_{\frac{3}{2}-iT}^{3-iT} \right) \frac{\zeta(s-1)x^s}{\zeta(2(s-1))s} R(s) ds \right| \\ & \ll \int_{\frac{3}{2}}^3 \left| \frac{\zeta(\sigma-1+iT)}{\zeta(2(\sigma-1+iT))} R(s) \frac{x^3}{T} \right| d\sigma \ll \frac{x^3}{T} = x^{\frac{3}{2}} \end{aligned}$$

and

$$\left| \frac{1}{2\pi i} \int_{\frac{3}{2}+iT}^{\frac{3}{2}-iT} \frac{\zeta(s-1)x^s}{\zeta(2(s-2))s} R(s) ds \right| \ll \int_0^T \left| \frac{\zeta(1/2+it)}{\zeta(1+2it)} \frac{x^{\frac{3}{2}}}{t} \right| dt \ll x^{\frac{3}{2}+\varepsilon}.$$

Note the fact that  $\zeta(2) = \frac{\pi^2}{6}$ , then from the above we can obtain

$$\sum_{\substack{n \in \mathcal{A} \\ n \leq x}} U(n) = \frac{3x^2}{\pi^2} \prod_p \left( 1 + \frac{p^{2k-2} - 1}{p^{2k+1} + p^{2k} - p^{2k-1} - p^{2k-2}} \right) + O\left(x^{\frac{3}{2}+\varepsilon}\right).$$

This completes the proof of Theorem 1.

Now we come to prove Theorem 2. Let

$$g(s) = 1 + \sum_{\substack{n \in \mathcal{A} \\ n \leq x}} \frac{V(n)}{n^s}.$$

From the Euler product formula [2] and the definition of  $V(n)$ , we also have

$$\begin{aligned} g(s) &= \prod_p \left( 1 + \frac{V(p)}{p^s} + \frac{V(p^2)}{p^{2s}} + \dots + \frac{V(p^k)}{p^{ks}} \right) \\ &= \prod_p \left( 1 + \frac{p-1}{p^s} + \frac{p^2-1}{p^{2s}} + \dots + \frac{p^k-1}{p^{ks}} \right) \\ &= \prod_p \left( \frac{1 - \frac{1}{p^{(k+1)(s-1)}}}{1 - \frac{1}{p^{s-1}}} - \frac{1 - \frac{1}{p^{ks}}}{p^s - 1} \right) \\ &= \zeta(s-1) \prod_p \left( 1 - \frac{1}{p^{(k+1)(s-1)}} - \frac{(p^{ks} - 1)(p^{s-1} + 1)}{(p^{ks} - p^{(k-1)s})p^{2s-1}} \right). \end{aligned}$$

Now applying Perron formula [3], and the method of proving Theorem 1, we can also obtain the result of Theorem 2.

This completes the proof of Theorems.

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# An equation involving the Smarandache ceil function

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**Abstract** In this paper, we use the elementary methods to study the properties of the infinity series  $\sum_{\substack{n=1 \\ n \in \mathcal{A}}}^{\infty} \frac{1}{n^s}$ , where  $\mathcal{A}$  denotes the set of all positive integers  $n$  such that the equation  $S_k(n) = a_k(n)$ , and give an interesting identity for it.

**Keywords** Smarandache ceil function; Infinity series; Identity.

## §1. Introduction

For any fixed positive integer  $k$  and any positive integer  $n$ , the Smarandache ceil function  $S_k(n)$  is defined as follows:

$$S_k(n) = \min\{m \in N : n|m^k\}.$$

This was introduced by Professor F.Smarandache. About this function, many scholar had studied its properties, see [1] and [2]. In [1], Ibstedt presented the following properties:

$$(\forall a, b \in N) (a, b) = 1 \Rightarrow S_k(a \cdot b) = S_k(a) \cdot S_k(b),$$

and  $S_k(p^\alpha) = p^{\lceil \frac{\alpha}{k} \rceil}$ , where  $p$  is a prime and  $\lceil x \rceil$  denotes the smallest integer greater than  $x$ . That is,  $S_k(n)$  is a multiplicative function. Therefore, if  $n = p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_r^{\alpha_r}$  is the prime power decomposition of  $n$ , then the following identity is obviously:

$$S_k(n) = S_k(p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_r^{\alpha_r}) = p_1^{\lceil \frac{\alpha_1}{k} \rceil} p_2^{\lceil \frac{\alpha_2}{k} \rceil} \cdots p_r^{\lceil \frac{\alpha_r}{k} \rceil}.$$

For any positive integer  $n$ , the Smarandache  $k$ -th power complements  $a_k(n)$  is the smallest positive integer such that  $na_k(n)$  is a complete  $k$ -th power. That is,

$$a_k(n) = \min\{l \mid n \cdot l = m^k, l \geq 0, m \in N^+\}.$$

If  $n = p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_r^{\alpha_r}$  denotes the factorization  $n$  into prime powers, then from the definition of  $a_k(n)$ , we know that it is also a multiplicative function, therefore

$$a_k(n) = a_k(p_1^{\alpha_1}) a_k(p_2^{\alpha_2}) \cdots a_k(p_r^{\alpha_r}).$$

Let  $\mathcal{A}$  denotes the set of the positive integers  $n$  such that the equation  $S_k(n) = a_k(n)$ . That is,  $\mathcal{A} = \{n \in N, S_k(n) = a_k(n)\}$ . In this paper, we use the elementary methods to study

the properties of the infinity series  $\sum_{\substack{n=1 \\ n \in \mathcal{A}}}^{\infty} \frac{1}{n^s}$ , and give an interesting identity for it. That is, we shall prove the following conclusion:

**Theorem.** *Let  $k \geq 2$  be a given positive integer. Then for any real number  $s > 1$ , we have the identity:*

$$\sum_{\substack{n=1 \\ n \in \mathcal{A}}}^{\infty} \frac{1}{n^s} = \frac{\zeta((k-1)s)}{\zeta((k^2-1)s)},$$

where  $\zeta(s)$  is the Riemann zeta-function.

**Corollary 1.** *Taking  $k = 2$  and  $s = 2$  in the above theorem, then we have the identities:*

$$\sum_{\substack{n=1 \\ n \in \mathcal{A}}}^{\infty} \frac{1}{n^2} = \frac{315}{2\pi^4}.$$

**Corollary 2.** *Taking  $k = 3$  and  $s = 1$  in the above theorem, then we have the identities:*

$$\sum_{\substack{n=1 \\ n \in \mathcal{A}}}^{\infty} \frac{1}{n} = \frac{1575}{\pi^6}.$$

## §2. Proof of the theorem

In this section, we will complete the proof of the theorem. First, we define the arithmetical function  $b(n)$  as follows:

$$b(n) = \begin{cases} 1, & \text{if } n \in \mathcal{A}, \\ 0, & \text{otherwise.} \end{cases}$$

Now let  $n = p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_s^{\alpha_s}$  denotes the factorization  $n$  into prime powers. Then from the introduction of this paper we know that  $S_k(n)$  and  $a_k(n)$  both are multiplicative functions, so we only discuss the case of  $n = p^i$ .

If  $i = lk + n$ , ( $l \geq 0, 0 \leq n < k$ ), then from the definition of  $S_k(n)$  and  $a_k(n)$ , we can easily get:

$$S_k(p^i) = p^{\lceil \frac{i}{k} \rceil} = \begin{cases} p^l, & \text{if } n = 0, \\ p^{l+1}, & \text{if } 0 < n < k. \end{cases}$$

$$a_k(p^i) = \begin{cases} 1, & \text{if } n = 0, \\ p^{k-n}, & \text{if } 0 < n < k. \end{cases}$$

So  $S_k(p^i) = a_k(p^i)$ , if and only if  $l+1 = k-n$ , i.e.  $n = k-l-1$ , or  $i = lk+n = lk+k-l-1 = (k-1)(l+1)$ . Hence,  $p^i = p^{(k-1)(l+1)}$ , where  $0 \leq l \leq k-1$ .

For any real number  $s > 1$ , it is clear that

$$\sum_{\substack{n=1 \\ n \in \mathcal{A}}}^{\infty} \frac{1}{n^s} = \sum_{n=1}^{\infty} \frac{b(n)}{n^s} < \sum_{n=1}^{\infty} \frac{1}{n^s},$$

and  $\sum_{n=1}^{\infty} \frac{1}{n^s}$  is convergent if  $s > 1$ . Thus  $\sum_{\substack{n=1 \\ n \in \mathcal{A}}}^{\infty} \frac{1}{n^s}$  is also convergent if  $s > 1$ , so from the Euler product formula (see [3]), we have

$$\begin{aligned} \sum_{\substack{n=1 \\ n \in \mathcal{A}}}^{\infty} \frac{1}{n^s} &= \sum_{n=1}^{\infty} \frac{b(n)}{n^s} = \prod_p \left( 1 + \frac{b(p)}{p^s} + \frac{b(p^2)}{p^{2s}} + \dots \right) \\ &= \prod_p \left( 1 + \sum_{l=0}^{k-1} \frac{b(p^{(k-1)(l+1)})}{p^{(k-1)(l+1)s}} \right) \\ &= \prod_p \left( 1 + \sum_{l=0}^{k-1} \frac{1}{p^{(k-1)(l+1)s}} \right) \\ &= \prod_p \left( 1 + \frac{1}{p^{(k-1)s}} \sum_{l=0}^{k-1} \frac{1}{p^{(k-1)ls}} \right) \\ &= \prod_p \left( 1 + \frac{1 - \frac{1}{p^{k(k-1)s}}}{p^{(k-1)s} - 1} \right) \\ &= \frac{\zeta((k-1)s)}{\zeta((k^2-1)s)}, \end{aligned}$$

where  $\zeta(s)$  is the Riemann zeta-function.

This completes the proof of Theorem.

Note that  $\zeta(2) = \frac{\pi^2}{6}$ ,  $\zeta(6) = \frac{\pi^6}{945}$  and  $\zeta(8) = \frac{\pi^8}{9450}$ , we may immediately deduce the corollaries.

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# Smarandache Bcc-algebras

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**Abstract** The notion of Smarandache BCC-algebras and Smarandache BCC-ideas is introduced. Conditions for a (special) subset to be a Smarandache BCC-ideal are given.

**Keywords** Smarandache BCC-algebra; Smarandache BCC-ideal.

## §1. Introduction

Generally, in any human field, a Smarandache Structure on a set  $A$  means a weak structure  $W$  on  $A$  such that there exists a proper subset  $B$  of  $A$  which is embedded with a strong structure  $S$ . In [10], W.B.Vasantha Kandasamy studied the concept of Smarandache groupoids, subgroupoids, ideal of groupoids, semi-normal subgroupoids, Smarandache Bol groupoids and strong Bol groupoids and obtained many interesting results of congruences, and it was studied by R.Padilla [9]. In this paper, we discuss the Smarandache structure on BCC-algebras, and introduce the notion of Smarandache ideas, and investigate its properties. We give conditions for a (special) subset to be a Smarandache BCC-ideal.

## §2. Preliminaries

BCC-algebras were introduced by Komori [7] in a connection with some problems on BCK-algebras in [11], and Dudek [1, 2] redefined the notion of BCC-algebras by using a dual form of the ordinary definition in the sense of Komori.

An algebra  $(X; *, 0)$  of type  $(2, 0)$  is called a BCC-algebra if it satisfies the following conditions.

- (a1)  $(\forall x, y, z \in X) (((x * y) * (z * y)) * (x * z)),$
- (a1)  $(\forall x \in X) (0 * x = 0),$
- (a1)  $(\forall x \in X) (x * 0 = 0),$
- (a1)  $(\forall x, y \in X) (x * y = 0, y * x = 0 \implies x = y).$

Note that every BCK-algebra is BCC-algebra, but the converse is not true. A BCC-algebra which is not a BCK-algebra is called a proper BCC-algebra. The smallest proper BCC-algebra has four elements and for every  $n \geq 4$  there exists at least one proper BCC-algebra [2].

A nonempty subset  $I$  of a BCC-algebra  $X$  is called a BCC-ideal of  $X$  if it satisfies the following assertions:

(a5)  $0 \in I$ ,

(a6)  $(\forall x, z \in X) (\forall y \in I) ((x * y) * z \in I \implies x * z \in I)$ .

Note that every BCC-algebra  $X$  satisfies the following assertions.

(b1)  $(\forall x \in X) (x * x = 0)$ ,

(b2)  $(\forall x, y \in X) (x * y \leq x)$ ,

(b3)  $(\forall x, y, z \in X) (x * y \implies x \leq z \leq y * z, z * y \leq z * x)$ ,

where  $x \leq y$  if and only if  $x \leq y = 0$ .

### §3. Smarandache BCC-algebra

We know that every proper BCC-algebra has at least four elements (see [2]), and that if  $X$  is a BCC-algebra then  $\{0, a\}, a \in X$ , is a BCC-algebra with respect to the same operation on  $X$ . Now let us consider a proper BCC-algebra  $X = \{0, 1, 2, 3, 4\}$  with the following Cayley table :

*	0	1	2	3	4
0	0	0	0	0	0
1	1	0	1	0	1
2	2	2	0	1	2
3	3	3	1	0	3
4	4	0	0	0	0

Table 3.1

Then  $\{0, 1\}, \{0, 2\}, \{0, 3\}, \{0, 4\}, \{0, 1, 2\}$  and  $\{0, 1, 3\}$  are BCC-algebras with respect to the operation  $*$  on  $X$ , and note that  $X$  does not contain BCC-algebras of order 4. Based on this result, we give the following definition.

**Definition 3.1.** A Smarandache BCC-algebra is defined to be a BCC-algebra algebra  $X$  in which there exists a proper subset  $Q$  of  $X$  such that

(i)  $0 \in Q$ , and  $|Q| \geq 4$ ,

(ii)  $Q$  is a BCC-algebra with respect to the operation on  $X$ .

Note that any proper BCC-algebra  $X$  with four elements can be Smarandache. Hence if  $X$  is a Smarandache BCC-algebra, then  $|x| \geq 5$ . Notice that the BCC-algebra  $X = \{0, 1, 2, 3, 4\}$  with Table 3.1 is not a Smarandache BCC-algebra.



**Example 3.2.** (1) Let  $X = \{0, a, b, c, d, e\}$  be a set with the following Cayley table:

*	0	a	b	c	d	e
0	0	0	0	0	0	0
a	a	0	0	0	0	a
b	b	b	0	0	a	a
c	c	b	a	0	a	a
d	d	d	d	d	0	a
e	e	e	e	e	e	0

Table 3.2

Then  $(X; *, 0)$  is a Smarandache BCC-algebra. Note that  $Q = \{0, a, b, c\}$  is a BCK-algebra which is contained in  $X$ .

(2) Let  $\{X; *, 0\}$  be a finite BCK-chain containing at least four elements and let  $c$  be its maximal element. Let  $Y = X \cup \{d\}$ , where  $d \notin X$ , and define a binary operation  $\odot$  on  $Y$  as follows:

$$x \odot y = \begin{cases} x * y, & \text{if } x, y \in X; \\ 0, & \text{if } x \in X, y = d; \\ d, & \text{if } x = d, y = 0; \\ c, & \text{if } x = d, y \in X. \end{cases}$$

Then  $(Y; \odot, 0)$  is a Smarandache BCC-algebra.

(3) Let  $\{X; *, 0\}$  be a BCC-algebra containing at least four elements in which  $a$  is the small atom. Let  $Y = X \cup \{\omega\}$ , where  $\omega \notin X$ , and define a binary operation  $\odot$  on  $Y$  as follows:

$$x \odot y = \begin{cases} x * y, & \text{if } x, y \in X; \\ 0, & \text{if } y \in X, x = \omega; \\ d, & \text{if } x = \omega = y; \\ c, & \text{if } x \in X/\{0\}, y = \omega. \end{cases}$$

Then  $(Y; \odot, 0)$  is a Smarandache BCC-algebra.

In what follows, let  $X$  and  $Q$  denote a Smarandache BCC-algebra and non-trivial BCC-algebra which is properly contained in  $X$ , respectively, unless otherwise specified.

**Definition 3.3.** A nonempty subset  $I$  of  $X$  is called a Smarandache BCC-ideal of  $X$  related to  $Q$  if it satisfies:

- (c1)  $0 \in I$ ,
- (c2)  $(\forall x, z \in Q) (\forall y \in I) ((x * y) * z \in I \implies x * z \in I)$ .

If  $I$  is a Smarandache BCC-ideal of  $X$  related to every non-trivial BCC-algebra contained in  $X$ , we simply say that  $I$  is a Smarandache BCC-ideal of  $X$ .

**Example 3.4.** (1) Let  $X = \{0, a, b, c, d, e\}$  be the Smarandache BCC-algebra described in Example 3.2(1). Then  $I = \{0, a\}$  and  $J = \{0, a, b, c, d\}$  are Smarandache BCC-ideals of  $X$  related to  $Q = \{0, a, b, c\}$ .

**Proposition 3.5.** Every Smarandache BCC-ideals of X related to Q satisfies:

(c3)  $(\forall x \in Q) (\forall a \in I) (x * a \in I \implies x \in I),$

(c4)  $(\forall x \in Q) (\forall a \in I) (a * x \in I),$

(c5)  $(\forall x \in Q) (\forall a, b \in I) (x * ((x * a) * b \in I)).$

**Proof.** (c3) Taking  $z = 0$  and  $y = a$  in (c2) and using (a3) induces the desired implication.

(c4) For every  $x \in Q$  and  $a \in I$ , we have  $(a * a) * x = 0 * x = 0 \in I$  and so  $a * x \in I$  by (c2).

(c5) Let  $x \in Q$  and  $a, b \in I$ . Then  $(x * a) * (a * x) = 0 \in I$ , and so  $x * (x * a) \in I$  by (c2).

Since

$$((x * b) * ((x * a) * b)) * (x * (x * a)) = 0 \in I,$$

it follows from (c3) that  $(x * b) * ((x * a) * b) \in I$  so from (c2) that  $x * ((x * a) * b) \in I$ .

**Corollary 3.6.** For every Smarandache BCC-ideal I of X related to Q, the following implication is valid:

$$(\forall x \in Q)(\forall a \in I)(x \leq a \implies x \in I).$$

**Corollary 3.7.** Let I be a Smarandache BCC-ideal I of X related to Q . Then

$$(\forall x \in Q)(\forall a, b \in I)(x * a \leq b \implies x \in I).$$

**Theorem 3.8.** Let  $Q_1$  and  $Q_2$  be non-trivial BCK-algebras which are properly contained in X such that  $Q_1 \subset Q_2$  . Then every Smarandache BCC-ideal of X related to  $Q_2$  is a Smarandache BCC-ideal of X related to  $Q_1$ .

**Proof.** Straightforward.

**Corollary 3.9.** If Q is the largest BCK-algebra which is properly contained in X, then every Smarandache BCC-ideal of X related to Q is a Smarandache BCC-ideal of X.

The converse of Theorem 3.8 is not true in general as seen in the following example.

**Example 3.10.** Consider a Smarandache BCC-algebra  $X = \{0, 1, 2, 3, 4, 5\}$  with the following Cayley table:

*	0	1	2	3	4	5
0	0	0	0	0	0	0
1	1	0	0	0	0	1
2	2	1	0	0	0	1
3	3	1	1	0	1	1
4	4	1	1	1	0	1
5	5	5	5	5	5	0

Table 3.3

Note that  $Q_1 := \{0, 1, 2, 3\}$  and  $Q_2 := \{0, 1, 2, 3, 4\}$  are BCK-algebras. Then the set  $Q_1$  is a Smarandache BCC-ideal of X related to  $Q_1$ , but not  $Q_2$ . In fact, we know that  $(4 * 2) * 0 = 1 \in Q_1$  and  $4 * 0 = 4 \notin Q_1$ .

**Remark 3.11.** Note that every BCC-ideal of X is a Smarandache BCC-ideal of X, but the converse is not valid. Example 3.10 shows that there exists a BCC-algebra Q of order

$n \geq 4$  which is properly contained in a Smarandache BCC-algebra  $X$  such that a Smarandache BCC-ideal of  $X$  related to  $Q$  is not a BCC-ideal of  $X$ .

We provide convide conditions for a subset to be a Smarandache BCC-ideal.

**Theorem 3.12.** If  $I$  is a subset of  $Q$  that satisfies conditions (c1) and (c3), then  $I$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ .

**Proof.** Let  $x, y \in Q$  and  $a \in I$  be such that  $(x * a) * y \in I$ . Since  $a \in I \subseteq Q$  and  $Q$  is a BCK-algebra, it follows that  $(x * y) * a = (x * a) * y \in I$ . So from (c3) that  $x * y \in I$ . Hence  $I$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ .

**Theorem 3.13.** If a nonempty subset  $I$  of  $X$  satisfies conditions (c1) and (c5), then  $I$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ .

**Proof.** Let  $x, y \in Q$  and  $a \in I$  be such that  $(x * a) * y \in I$ . Taking  $b = 0$  in (c5) and using (a3), we have  $(x * x) * a \in I$ . It follows from (a3), (a1) and (c5) that

$$x * y = (x * y) * 0 = (x * y) * (((x * y) * ((x * a) * y)) * (x * (x * a))) \in I.$$

Thus  $I$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ .

**Theorem 3.14.** Let  $H$  be a BCC-subalgebra of  $X$ . Then  $H$  is a Smarandache BCC-ideal of  $X$  related to  $Q$  if and only if it satisfies:

$$(\forall x \in H)(\forall y, z \in Q)((y * x) * z \in H \implies y * z \in H).$$

**Proof.** Straightforward.

Given an element  $\omega \in X \setminus \{0\}$ , consider the set

$$[0, \omega] := \{x \in X \mid x \leq \omega\}.$$

which is called the initial segment of  $\omega$ [5]. Obviously,  $0 \in [0, \omega]$  for all  $x \in \omega$ . Since  $x \leq \omega$  is equivalent to  $x\omega = 0$ , the initial segment of  $\omega$  is defacto the left annihilator of  $\omega$ . In general,  $[0, \omega]$  is not a Smarandache BCC-ideal of  $X$ , but it is a subalgebra. For example, let  $X$  be the Smarandache BCC-algebra in example 3.2(1). Then  $[0, e] = \{0, e\}$  is not a Smarandache BCC-ideal of  $X$  related to  $Q = \{0, a, b, c\}$  since  $(b * e) * d = 0 \in [0, e]$ , but  $b * d = a \notin [0, e]$ .

**Theorem 3.15.** For every  $c \in X \setminus \{0\}$ , if the inequality

$$(\forall x \in Q)(x * ((x * c) * c) \leq c$$

holds, then  $[0, c]$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ .

**Proof.** Let  $x \in Q$ . If  $b \in [0, c]$ , then  $b \leq c$  and hence  $(x * c) * c \leq (x * c) * b$  by (b3). It follows from (b3) and assumption that

$$x * ((x * c) * b) \leq x * ((x * c) * c) \leq c.$$

Now if  $a \in [0, c]$ , then  $x * c \leq x * a$ , and so

$$x * ((x * a) * b) \leq x * ((x * c) * b) \leq c.$$

This shows that  $x * ((x * a) * b) \in [0, c]$ . Applying Theorem 3.13, we conclude that  $[0, c]$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ .

**Theorem 3.16.** The initial segment  $[0, c]$ , where  $c \in X/\{0\}$ , is a Smarandache BCC-ideal of  $X$  related to  $Q$  if and only if the implication

$$(\forall x, y \in Q)((x * c) * y \leq c \implies x * z \in I)$$

is valid.

**Proof.** Let  $\forall x, y \in Q$  and  $a \in [0, c]$  be such that  $(x * a) * y \in [0, c]$ . Then  $a \leq c$  and  $(x * a) * y \leq c$ . The inequality  $z \leq c$  implies that  $(x * c) * y \leq (x * a) * y \leq c$  so from hypothesis that  $x * y \leq c$ , that is,  $x * y \in [0, c]$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ . Conversely assume that  $[0, c], c \in X/\{0\}$ , is a Smarandache BCC-ideal of  $X$  related to  $Q$  and let  $\forall x, y \in Q$  be such that  $(x * c) * y \leq c$ . Then  $(x * c) * y \in [0, c]$ . Since  $[0, c]$  is a Smarandache BCC-ideal of  $X$  related to  $Q$  and  $c \in [0, c]$ , it follows from (c2) that  $x * y \in [0, c]$  so that  $x * y \leq c$ . This completes the proof.

**Corollary 3.17.** If  $[0, c], c \in X/\{0\}$ , is a Smarandache BCC-ideal of  $X$  related to  $Q$ , then

$$(\forall x, y \in Q)((x * c) \leq c \implies x \leq c).$$

**Theorem 3.18.** For every  $c \in X/\{0\}$ , if the equality

$$(\forall x, y \in Q)((x * c) * y) * c = (x * y) * c$$

is valid, then  $[0, c]$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ .

**Proof.** Let  $\forall x, y \in Q$  and  $a \in [0, c]$  be such that  $(x * a) * y \in [0, c]$ . Then  $a \leq c$  and  $(x * a) * y \leq c$ . It follows that

$$(x * y) * c = ((x * c) * y) * c \leq ((x * a) * y) * c \leq c * c = 0,$$

so that  $(x * y) * c = 0$ , i.e.,  $x * y \leq c$ . Hence  $x * y \in [0, c]$  and therefore  $[0, c]$  is a Smarandache BCC-ideal of  $X$  related to  $Q$ .

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# On the asymptotic property for Smarandache additive factorial complements

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**Abstract** The main purpose of this paper is to study the mean value properties of the Smarandache additive factorial complements, and give an interesting asymptotic formula for it.

**Keywords** Smarandache additive factorial complements; Asymptotic formula.

## §1. Introduction

For any positive integer  $n$ , the Smarandache factorial complements quotients of  $n$ , denoted by  $a(n)$ , is defined as follows

$$c(n) = \min\{k | nk = m!, k \geq 0, m \in N^+\}.$$

In problem 45 of reference [1], professor F.Smarandache asked us to study the properties of the factorial complements. Analogously, we can define the Smarandache additive factorial complements  $a(n)$ :

$$a(n) = \min\{k | n + k = m!, k \geq 0, m \in N^+\}.$$

About arithmetical properties of the this sequence, it seems that none had studied it before. In this paper, we use the elementary method to study the mean value properties of the Smarandache additive factorial complements, and obtain an interesting asymptotic formula for it. That is, we shall prove the following:

**Theorem.** For any real number  $x \geq 1$ , we have the asymptotic formula

$$\sum_{n \leq x} \frac{1}{a(n) + 1} = \frac{\ln^2 x}{2 \ln \ln x} + O\left(\frac{\ln^2 x \ln \ln \ln x}{(\ln \ln x)^2}\right).$$

## §2. Proof of the theorem

In this section, we will complete the proof of the theorem. For any real number  $x$ , let positive integer  $m$  satisfy

$$M! \leq x < (M + 1)!. \quad (1)$$

Taking the logistic computation on both sides of the inequality, we get

$$\sum_{i=1}^M \ln i \leq \ln x < \sum_{i=1}^{M+1} \ln i.$$

And then using the Euler's summation formula we have

$$\sum_{i=1}^M \ln i = M \ln M - M + O(\ln M) \quad (2)$$

and

$$\sum_{i=1}^{M+1} \ln i = M \ln M - M + O(\ln M). \quad (3)$$

Combining (2) and (3), we can easily deduce that

$$\ln x = M \ln M - M + O(\ln M).$$

So we get

$$M = \frac{\ln x}{\ln M - 1} + O(1).$$

Similarly, taking logistic computation on both sides we have

$$\ln M = \ln \ln x + O(\ln \ln M) \quad (4)$$

and

$$M = \frac{\ln x}{\ln \ln x} + O\left(\frac{\ln x \ln \ln \ln x}{(\ln \ln x)^2}\right). \quad (5)$$

According to the definition of  $a(n)$  and (1), we can write

$$\begin{aligned} \sum_{n \leq x} \frac{1}{a(n) + 1} &= \sum_{1 \leq m \leq M-1} \left( \sum_{m! \leq n < (m+1)!} \frac{1}{a(n) + 1} \right) + \sum_{M! \leq n \leq x} \frac{1}{a(n) + 1} \\ &= \sum_{1 \leq m \leq M-1} \sum_{i=1}^{m \cdot m!} \frac{1}{i} + \sum_{n \leq x - M! + 1} \frac{1}{n} \\ &= \sum_{1 \leq m \leq M-1} \left( \ln(m \cdot m!) + \gamma - 1 + O\left(\frac{1}{m \cdot m!}\right) \right) + O(\ln(M \cdot M!)), \end{aligned}$$

where  $\gamma$  is the Euler's constant. Now combining the Stirling Formula (see reference [2]), we can get

$$\begin{aligned} \sum_{n \leq x} \frac{1}{a(n) + 1} &= \sum_{1 \leq m \leq M-1} \ln m! + \sum_{1 \leq m \leq M-1} \ln m + O(M \ln M) \\ &= \sum_{1 \leq m \leq M-1} m \ln(m+1) - \sum_{1 \leq m \leq M-1} m + O(M \ln M). \end{aligned}$$

Applying Abel's identity (see reference [3]), we have

$$\sum_{n \leq x} \frac{1}{a(n) + 1} = \frac{1}{2} M^2 \ln M - \frac{3}{4} M^2 + O(M \ln M).$$

So from (4) and (5), we obtain

$$\sum_{n \leq x} \frac{1}{a(n) + 1} = \frac{\ln^2 x}{2 \ln \ln x} + O\left(\frac{\ln^2 x \ln \ln \ln x}{(\ln \ln x)^2}\right).$$

This completes the proof of Theorem.

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# The Smarandache minimum and maximum functions

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**Abstract** This papers deals with the introduction and preliminary study of the Smarandache minimum and maximum functions.

**Keywords** Smarandache minimum and maximum functions; arithmetical properties.

1. Let  $f: N^* \rightarrow N$  be a given arithmetic function and  $A \subset N$  a given set. The arithmetic function

$$F_f^A(n) = \min\{k \in A : n \mid f(k)\} \quad (1)$$

has been introduced in [4] and [5].

For  $A = N, f(k) = k!$  one obtains the Smarandache function; For  $A = N^*, A = p = \{2, 3, 5, \dots\}$  = set of all primes, one obtains a function

$$P(n) = \min\{k \in P : n \mid k!\} \quad (2)$$

For the properties of this function, see [4] and [5]. The “dual” function of (1) has been defined by

$$G_g^A(n) = \max\{k \in A : g(k) \mid n\}, \quad (3)$$

where  $g: N^* \rightarrow N$  is a given function, and  $A \subset N$  is a given set. Particularly, for  $A = N^*, g(k) = k!$ , one obtains the dual of the Smarandache function,

$$S_*(n) = \max\{k \geq 1 : k! \mid n\} \quad (4)$$

For the properties of this function, see [4] and [5]. F.Luca [3], K.Atanassov [1] and L.le [2] have proved in the affirmative a conjecture of the author.

For  $A = N^*$  and  $f(k) = g(k) = \varphi(k)$  in (1), resp.(3) one obtains the Euler minimum, resp. maximum-function, defined by

$$E(n) = \min\{k \geq 1 : n \mid \varphi(k)\}, \quad (5)$$

$$E_*(n) = \max\{k \geq 1 : \varphi(k) \mid n\} \quad (6)$$

For the properties of these function, see [6]. When  $A = N^*$ ,  $f(k) = d(k)$  =number of divisors of  $k$ , one obtains the divisor minimum function (see [4], [5] and [7])

$$D(n) = \min\{k \geq 1 : n \mid d(k)\}. \quad (7)$$

It is interesting to note that the divisor maximum function (i.e., the “ dual” of  $D(n)$ ) given by

$$D_*(n) = \max\{k \geq 1 : d(k) \mid n\} \quad (8)$$

is not well defined! Indeed, for any prime  $p$  one has  $d(p^{n-1}) = n \mid n$  and  $p^{n-1}$  is unbounded as  $p \rightarrow \infty$ . For a finite set  $A$ , however  $D_*^A(n)$  does exist. On one hand, it has been shown in [4] and [5] that

$$\sum(n) = \min\{k \geq 1 : n \mid \sigma(k)\} \quad (9)$$

(denoted there by  $F_\sigma(n)$ ) is well defined. (Here  $\sigma(k)$  denotes the sum of all divisors of  $k$ ). The dual of the sum-of-divisors minimum function is

$$\sum_*(n) = \max\{k \geq 1 : \sigma(k) \mid n\} \quad (10)$$

Since  $\sigma(1) = 1 \mid n$  and  $\sigma(k) \geq k$ , clearly  $\sum_*(n) \leq n$ , so this function is well defined (see [8]).

**2.** The Smarandache minimum function will be defined for  $A = N^*$ ,  $f(k) = S(k)$  in (1). Let us denote this function by  $S_{\min}$  :

$$S_{\min}(n) = \min\{k \geq 1 : n \mid S(k)\} \quad (11)$$

Let us assume that  $S(1) = 1$ , i. e.,  $S(n)$  is defined by (1) for  $A = N^*$ ,  $f(k) = k!$  :

$$S(n) = \min\{k \geq 1 : n \mid k!\} \quad (12)$$

Otherwise (i.e.when  $S(1) = 0$ ) by  $n \mid 0$  for all  $n$ , by (11) for one gets the trivial function  $S_{\min}(n) = 0$ . By this assumption, however, one obtains a very interesting (and difficult) function  $s_{\min}$  given by (11). Since  $n \mid S(n!) = n$ , this function is correctly defined.

The Smarandache maximum function will be defined as the dual of  $S_{\min}$  :

$$S_{\max}(n) = \max\{k \geq 1 : S(k) \mid n\}. \quad (13)$$

We prove that this is well defined. Indeed, for a fixed  $n$ , there are a finite number of divisors of  $n$ , let  $i \mid n$  be one of them. The equation

$$S(k) = i \quad (14)$$

is well-known to have a number of  $d(i!) - d((i-1)!)$  solutions, i. e., in a finite number. This implies that for a given  $n$  there are at most finitely many  $k$  with  $S(k) \mid k$ , so the maximum in (13) is attained.

Clearly  $S_{\min}(1) = 1, S_{\min}(2) = 2, S_{\min}(3) = 3, S_{\min}(4) = 4, S_{\min}(5) = 5, S_{\min}(6) = 9, S_{\min}(7) = 7, S_{\min}(8) = 32, S_{\min}(9) = 27, S_{\min}(10) = 25, S_{\min}(11) = 11$ , etc, which can be determined from a table of Smarandache numbers:

n	1	2	3	4	5	6	7	8	9	10	11	12	13
S(n)	1	2	3	4	5	3	7	4	6	5	11	4	13

n	14	15	16	17	18	19	20	21	22	23	24	25
S(n)	7	5	6	7	6	19	5	7	11	23	4	10

We first prove that:

**Theorem 1.**  $S_{\min}(n) \geq n$  for all  $n \geq 1$ , with equality only for

$$n = 1, 4, p(p = \text{prime}) \tag{15}$$

**Proof.** Let  $n \mid S(k)$ . If we would have  $k < n$ , then since  $S(k) \leq k < n$  we should get  $S(k) < n$ , in contradiction with  $n \mid S(k)$ . Thus  $k \geq n$ , and taking minimum, the inequality follows. There is equality for  $n = 1$  and  $n = 4$ . Let now  $n > 4$ . If  $n = p = \text{prime}$ , then  $p \mid S(p) = p$ , but for  $k < p, p \nmid S(k)$ . Indeed, by  $S(k) \leq k < p$  this is impossible. Reciprocally, if  $\min\{k \geq 1 : n \mid S(k)\} = n$ , then  $n \mid S(n)$ , and by  $S(n) \leq n$  this is possible only when  $S(n) = n$ , i. e., when  $n = 1, 4, p(p = \text{prime})$ .

**Theorem 2.** For all  $n \geq 1$ ,

$$S_{\min}(n) \leq n! \leq S_{\max}(n) \tag{16}$$

**Proof.** Since  $S(n!) = n$ , definition (11) gives the left side of (16), while definition (13) gives the right side inequality.

**Corollary.** The series  $\sum_{n \geq 1} \frac{1}{S_{\min}(n)}$  is divergent, while the series  $\sum_{n \geq 1} \frac{1}{S_{\max}(n)}$  is convergent.

**Proof.** Since  $\sum_{n \geq 1} \frac{1}{S_{\max}(n)} \leq \sum_{n \geq 1} \frac{1}{n!} = e - 1$  by (16), this series is convergent. On the other hand,

$$\sum_{n \geq 1} \frac{1}{S_{\min}(n)} \geq \sum_p \frac{1}{S_{\min}(p)} = \sum_p \frac{1}{p} = +\infty,$$

so the first series is divergent.

**Theorem 3.** For all primes  $p$  one has

$$S_{\max}(p) = p! \tag{17}$$

**Proof.** Let  $S(k) \mid p$ . Then  $S(k) = 1$  or  $S(k) = p$ . We prove that if  $S(k) = p$ , then  $k \leq p!$ . Indeed, this follows from the definition (12), since  $S(k) = \min\{m \geq 1 : k \mid m!\} = p$  implies  $k \mid p!$ , so  $k \leq p!$ . Therefore the greatest value of  $k$  is  $k = p!$ , when  $S(k) = p \mid p$ . This proves relation (17).

**Theorem 4.** For all primes  $p$ ,

$$S_{\min}(2p) \leq p^2 \leq S_{\max}(2p) \tag{18}$$

and more generally; for all  $m \leq p$ ,

$$S_{\min}(mp) \leq p^m \leq S_{\max}(mp) \quad (19)$$

**Proof.** (19) follows by the known relation  $S(p^m) = mp$  if  $m \leq p$  and the definition (11), (13). Particularly, for  $m = 2$ , (19) reduces to (18). For  $m = p$ , (19) gives

$$S_{\min}(p^2) \leq p^p \leq S_{\max}(p^2) \quad (20)$$

This case when  $m$  is also an arbitrary prime is given in.

**Theorem 5.** For all odd primes  $p$  and  $q, p < q$  one has

$$S_{\min}(pq) \leq q^p \leq p^q \leq S_{\max}(pq) \quad (21)$$

(21) holds also when  $p = 2$  and  $q \geq 5$ .

**Proof.** Since  $S(q^p) = pq$  and  $S(p^q) = qp$  for primes  $p$  and  $q$ , the extreme inequalities of (21) follow from the definition (11) and (13). For the inequality  $q^p < p^q$  remark that this is equivalent to  $f(p) > f(q)$ , where  $f(x) = \frac{\ln x}{x} (x \geq 3)$ .

Since  $f'(x) = \frac{1 - \ln x}{x^2} = 0 \Leftrightarrow x = e$  immediately follows that  $f$  is strictly decreasing for  $x \geq e = 2.71$ . From the graph of this function, since  $\frac{\ln 2}{2} = \frac{\ln 4}{4}$  we get that

$$\frac{\ln 2}{2} < \frac{\ln 3}{3},$$

but

$$\frac{\ln 2}{2} > \frac{\ln q}{q}$$

for  $q \geq 5$ . Therefore (21) holds when  $p = 2$  and  $q \geq 5$ . Indeed,  $f(q) \leq f(5) < f(4) = f(2)$ .

**Remark.** For all primes  $p, q$

$$S_{\min}(pq) \leq \min\{p^q, q^p\} \quad (22)$$

and

$$S_{\max}(pq) \geq \max\{p^q, q^p\}. \quad (23)$$

For  $p = q$  this implies relation (21).

**Proof.** Since  $S(q^p) = S(p^q) = pq$ , one has

$$S_{\min}(pq) \leq p^q, S_{\min}(pq) \leq q^p, S_{\max}(pq) \leq p^q, S_{\max}(pq) \leq q^p$$

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# Some properties of the Pseudo-Smarandache function

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**Abstract** Charles Ashbacher [1] has posed a number of questions relating to the pseudo-smarandache function  $Z(n)$ . In this note we show that the ratio of consecutive values  $Z(n+1)/Z(n)$  and  $Z(n-1)/Z(n)$  are unbounded; that  $Z(2n)/Z(n)$  is unbounded; that  $n/Z(n)$  takes every integer value infinitely often; and that the  $\sum_n 1/Z(n)^\alpha$  is convergent for any  $\alpha > 1$ .

## §1. Introduction

We defined the  $m$ -th triangular number  $T(m) = \frac{m(m+1)}{2}$ . Kashihara [2] has defined the pseudo-Smarandache function  $Z(n)$  by

$$Z(n) = \min\{m : n|T(m)\}.$$

Charles Ashbacher [1] has posed a number of questions relating to pseudo-Smarandache function  $Z(n)$ . In this note, we show that the ratio of consecutive values  $Z(n)/Z(n-1)$  and  $Z(n)/Z(n+1)$  are unbounded; that  $Z(2n)/Z(n)$  is unbounded; and that  $n/Z(n)$  takes every integer value infinitely often. He notes that the series  $\sum_n 1/Z(n)^\alpha$  is divergent for  $\alpha = 1$  and asks whether it is convergent for  $\alpha = 2$ . He further suggests that the least value  $\alpha$  for which the series converges "may never be known". We resolve this problem by showing that the series converges for all  $\alpha > 1$ .

## §2. Some Properties of the Pseudo-Smarandache Function

We record some elementary properties of the function  $Z$ .

**Lemma 1.** (1) If  $n \geq T(m)$ , then  $Z(n) \geq m$ ,  $Z(T(m)) = m$ .

(2) For all  $n$  we have  $\sqrt{n} < Z(n)$ .

(3)  $Z(n) \leq 2n - 1$ , and if  $n$  is odd, then  $Z(n) \leq n - 1$ .

(4) If  $p$  is an odd prime dividing  $n$ , then  $Z(n) \geq p - 1$ .

(5)  $Z(2^k) = 2^{k+1} - 1$ .

(6) If  $p$  is an odd prime, then  $Z(p^k) = p^k - 1$  and  $Z(2p^k) = p^k - 1$  or  $p^k$  according as  $p^k \equiv 1$  or  $3 \pmod{4}$ .

We shall make use of Dirichlet's Theorem on primes in arithmetic progression in the following form.

**Lemma 2.** Let  $a, b$  be coprime integers. Then the arithmetic progression  $a + bt$  is prime for infinitely many values of  $t$ .

### §3. Successive Values of the Pseudo-Smarandache Function

Using the properties (3) and (5), Ashbacher observed that  $|Z(2^k) - Z(2^k - 1)| > 2^k$  and so the difference between the consecutive of  $Z$  is unbounded. He asks about the ratio of consecutive values.

**Theorem 1.** For any given  $L > 0$  there are infinitely many values of  $n$  such that  $Z(n + 1)/Z(n) > L$ , and there are infinitely many values of such that  $Z(n - 1)/Z(n) > L$ .

**Proof.** Choose  $k \equiv 3 \pmod{4}$ , so that  $T(k)$  is even and  $(k + 1)|(m + 1)$ . There are satisfied if  $m \equiv k \pmod{k(k + 1)}$ , that is,  $m = k + k(k + 1)t$  for some  $t$ . We have  $m(m + 1) = k(1 + (k + 1)t)(k + 1)(1 + kt)$ , so that if  $n = k(k + 1)(k + 1)(1 + kt)/2$ , we have  $n|T(m)$ . Now consider  $n + 1 = T(k) + 1 + kT(k)t$ . We have  $k|T(k)$ , so  $T(k) + 1$  is coprime to both  $k$  and  $T(k)$ . Thus the arithmetic progression  $T(k) + 1 + kT(k)t$  has initial term coprime to its increment and by Dirichlet's Theorem contains infinitely many primes. We find that there are infinitely many values of  $t$  for which  $n + 1$  is prime and so  $Z(n) \leq m = k + k(k + 1)t$  and  $Z(n + 1) = n = T(k)(1 + kt)$ . Hence

$$\frac{Z(n + 1)}{Z(n)} \geq \frac{n}{m} = \frac{T(k) + kT(k)t}{k + 2T(k)t} > \frac{k}{3}.$$

A similar argument holds if we consider the arithmetic progression  $T(k) - 1 + kT(k)t$ . We then find infinitely many values of  $t$  for which  $n - 1$  is prime and

$$\frac{Z(n - 1)}{Z(n)} \geq \frac{n - 2}{m} = \frac{T(k) - 2 + kT(k)t}{k + 2T(k)t} > \frac{k}{4}.$$

The Theorem follows by taking  $k > 4L$ .

We note that this Theorem, combined with Lemma 1(2), given another proof of the result that the differences of consecutive values is unbounded.

### §4. Divisibility of the Pseudo-Smarandache Function

**Theorem 2.** For any integer  $k \geq 2$ , the equation  $n/Z(n) = k$  has infinitely many solutions  $n$ .

**Proof.** Fix an integer  $k \geq 2$ . Let  $p$  be a prime  $\equiv -1 \pmod{2k}$  and put  $p + 1 = 2kt$ . Put  $n = T(p)/t = p(p + 1)/2t = pk$ . Then  $n|T(p)$  so that  $Z(n) \leq p$ . We have  $p|n$ , so  $Z(n) \geq p - 1$ ; That is,  $Z(n)$  must be either  $p$  or  $p - 1$ . Suppose, if possible, that it is the latter. In this case we have  $2n|p(p + 1)$  and  $2n|(p - 1)p$ , so  $2n$  divides  $p(p + 1) - (p - 1)p = 2p$ ; but this is impossible since  $k > 1$  and so  $n > p$ . We conclude that  $Z(n) = p$  and  $n/Z(n) = k$  as required. Further, for any given value of  $k$  there are infinitely many prime values of  $p$  satisfying the congruence condition and infinitely many values of  $n = Y(p)$  such that  $Z/Z(n) = k$ .

## §5. Another Divisibility Question

**Theorem 3.** The ratio  $Z(2n)/Z(n)$  is not bounded above.

**Proof.** Fix an integer  $k$ , let  $p \equiv -1 \pmod{2^k}$  be prime and put  $n = T(p)$ . Then  $Z(n) = p$ . Consider  $Z(2n) = m$ . We have  $2^k p | p(p+1) = 2n$  and this divides  $m(m+1)/2$ . We have  $m = \epsilon \pmod{p}$  and  $m \equiv \delta \pmod{2^{k+1}}$  where each of  $\epsilon, \delta$  can be either 0 or  $-1$ .

Let  $m = pt + \epsilon$ . Then  $m \equiv \epsilon - t \equiv \delta \pmod{2^k}$ . This implies that either  $t = 1$  or  $t \geq 2^k - 1$ . Now if  $t = 1$  then  $m \leq p$  and  $T(m) \leq T(p) = n$ , which is impossible since  $2n \leq T(m)$ . Hence  $t \geq 2^k - 1$ . Since  $Z(2n)/Z(n) = m/p > t/2$ , we see that the ratio  $Z(2n)/Z(n)$  can be made as large as desired.

## §6. Convergence of A Series

Ashbacher observes that the series  $\sum_n 1/Z(n)^\alpha$  diverges for  $\alpha = 1$  and asks whether it converges for  $\alpha = 2$ .

**Lemma 3.**

$$\log n \leq \sum_{m=1}^n 1/Z(n)^\alpha \leq 1 + \log n;$$

$$\frac{1}{2}(\log n)^2 - 0.257 \leq \sum_{m=1}^n \frac{\log m}{m} \leq \frac{1}{2}(\log n)^2 + 0.110,$$

for  $n \geq 4$ .

**Proof.** For the first part, we have  $\frac{1}{m} \leq \frac{1}{t} \leq \frac{1}{m-1}$  for  $t \in [m-1, m]$ . Integrating,

$$\frac{1}{m} \leq \int_{m-1}^m \frac{1}{t} dt \leq \frac{1}{m-1}$$

Summing,

$$\sum_2^n \frac{1}{m} \leq \int_1^n \frac{1}{t} dt \leq \sum_2^n \frac{1}{m-1}$$

That is ,

$$\sum_1^n \frac{1}{m} \leq 1 + \log n$$

and

$$\log n \leq \sum_1^{n-1} \frac{1}{m}$$

The result follows.

For the second part, we similarly have  $\log m/m \leq \log t/t \leq \log(m-1)/(m-1)$ , for  $t \in [m-1, m]$  when  $m \geq 4$ , since  $\log x/x$  is monotonic decreasing for  $x \geq e$ .

Integrating,

$$\frac{\log m}{m} \leq \int_{m-1}^m \frac{\log t}{t} dt \leq \frac{m-1}{m}.$$



Summing,

$$\sum_4^n \frac{\log m}{m} \leq \int_3^n \frac{\log t}{t} dt \leq \sum_4^n \frac{m-1}{m}.$$

That is,

$$\begin{aligned} & \sum_1^n \frac{\log m}{m} - \frac{\log 2}{2} - \frac{\log 3}{3} \\ & \leq \frac{1}{2}(\log n)^2 - \frac{1}{2}(\log 3)^2 \\ & \leq \sum_1^n \frac{\log m}{m} - \frac{\log n}{n} - \frac{\log 2}{2}. \end{aligned}$$

We approximate the numerical values

$$\frac{\log 2}{2} + \frac{\log 3}{3} - \frac{1}{2}(\log 3)^2 < 0.110$$

and

$$\frac{\log 2}{2} - \frac{1}{2}(\log 3)^2 > -0.257$$

to obtain the result.

**Lemma 4.** Let  $d(m)$  be the function which counts the divisors of  $m$ . For  $n \geq 2$  we have

$$\sum_{m=1}^n d(m)/m < 7(\log n)^2.$$

**Proof.** We verify the assertion numerically for  $n \leq 6$ . Now assume that  $n \geq 8 > e^2$ , we have

$$\begin{aligned} \sum_{m=1}^n \frac{d(m)}{m} &= \sum_{m=1}^n \sum_{de=m} \frac{1}{m} = \sum_{d \leq n} \sum_{de \leq n} \frac{1}{de} \\ &= \sum_{d \leq n} \frac{1}{d} \sum_{e < n/d} \frac{1}{e} \leq \sum_{d \leq n} \frac{1}{d} (1 + \log(n/d)) \\ &\leq (1 + \log n)^2 - \frac{1}{2}(\log n)^2 + 0.257 \\ &= 1.257 + 2 \log n + \frac{1}{2}(\log n)^2 \\ &< \frac{4}{3} \left( \frac{\log n}{2} \right)^2 + 2 \log n \left( \frac{\log n}{2} \right) + \frac{1}{2}(\log n)^2 \\ &< 2(\log n)^2 \end{aligned}$$

**Lemma 5.** Fix an integer  $t \geq 5$ . Let  $e^t > Y > e^{(t-1)/2}$ . The number of integers  $n$  with  $e^{t-1} > n > e^t$  such that  $Z(n) \leq Y$  is at most  $196Yt^2$ .

**Proof.** Consider such an  $n$  with  $m = Z(n) \leq Y$ . Now  $n|m(m+1)$ , say  $k_1 n_1 = m$  and  $k_2 n_2 = m+1$ , with  $n = n_1 n_2$ . Thus  $k = k_1 k_2 = m(m+1)/n$  and  $k_1 n_1 \leq Y$ . The value

of  $k$  is bounded below by 2 and above by  $m(m + 1)/n \leq 2Y^2/e^{t-1} = K$ , say. Given a pair  $(k_1, k_2)$ , the possible values of  $n_1$  are bounded above by  $Y/k_1$  and must satisfy the congruence condition  $k_1 n_1 + 1 \equiv 0$  modulo  $k_2$ : there are therefore at most  $Y/k_1 k_2 + 1$  such values. Since  $Y/k \geq Y/K = e^{t-1}/2Y > 1/2e$ , we have  $Y/k + 1 < (2e + 1)Y/k < 7Y/k$ . Given values for  $k_1, k_2$  and  $n_1$ , the value of  $n_2$  is fixed as  $n_2 = (k_1 n_1 + 1)/k_2$ . There are thus at most  $\sum d(k)$  possible pairs  $(k_1, k_2)$  and hence at most  $\sum 7Yd(k)/k$  possible quadruples  $(k_1, k_2, n_1, n_2)$ . We have  $K > 2$ , so that the previous Lemma applies and we can deduce that the number of values of  $n$  satisfying the given conditions is most  $49Y(\log K)^2$ . Now  $K = 2Y^2/e^{t-1} < 2e^{t+1}$  so  $\log K < t + 1 + \log 2 < 2t$ . This establishes the claimed upper bound of  $196Yt^2$ .

**Theorem 4.** Fix  $\frac{1}{2} < \beta < 1$  and integer  $t \geq 5$ . The number of integers  $n$  with  $e^{t-1} < n < e^t$ , such that  $Z(n) < n^\beta$  is at most  $196t^2 e^{\beta t}$ .

**Proof.** We apply the previous result with  $Y = e^{\beta t}$ . The conditions of  $\beta$  ensure that the previous Lemma is applicable and the upper bound on the number of such  $n$  is  $196t^2 e^{\beta t}$  as claimed.

**Theorem 5.** The series

$$\sum_{n=1}^{\infty} \frac{1}{Z(n)^\alpha}$$

is convergent for any  $\alpha > \sqrt{2}$ .

**Proof.** We note that if  $\alpha > 2$  then  $\frac{1}{Z(n)^\alpha} < \frac{1}{n^\alpha}$  and the series is convergent. So we may assume  $\sqrt{2} < \alpha < 2$ . Fix  $\beta$  with  $\frac{1}{\alpha} < \beta < \frac{\alpha}{2}$ . We have  $\frac{1}{2} < \beta < \sqrt{\frac{1}{2}} < \frac{\alpha}{2}$ .

We split the positive integers  $n > e^4$  into two classes A and B. We let class A be the union of the  $A_t$  where, for positive integer  $t \geq 5$  we put into class  $A_t$  those integers  $n$  such that  $e^{t-1} < n < e^t$  for integer  $t$  and  $Z(n) \leq n^\beta$ . All values of  $n$  with  $Z(n) > n^\beta$  we put into class B. We consider the sum of  $\frac{1}{Z(n)^\alpha}$  over each of the two classes. Since all terms are positive, it is sufficient to prove that each series separately is convergent.

Firstly we observe that for  $n \in B$ , we have  $\frac{1}{Z(n)^\alpha} < \frac{1}{n^{\alpha\beta}}$  and since  $\alpha\beta > 1$  the series summed over the class B is convergent.

Consider the elements  $n$  of  $A_t$ : so for such  $n$  we have  $e^{t-1} < n < e^t$  and  $Z(n) < n^\beta$ . By the previous result, the number of values of  $n$  satisfying these conditions is at most  $196t^2 e^{\beta t}$ . For  $n \in A_t$ , we have  $Z(n) > \sqrt{n}$ , so  $1/Z(n)^\alpha \leq 1/n^{\alpha/2} < 1/e^{\alpha(t-1)/2}$ . Hence the sum of the subseries  $\sum_{n \in A_t} \frac{1}{Z(n)^\alpha}$  is at most  $196t^2 e^{\alpha/2} e^{(\beta-\alpha/2)t}$ . Since  $\beta < \alpha/2$  for  $\alpha > \sqrt{2}$ , the sum over all  $t$  of these terms is finite.

We conclude that  $\sum \frac{1}{Z(n)^\alpha}$  is convergent for any  $\alpha > \sqrt{2}$ .

**Theorem 6.** The series

$$\sum_{n=1}^{\infty} \frac{1}{Z(n)^\alpha}$$

is convergent for any  $\alpha > 1$ .

**proof.** We fix  $\beta_0 = 1 > \beta_1 > \dots > \beta_r = \frac{1}{2}$  with  $\beta_j < \alpha\beta_{j+1}$  for  $0 \leq j \leq r - 1$ . We defined a partition of the integers  $e^{t-1} < n < e^t$  into classes  $B_t$  and  $C_t(j)$ ,  $1 \leq j \leq r - 1$ . Into  $B_t$  place those  $n$  with  $Z(n) > n^{\beta_1}$ . Into  $C_t(j)$  place those  $n$  with  $n^{\beta_{j+1}} < Z(n) < n^{\beta_j}$ . Since  $\beta_r = \frac{1}{2}$  we see that every  $n$  with  $e^{t-1} < n < e^t$  is placed into one of the classes.

The number of elements in  $C_t(j)$  is at most  $196t^2e^{\beta_j t}$  and so

$$\sum_{n \in C_t(j)} \frac{1}{Z(n)^\alpha} < 196t^2 e^{\beta_j t} e^{-\beta_j \alpha(t-1)} = 196t^2 e^{\beta_{j+1} \alpha} e^{(\beta_j - \alpha \beta_{j+1})t}.$$

For each  $j$  we have  $\beta_j < \alpha \beta_{j+1}$  so each sum over  $t$  converges.

The sum over the union of the  $B_t$  is bounded above by

$$\sum_n \frac{1}{n^{\alpha \beta_1}},$$

which is convergent since  $\alpha \beta_1 > \beta_0 = 1$ .

We conclude that  $\sum_{n=1}^{\infty} \frac{1}{Z(n)^\alpha}$  is convergent.

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# An equation involving the Euler function and Smarandache function

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**Abstract** For any positive integer  $n$ , let  $\phi(n)$  be the Euler function, and  $S(n)$  denotes the Smarandache function. The main purpose of this paper is using the elementary methods to study the number of the solutions of the equation  $\phi(n) = S(n^k)$ , where  $k$  is any fixed positive integer, and give all solutions for this equation.

**Keywords** Euler function; Smarandache function; Equation; Solutions.

## §1. Introduction

For any positive integer  $n$ , let  $S(n)$  denotes the Smarandache function,  $S(n)$  is defined as the smallest positive integer  $m$  such that  $n|m!$ . From the definition one can easily deduce that if  $n = p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_k^{\alpha_k}$  is the factorization of  $n$  into prime powers, then  $S(n) = \max\{S(p_i^{\alpha_i})\}$ , where the maximum is taken over the  $i$ 's from 1 to  $k$ . Let  $\phi(n)$  denotes the Euler function. That is,  $\phi(n)$  denotes the number of all positive integers not exceeding  $n$  which are relatively prime to  $n$ . It is clear that  $\phi(n)$  is a multiplicative function.

In this paper, we shall study the number of the solutions of the equation  $\phi(n) = S(n^k)$ , where  $k$  is any fixed positive integer. About this problem, it is easy to get that  $n = 1$  be a solution of the equation, but now we don't know whether it have finite solutions or not. Here, we shall use the elementary methods to solve this problem, and give all solutions for this equation for any fixed positive integer  $k$ . That is, we shall prove the following conclusions:

**Theorem 1.** *The equation  $\phi(n) = S(n^2)$  have three solutions, namely  $n = 1, 24, 50$ .*

**Theorem 2.** *The equation  $\phi(n) = S(n^3)$  have three solutions, namely  $n = 1, 48, 98$ .*

**Theorem 3.** *The equation  $\phi(n) = S(n^4)$  has one solution, namely  $n = 1$ .*

**Note.** *Using the similarly method, we can also deduce that the equation  $\phi(n) = S(n^k)$  have the finite solutions, where  $k$  be any fixed positive integer.*

## §2. Proof of the theorem

In this section, we will complete the proof of the theorem. First, we need one simple lemma which is necessary in the proof of Theorems.

**Lemma** *If  $p$  is prime, then  $S(p^k) \leq kp$ . If  $k < p$ , then  $S(p^k) = kp$ , where  $k$  be any fixed positive integer.*

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**Proof.** ( See reference [2] ).

Now we shall complete the proofs of Theorems.

**The proof of Theorem 1.** Let  $n = p_1^{\alpha_1} p_2^{\alpha_2} \cdots p_k^{\alpha_k}$ , then from the definitions of  $S(n)$  and  $\phi(n)$  we have

$$S(n^2) = \max\{S(p_i^{2\alpha_i})\} = S(p^{2\alpha}),$$

where  $p$  be prime, and

$$\phi(n) = p^{\alpha-1}(p-1)\phi(n_1),$$

where  $(n_1, p) = 1$ . That is, the largest common factor  $n_1$  and  $p$  is 1.

It is clear that  $n = 1$  is a solution of the equation  $\phi(n) = S(n^2)$ . If  $n > 1$  then we will discuss the problem in the following cases:

(i) Let  $\alpha = 1$ .

If  $p = 2$ , then  $S(2^2) = 4$ ,  $\phi(n) = (2-1)\phi(n_1)$ , from  $S(n^2) = S(2^2) = \phi(n) = \phi(n_1)$ , we get  $\phi(n_1) = 4$ , so  $n_1 = 5$ , then  $n = 2^2 \times 5$ . But now  $S(2^4 \cdot 5^2) = 10 \neq \phi(2^2 \times 5)$ , hence the equation has no solution in this case.

If  $p \geq 3$ , then from Lemma we have  $S(p^2) = 2p$ ,  $\phi(n) = (p-1)\phi(n_1)$ , note that  $p \nmid (p-1)\phi(n_1)$ , hence the equation has no solution in this case.

(ii) Let  $\alpha = 2$ .

If  $p = 2$ , then  $S(2^4) = 6 = 2\phi(n_1)$ , no solution.

If  $p = 3$ , then  $S(3^4) = 9 = 3 \times 2\phi(n_1)$ , no solution.

If  $p = 5$ , then  $S(5^4) = 20 = 5 \times 4\phi(n_1)$ , so  $n_1 = 2$ , hence  $n = 5^2 \times 2$  is a solution.

If  $p \geq 7$ , then  $S(p^4) = 4p = p(p-1)\phi(n_1)$ , note that  $p-1 > 4$ , hence no solution.

(iii) Let  $\alpha = 3$ .

If  $p = 2$ , then  $S(2^6) = 8 = 4\phi(n_1)$ , so  $n_1 = 3$ , hence  $n = 2^3 \times 3$  is a solution.

If  $p = 3$ , then  $S(3^6) = 15 = 3^2 \times 2\phi(n_1)$ , no solution.

If  $p = 5$ , then  $S(5^6) = 25 = 5^2 \times 4\phi(n_1)$ , no solution.

If  $p = 7$ , then  $S(7^6) = 42 = 7^2 \times 6\phi(n_1)$ , no solution.

If  $p > 7$ , then  $S(p^6) = 6p = p(p-1)\phi(n_1)$ , note that  $p-1 > 6$ , no solution.

(iv) Let  $\alpha = 4$ .

If  $p = 2$ , then  $S(2^8) = 10 = 8\phi(n_1)$ , no solution.

If  $p \geq 3$ , from Lemma we have  $S(p^{2\alpha}) < 2p\alpha$ , note that  $\phi(n) = p^{\alpha-1}(p-1)\phi(n_1)$  and  $p^{\alpha-1} > 2p\alpha$ , no solution.

(v) Let  $\alpha = 5$ .

If  $p = 2$ , then  $S(2^{10}) = 12 = 2^4\phi(n_1)$ , no solution.

If  $p \geq 3$ , from Lemma we have  $S(p^{2\alpha}) < 2p\alpha$ , note that  $\phi(n) = p^{\alpha-1}(p-1)\phi(n_1)$  and  $p^{\alpha-1} > 2p\alpha$ , no solution.

(vi) Let  $\alpha \geq 6$ .

If  $p \geq 2$ , from Lemma we have  $S(p^{2\alpha}) < 2p\alpha$ , note that  $\phi(n) = p^{\alpha-1}(p-1)\phi(n_1)$  and  $p^{\alpha-1} > 2p\alpha$ , no solution.

Combining (i) to (vi), we may immediately get that the equation  $\phi(n) = S(n^2)$  have three solutions, namely  $n = 1, 24, 50$ . This completes the proof of Theorem 1.

Similarly, using the same methods we can also deduce the results of Theorem 2 and Theorem 3. This complete the proofs of Theorems.

For the general positive integer  $k$ , from the methods of proving our Theorems we can get that the equation  $\phi(n) = S(n^k)$  have finite solutions.

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# Recursive Palindromic Smarandache Values

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**Abstract** In [1] Recursive Prime Numbers were studied and shown to be finite. This article deals with the same "recursive" topic, but applies the method to numbers whose Smarandache value,  $S(n)$ , gives a palindromic number. Here,  $S(n)$  denotes the Smarandache function of least  $m$  such that  $n$  divides  $m!$ , and a palindrome is an integer that reads the same forwards and backwards (23432, for example). This sequence of recursive palindromic Smarandache values is shown to be finite with 1514384 being the last term.

Recursive palindromic Smarandache values (RPSV) are integers  $n > 0$ , such that  $S(n)$  gives a palindromic value, and repeatedly deleting the rightmost digits of  $n$  and taking  $S(n)$  at each step also gives a palindromic value until only a single digit remains. (Note that the numbers are not permitted to have zeroes.) Example:

n	S(n)
94649	1514384
373	151438
797	15143
1514	757
151	151
15	5
1	1

The same algorithm outlined in [1] was used to generate all RPSV sets beginning with each digit 1 through 9. To summarize the basic algorithm, two arrays are defined:  $A_1$ , contains only the initial digit, then  $A_2$  is filled with any integers that give palindromic Smarandache values after multiplying the integers in  $A_1$  by 10 and adding  $y$ , with  $1 \leq y \leq 9$ .  $A_1$  is then updated with the  $A_2$  values. This process is repeated until no solutions are found and thus  $A_2$  is empty.

This is enough to prove that the sequence is finite. And using this algorithm, RPSVs were found to be finite with 1514384 being the last term.

As in [1], genetic trees can be constructed from each digit for visualization and comparison purposes. Below, only the genetic tree for the digit 5 is produced. It is left to readers so inclined to construct the other trees. (However, the full sequence of RPSV numbers is given at the end of this article.)

Tree of recursive palindromic Smarandache values with starting digit 5:

```

5

54      55      56

543     567

5436

54362   54365

543654

```

To show that the numbers in the genetic tree above are recursively palindromic when  $S(n)$  is applied, let us demonstrate with 54365:

$n$	$S(n)$
54365	131
5436	151
543	181
54	9
5	5

**Unsolved Questions:** What is the sequence of RPSVs when the leftmost digits are repeatedly deleted? Is the sequence finite?

Full Sequence of RPSVs: 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 14, 15, 16, 18, 21, 22, 24, 27, 28, 32, 33, 35, 36, 42, 44, 45, 48, 54, 55, 56, 63, 64, 66, 72, 77, 81, 84, 88, 96, 99, 112, 121, 126, 128, 144, 151, 154, 162, 165, 168, 181, 189, 216, 224, 242, 275, 288, 324, 336, 352, 353, 362, 363, 448, 453, 484, 543, 567, 648, 724, 726, 727, 847, 968, 1212, 1267, 1441, 1448, 1512, 1514, 1515, 1629, 1812, 1815, 1818, 2424, 2751, 2757, 2882, 3247, 3535, 3537, 3624, 3629, 3635,



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3636, 4536, 4847, 4848, 4849, 5436, 7248, 7272, 7277, 8472, 12127, 12672, 15125, 15143, 18154, 18181, 24245, 27512, 27573, 27576, 32476, 35353, 36359, 36362, 48471, 54362, 54365, 72724, 72727, 72771, 126723, 151436, 151437, 151438, 181542, 181543, 275127, 275762, 363594, 363629, 484718, 543654, 1514384.

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# Smarandache Idempotents in finite ring $Z_n$ and in Group Ring $Z_n G$

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**Abstract** In this paper we analyze and study the Smarandache idempotents (S-idempotents) in the ring  $Z_n$  and in the group ring  $Z_n G$  of a finite group  $G$  over the finite ring  $Z_n$ . We have shown the existence of Smarandache idempotents (S-idempotents) in the ring  $Z_n$  when  $n = 2^m p$  (or  $3p$ ), where  $p$  is a prime  $> 2$  (or  $p$  a prime  $> 3$ ). Also we have shown the existence of Smarandache idempotents (S-idempotents) in the group ring  $Z_2 G$  and  $Z_2 S_n$  where  $n = 2^m p$  ( $p$  a prime of the form  $2^m t + 1$ ).

## §1. Introduction

This paper has 4 sections. In section 1, we just give the basic definition of S-idempotents in rings. In section 2, we prove the existence of S-idempotents in the ring  $Z_n$  where  $n = 2^m p$ ,  $m \in \mathbb{N}$  and  $p$  is an odd prime. We also prove the existence of S-idempotents for the ring  $Z_n$  where  $n$  is of the form  $n = 3p$ ,  $p$  is a prime greater than 3. In section 3, we prove the existence of S-idempotents in group rings  $Z_2 G$  of cyclic group  $G$  over  $Z_2$  where order of  $G$  is  $n$ ,  $n = 2^m p$  ( $p$  a prime of the form  $2^m t + 1$ ). We also prove the existence of S-idempotents for the group ring  $Z_2 S_n$  where  $n = 2^m p$  ( $p$  a prime of the form  $2^m t + 1$ ). In the final section, we propose some interesting number theoretic problems based on our study.

Here we just recollect the definition of Smarandache idempotents (S-idempotent) and some basic results to make this paper a self contained one.

**Definition 1.1[5].** Let  $R$  be a ring. An element  $x \in R$  is said to be a Smarandache idempotent (S-idempotent) of  $R$  if  $x^2 = x$  and there exist  $a \in R$ ,  $a \neq 0$  such that

- i.  $a^2 = x$
- ii.  $xa = x$  or  $ax = a$ .

**Example 1.1.** Let  $Z_{10} = \{0, 1, 2, \dots, 9\}$  be the ring of integers modulo 10. Here

$$6^2 \equiv 6 \pmod{10}, \quad 4^2 \equiv 6 \pmod{10}$$

and

$$6 \cdot 4 \equiv 4 \pmod{10}.$$

So 6 is a S-idempotent in  $Z_{10}$ .

**Example 1.2.** Take  $Z_{12} = \{0, 1, 2, \dots, 11\}$  the ring of integers modulo 12. Here

$$4^2 \equiv 4(\text{mod}12), \quad 8^2 \equiv 4(\text{mod}12)$$

and

$$4 \cdot 8 \equiv 8(\text{mod}12).$$

So 4 is a S-idempotent in  $Z_{12}$ .

**Example 1.3.** In  $Z_{30} = \{0, 1, 2, \dots, 29\}$  the ring of integers modulo 30, 25 is a S-idempotent. As

$$25^2 \equiv 25(\text{mod}30), \quad 5^2 \equiv 25(\text{mod}30)$$

and

$$25 \cdot 5 \equiv 5(\text{mod}30).$$

So 25 is a S-idempotent in  $Z_{30}$ .

**Theorem 1.1** [5]. *Let  $R$  be a ring. If  $x \in R$  is a S-idempotent then it is an idempotent in  $R$ .*

**Proof.** From the very definition of S-idempotents.

## §2. S-idempotents in the finite ring $Z_n$

In this section, we find conditions for  $Z_n$  to have S-idempotents and prove that when  $n$  is of the form  $2^m p$ ,  $p$  a prime  $\geq 2$  or  $n = 3p$  ( $p$  a prime  $\geq 3$ ) has S-idempotents. We also explicitly find all the S-idempotents.

**Theorem 2.1.**  $Z_p = \{0, 1, 2, \dots, p-1\}$ , the prime field of characteristic  $p$ , where  $p$  is a prime has no non-trivial S-idempotents.

**Proof.** Straightforward, as every S-idempotents are idempotents and  $Z_p$  has no non-trivial idempotents.

**Theorem 2.2:** *The ring  $Z_{2p}$ , where  $p$  is an odd prime has S-idempotents.*

**Proof.** Here  $p$  is an odd prime, so  $p$  must be of the form  $2m + 1$  i.e  $p = 2m + 1$ . Take

$$x = p + 1 \quad \text{and} \quad a = p - 1.$$

Here

$$\begin{aligned} p^2 = (2m + 1)^2 &= 4m^2 + 4m + 1 \\ &= 2m(2m + 1) + 2m + 1 \\ &= 2pm + p \\ &\equiv p(\text{mod}2p). \end{aligned}$$

So

$$p^2 \equiv p(\text{mod}2p).$$

Again

$$\begin{aligned}x^2 &= (p+1)^2 \equiv p^2 + 1 \pmod{2p} \\ &\equiv p + 1 \pmod{2p}.\end{aligned}$$

Therefore

$$x^2 = x.$$

Also

$$a^2 = (p-1)^2 \equiv p + 1 \pmod{2p},$$

therefore

$$a^2 = x.$$

And

$$\begin{aligned}xa &= (p+1)(p-1) \\ &= p^2 - 1 \\ &\equiv p - 1 \pmod{2p}\end{aligned}$$

therefore

$$xa = a.$$

So  $x = p + 1$  is a S-idempotent in  $Z_{2p}$ .

**Example 2.1.** Take  $Z_6 = Z_{2 \cdot 3} = \{0, 1, 2, 3, 4, 5\}$  the ring of integers modulo 6. Then  $x = 3 + 1 = 4$  is a S-idempotent. As

$$x^2 = 4^2 \equiv 4 \pmod{6},$$

take  $a = 2$ , then  $a^2 = 2^2 \equiv 4 \pmod{6}$ .

Therefore

$$a^2 = x,$$

and

$$xa = 4 \cdot 2 \equiv 2 \pmod{6}$$

i.e

$$xa = a.$$

**Theorem 2.3.** *The ring  $Z_{2^2p}$ ,  $p$  a prime  $> 2$  and is of the form  $4m + 1$  or  $4m + 3$  has (at least) two S-idempotents.*

**Proof.** Here  $p$  is of the form  $4m + 1$  or  $4m + 3$ .

If  $p = 4m + 1$ , then  $p^2 \equiv p \pmod{2^2p}$ . As

$$\begin{aligned}p^2 &= (4m+1)^2 \\ &= 16m^2 + 8m + 1 \\ &= 4m(4m+1) + 4m + 1 \\ &= 4pm + p \\ &\equiv p \pmod{2^2p},\end{aligned}$$

therefore

$$p^2 \equiv p \pmod{2^2 p}.$$

Now, take  $x = 3p + 1$  and  $a = p - 1$  then

$$\begin{aligned} x^2 = (3p + 1)^2 &= 9p^2 + 6p + 1 \\ &\equiv 9p + 6p + 1 \pmod{2^2 p} \\ &\equiv 3p + 1 \pmod{2^2 p} \end{aligned}$$

therefore

$$a^2 = x.$$

And

$$\begin{aligned} xa &= (3p + 1)(p - 1) \\ &= 3p^2 - 3p + p - 1 \\ &\equiv p - 1 \pmod{2^2 p} \end{aligned}$$

therefore

$$xa = a.$$

So  $x$  is an S-idempotent.

Similarly, we can prove that  $y = p$ , (here take  $a = 3p$ ) is another S-idempotent. These are the only two S-idempotents in  $Z_{2^2 p}$  when  $p = 4m + 1$ . If  $p = 4m + 3$ , then  $p^2 \equiv 3p \pmod{2^2 p}$ .

As above, we can show that  $x = p + 1$ , ( $a = 3p - 1$ ) and  $y = 3p$ , ( $a = p$ ) are the two S-idempotents. So we are getting a nice pattern here for S-idempotents in  $Z_{2^2 p}$ :

I. If  $p = 4m + 1$ , then  $x = 3p + 1$ , ( $a = p - 1$ ) and  $y = p$ , ( $a = 3p$ ) are the two S-idempotents.

II. If  $p = 4m + 3$ ,  $x = p + 1$ , ( $a = 3p - 1$ ) and  $y = 3p$ , ( $a = p$ ) are the two S-idempotents.

**Example 2.2.** Take  $Z_{2^2 \cdot 5} = \{0, 1, \dots, 19\}$ , here  $5 = 4 \cdot 1 + 1$ . So  $x = 3 \cdot 5 + 1 = 16$ , ( $a = 5 - 1 = 4$ ) is an S-idempotent. As  $16^2 \equiv 16 \pmod{20}$ ,  $4^2 \equiv 16 \pmod{20}$  and  $16 \cdot 4 \equiv 4 \pmod{20}$ . Also  $y = 5$ , ( $a = 3 \cdot 5 = 15$ ) is another S-idempotent. As  $5^2 \equiv 5 \pmod{20}$ ,  $15^2 \equiv 5 \pmod{20}$  and  $5 \cdot 15 \equiv 15 \pmod{20}$ .

**Example 2.3.** In the ring  $Z_{2^2 \cdot 7} = \{0, 1, \dots, 27\}$ , here  $7 = 4 \cdot 1 + 3$ ,  $x = 7 + 1 = 8$ , ( $a = 3 \cdot 7 - 1 = 20$ ) is an S-idempotent. As  $8^2 \equiv 8 \pmod{28}$ ,  $20^2 \equiv 8 \pmod{28}$  and  $8 \cdot 20 \equiv 20 \pmod{28}$ . Also  $y = 3 \cdot 7 = 21$ , ( $a = 7$ ) is another S-idempotent. As  $21^2 \equiv 21 \pmod{28}$ ,  $7^2 \equiv 21 \pmod{28}$  and  $21 \cdot 7 \equiv 7 \pmod{28}$ .

**Theorem 2.4.** The ring  $Z_{2^3 p}$ ,  $p$  a prime  $> 2$  has (at least) two S-idempotents of  $\phi(2^3)$  types (where  $\phi(n)$  is the number of integer less than  $n$  and relatively prime to  $n$ ).

**Proof.** As  $p$  is prime  $> 2$ . So  $p$  is one of the  $8m + 1, 8m + 3, 8m + 5, 8m + 7$ . Now we will get the following two S-idempotents for each  $\phi(2^3) = 4$  types of prime  $p$ .

I. If  $p = 8m + 1$ , then  $x = 7p + 1$ , ( $a = p - 1$ ) and  $y = p$ , ( $a = 7p$ ) are S-idempotents.

II. If  $p = 8m + 3$ , then  $x = 5p + 1$ , ( $a = 3p - 1$ ) and  $y = 3p$ , ( $a = 5p$ ) are S-idempotents.

III. If  $p = 8m + 5$ , then  $x = 3p + 1$ , ( $a = 5p - 1$ ) and  $y = 5p$ , ( $a = 3p$ ) are S-idempotents.

IV. If  $p = 8m + 7$ , then  $x = p + 1$ , ( $a = 7p - 1$ ) and  $y = 7p$ , ( $a = p$ ) are S-idempotents.

**Example 2.4.** In the ring  $Z_{2^3 \cdot 3} = \{0, 1, \dots, 23\}$ , here  $3 = 8 \cdot 0 + 3$ . So  $x = 5 \cdot 3 + 1 = 16$ , ( $a = 3 \cdot 3 - 1 = 8$ ) is an S-idempotent. As  $16^2 \equiv 16 \pmod{24}$ ,  $8^2 \equiv 16 \pmod{24}$  and  $16 \cdot 8 \equiv 8 \pmod{24}$ . Also  $y = 3 \cdot 3 = 9$ , ( $a = 5 \cdot 3 = 15$ ) is another S-idempotent. As  $9^2 \equiv 9 \pmod{24}$ ,  $15^2 \equiv 9 \pmod{24}$  and  $9 \cdot 15 \equiv 15 \pmod{24}$ .

**Example 2.5.** Take  $Z_{2^3 \cdot 13} = Z_{104} = \{0, 1, \dots, 103\}$ , here  $13 = 8 \cdot 1 + 5$ . So  $x = 3 \cdot 13 + 1 = 40$ , ( $a = 5 \cdot 13 - 1 = 64$ ) is an S-idempotent. As  $40^2 \equiv 40 \pmod{104}$ ,  $64^2 \equiv 40 \pmod{104}$  and  $40 \cdot 64 \equiv 64 \pmod{104}$ . Also  $y = 5 \cdot 13 = 65$ , ( $a = 3 \cdot 13 = 39$ ) is another S-idempotent. As  $65^2 \equiv 65 \pmod{104}$ ,  $39^2 \equiv 65 \pmod{104}$  and  $65 \cdot 39 \equiv 39 \pmod{104}$ .

**Theorem 2.5.** *The ring  $Z_{2^4 p}$ ,  $p$  a prime  $> 2$  has (at least) two S-idempotents for each of  $\phi(2^4)$  types of prime  $p$ .*

**Proof.** As above, we can list the S-idempotents for all  $\phi(2^4) = 8$  types of prime  $p$ .

I. If  $p = 16m + 1$ , then  $x = 15p + 1$ , ( $a = p - 1$ ) and  $y = p$ , ( $a = 15p$ ) are S-idempotents.

II. If  $p = 16m + 3$ , then  $x = 13p + 1$ , ( $a = 3p - 1$ ) and  $y = 3p$ , ( $a = 13p$ ) are S-idempotents.

III. If  $p = 16m + 5$ , then  $x = 11p + 1$ , ( $a = 5p - 1$ ) and  $y = 5p$ , ( $a = 11p$ ) are S-idempotents.

IV. If  $p = 16m + 7$ , then  $x = 9p + 1$ , ( $a = 7p - 1$ ) and  $y = 7p$ , ( $a = 9p$ ) are S-idempotents.

V. If  $p = 16m + 9$ , then  $x = 7p + 1$ , ( $a = 9p - 1$ ) and  $y = 9p$ , ( $a = 7p$ ) are S-idempotents.

VI. If  $p = 16m + 11$ , then  $x = 5p + 1$ , ( $a = 11p - 1$ ) and  $y = 11p$ , ( $a = 5p$ ) are S-idempotents.

VII. If  $p = 16m + 13$ , then  $x = 3p + 1$ , ( $a = 13p - 1$ ) and  $y = 13p$ , ( $a = 13p$ ) are S-idempotents.

VIII. If  $p = 16m + 15$ , then  $x = p + 1$ , ( $a = 15p - 1$ ) and  $y = 15p$ , ( $a = p$ ) are S-idempotents.

**Example 2.6.** In the ring  $Z_{2^4 \cdot 17} = Z_{272} = \{0, 1, \dots, 271\}$ , here  $17 = 16 \cdot 1 + 1$ . So  $x = 15 \cdot 17 + 1 = 256$ , ( $a = 17 - 1 = 16$ ) is an S-idempotent. As  $256^2 \equiv 256 \pmod{272}$ ,  $16^2 \equiv 256 \pmod{272}$  and  $256 \cdot 16 \equiv 16 \pmod{272}$ . Also  $y = 17$ , ( $a = 15 \cdot 17 = 255$ ) is another S-idempotent. As  $17^2 \equiv 17 \pmod{272}$ ,  $255^2 \equiv 17 \pmod{272}$  and  $17 \cdot 255 \equiv 255 \pmod{272}$ .

We can generalize the above result as followings:

**Theorem 2.6.** *The ring  $Z_{2^n p}$ ,  $p$  a prime  $> 2$  has (at least) two S-idempotents for each of  $\phi(2^n)$  types of prime  $p$ .*

**Proof.** Here  $p$  is one of the  $\phi(2^n)$  form:

$$2^n m_1 + 1, \quad 2^n m_2 + 3, \quad \dots \quad 2^n m_{\phi(2^n)} + (2^n - 1).$$

We can find the two S-idempotents for each  $p$  as above. We are showing here for the prime  $p = 2^n m_1 + 1$  only. If

$$p = 2^n m_1 + 1,$$

then

$$x = (2^n - 1)p + 1, \quad (a = p - 1)$$

and

$$y = p, \quad (a = (2^n - 1)p)$$

are S-idempotents.

Similarly we can find S-idempotents for each of the  $\phi(2^n)$  form of prime  $p$ .

**Theorem 2.7.** *The ring  $Z_{3p}$ ,  $p$  a prime  $> 3$  has (at least) two S-idempotents of  $\phi(3)$  types.*

**Proof.** Here  $p$  can be one of the form  $3m + 1$  or  $3m + 2$ . We can apply the Theorem 2.6 for  $Z_{3p}$  also.

I. If  $p = 3m + 1$ , then  $x = 2p + 1, (a = p - 1)$  and  $y = p, (a = 2p)$  are S-idempotents.

II. If  $p = 3m + 2$ , then  $x = p + 1, (a = 2p - 1)$  and  $y = 2p, (a = p)$  are S-idempotents.

**Example 2.7.** In the ring  $Z_{3 \cdot 5} = Z_{15} = \{0, 1, \dots, 14\}$ , here  $5 = 3 \cdot 1 + 2$ . So  $x = 5 + 1 = 6, (a = 2 \cdot 5 - 1 = 9)$  is an S-idempotent. As  $6^2 \equiv 6(\text{mod}15), 9^2 \equiv 6(\text{mod}15)$  and  $6 \cdot 9 \equiv 9(\text{mod}15)$ . Also  $y = 2 \cdot 5 = 10, (a = 5)$  is another S-idempotent. As  $10^2 \equiv 10(\text{mod}15), 5^2 \equiv 10(\text{mod}15)$  and  $10 \cdot 5 \equiv 5(\text{mod}15)$ .

**Remark:** The above result is not true for the ring  $Z_{3^2 p}, p$  prime  $> 3$ . As, for  $p = 9m + 5; x = 4p + 1, (a = 5p - 1)$  should be an S-idempotent from the above result. But we see it is not the case in general; for take the ring  $Z_{3^2 \cdot 23} = Z_{207} = \{0, 1, \dots, 206\}$ . Here  $p = 9 \cdot 2 + 5$ . Now take

$$x = 4 \cdot 23 + 1 = 93 \quad \text{and} \quad a = 5 \cdot 23 - 1 = 114.$$

But

$$x^2 \not\equiv x(\text{mod}207).$$

So  $x$  is not even an idempotent. So  $x = 4p + 1$  is not an S-idempotent of  $Z_{3^2 p}$ .

### §3. S-idempotents in the group rings $Z_2 G$

Here we prove the existence of Smarandache idempotents for the group rings  $Z_{3^2 p}$  of the cyclic group  $G$  of order  $2^n p$  where  $p$  is a prime of the form  $2^n t + 1$ .

**Example 3.2.** Let  $G = \{g/g^{52} = 1\}$  be the cyclic group of order  $2^2 \cdot 13$ . Consider the group ring  $Z_2 G$  of the group  $G$  over  $Z_2$ . Take

$$x = 1 + g^4 + g^8 + g^{12} + \dots + g^{44} + g^{48}$$

and

$$a = 1 + g^2 + g^4 + \dots + g^{22} + g^{24}$$

then

$$x^2 = x, \quad \text{and} \quad a^2 = x$$

also

$$x \cdot a = x.$$

So  $x = 1 + g^4 + g^8 + g^{12} + \dots + g^{44} + g^{48}$  is a S-idempotent in  $Z_2 G$ .

**Theorem 3.1.** Let  $Z_2 G$  be the group ring of the finite cyclic group  $G$  of order  $2^2 p$ , where  $p$  is a prime of the form  $2^2 m + 1$ , then the group ring  $Z_2 G$  has non-trivial S-idempotents.

**Proof.** Here  $G$  is a cyclic group of order  $2^2 p$ , where  $p$  of the form  $2^2 m + 1$ .

Take

$$x = 1 + g^4 + g^8 + \dots + g^{16m}$$

and

$$a = 1 + g^2 + g^4 + \dots + g^{8m}$$

then

$$\begin{aligned} x^2 &= (1 + g^4 + g^8 + \dots + g^{16m})^2 \\ &= 1 + g^4 + g^8 + \dots + g^{16m} \\ &= x. \end{aligned}$$

And

$$\begin{aligned} a^2 &= (1 + g^2 + g^4 + \dots + g^{8m})^2 \\ &= 1 + (g^2)^2 + (g^4)^2 + \dots + (g^{8m})^2 \\ &= x. \end{aligned}$$

Also

$$\begin{aligned} x \cdot a &= (1 + g^4 + g^8 + \dots + g^{16m})(1 + g^2 + g^4 + \dots + g^{8m}) \\ &= 1 + g^4 + g^8 + \dots + g^{16m} \\ &= x. \end{aligned}$$

So  $x = 1 + g^4 + g^8 + \dots + g^{16m}$  is a S-idempotent in  $Z_2G$ .

**Example 3.3.** Let  $G = \{g/g^{136} = 1\}$  be the cyclic group of order  $2^3 \cdot 17$ . Consider the group ring  $Z_2G$  of the group  $G$  over  $Z_2$ .

Take

$$x = 1 + g^8 + g^{16} + \dots + g^{128}$$

and

$$a = 1 + g^4 + g^8 + \dots + g^{64}$$

then

$$\begin{aligned} x^2 &= (1 + g^8 + g^{16} + \dots + g^{128})^2 \\ &= 1 + g^8 + g^{16} + \dots + g^{128} \\ &= x. \end{aligned}$$

And

$$\begin{aligned} a^2 &= (1 + g^4 + g^8 + \dots + g^{64})^2 \\ &= 1 + (g^4)^2 + (g^8)^2 + \dots + (g^{64})^2 \\ &= x. \end{aligned}$$

Also

$$\begin{aligned} x \cdot a &= (1 + g^8 + g^{16} + \dots + g^{128})(1 + g^4 + g^8 + \dots + g^{64}) \\ &= 1 + g^8 + g^{64} + \dots + g^{128} \\ &= x. \end{aligned}$$

So  $x = 1 + g^8 + g^{16} + \dots + g^{128}$  is a S-idempotent in  $Z_2G$ .



**Theorem 3.2.** Let  $Z_2G$  be the group ring of a finite cyclic group  $G$  of order  $2^3p$ , where  $p$  is a prime of the form  $2^3m + 1$ , then the group ring  $Z_2G$  has non-trivial  $S$ -idempotents.

**Proof.** Here  $G$  is a cyclic group of order  $2^3p$ , where  $p$  of the form  $2^3m + 1$ .

Take

$$x = 1 + g^8 + g^{16} + \dots + g^{8(p-1)}$$

and

$$a = 1 + g^4 + g^8 + \dots + g^{4(p-1)}$$

then

$$\begin{aligned} x^2 &= (1 + g^8 + g^{16} + \dots + g^{8(p-1)})^2 \\ &= 1 + g^8 + g^{16} + \dots + g^{8(p-1)} \\ &= x. \end{aligned}$$

And

$$\begin{aligned} a^2 &= (1 + g^4 + g^8 + \dots + g^{4(p-1)})^2 \\ &= 1 + (g^4)^2 + (g^8)^2 + \dots + (g^{4(p-1)})^2 \\ &= x. \end{aligned}$$

Also

$$\begin{aligned} x \cdot a &= (1 + g^8 + g^{16} + \dots + g^{8(p-1)})(1 + g^4 + g^8 + \dots + g^{4(p-1)}) \\ &= 1 + g^8 + g^{16} + \dots + g^{8(p-1)} \\ &= x. \end{aligned}$$

So  $x = 1 + g^8 + g^{16} + \dots + g^{8(p-1)}$  is a  $S$ -idempotent in  $Z_2G$ .

We can generalize the above two results as followings:

**Theorem 3.3.** Let  $Z_2G$  be the group ring of a finite cyclic group  $G$  of order  $2^np$ , where  $p$  is a prime of the form  $2^nt + 1$ , then the group ring  $Z_2G$  has non-trivial  $S$ -idempotents.

**Proof.** Here  $G$  is a cyclic group of order  $2^np$ , where  $p$  of the form  $2^nt + 1$ .

Take

$$x = 1 + g^{2^n} + g^{2^{n \cdot 2}} + \dots + g^{2^n(p-1)}$$

and

$$a = 1 + g^{2^{n-1}} + g^{2^{n-1} \cdot 2} + \dots + g^{2^{n-1} \cdot (p-1)}$$

then

$$\begin{aligned} x^2 &= (1 + g^{2^n} + g^{2^{n \cdot 2}} + \dots + g^{2^n(p-1)})^2 \\ &= 1 + g^{2^n} + g^{2^{n \cdot 2}} + \dots + g^{2^n(p-1)} \\ &= x. \end{aligned}$$

And

$$\begin{aligned} a^2 &= (1 + g^{2^{n-1}} + g^{2^{n-1} \cdot 2} + \dots + g^{2^{n-1} \cdot (p-1)})^2 \\ &= 1 + (g^{2^{n-1}})^2 + (g^{2^{n-1} \cdot 2})^2 + \dots + (g^{2^{n-1} \cdot (p-1)})^2 \\ &= x. \end{aligned}$$

Also

$$\begin{aligned} x \cdot a &= (1 + g^{2^n} + g^{2^n \cdot 2} + \dots + g^{2^n(p-1)})(1 + g^{2^{n-1}} + g^{2^{n-1} \cdot 2} + \dots + g^{2^{n-1} \cdot (p-1)}) \\ &= 1 + g^{2^n} + g^{2^n \cdot 2} + \dots + g^{2^n(p-1)} \\ &= x. \end{aligned}$$

So  $x = 1 + g^{2^n} + g^{2^n \cdot 2} + \dots + g^{2^n(p-1)}$  is a S-idempotent in  $Z_2G$ .

**Corollary 3.1.** *Let  $Z_2S_n$  be the group ring of a symmetric group  $S_n$  where  $n = 2^n p$ , and  $p$  is a prime of the form  $2^nt + 1$ , then the group ring  $Z_2S_n$  has non-trivial S-idempotents.*

**Proof.** Here  $Z_2S_n$  is a group ring where  $n = 2^n p$ , and  $p$  of the form  $2^nt + 1$ . Clearly  $Z_2S_n$  contains a finite cyclic group of order  $2^n p$ . Then by the Theorem 3.3,  $Z_2S_n$  has a non-trivial S-idempotent.

## §4. Conclusions

Here we have mainly proved the existence of S-idempotents in certain types of group rings. But it is interesting to enumerate the number of S-idempotents for the group rings  $Z_2G$  and  $Z_2S_n$  in the Theorem 3.3 and Corollary 3.1. We feel that  $Z_2G$  can have only one S-idempotent but we are not in a position to give a proof for it. Also, the problem of finding S-idempotents in  $Z_pS_n$  (and  $Z_pG$ ) where  $(p, n) = 1$  (and  $(p, |G|) = 1$ ) or  $(p, n) = d \neq 1$  (and  $(p, |G|) = d \neq 1$ ) are still interesting number theoretic problems.

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# Smarandache Idempotents in Loop Rings $Z_t L_n(m)$ of the Loops $L_n(m)$

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**Abstract** In this paper we establish the existence of S-idempotents in case of loop rings  $Z_t L_n(m)$  for a special class of loops  $L_n(m)$ ; over the ring of modulo integers  $Z_t$  for a specific value of  $t$ . These loops satisfy the conditions  $g_i^2$  for every  $g_i \in L_n(m)$ . We prove  $Z_t L_n(m)$  has an S-idempotent when  $t$  is a perfect number or when  $t$  is of the form  $2^i p$  or  $3^i p$  (where  $p$  is an odd prime) or in general when  $t = p_1^i p_2$  ( $p_1$  and  $p_2$  are distinct odd primes), It is important to note that we are able to prove only the existence of a single S-idempotent; however we leave it as an open problem whether such loop rings have more than one S-idempotent.

## §1. Basic Results

This paper has three sections. In section one, we give the basic notions about the loops  $L_n(m)$  and recall the definition of S-idempotents in rings. In section two, we establish the existence of S-idempotents in the loop ring  $Z_t L_n(m)$ . In the final section, we suggest some interesting problems based on our study.

Here we just give the basic notions about the loops  $L_n(m)$  and the definition of S-idempotents in rings.

**Definition 1.1** [4]. Let  $R$  be a ring. An element  $x \in R \setminus \{0\}$  is said to be a Smarandache idempotents (S-idempotent) of  $R$  if  $x^2 = x$  and there exist  $a \in R \setminus \{x, 0\}$  such that

- i.  $a^2 = x$
- ii.  $xa = x$  or  $ax = a$ .

For more about S-idempotent please refer [4].

**Definition 1.2** [2]. A positive integer  $n$  is said to be a perfect number if  $n$  is equal to the sum of all its positive divisors, excluding  $n$  itself. e.g. 6 is a perfect number. As  $6 = 1 + 2 + 3$ .

**Definition 1.3** [1]. A non-empty set  $L$  is said to form a loop, if in  $L$  is defined a binary operation, called product and denoted by  $'.'$  such that

1. For  $a, b \in L$  we have  $a.b \in L$ . (closure property.)
2. There exists an element  $e \in L$  such that  $a.e = e.a = a$  for all  $a \in L$ . ( $e$  is called the identity element of  $L$ .)
3. For every ordered pair  $(a, b) \in L \times L$  there exists a unique pair  $(x, y) \in L \times L$  such that  $ax = b$  and  $ya = b$ .

**Definition 1.4 [3].** Let  $L_n(m) = \{e, 1, 2, 3, \dots, n\}$  be a set where  $n > 3$ ,  $n$  is odd and  $m$  is a positive integer such that  $(m, n) = 1$  and  $(m - 1, n) = 1$  with  $m < n$ . Define on  $L_n(m)$ , a binary operation  $'.'$  as following:

- i.*  $e.i = i.e = i$  for all  $i \in L_n(m) \setminus \{e\}$
- ii.*  $i^2 = e$  for all  $i \in L_n(m)$
- iii.*  $i.j = t$ , where  $t \equiv (mj - (m - 1)i) \pmod{n}$  for all  $i, j \in L_n(m)$ ,  
 $i \neq e$  and  $j \neq e$ .

Then  $L_n(m)$  is a loop. This loop is always of even order; further for varying  $m$ , we get a class of loops of order  $n + 1$  which we denote by

$$L_n = \{L_n(m) | n > 3, n \text{ is odd and } (m, n) = 1, (m - 1, n) = 1 \text{ with } m < n\}.$$

**Example 1.1 [3].** Consider  $L_5(2) = \{e, 1, 2, 3, 4, 5\}$ . The composition table for  $L_5(2)$  is given below:

·	e	1	2	3	4	5
e	e	1	2	3	4	5
1	1	e	3	5	2	4
2	2	5	e	4	1	3
3	3	4	1	e	5	2
4	4	3	5	2	e	1
5	5	2	4	1	3	e

This loop is non-commutative and non-associative and of order 6.

## §2. Existence of S-idempotents in the Loop Rings $Z_tL_n(m)$

In this section we will prove the existence of an S-idempotent in the loop ring  $Z_tL_n(m)$  when  $t$  is an even perfect number. Also we will prove that the loop ring  $Z_tL_n(m)$  has an S-idempotent when  $t$  is of the form  $2^i p$  or  $3^i p$  (where  $p$  is an odd prime) or in general when  $t = p_1^i p_2$  ( $p_1$  and  $p_2$  are distinct odd primes).

**Theorem 2.1.** Let  $Z_tL_n(m)$  be a loop ring, where  $t$  is an even perfect number of the form  $t = 2^s(2^{s+1} - 1)$  for some  $s > 1$ , then  $\alpha = 2^s + 2^s g_i \in Z_tL_n(m)$  is an S-idempotent.

**Proof.** As  $t$  is an even perfect number,  $t$  must be of the form

$$t = 2^s(2^{s+1} - 1), \quad \text{for some } s > 1$$

where  $2^{s+1} - 1$  is a prime.

Consider

$$\alpha = 2^s + 2^s g_i \in Z_tL_n(m).$$

Choose

$$\beta = (t - 2^s) + (t - 2^s)g_i \in Z_tL_n(m).$$

Clearly

$$\begin{aligned}
 \alpha^2 &= (2^s + 2^s g_i)^2 \\
 &= 2 \cdot 2^{2s} (1 + g_i) \\
 &\equiv 2^s (1 + g_i) \quad [2^s \cdot 2^{s+1} \equiv 2^s \pmod{t}] \\
 &= \alpha.
 \end{aligned}$$

Now

$$\begin{aligned}
 \beta^2 &= ((t - 2^s) + (t - 2^s)g_i)^2 \\
 &= 2 \cdot (t - 2^s)^2 (1 + g_i) \\
 &\equiv 2^s (1 + g_i) \\
 &= \alpha.
 \end{aligned}$$

Also

$$\begin{aligned}
 \alpha\beta &= [2^s + 2^s g_i][(t - 2^s) + (t - 2^s)g_i] \\
 &= 2^s (1 + g_i)(t - 2^s)(1 + g_i) \\
 &\equiv -2 \cdot 2^s \cdot 2^s (1 + g_i) \\
 &\equiv (t - 2^s)(1 + g_i) \\
 &= \beta.
 \end{aligned}$$

So we get

$$\alpha^2 = \alpha, \quad \beta^2 = \alpha \quad \text{and} \quad \alpha\beta = \beta.$$

Therefore  $\alpha = 2^s + 2^s g_i$  is an S-idempotent.

**Example 2.1.** Take the loop ring  $Z_6 L_n(m)$ . Here 6 is an even perfect number. As  $6 = 2 \cdot (2^s - 1)$ , so  $\alpha = 2 + 2g_i$  is an S-idempotent. For

$$\begin{aligned}
 \alpha^2 &= (2 + 2g_i)^2 \\
 &\equiv 2 + 2g_i \\
 &= \alpha.
 \end{aligned}$$

Choose now

$$\beta = (6 - 2) + (6 - 2)g_i.$$

then

$$\begin{aligned}
 \beta^2 &= (4 + 4g_i)^2 \\
 &\equiv (2 + 2g_i) \\
 &= \alpha.
 \end{aligned}$$

And

$$\begin{aligned}
 \alpha\beta &= (2 + 2g_i)(4 + 4g_i) \\
 &= 8 + 8g_i + 8g_i + 8 \\
 &\equiv 4 + 4g_i \\
 &= \beta.
 \end{aligned}$$

So  $\alpha = 2 + 2g_i$  is an S-idempotent.

**Theorem 2.2.** Let  $Z_{2p}L_n(m)$  be a loop ring where  $p$  is an odd prime such that  $p \mid 2^{t_0+1} - 1$  for some  $t_0 \geq 1$ , then  $\alpha = 2^{t_0} + 2^{t_0}g_i \in Z_{2p}L_n(m)$  is an S-idempotent.

**Proof.** Suppose  $p \mid 2^{t_0+1} - 1$  for some  $t_0 \geq 1$ . Take  $\alpha = 2^{t_0} + 2^{t_0}g_i \in Z_{2p}L_n(m)$  and  $\beta = (2p - 2^{t_0}) + (2p - 2^{t_0})g_i \in Z_{2p}L_n(m)$ .

Clearly

$$\begin{aligned}\alpha^2 &= (2^{t_0} + 2^{t_0}g_i)^2 \\ &= 2 \cdot 2^{2t_0}(1 + g_i) \\ &= 2^{t_0+1} \cdot 2^{t_0}(1 + g_i) \\ &\equiv 2^{t_0}(1 + g_i) \\ &= \alpha.\end{aligned}$$

As

$$2^{t_0} \cdot 2^{t_0+1} \equiv 2^{t_0} \pmod{2p}$$

Since

$$\begin{aligned}2^{t_0+1} &\equiv 1 \pmod{p} \\ \Leftrightarrow 2^{t_0} \cdot 2^{t_0+1} &\equiv 2^{t_0} \pmod{2p} \text{ for } \gcd(2^{t_0}, 2p) = 2, \quad t_0 \geq 1.\end{aligned}$$

Also

$$\begin{aligned}\beta^2 &= [(2p - 2^{t_0}) + (2p - 2^{t_0})g_i]^2 \\ &= 2(2p - 2^{t_0})^2(1 + g_i) \\ &\equiv 2 \cdot 2^{2t_0}(1 + g_i) \\ &= 2^{t_0+1} \cdot 2^{t_0}(1 + g_i) \\ &\equiv 2^{t_0}(1 + g_i) \\ &= \alpha.\end{aligned}$$

And

$$\begin{aligned}\alpha\beta &= [2^{t_0} + 2^{t_0}g_i][(2p - 2^{t_0}) + (2p - 2^{t_0})g_i] \\ &\equiv -2^{t_0}(1 + g_i)2^{t_0}(1 + g_i) \\ &= -2 \cdot 2^{2t_0}(1 + g_i) \\ &\equiv (2p - 2^{t_0})(1 + g_i) \\ &= \beta.\end{aligned}$$

So we get

$$\alpha^2 = \alpha, \quad \beta^2 = \alpha \quad \text{and} \quad \alpha\beta = \beta.$$

Hence  $\alpha = 2^{t_0} + 2^{t_0}g_i$  is an S-idempotent.

**Example 2.2.** Consider the loop ring  $Z_{10}L_n(m)$ . Here  $5 \mid 2^{3+1} - 1$ , so  $t_0 = 3$ .

Take

$$\alpha = 2^3 + 2^3 g_i \text{ and } \beta = 2 + 2g_i.$$

Now

$$\begin{aligned} \alpha^2 &= (8 + 8g_i)^2 \\ &= 64 + 128g_i + 64 \\ &\equiv 8 + 8g_i \\ &= \alpha. \end{aligned}$$

And

$$\begin{aligned} \beta^2 &= (2 + 2g_i)^2 \\ &= 4 + 8g_i + 4 \\ &\equiv 8 + 8g_i \\ &= \alpha. \end{aligned}$$

Also

$$\begin{aligned} \alpha\beta &= (8 + 8g_i)(2 + 2g_i) \\ &= 16 + 16g_i + 16g_i + 16 \\ &\equiv 2 + 2g_i \\ &= \beta. \end{aligned}$$

So  $\alpha = 8 + 8g_i$  is an S-idempotent.

**Theorem 2.3.** Let  $Z_{2^i p} L_n(m)$  be a loop ring where  $p$  is an odd prime such that  $p \mid 2^{t_0+1} - 1$  for some  $t_0 \geq i$ , then  $\alpha = 2^{t_0} + 2^{t_0} g_i \in Z_{2^i p} L_n(m)$  is an S-idempotent.

**Proof.** Note that  $p \mid 2^{t_0+1} - 1$  for some  $t_0 \geq i$ .

Therefore

$$\begin{aligned} 2^{t_0+1} &\equiv 1 \pmod{p} \text{ for some } t_0 \geq i \\ \Leftrightarrow 2^{t_0} \cdot 2^{t_0+1} &\equiv 2^{t_0} \pmod{2^i p} \text{ as } \gcd(2^{t_0}, 2^i p) = 2^i, \quad t_0 \geq 1. \end{aligned}$$

Now take

$$\alpha = 2^{t_0} + 2^{t_0} g_i \in Z_{2^i p} L_n(m) \text{ and } \beta = (2^i p - 2^{t_0}) + (2^i p - 2^{t_0}) g_i \in Z_{2^i p} L_n(m).$$

Then it is easy to see that

$$\alpha^2 = \alpha, \quad \beta^2 = \alpha \quad \text{and} \quad \alpha\beta = \beta.$$

Hence  $\alpha = 2^{t_0} + 2^{t_0} g_i$  is an S-idempotent.

**Example 2.3.** Take the loop ring  $Z_{2^3 \cdot 7} L_n(m)$ . Here  $7 \mid 2^{5+1} - 1$ , so  $t_0 = 5$ .

Take

$$\alpha = 2^5 + 2^5 g_i \text{ and } \beta = (2^3 \cdot 7 - 2^5) + (2^3 \cdot 7 - 2^5) g_i.$$

Now

$$\begin{aligned}\alpha^2 &= (32 + 32g_i)^2 \\ &= 1024 + 2048g_i + 1024 \\ &\equiv 32 + 32g_i \\ &= \alpha.\end{aligned}$$

And

$$\begin{aligned}\beta^2 &= (24 + 24g_i)^2 \\ &= 576 + 1152g_i + 576 \\ &\equiv 24 + 24g_i \\ &= \alpha.\end{aligned}$$

Also

$$\begin{aligned}\alpha\beta &= (32 + 32g_i)(24 + 24g_i) \\ &\equiv 24 + 24g_i \\ &= \beta.\end{aligned}$$

So  $\alpha = 32 + 32g_i$  is an S-idempotent.

**Theorem 2.4.** Let  $Z_{3^i p} L_n(m)$  be a loop ring where  $p$  is an odd prime such that  $p \mid 2 \cdot 3^{t_0} - 1$  for some  $t_0 \geq i$ , then  $\alpha = 3^{t_0} + 3^{t_0} g_i \in Z_{3^i p} L_n(m)$  is an S-idempotent.

**Proof.** Suppose  $p \mid 2 \cdot 3^{t_0} - 1$  for some  $t_0 \geq i$ .

Take

$$\alpha = 3^{t_0} + 3^{t_0} g_i \in Z_{3^i p} L_n(m) \quad \text{and} \quad \beta = (3^i p - 3^{t_0}) + (3^i p - 3^{t_0}) g_i \in Z_{3^i p} L_n(m).$$

Then

$$\begin{aligned}\alpha^2 &= (3^{t_0} + 3^{t_0} g_i)^2 \\ &= 2 \cdot 3^{2t_0} (1 + g_i) \\ &= 2 \cdot 3^{t_0} 3^{t_0} (1 + g_i) \\ &\equiv 3^{t_0} (1 + g_i) \\ &= \alpha.\end{aligned}$$

As

$$\begin{aligned}2 \cdot 3^{t_0} &\equiv 1 \pmod{p} \quad \text{for some } t_0 \geq i \\ \Leftrightarrow 2 \cdot 3^{t_0} \cdot 3^{t_0} &\equiv 3^{t_0} \pmod{3^i p} \quad \text{as } \gcd(3^{t_0}, 3^i p) = 3^i, \quad t_0 \geq 1.\end{aligned}$$

Similarly

$$\beta^2 = \alpha \quad \text{and} \quad \alpha\beta = \beta.$$

So  $\alpha = 3^{t_0} + 3^{t_0} g_i$  is an S-idempotent.



**Example 2.4.** Take the loop ring  $Z_{3^2.5}L_n(m)$ . Here  $5 \mid 2 \cdot 3^5 - 1$ , so  $t_0 = 5$ .

Take

$$\alpha = 3^5 + 3^5 g_i \quad \text{and} \quad \beta = (3^{2 \cdot 5} - 3^5) + (3^{2 \cdot 5} - 3^5) g_i.$$

Now

$$\begin{aligned} \alpha^2 &= (18 + 18g_i)^2 \\ &\equiv 18 + 18g_i \\ &= \alpha. \end{aligned}$$

And

$$\begin{aligned} \beta^2 &= (27 + 27g_i)^2 \\ &\equiv 18 + 18g_i \\ &= \alpha. \end{aligned}$$

Also

$$\alpha\beta = \beta.$$

So  $\alpha = 3^5 + 3^5 g_i$  is an S-idempotent.

We can generalize Theorem 2.3 and Theorem 2.4 as following:

**Theorem 2.5.** Let  $Z_{p_1^i p_2} L_n(m)$  be a loop ring where  $p_1$  and  $p_2$  are distinct odd primes and  $p_2 \mid 2 \cdot p_1^{t_0} - 1$  for some  $t_0 \geq i$ , then  $\alpha = p_1^{t_0} + p_1^{t_0} g_i \in Z_{p_1^i p_2} L_n(m)$  is an S-idempotent.

**Proof.** Suppose  $p_2 \mid 2 \cdot p_1^{t_0} - 1$  for some  $t_0 \geq i$ .

Take

$$\alpha = p_1^{t_0} + p_1^{t_0} g_i \in Z_{p_1^i p_2} L_n(m) \quad \text{and} \quad \beta = (p_1^i p_2 - p_1^{t_0}) + (p_1^i p_2 - p_1^{t_0}) g_i \in Z_{p_1^i p_2} L_n(m).$$

Then

$$\begin{aligned} \alpha^2 &= (p_1^{t_0} + p_1^{t_0} g_i)^2 \\ &= 2 \cdot p_1^{2t_0} (1 + g_i) \\ &= 2 \cdot p_1^{t_0} p_1^{t_0} (1 + g_i) \\ &\equiv p_1^{t_0} (1 + g_i) \\ &= \alpha. \end{aligned}$$

As

$$2 \cdot p_1^{t_0} \equiv 1 \pmod{p_2} \quad \text{for some } t_0 \geq i$$

$$\Leftrightarrow 2 \cdot p_1^{t_0} \cdot p_1^{t_0} \equiv p_1^{t_0} \pmod{p_1^i p_2} \quad \text{as } \gcd(p_1^{t_0}, p_1^i p_2) = p_1^i, \quad t_0 \geq i.$$

Similarly

$$\beta^2 = \alpha \quad \text{and} \quad \alpha\beta = \beta.$$

So  $\alpha = p_1^{t_0} + p_1^{t_0} g_i$  is an S-idempotent.

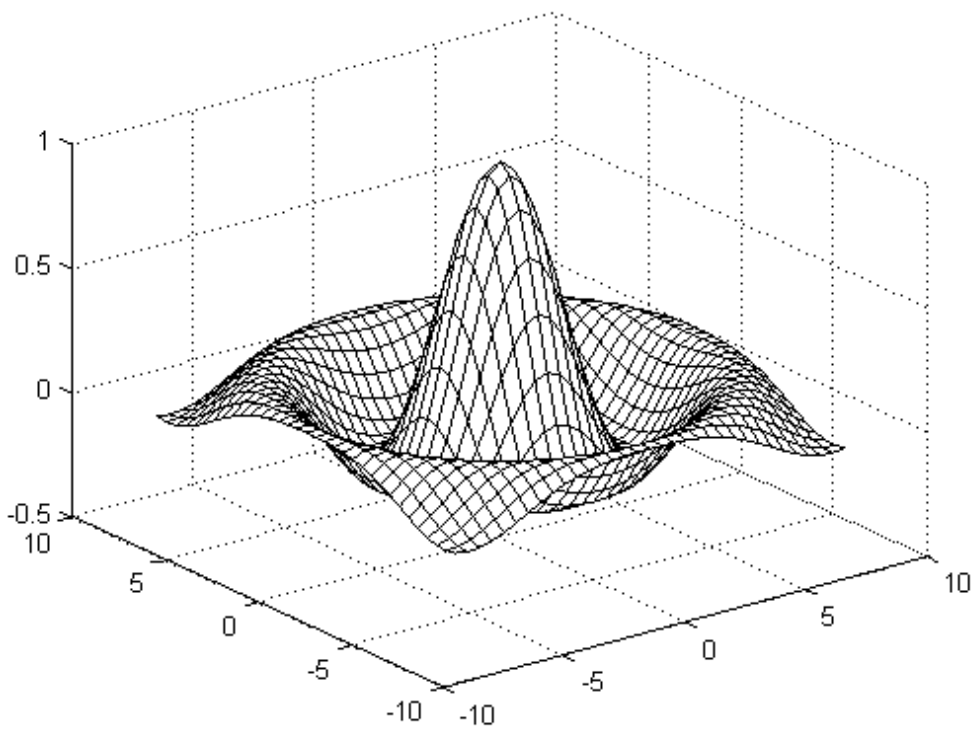
### §3. Conclusion

We see in all the 5 cases described in the Theorem 2.1 to 2.5 we are able to establish the existence of one non-trivial S-idempotent. however we are not able to prove the uniqueness of this S-idempotent. Hence we suggest the following problems:

- Does the loop rings described in the Theorems 2.1 to 2.5 can have more than one S-idempotent?
- Does the loop rings  $Z_t L_n(m)$  have S-idempotent when  $t$  is of the form  $t = p_1 p_2 \dots p_s$  where  $p_1 p_2 \dots p_s$  are distinct odd primes?

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