Proof that there are no odd perfect numbers

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1. Abstract

If y is an odd perfect number, let p be one of the prime factors of y, the exponent of p be an integer $n(n \geqq 1)$, the prime factors other than p and different from each other be $p_1, p_2, \cdots, p_r, \cdots, p_s$ and the even exponent of p_k be q_k.

$$y/p^n = (1 + p + p^2 + \cdots + p^n) \prod_{k=1}^{r} (1 + p_k + {p_k}^2 + \cdots + {p_k}^{q_k}) / (2p^n) = \prod_{k=1}^{r} {p_k}^{q_k}$$

must be satisfied. Let m be a non negative integer and q be a positive integer,

$$n = 4m + 1$$

$$p = 4q + 1$$

Letting a and b be odd integers, satisfying following expressions,

$$a = \prod_{k=1}^{r} (1 + p_k + {p_k}^2 + \cdots + {p_k}^{q_k})$$

$$b = \prod_{k=1}^{r} {p_k}^{q_k}$$

$$a(p^n + \cdots + 1) - 2bp^n = 0$$

is established. This is a known content proven by Euler. Let $s(s \geqq r)$ be an integer, v be a rational number,

$$v = \prod_{k=1}^{s} (1 + p_k + {p_k}^2 + \cdots + {p_k}^{q_k}) / \prod_{k=1}^{s} {p_k}^{q_k}$$

holds. By the consideration of this research paper, since it turned out that if v is not an integer, due to the uniqueness of a/b for any p satisfing the equation $a(p^n + \cdots + 1) - 2bp^n = 0$ the solution (a, b, p, n) satisfing this equation was found to be at most one. Then since by the uniqueness of $a(p^n + \cdots + 1)/(bp^n)$ we proved that there is no solution for $a(p^n + \cdots + 1) - 2bp^n = 0$ other than $(a, b, p, n) = (1,1,1,1)$, we have obtained a conclusion that there are no odd perfect numbers.

2. Introduction

The perfect number is one in which the sum of the divisors other than itself is the same value as itself, and the smallest perfect number is

$$1 + 2 + 3 = 6$$

It is 6. Whether an odd perfect number exists or not is currently an unsolved problem in mathematics.

3. Proof

Let y be an odd perfect number, one of the prime factors of y be an odd prime p and an exponent of p be an integer $n(n \geqq 1)$. Let the prime factors other than p and different from each other be $p_1, p_2, \cdots, p_r$, q_k be the index of p_k, and an integer a be the product of series of prime numbers other than prime p.

$$a = \prod_{k=1}^{r}(1 + p_k + {p_k}^2 + \cdots + {p_k}^{q_k}) \ \ldots ①$$

The number of terms N of variable a is

$$N = \prod_{k=1}^{r}(q_k + 1) \ \ldots ②$$

When y is a perfect number,

$$y = a(1 + p + p^2 + \cdots + p^n) - y \ (n > 0)$$

is established.

$$a \sum_{k=0}^{n} p^k / 2 = y$$

$$a \sum_{k=0}^{n} p^k / (2p^n) = y/p^n \ \ldots ③$$

3.1. If q_k has at least one odd integer

Letting the number of terms where q_k is an odd integer be a positive integer u, because $y/p^n = \prod_{k=1}^{r} {p_k}^{q_k}$ is an odd integer, the denominator on the left side of the expression ③ has a prime factor 2, from the expression ② variable a has more than u prime factor 2 and variable a is an even integer. Therefore, $\sum_{k=0}^{n} p^k$ must be an odd integer, n is an even integer and u is 1.

3.2. When all q_k are even integers

y/p^n is an odd integer, the denominator on the left side of the expression ③ is an even integer, and since N is an odd integer when q_k are all even integers, variable a is an odd integer. Therefore, $\sum_{k=0}^{n} p^k$ is necessary to include one prime factor 2, $\sum_{k=0}^{n} p^k \equiv 0 \ (mod\ 2)$ is established, and n must be an odd integer.

From 3.1, 3.2, in order to have an odd perfect number, only one exponent of the prime factor of y must be an odd integer. We consider the case of 3.2 below.

In order for y to be an odd perfect number, the following expression must be established.

$$y/p^n = (1 + p + p^2 + \cdots + p^n)\prod_{k=1}^{r}(1 + p_k + {p_k}^2 + \cdots + {p_k}^{q_k})/(2p^n) = \prod_{k=1}^{r}{p_k}^{q_k}$$

However, $q_1, q_2, \cdots, q_r$ are all even integers.

Here, let b be an odd integer

$$b = \prod_{k=1}^{r}{p_k}^{q_k} \quad \ldots④$$

A following expression is established.

$y/p^n = a(1 + p + p^2 + \cdots + p^n)/(2p^n) = b$

$a(p^{n+1} - 1)/(2(p - 1)p^n) = b$

$(a - 2b)p^{n+1} + 2bp^n - a = 0$ ...⑤

$(ap - 2bp + 2b)p^n = a$

Since $ap - 2bp + 2b$ is an odd integer, a/p^n is an odd integer. Let a/p^n be an odd integer c.

$ap - 2bp + 2b = c \ (c > 0)$ ...⑥

$(2b - a)p = 2b - c$

Since variable a is an odd integer, $2b - a$ is an odd integer and $2b - a \neq 0$

$p = (2b - c)/(2b - a)$

Since $n \geqq 1$,

$a - c = cp^n - c \geqq cp - c > 0$

$a > c$

is.

From the equation ⑥

$2b(p - 1) - (ap - c) = 0$

$2b - c(p^{n+1} - 1)/(p - 1) = 0$

$(p^n + \cdots + 1)/2$ is an odd integer, $n = 4m + 1$ must be hold with m as an integer.

$2b(p - 1) = c(p^{n+1} - 1)$

$2b = c(p^n + \cdots + 1)$

$2b = c(p + 1)(p^{n-1} + p^{n-3} + \cdots + 1)$ ...⑦

Since b is an odd integer when $p + 1$ is not a multiple of 4, $p - 1$ must be a multiple of 4. A positive integer is taken as q.

$p = 4q + 1$

is established. Up to this point, the conditions proved by Euler.

When $p > 1$

$p^n - 1 < p^n$

$(p^n - 1)/(p - 1) < p^n/(p - 1)$

$p^{n-1} + \cdots + 1 < p^n/(p - 1)$

Since p is an odd prime number satisfying $p = 4q + 1$ and $p \geqq 5$,

$p^{n-1} + \cdots + 1 < p^n/4$

$2b - a = c(p^n + \cdots + 1) - cp^n = c(p^{n-1} + \cdots + 1)$

$2b - a < cp^n/4 = a/4$

$2b < 5a/4$

$a > 8b/5$ ...⑧

Let a_k and b_k be odd integers and if

$a_k = 1 + p_k + p_k^2 + \cdots + p_k^{q_k}$, $b_k = p_k^{q_k}$,

$a_k - b_k < b_k/(p_k - 1)$

$a_k < b_k p_k/(p_k - 1)$

$$a = \prod_{k=1}^{r} a_k < \prod_{k=1}^{r} b_k p_k/(p_k - 1) = b \prod_{k=1}^{r} p_k/(p_k - 1)$$

$$a/b < \prod_{k=1}^{r} p_k/(p_k - 1)$$

When $r = 1$, since $a/b < 3/2$ is established, it becomes inappropriate contrary to inequality ⑧.

From the expression ⑦,

$b = c(p + 1)/2 \times (p^{n-1} + p^{n-3} + \cdots + 1)$

holds. Since $(p + 1)/2$ is the product of only prime numbers of b, let d_k be the index,

$$(p + 1)/2 = \prod_{k=1}^{r} {p_k}^{d_k}$$

$$p = 2\prod_{k=1}^{r} {p_k}^{d_k} - 1 \quad \ldots ⑨$$

From $a = cp^n$ and the expression ⑦,

$2bp^n = a(p^n + \cdots + 1)$

$a(p^n + \cdots + 1)/(2bp^n) = 1 \quad \ldots (A)$

When $r = 1$,

$a = ({p_1}^{q_1+1} - 1)/(p_1 - 1)$

$b = {p_1}^{q_1}$

The equation (A) does not hold since there is no odd perfect number when $r = 1$.

Let R be a rational number,

$R = a(p^n + \cdots + 1)/(2bp^n)$

Let b' be a rational number and let A_k and B_k to be odd integers,

$b' = (p_k{}^{q_k+1} - 1)/(p_k{}^{q_k}(p_k - 1)) > 1$

$A_k = (p_k{}^{q_k+1} - 1)/(p_k - 1)$

$B_k = p_k{}^{q_k}$

Define the operation [multiplication] and the operation [division] as follows. Assuming that p in the equation of R is replaced by p' by multiplying A_i/B_i, define operation [multiplication] to R as follows.

$p' = 2\prod_{k=1}^{r} p_k{}^{d_k} \times p_i{}^{d_i} - 1$

$0 \leqq d_i \leqq q_i$

Here, let i be $i > r$. Suppose operation [division] is division by A_j/B_j for R, and if p_j is included in p in the expression R, p_j is deleted as $d_j = 0$. Here, assuming that j satisfies $1 \leqq j \leqq r$.

When operation [multiplication] by b' is performed on R, there are both cases that p_k increases p or does not change. When this operation is performed, the rate of change of R is $A_{r+1}p^n(p'^n + \cdots + 1)/(B_{r+1}p'^n(p^n + \cdots + 1))$, if p after variation is p'. If the rate of change of R is 1,

$A_{r+1}p^n(p'^n + \cdots + 1)/(B_{r+1}p'^n(p^n + \cdots + 1)) = 1$

$A_{r+1}p^n(p'^n + \cdots + 1) = B_{r+1}p'^n(p^n + \cdots + 1)$

This expression does not hold since the right side is not a multiple of p when $p' > p$, and $A_{r+1} > B_{r+1}$ holds when $p' = p$. Due to this operation, R may be larger or smaller than the original value since the rate of change of R does not become 1.

Assuming that $R = 1$ in some r, letting x be an integer and by multiplying fractions $b' = A_{r+1}/B_{r+1}$, $b'' = A_{r+2}/B_{r+2}$, $\cdots b''^{\cdots\prime} = A_x/B_x$ to R. Furthermore, letting $t(t < r)$ be an integer and assuming that $A_{t+1}A_{t+2} \ldots A_r$ is not a multiple of p, R is divided by A_{t+1}/B_{t+1}, A_{t+2}/B_{t+2}, $\cdots A_r/B_r$ and it is assumed that finally $R = 1$. At this time, assuming that n changes to n_{r+1}, the change rate of R by this operation when multiplying by A_{r+1}/B_{r+1} is

$A_{r+1}p^n(p^{n_{r+1}} + \cdots + 1)/(B_{r+1}p^{n_{r+1}}(p^n + \cdots + 1))$

$$1 \times B_{t+1}p^n(p^{n_{t+1}} + \cdots + 1)/(A_{t+1}p^{n_{t+1}}(p^n + \cdots + 1)) \times \ldots \times B_r p^{n_{r-1}}(p^{n_r} + \cdots + 1)/(A_r p^{n_r}(p^{n_{r-1}} + \cdots + 1)) \times A_{r+1}p^{n_r}(p^{n_{r+1}} + \cdots + 1)/(B_{r+1}p^{n_{r+1}}(p^{n_r} + \cdots + 1)) \times A_{r+2}p^{n_{r+1}}(p^{n_{r+2}} + \cdots + 1)/(B_{r+2}p^{n_{r+2}}(p^{n_{r+1}} + \cdots + 1)) \times \ldots \times A_x p^{n_{x-1}}(p^{n_x} + \cdots + 1)/(B_x p^{n_x}(p^{n_{x-1}} + \cdots + 1)) = 1$$

$$B_{t+1}B_{t+2} \ldots B_r A_{r+1}A_{r+2} \ldots A_x p^{n-n_x}(p^{n_x} + \cdots + 1) = A_{t+1}A_{t+2} \ldots A_r B_{r+1}B_{r+2} \ldots B_x(p^n + \cdots + 1) \ \ldots (B)$$

When $n_x < n$, it becomes contradiction since the right side of above expression does not include the prime factor p.

When $n_x = n$,

$B_{t+1}B_{t+2} \ldots B_r A_{r+1}A_{r+2} \ldots A_x = A_{t+1}A_{t+2} \ldots A_r B_{r+1}B_{r+2} \ldots B_x \ldots (C)$

Let $s(s \geqq r)$ be an integer and v be a rational number, if

$$v = \prod_{k=1}^{s}(1 + p_k + p_k{}^2 + \cdots + p_k{}^{q_k})/\prod_{k=1}^{s} p_k{}^{q_k}$$

holds, assume that v is not an integer. $\cdots$(D)

Let e_r, f_r be odd integers and g_r be a rational number,

$$e_r = \prod\nolimits_{k=1}^{r}(p_k{}^{q_k} + \cdots + 1)$$

$$f_r = \prod\nolimits_{k=1}^{r} p_k{}^{q_k}$$

$g_r = e_r/f_r$

holds.

$g_{r+1} = e_{r+1}/f_{r+1} = e_r/f_r \times (p_{r+1}{}^{q_{r+1}} + \cdots + 1)/p_{r+1}{}^{q_{r+1}} > e_r/f_r = g_r$

Let $q_1{}'$ be an even integer and $q_1' > q_1$ holds. Let g_r be $g_r{}'$ when q_1 becomes q_1',

$g_r' = (p_1{}^{q_1}(p_1{}^{q_1{}'} + \cdots + 1)/p_1{}^{q_1{}'}(p_1{}^{q_1} + \cdots + 1))g_r > g_r$

is established.

It is assumed that q_k becomes $q_k - h_k$ by changing q_k than before for g_r. h_k is an even integer. Then assume that r becomes $s(s > r)$, $g_s = g_r$ and g_s is not changed.

$$g_s/g_r = p_{r+1}{}^{q_{r+1}} \times \dots \times p_s{}^{q_s}/((p_{r+1}{}^{q_{r+1}} + \cdots + 1) \times \dots \times (p_s{}^{q_s} + \cdots + 1)) \times p_1{}^{q_1} \times \dots$$
$$\times p_r{}^{q_r}\left(p_1{}^{q_1-h_1} + \cdots + 1\right) \dots (p_r{}^{q_r-h_r} + \cdots + 1)/(p_1{}^{q_1-h_1} \times \dots$$
$$\times p_r{}^{q_r-h_r}(p_1{}^{q_1} + \cdots + 1) \dots (p_r{}^{q_r} + \cdots + 1)) = 1$$

$$p_{r+1}{}^{q_{r+1}} \times \dots \times p_s{}^{q_s}/((p_{r+1}{}^{q_{r+1}} + \cdots + 1) \times \dots \times (p_s{}^{q_s} + \cdots + 1)) \times p_1{}^{h_1} \times \dots$$
$$\times p_r{}^{h_r}\left(p_1{}^{q_1-h_1} + \cdots + 1\right) \dots (p_r{}^{q_r-h_r} + \cdots$$
$$+ 1)/((p_1{}^{q_1} + \cdots + 1) \dots (p_r{}^{q_r} + \cdots + 1)) = 1$$

$$p_{r+1}{}^{q_{r+1}} \times \dots \times p_s{}^{q_s} \times p_1{}^{h_1} \times \dots \times p_r{}^{h_r}\left(p_1{}^{q_1-h_1} + \cdots + 1\right) \dots \left(p_r{}^{q_r-h_r} + \cdots + 1\right)$$
$$= (p_1{}^{q_1} + \cdots + 1) \dots (p_r{}^{q_r} + \cdots + 1)(p_{r+1}{}^{q_{r+1}} + \cdots + 1) \dots (p_s{}^{q_s} + \cdots + 1)$$

When $h_k < 0 (1 \leqq k \leqq r)$, multiply both sides by $p_k{}^{-h_k}$ so that both sides become integers. When $\prod_{k=r+1}^{s}(A_k/B_k)$ is not an integer, if both sides are divided by the prime numbers from p_{r+1} to p_s, at least one prime number among the prime numbers from p_{r+1} to p_s are left on the left side. Since $a = \prod_{k=1}^{r} A_k = cp^n$ holds and from the expression ⑦, c must be a product of primes from p_1 to p_r. Thereby, the above equation does not hold, since it is inappropriate when there is even one prime number other than p_1 to p_r and p. When changing the value of p_k, it is equivalent to dividing by $p_k{}^{q_k}$ and then multiplying by new $p_k{}^{q_k}$, so it is sufficient to consider only the changes of q_k and r. From above, since g_r does not chord the original value when q_k or r is increased or decreased, it takes unique values for the variables p_k, q_k, r.

From the above proof,

$g_r = A_1 A_2 \dots A_s/B_1 B_2 \dots B_s \times A_{r+1} A_{r+2} \dots A_x/B_{r+1} B_{r+2} \dots B_x$

g_r must be represented uniquely, and the expression (C) does not satisfied. When dividing by the prime number in the expression ⑨, a contradiction arises since the prime number not included in b is in the expression ⑨. Therefore, when $\prod_{k=r+1}^{s}(A_k/B_k)$ is not an integer and p holds $p \equiv 1 \pmod 4$ and $p \geqq 5$, the number of the solution (a, b, p, n) satisfying $R = 1$ is at most one.

Since $(a, b, p, n) = (1,1,1,1)$ is inappropriate solution for the equation (A). At this time, since $a = b = 1$ and $r = 0$ that $\prod_{k=r+1}^{s}(A_k/B_k)$ is not an integer is same that the condition (D) holds, and since the expression (C) becomes contradiction, there is one inappropriate solution when $n_x = n = 1$. Therefore, if the condition (D) holds, there are no odd perfect numbers when $n = 1$.

In the proof of the expression (B), it is assumed that p changes on the way, and finally p becomes p_x.

$A_1 \ldots A_r = cp^n$

$2B_1 \ldots B_r = c(p^n + \cdots + 1)$

$A_1 \ldots A_x = c' {p_x}^{n_x}$

$2B_1 \ldots B_x = c'({p_x}^{n_x} + \cdots + 1)$

It is assumed that the above expressions are satisfied.

$$B_{t+1}B_{t+2} \ldots B_r A_{r+1}A_{r+2} \ldots A_x p^n({p_x}^{n_x} + \cdots + 1)$$
$$= A_{t+1}A_{t+2} \ldots A_r B_{r+1}B_{r+2} \ldots B_x {p_x}^{n_x}(p^n + \cdots + 1)$$
$$B_{t+1}B_{t+2} \ldots B_r A_1 \ldots A_r A_{r+1}A_{r+2} \ldots A_x p^n({p_x}^{n_x} + \cdots + 1)$$
$$= A_1 \ldots A_r A_{t+1}A_{t+2} \ldots A_r B_{r+1}B_{r+2} \ldots B_x {p_x}^{n_x}(p^n + \cdots + 1)$$
$$B_{t+1}B_{t+2} \ldots B_r c' {p_x}^{n_x} p^n({p_x}^{n_x} + \cdots + 1)$$
$$= A_1 \ldots A_r A_{t+1}A_{t+2} \ldots A_r B_{r+1}B_{r+2} \ldots B_x {p_x}^{n_x}(p^n + \cdots + 1)$$
$$B_{t+1}B_{t+2} \ldots B_r c' p^n({p_x}^{n_x} + \cdots + 1) = A_1 \ldots A_r A_{t+1}A_{t+2} \ldots A_r B_{r+1}B_{r+2} \ldots B_x(p^n + \cdots + 1)$$
$$B_1 \ldots B_r B_{t+1}B_{t+2} \ldots B_r c' p^n({p_x}^{n_x} + \cdots + 1)$$
$$= A_1 \ldots A_r A_{t+1}A_{t+2} \ldots A_r B_1 \ldots B_r B_{r+1}B_{r+2} \ldots B_x(p^n + \cdots + 1)$$
$$B_1 \ldots B_r B_{t+1}B_{t+2} \ldots B_r c' p^n({p_x}^{n_x} + \cdots + 1)$$
$$= A_1 \ldots A_r A_{t+1}A_{t+2} \ldots A_r c'({p_x}^{n_x} + \cdots + 1)/2 \times (p^n + \cdots + 1)$$
$$B_1 \ldots B_r B_{t+1}B_{t+2} \ldots B_r p^n = A_1 \ldots A_r A_{t+1}A_{t+2} \ldots A_r/2 \times (p^n + \cdots + 1)$$

$$c(p^n + \cdots + 1)/2 \times B_{t+1}B_{t+2} \ldots B_r p^n = cp^n A_{t+1}A_{t+2} \ldots A_r/2 \times (p^n + \cdots + 1)$$
$$B_{t+1}B_{t+2} \ldots B_r = A_{t+1}A_{t+2} \ldots A_r$$

is established. It becomes contradiction since $A_k > B_k$ holds when the operations [division] are performed.

Consider a tree whose vertex is $(a, b, p, n) = (1,1,1,1)$, and when the operations [multiplication] are performed, it becomes a child node. For example, consider a child node connected to a vertex as follows.

$(a, b, p, n) = (13,9,5,5)$ as $p_1 = 3$, $q_1 = 2$ and $d_1 = 1$

$(a, b, p, n) = (13,9,17,9)$ as $p_1 = 3$, $q_1 = 2$ and $d_1 = 2$

$(a, b, p, n) = (57,49,97,13)$ as $p_1 = 7$, $q_1 = 2$ and $d_1 = 2$

Suppose that the operations [multiplication] for changing the value of p are performed first, and then the operations [multiplication] for not changing the value of p are performed to create a tree structure. Here, when there is a solution in a certain p and there is a solution even in the other value p', considering a set of line segments connecting these two points in four-dimensional space (a, b, p, n). If $R = 1$ holds again when performing operation [multiplication] from one point where $R = 1$,

$$1 \times A_{r+1}p^n(p_{r+1}^{n_{r+1}} + \cdots + 1)/(B_{r+1}p_{r+1}^{n_{r+1}}(p^n + \cdots + 1)) \times A_{r+2}p_{r+1}^{n_{r+1}}(p_{r+2}^{n_{r+2}} + \cdots + 1)/(B_{r+2}p_{r+2}^{n_{r+2}}(p_{r+1}^{n_{r+1}} + \cdots + 1)) \times \ldots \times A_x p_{x-1}^{n_{x-1}}(p_x^{n_x} + \cdots + 1)/(B_x p_x^{n_x}(p_{x-1}^{n_{x-1}} + \cdots + 1)) = 1$$

$$A_{r+1}A_{r+2} \ldots A_x/(B_{r+1}B_{r+2} \ldots B_x) = p_x^{n_x}(p^n + \cdots + 1)/(p^n(p_x^{n_x} + \cdots + 1))$$

$$A_1A_2 \ldots A_x(p_x^{n_x} + \cdots + 1)/(B_1B_2 \ldots B_x p_x^{n_x}) = A_1A_2 \ldots A_r(p^n + \cdots + 1)/(B_1B_2 \ldots B_r p^n) \quad \ldots (E)$$

Assume that $G_r = A_1A_2 \ldots A_r(p^n + \cdots + 1)/(B_1B_2 \ldots B_x p^n)$ holds. Here, it is assumed that q_k becomes $q_k - h_k$ by changing q_k than before and n becomes $n - h(n - h \geqq 0)$ for G_r. h_k is an even integer and h is a non-negative integer that is a multiple of 4 or n. If h is n, since it means that p has been deleted, the operation [multiplication] is performed with the new value p. Then assuming that r becomes $s(s > r)$, $G_s = G_r$ and G_s is not changed, by the same calculation of g_s/g_r,

$$G_s/G_r = p_{r+1}^{q_{r+1}} \times \ldots \times p_s^{q_s}/((p_{r+1}^{q_{r+1}} + \cdots + 1) \times \ldots \times (p_s^{q_s} + \cdots + 1)) \times p_1^{q_1} \times p_2^{q_2} \times \ldots \times p_r^{q_r}p^n\left(p_1^{q_1-h_1} + \cdots + 1\right) \ldots (p_r^{q_r-h_r} + \cdots + 1)(p^{n-h} + \cdots + 1)/(p_1^{q_1-h_1} \times \ldots \times p_r^{q_r-h_r}p^{n-h}(p_1^{q_1} + \cdots + 1) \ldots (p_r^{q_r} + \cdots + 1)(p^n + \cdots + 1)) = 1$$

$$p_{r+1}^{q_{r+1}} \times \ldots \times p_s^{q_s}p_1^{q_1} \times \ldots \times p_r^{h_r}\left(p_1^{q_1-h_1} + \cdots + 1\right) \ldots \left(p_r^{q_r-h_r} + \cdots + 1\right)(p^n + \cdots + p^h) = (p_1^{q_1} + \cdots + 1) \ldots (p_r^{q_r} + \cdots + 1)(p^n + \cdots + 1)(p_{r+1}^{q_{r+1}} + \cdots + 1) \ldots (p_s^{q_s} + \cdots + 1)$$

Since $\prod_{k=1}^{r} A_k = cp^n$ holds,

$$p_{r+1}^{q_{r+1}} \times \ldots \times p_s^{q_s}p_1^{q_1} \times \ldots \times p_r^{h_r}\left(p_1^{q_1-h_1} + \cdots + 1\right) \ldots \left(p_r^{q_r-h_r} + \cdots + 1\right)(p^{n-h} + \cdots + 1) = cp^{n-h}(p^n + \cdots + 1)(p_{r+1}^{q_{r+1}} + \cdots + 1) \ldots (p_s^{q_s} + \cdots + 1)$$

When $h_k < 0(1 \leqq k \leqq r)$, multiply both sides by $p_k^{-h_k}$ so that both sides become integers. When $\prod_{k=r+1}^{s}(A_k/B_k)$ is not an integer, if both sides are divided by the prime numbers from p_{r+1} to p_s, at least one prime number among the prime numbers from p_{r+1} to p_s are left on the left side. Because c and $p^n + \cdots + 1$ are products of prime numbers from p_1 to p_r and in the case of $s > r + 1$, the left side has prime numbers that is not on the right side as a factor, this expression does not hold.

In the case of $s = r + 1$, when $p \neq p_s$, this expression does not hold in the same way. When $p = p_s$ and $q_s > n - h$, since there is a prime factor p only on the left side, this expression does not hold. Therefore, since except for the case of $s = r + 1$, $p = p_s$ and $q_s < n - h$ G_r must be uniquely expressed, the expression (E) does not hold. When $s = r + 1$, $p = p_s$ and $q_s < n - h$, substituting $B_x = p^{q_s}$ into the expression (E) as $x = r + 1$,

$$A_1 A_2 \dots A_r (p^{q_s} + \cdots + 1)({p_x}^{n_x} + \cdots + 1)/(B_1 B_2 \dots B_r p^{q_s} {p_x}^{n_x})$$
$$= A_1 A_2 \dots A_r (p^n + \cdots + 1)/(B_1 B_2 \dots B_r p^n)$$
$$(p^{q_s} + \cdots + 1)({p_x}^{n_x} + \cdots + 1)/(p^{q_s} {p_x}^{n_x}) = (p^n + \cdots + 1)/p^n$$
$$(p^{q_s} + \cdots + 1)({p_x}^{n_x} + \cdots + 1)p^{n-q_s} = (p^n + \cdots + 1){p_x}^{n_x}$$

Since the right side does not have a prime number p as a factor, this expression does not hold. From the above, when $\prod_{k=r+1}^{s}(A_k/B_k)$ is not an integer, the expression (E) does not hold.

When one point is $(a, b, p, n) = (1,1,1,1)$, since $r = 0$, that $\prod_{k=r+1}^{s}(A_k/B_k)$ is not an integer is same that the condition (D) holds. If the condition (D) holds, when $s > r + 1$ or $p \neq p_s$, $G_s \neq G_r$ holds similarly and when $s = r + 1$ and $p = p_s$ it becomes inappropriate, since prime number p_s is 1.

If the condition (D) does not hold, $v = a/b$ when $s = r$. Because the equation (A) must be satisfied at a point other than the point $(a, b, p, n) = (1,1,1,1)$, considering v becomes an integer,

$$v = a/b = 2p^n/(p^n + \cdots + 1)$$
$$2p^n = v(p^n + \cdots + 1)$$

Let w be an integer and if $v = wp^n$ holds,

$$2 = w(p^n + \cdots + 1)$$

When $p \equiv 1 \pmod 4$, $p \geqq 5$ and $n \equiv 1 \pmod 4$, $n \geqq 1$,

$$p^n + \cdots + 1 \geqq 6$$

At this time, it becomes inappropriate, since w is not an integer. Therefore, except for $(a, b, p, n) = (1,1,1,1)$, there is no solution satisfying the equation (A). From the above, there are no odd perfect numbers.

4. Complement

From the equation ⑤,

$2bp^n(p-1) = a(p^{n+1}-1)$

$2 = a(p^{n+1}-1)/(bp^n(p-1))$

$2 = (p_1{}^{q_1+1}-1)(p_2{}^{q_2+1}-1)\ldots(p_r{}^{q_r+1}-1)(p^{n+1}-1)$

$/(p_1{}^{q_1}p_2{}^{q_2}\ldots p_r{}^{q_r}p^n(p_1-1)(p_2-1)\ldots(p_r-1)(p-1))$

$2(p_1{}^{q_1+1}-p_1{}^{q_1})(p_2{}^{q_2+1}-p_2{}^{q_2})\ldots(p_r{}^{q_r+1}-p_r{}^{q_r})(p^{n+1}-p^n)$

$= (p_1{}^{q_1+1}-1)(p_2{}^{q_2+1}-1)\ldots(p_r{}^{q_r+1}-1)(p^{n+1}-1)$

We consider when $r = 2$.

$(p_1{}^{q_1+1}-1)(p_2{}^{q_2+1}-1)(p^{n+1}-1) = 2(p_1{}^{q_1+1}-p_1{}^{q_1})(p_2{}^{q_2+1}-p_2{}^{q_2})(p^{n+1}-p^n)$

Let s, t, u be integers,

$s = p_1{}^{q_1+1}-1$

$t = p_2{}^{q_2+1}-1$

$u = p^{n+1}-1$

are.

$stu = 2(p_1{}^{q_1+1}-1-(p_1{}^{q_1}-1))(p_2{}^{q_2+1}-1-(p_2{}^{q_2}-1))(p^{n+1}-1-(p^n-1))$

$stu = 2(s-(s+1)/p_1+1)(t-(t+1)/p_2+1)(u-(u+1)/p+1)$

$pp_1p_2stu = 2((s+1)p_1-(s+1))((t+1)p_2+(t+1))\big((u+1)p+(u+1)\big)$

$pp_1p_2stu = 2(s+1)(p_1-1)(t+1)(p_2-1)(u+1)(p-1)$

$stu/((s+1)(t+1)(u+1)) = 2(p_1-1)(p_2-1)(p-1)/(p_1p_2p)$

Since $stu/((s+1)(t+1)(u+1))$ is a monotonically increasing function for variables s, t and u, if

$s \geqq 3^{2+1}-1 = 26,\ p_1 = 3,\ q_1 = 2$

$t \geqq 7^{2+1}-1 = 342,\ p_2 = 7,\ q_2 = 2$

$u \geqq 5^2-1 = 24,\ p = 5,\ n = 1$

holds,

$stu/((s+1)(t+1)(u+1)) \geqq 26\times 342\times 24/(27\times 343\times 25) = 7904/8575$

$2(p_1-1)(p_2-1)(p-1)/(p_1p_2p) = 2\times 2\times 6\times 4/(3\times 7\times 5) = 32/35$

Since $stu/((s+1)(t+1)(u+1))$ is limited to 1 when s, t and u are infinite,

$stu/((s+1)(t+1)(u+1)) < 1$

If $f(p_1, p_2, p) = 2(p_1 - 1)(p_2 - 1)(p - 1)/(p_1 p_2 p)$ holds, it is sufficient to consider a combination where $f(p_1, p_2, p) < 1$.

$f(3,7,5) = 2 \times 2 \times 6 \times 4/(3 \times 7 \times 5) = 32/35$

$f(3,11,5) = 2 \times 2 \times 10 \times 4/(3 \times 11 \times 5) = 32/33$

$f(3,13,5) = 2 \times 2 \times 12 \times 4/(3 \times 13 \times 5) = 64/65$

$f(3,17,5) = 2 \times 2 \times 16 \times 4/(3 \times 17 \times 5) = 256/255$

$f(3,7,13) = 2 \times 2 \times 6 \times 12/(3 \times 7 \times 13) = 96/91$

$f(3,5,17) = 2 \times 2 \times 4 \times 16/(3 \times 5 \times 17) = 256/255$

From the above, when $r = 2$, a combination $(p_1, p_2, p) = (3,7,5), (3,11,5), (3,13,5)$ can be considered.

Let q_k be 2 and $n = 1$, if $g(p_1, p_2, p) = (p_1{}^3 - 1)(p_2{}^3 - 1)(p^2 - 1)/(p_1{}^3 p_2{}^3 p^2)$,

$g(3,7,5) = 26 \times 342 \times 24/(3^3 7^3 5^2) = 7904/8575 > 32/35$

$g(3,11,5) = 26 \times 1330 \times 24/(3^3 11^3 5^2) = 55328/59895$

$g(3,13,5) = 26 \times 2196 \times 24/(3^3 13^3 5^2) = 3904/4225$

Since the function g is the minimum in the case of $q_k = 2$ and $n = 1$, there is no solution q_k and n when $g > f$, so the case of $(p_1, p_2, p) = (3,7,5)$ becomes unsuitable.

$stu/((s + 1)(t + 1)(u + 1)) = 2(p_1 - 1)(p_2 - 1)(p - 1)/(p_1 p_2 p)$

$$(p_1{}^{q_1+1} - 1)(p_2{}^{q_2+1} - 1)(p^{n+1} - 1)/(p_1{}^{q_1+1} p_2{}^{q_2+1} p^{n+1})$$
$$= 2(p_1 - 1)(p_2 - 1)(p - 1)/(p_1 p_2 p)$$

If $F(p_1, p_2, p) = (p_1 - 1)(p_2 - 1)(p - 1)/(p_1 p_2 p)$,

$F(p_1{}^{q_1+1}, p_2{}^{q_2+1}, p^{n+1}) = 2F(p_1, p_2, p)$

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6. References

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