

# **Is There a "Simple" Proof of Fermat's Last Theorem?**

## **Part (2) Proofs of Lemmas Not Proved in Part (1)**

by

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## Appendix A — Lemma 3.0

### Lemma 3.0.

Let  $p$  be an odd prime, and let  $t$  be a positive integer. Then there exists an infinity of odd primes  $q$  such that  $(p, q - 1) = (t, q - 1) = 1$ .

### Proof<sup>1</sup>:

*First part:*

We first prove that for all  $k \geq 2$ ,  $p \cdot t$  cannot be a factor of every element of the set  $S'_k = \{q_k - 1, q_{k+1} - 1, q_{k+2} - 1, \dots\}$ , where  $q_k$  is the  $k$ th prime. This implies that there exists a  $q_{k+h}$ ,  $h \geq 0$ , such that  $(p, q_{k+h} - 1) = (t, q_{k+h} - 1) = 1$ .

1. Let the set  $S_k$  be all primes beginning with the  $k$ th. I.e.,  $S_k = \{q_k, q_{k+1}, q_{k+2}, \dots\}$ . Thus, e.g., if  $k = 5$ , then  $S_k = \{11, 13, 17, 19, \dots\}$ , and  $S'_k = \{10, 12, 16, 18, \dots\}$ .

Clearly,  $S_k$  contains all but a finite number of primes.

2. Now assume to the contrary that there exists a  $k \geq 2$  such that, for each  $h \geq 0$ ,  $q_{k+h} - 1 = m \cdot p \cdot t$ ,  $m \geq 1$ . But then  $q_{k+h} = 1 + m \cdot p \cdot t$ , and thus  $S_{k+h}$  is a subset of the set  $\{1 + v \cdot p \cdot t\}$ ,  $v \geq 1$ .

3. We recall that Dirichlet’s celebrated Theorem asserts that every arithmetic sequence  $\{a + v \cdot b\}$ ,  $(a, b) = 1$ , contains an infinity of primes. We also recall, from the theory of congruences in elementary classical number theory, that  $\{a + v \cdot b\} \cap \{a' + v \cdot b\} = \emptyset$  if  $a$  is not congruent to  $a'$  mod  $b$ .

4. Now  $\{1 + v \cdot p \cdot t\}$ ,  $v \geq 1$ , constitutes a residue class mod  $p \cdot t$ , and, clearly,  $(1, p \cdot t) = 1$ . Every prime  $q_{k+h}$ ,  $h \geq 0$ , is in this residue class, by our assumption in step 2.

But by the second statement we recalled in step 3, none of the primes  $q_{k+h}$ ,  $h \geq 0$ , can therefore be in the residue class  $\{2 + v \cdot p \cdot t\}$ ,  $v \geq 1$ . Thus, there are only a finite number of primes in this residue class. And yet, since  $(2, p \cdot t) = 1$ , Dirichlet’s Theorem requires that there be an infinite number of primes in this residue class.

Hence our assumption has led to a contradiction, and therefore there exists at least one  $q$  having the properties set forth in our lemma statement.  $\square$

*Second part:*

The fact that there exists an *infinity* of primes  $q$  having the properties set forth in our lemma statement follows directly from the fact that the first part applied to *all*  $k \geq 2$  (paragraph immediately prior to step 1). That is, the first part is true no matter how large  $k$  is — in other words, no matter how large a prime we begin with in  $S_k$ .  $\square$

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1. This proof is an edited version of a proof by Michael O’Neill. Any errors are solely our fault.

## Appendix D — Proof of Lemma 6.0

### Lemma 6.0

Let  $p$  be the smallest prime exponent in a counterexample to FLT,  $x^p + y^p = z^p$ . Then there exists a prime  $q$  such that  $(x, q) = (y, q) = (z, q) = 1$  and such that at least one of  $x, y, z > q$ .

### Proof of Lemma 6.0

1. It was known, as of 1990, that the exponent  $p$  in a counterexample must be greater than about 125,000. By Lemma 1.0 in Part (1) of this paper, on the web site occampress.com, we know that  $p < x < y < z$ .

2. “Lucas proved...in 1891:  $y, z$  have at least two prime factors.”<sup>1</sup>

Let  $P$  denote all the primes  $\leq z$ . Let the primes in  $P$  be listed in order of increasing magnitude, and let them be designated  $p_1 = 2, p_2 = 3, p_3 = 5, \dots, p_t =$  the largest prime in  $P$ . If all the primes in  $x, y, z$  do not exhaust all the primes in  $P$ , then we have our  $q$ : it is simply one of the primes in  $P$  that is not a factor of  $x, y$ , or  $z$ .

3. Therefore we must assume that  $x, y$ , and  $z$  contain all primes in  $P$ . If  $p_t$  is a factor in a product  $H$  of primes  $p_j, 2 \leq p_j \leq p_t$ , then there exists a prime  $p'$  such that  $p_t < p' < 2p_t$ , by “Bertrand’s Postulate” in Part (1) of this paper, on the web site occampress.com.. Clearly,  $p' < H$ , since all primes are  $\geq 2$ .

Thus we have our  $q$  (namely  $p'$ ) if  $p_t$  is a factor in a product  $H$ . Therefore, we must assume that  $p_t = x$ . We now ask if  $p_{t-1}$  is a factor of  $y$ . By Bertrand’s Postulate, we know that  $p_{t-1} < p_t < 2p_{t-1}$ , and that therefore there is a prime  $p''$ ,  $2p_{t-1} < p'' < 4p_{t-1}$ . So if

$$y = p_{t-1}2^k, k > 1, \text{ or if}$$

$$y = p_{t-1}2J, \text{ where } J \text{ is a single prime } \geq 3, \text{ or a product of primes } \geq 3, \text{ or if}$$

$$y = p_{t-1}K, \text{ where } K \text{ is a product of at least two odd primes,}$$

then again we have our  $q$ , namely,  $p''$ .

So, if our desired  $q$  is not to exist, it must be the case that

$$y = p_{t-1}2 \text{ or}$$

$$y = p_{t-1}3.$$

But then  $z$  contains as factors all primes in  $P$  except  $p_t, p_{t-1}$ , and 2 or 3. But this is impossible, because if  $x$  is a prime, then, as Jonquières proved<sup>2</sup> in 1884,  $z$  must equal  $y + 1$ , and since there are more than 10,000 primes less than 125,000 (by the Prime Number Theorem<sup>3</sup>),  $z$  is far

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1. Ribenboim, Paulo, *13 Lectures on Fermat’s Last Theorem*, Springer-Verlag, N.Y., 1970, p. 64.

2. *ibid.*, p. 64.

too large to equal  $y + 1$ .

Thus  $q$  exists.  $\square$

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3. This theorem asserts: if  $\pi(x)$  denotes the number of primes that do not exceed  $x$ , then  $\pi(x)$  is asymptotic to  $x/(\log x)$ .

## Appendix F — Statement and Proof of Certain Numbered Statements and of Lemmas

### (1.8): Statement and Proof

*Exactly one of  $x, y, z$  must be even.*

#### **Proof:**

By (1.5) (see under "Initial Assumptions, Definitions, and Properties of Numbers Involved" in Part (1) of this paper, on the web site [occampress.com](http://occampress.com)), neither two or three of  $x, y, z$  contains the factor 2. If none of  $x, y, z$  contains the factor 2, then we have two odd integers summing to an odd integer, which is impossible.  $\square$

### (1.85): Statement and Proof

(1.85) *It suffices to prove FLT for 4 and for every odd prime  $\geq 3$ .*

#### **Proof:**

Fermat himself proved FLT for the exponent 4. A number  $n \geq 3$  that is not a multiple of 4 must be a multiple of an odd prime. Thus if  $n = pK$ , and we prove FLT for  $p$ , then we have proved it for  $n = pK$  because we have proved that, for all  $x, y, z$

$$x^p + y^p \neq z^p$$

hence for all  $u, v, w$

$$(u^K)^p + (v^K)^p \neq (w^K)^p$$

or

$$u^n + v^n \neq w^n$$

$\square$

### (1.90) (a)

*If  $a + b, c < m$ , and  $a + b = c$ , then  $a + b \equiv c \pmod{m}$ .*

### (1.90) (b)

*If  $a + b \equiv c \pmod{m}$ , and  $a \equiv a' \pmod{m}$ , and  $b \equiv b' \pmod{m}$ , and  $c \equiv c' \pmod{m}$ , then  $a' + b' \equiv c' \pmod{m}$ .*

For inequalities:

**(1.91) (a)**

If  $(a,m) = (b,m) = (c,m) = 1$ , then if  
 $a + b, c < m$ , and  
 $a + b \neq c$ ,  
then  $a + b$  is not  $\equiv c \pmod m$ .

**(1.91) (b)**

If  $(a,m) = (b,m) = (c,m) = 1$ , and if  
 $a \equiv a' \pmod m$ , and  $b \equiv b' \pmod m$ , and  $c \equiv c' \pmod m$ , then  
if  $a + b$  is not  $\equiv c \pmod m$  then  $a' + b'$  is not  $\equiv c' \pmod m$ .

**Proof of (1.91) (b):**

If  $a \equiv a' \pmod m$ , and  $b \equiv b' \pmod m$ , and  $c \equiv c' \pmod m$ , then, by definition of congruence, this implies that there exist integers  $h, j, k$  such that  $a' = a + hm$ ,  $b' = b + jm$  and  $c' = c + km$ .

We prove the contrapositive of our statement.

Assume  $a' + b' \equiv c' \pmod m$ . Then by definition of congruence, this implies that  $a + b + (h + j - k)m = c$ , which by definition of congruence implies that  $a + b \equiv c \pmod m$ .  $\square$

**(1.91) (c)**

If  $(a,m) = (b,m) = (c,m) = 1$ , and if  
 $a \equiv a' \pmod m$ , and  $b \equiv b' \pmod m$ , and  $c \equiv c' \pmod m$ , then  
if  $a^r + b^r \equiv c^r \pmod m$ ,  $r \geq 1$ ,  
then  $a^{r'} + b^{r'} \equiv c^{r'} \pmod m$  and  
 $a^r \equiv a^{r'} \pmod m$  and  $b^r \equiv b^{r'} \pmod m$  and  $c^r \equiv c^{r'} \pmod m$ .

**Proof of (1.91) (c):**

If  $a \equiv a' \pmod m$ , and  $b \equiv b' \pmod m$ , and  $c \equiv c' \pmod m$ , then, by definition of congruence, this implies that there exist integers  $h, j, k$  such that  $a' = a + hm$ ,  $b' = b + jm$  and  $c' = c + km$ . Therefore  $a = a' - hm$ ,  $b = b' - jm$  and  $c = c' - km$ , or,  $a = a' + h'm$ ,  $b = b' + j'm$  and  $c = c' + k'm$ .

Then  $a^r + b^r \equiv c^r \pmod m$  implies  $(a' + h'm)^r + (b' + j'm)^r \equiv (c' + k'm)^r \pmod m$ .

By the binomial theorem, this yields:

$(a'^r + (Hm)) + (b'^r + (Jm)) \equiv (c'^r + (Km)) \pmod m$ , or, since  $m \equiv 0 \pmod m$ ,  
 $a'^r + b'^r \equiv c'^r \pmod m$ .  $\square$

**(1.91) (d)**

If  $a + b$  is not  $\equiv c \pmod m$ , then  $a + b \neq c$ .

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In addition, we will need Fermat's Little Theorem, which states:\

**(1.92) (Fermat's Little Theorem)**

If  $q$  is a prime and  $(a, q) = 1$  then  $a^{q-1} \equiv 1 \pmod q$ .

Multiplying both sides of the congruence in (1.92) repeatedly by  $a$  yields

$$\begin{aligned} a^{(q-1)+1} &\equiv a \pmod{q}, \\ a^{(q-1)+2} &\equiv a^2 \pmod{q}, \\ a^{(q-1)+3} &\equiv a^3 \pmod{q}, \\ &\dots \end{aligned}$$

In other words, powers of  $a$  are congruent mod  $(q - 1)$ . Thus  $(q - 1)$  is a modulus that defines a set of  $(q - 1)$  congruence classes.

We will also need Euler’s generalization of Fermat’s Little Theorem:

**(1.93)**

If  $(a, m) = 1$  then  $a^{\phi(m)} \equiv 1 \pmod{m}$ , where  $\phi$  denotes Euler’s totient function.  $\phi(m)$  is the number of numbers  $n < m$  such that  $(n, m) = 1$ .

Multiplying both sides of the congruence in (1.92) repeatedly by  $a$  yields

$$\begin{aligned} a^{\phi(m)} &\equiv 1 \pmod{m}, \\ a^{\phi(m)+1} &\equiv a \pmod{m} \\ a^{\phi(m)+2} &\equiv a^2 \pmod{m} \\ &\dots \\ a^{2\phi(m)} &\equiv a^{\phi(m)} \pmod{m} \\ &\dots \end{aligned}$$

In other words, powers of  $a$  are congruent mod  $\phi(m)$ . Thus  $\phi(m)$  is a modulus that defines a set of  $\phi(m)$  congruence classes.

**(1.94)**

If  $a + b \equiv c \pmod{q^k}$ ,  $k \geq 2$ ,  
Then  $a + b \equiv c \pmod{q^{k-j}}$ ,  $1 \leq j < k$ .

**Proof of (1.94):**

By definition of congruence, if  $a + b \equiv c \pmod{q^k}$ ,  $k \geq 2$ , then there exists an  $h \geq 1$  such that  $a + b + hq^k = c$ . But then  $a + b + (hq^j)q^{k-j} = c$ , hence  $a + b \equiv c \pmod{q^{k-j}}$ .  $\square$

**(1.95)**

If  $(k, m) = d$   
Then the congruence  $ka \equiv b \pmod{m}$  is soluble iff  $d$  divides  $b$ .

**Proof of (1.95):**

See any textbook on elementary congruence theory.

**Lemma 0.0: Statement and Proof**

If  $x^p + y^p = z^p$ , then  $x + y > z$ .

**Proof.**

Assume the contrary, i.e., that  $x + y \leq z$ . Then, in the case that  $x + y = z$ ,  $(x + y)^p = z^p$ . By the binomial theorem, this implies that:

$$x^p + \binom{p}{1}x^{p-1}y + \dots + \binom{p}{p-1}xy^{p-1} + y^p = z^p$$

Clearly, the equation cannot hold if  $x^p + y^p = z^p$ . A similar argument applies if  $x + y < z$ .  $\square$

**Lemma 0.2: Statement and Proof**

If  $x^p + y^p = z^p$ , then:

- (a)  $x + y - z = Kdef$ , where  $K \geq 1, d, e, f > 1$ ;
  - (b)  $Kdef$  contains the factors 2 and  $p$ ;
  - (c)  $d$  is a factor of  $x$ ;  
 $e$  is a factor of  $y$ ;  
 $f$  is a factor of  $z$ ;
  - (d)  $(d, e, f) = 1$ ;
  - (e) if  $x^k + y^k - z^k \equiv 0 \pmod k$ , where  $k$  is a prime,  $3 \leq k < p$ , then  $Kdef$  contains a factor  $k$ .
- (e)  $p < (1/30)(x)$ . Thus, prior to Wiles’ proof of FLT, the smallest  $x$  in a counterexample was at least 3,750,000.

**Proof of Lemma 0.2 (a):**

See “Approach via Factors of  $x, y, z$ ” in Part (1) of this paper, on the web site [occam-press.com](http://occam-press.com).

**Proof of Lemma 0.2 (b):**

Since exactly one of  $x, y, z$  is a multiple of 2, the other two being odd, positive numbers,  $x + y - z$  must be a multiple of 2.

A basic result<sup>1</sup> of congruence theory states:

If  $k$  is an odd prime, then  $(a + b + c + \dots + g)^k \equiv a^k + b^k + c^k + \dots + g^k \pmod k$ .

Let  $a = x, b = y, c = -z$ . Then we have:

$$(x + y - z)^k \equiv x^k + y^k - z^k \pmod k, \text{ where } 3 \leq k \leq p. \tag{1}$$

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1. See, for example, Gauss’s *Disquisitiones Arithmeticae*, Article 51.



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By assumption  $x^p + y^p = z^p$ , so  $x^p + y^p - z^p = 0$  and hence, by (1),

$$(x + y - z)^p \equiv 0 \pmod{p}.$$

Since we know that  $x + y - z \neq 0$  (“Lemma 0.0” in Part (1) of this paper, on the web site [occampress.com](http://occampress.com).), we conclude that  $x + y - z$  is a non-zero multiple of  $p$ .  $\square$

**Proof of Lemma 0.2 (c):**

See “Approach via Factors of  $x, y, z$ ” in Part (1) of this paper, on the web site [occampress.com](http://occampress.com).

**Proof of Lemma 0.2 (d):**

By the basic result cited in the proof of part (b), we know that

$$(x + y - z)^k \equiv x^k + y^k - z^k \pmod{k}, \text{ where } 3 \leq k \leq p.$$

By part (a),  $(x + y - z) = Kdef$ . Therefore

$$(x + y - z)^k = (Kdef)^k \equiv x^k + y^k - z^k \pmod{k}. \tag{1}$$

It is not possible, by our assumption that  $p$  is the smallest prime in a counterexample, that  $x^k + y^k - z^k = 0$  if  $3 \leq k < p$ . Hence if  $x^k + y^k - z^k \equiv 0 \pmod{k}$ , it must be the case that  $x^k + y^k - z^k$  is a non-zero multiple of  $k$ . The result follows from (1).  $\square$

**Proof of Lemma 0.2 (e):**

By parts (a), (b), and (c) of this Lemma,  $x + y - z = Kdef$ , where  $K$  contains the factors 2 and  $p$ ,  $d, e, f > 1$ ,  $d, e, f$  are relatively prime, and  $d$  is a factor of  $x$ ,  $e$  is a factor of  $y$ , and  $f$  is a factor of  $z$ . By part (b) of “Lemma 1.5.” in Part (1) of this paper, on the web site [occampress.com](http://occampress.com),  $x + y - z < x$ . Since  $d, e$ , and  $f$  are each greater than 1 and are relatively prime factors of  $x, y$ , and  $z$ , and since one of  $d, e, f$  might be the factor 2 in  $K$ , we have  $Kdef \geq p(2)(3)(5) < x$ , hence  $p < (1/30)(x)$ . Prior to Wiles’ proof it was known that  $p$  was greater than 125,000. Hence, the smallest value of  $x$  was at least 1,375,000.  $\square$

**Proof of Lemma 0.2 (f):**

Follows directly, by definition of congruence, from parts (a) and (b).

**Lemma 0.3: Lemma and Proof**

*If  $k$  is an odd prime, then  $(x + y - z)^k \equiv x^k + y^k - z^k \pmod{k}$ .*

**Proof:** The Lemma is a specific case of the basic result<sup>1</sup>,

If  $k$  is an odd prime, then  $(a + b + c + \dots + g)^k \equiv a^k + b^k + c^k + \dots + g^k \pmod k$ .  $\square$

**Lemma 0.5: Statement and Proof**

If  $x^2 + y^2 = z^2$ , then  $x, y, z$  cannot be elements of a counterexample.

**Proof:**

1. Let  $x^2 + y^2 = z^2$ .
2. Raise both sides of this equation to the power  $p/2$ . We get:

$$(x^2 + y^2)^{p/2} = x^p + K + y^p = (z^2)^{p/2} = z^p$$

Clearly,  $x^p + y^p < z^p$ .  $\square$

**Lemma 0.6: Statement and Proof**

If FLT is true for the exponent  $n$ , then it is true for all multiples of  $n$ .

**Proof:**

If  $x^n + y^n \neq z^n$  for all  $x, y, z$ , then certainly  $(u^k)^n + (v^k)^n \neq (w^k)^n$ , for all  $u, v, w, k \geq 1$ .  $\square$

**Lemma 1.0: Statement and Proof**

- (a)  $p < x < y < z$ .
- (b)  $z < x + y < 2y < 2z$ .

**Proof of Lemma 1.0 (a):**

We quote from Ribenboim, Paulo, *13 Lectures on Fermat’s Last Theorem*, Springer-Verlag, N.Y., 1979, p. 226.

“In 1856, Grünert proved:

“(1A) If  $0 < x < y < z$  are integers and  $x^n + y^n = z^n$ , then  $x > n$ .

“Proof:

“ $x^n = z^n - y^n = (z - y)(z^{n-1} + z^{n-2}y + \dots + y^{n-1}) > (z - y)ny^{n-1}$ .

“Hence

$$0 < (z - y) < \frac{x^n}{ny^{n-1}} < \frac{x}{n}$$

“and

1. See, for example, Gauss’s *Disquisitiones Arithmeticae*, Article 51.

$$y + 1 \leq z < y + \frac{x}{n}$$

“so  $n < x$ .”  $\square$

**Proof of Lemma 1.0 (b):**

$z < x + y$  by part (a) of Lemma 1.5, below;

$x + y < 2y$  by part (a) of this Lemma;

$2y < 2z$  by part (a) of this Lemma.  $\square$

**Lemma 1.5: Statement and Proof**

Let  $x, y, z, p$  be elements of the minimum counterexample. Then for all  $k, 1 \leq k < p$ ,  $k$  real and not merely integral:

- (a)  $x^k + y^k > z^k$ , i.e.,  $x^k + y^k - z^k > 0$ ; <sup>1, 2</sup>
- (b)  $x^k + y^k - z^k < x^k$ ;
- (c)  $x^k + y^k$  increases monotonically with increasing  $k$ ;
- (d)  $z^k$  increases monotonically with increasing  $k$ ;
- (e)  $(x^k + y^k)/z^k > (x^{k+1} + y^{k+1})/z^{k+1}$ .
- (f) Let  $f(k) = x^k + y^k - z^k$ . Then the slope of  $f$ , namely,  $x^k(\ln x) + y^k(\ln y) - z^k(\ln z)$ , is positive for all  $k$ , where  $1 \leq k < p - 1$ ,  $k$  real and not merely integral. Thus  $x^k + y^k - z^k < x^{k+1} + y^{k+1} - z^{k+1}$  for integral  $k, 1 \leq k \leq p - 2$ .
- (g)  $x^k + y^k - z^k \geq Kdef + k - 1$ , where here  $k$  is integral and  $Kdef$  are as defined in “Lemma 0.2” in Part (1) of this paper, on the web site occampress.com. Hence, in particular, since the maximum of the function  $x^k + y^k - z^k$  occurs at  $p - 1 \leq k < p$ , it has value  $\geq Kdef + p - 2$ .
- (h)  $x^k < y^k < z^k < x^k + y^k < 2y^k < 2z^k$ .
- (i) Let  $f(k)$  be as defined in Part (f). Then  $f(k + 1) < f(k)$  for all  $k > p$ .
- (j) If  $k \neq k'$ , then  $f(k) \neq f(k')$ .

**Remark:** Parts (b) and (g) imply that  $Kdef + k - 1 \leq x^k + y^k - z^k < x^k$ . This in turn implies that  $x^k + y^k - z^k$  increases by 1 with each incremental increase in  $k$ , which is definitely surprising.

*Note:* The proofs of parts (a), (c), (d), and (e) are Ed Boyda’s improvements of our clumsy originals. Any errors in these proofs are due to our faulty transcriptions. The proof of part (f) is entirely Boyda’s, but, again, any errors are due to our faulty transcription.

**Proof of Lemma 1.5 (a)**

By assumption of a counterexample,  $x^p + y^p = z^p$ . Then since  $z > x, y$ , for  $a$  such that  $p > a >$

1. Students of the phenomenon of mathematical intuition might be interested to know that from the moment we realized that, if a counterexample  $x^p + y^p = z^p$  exists, then  $x + y$  must be greater than  $z$ , we were convinced this would be part of a “simple” proof of FLT if we were able to discover one. We have no explanation for this conviction, nor do we claim that this conviction will be vindicated.

2. Part (a) shows that no Pythagorean triple, i.e., no  $x, y, z$  such that  $x^2 + y^2 = z^2$ , can be elements of a counterexample.

0, where  $a$  is real:

$$z^a (x^{(p-a)} + y^{(p-a)}) = z^a x^{(p-a)} + z^a y^{(p-a)} = u^a x^a x^{(p-a)} + v^a y^a y^{(p-a)}, \text{ where } z^a = u^a x^a = v^a y^a.$$

Thus  $z^a (x^{(p-a)} + y^{(p-a)}) = u^a x^p + v^a y^p$ , which is certainly greater than  $x^p + y^p$  and therefore, by our assumption that  $x^p + y^p = z^p$ , is greater than  $z^p$ . That is,

$$z^a (x^{(p-a)} + y^{(p-a)}) > z^p. \text{ Hence, dividing both sides by } z^a, \text{ we get}$$

$$x^{(p-a)} + y^{(p-a)} > z^{(p-a)}. \quad \square$$

**Proof of Lemma 1.5 (b)**

Assume, to the contrary, that  $x^k + y^k - z^k \geq x^k$ ,  $1 \leq k \leq p-1$ . Then  $y^k - z^k \geq 0$ , which is a contradiction, since  $y < z$   $\square$

**Proof of Lemma 1.5 (c)**

Follows directly from a known property of the exponentiation function, and the fact that  $x, y, k$  are positive integers, and  $x, y$  are fixed.  $\square$

**Proof of Lemma 1.5 (d)**

Follows directly from a known property of the exponentiation function, and the fact that  $z, k$  are positive integers, and  $z$  is fixed.  $\square$

**Proof of Lemma 1.5 (e)**

For  $a, b$ , such that  $0 < a < b < p$ :

$$\begin{aligned} (x^p + y^p)/z^p &< z^a (x^{(p-a)} + y^{(p-a)})/z^p = \\ (x^{(p-a)} + y^{(p-a)})/z^{(p-a)} &< \\ z^b (x^{(p-b)} + y^{(p-b)})/z^p &= \\ (x^{(p-b)} + y^{(p-b)})/z^{(p-b)}. &\quad \square \end{aligned}$$

**Proof of Lemma 1.5 (f)**

1. We begin by asserting that:

(1)

$$\frac{(x^k)\left(\frac{x}{y}\right) + y^k}{z^k} > \frac{z}{y} > \frac{\ln z}{\ln y}$$

*Is There a “Simple” Proof of Fermat’s Last Theorem? Part (2)*

*Proof:*

1.1 We can rewrite (1) as:  
(2)

$$\frac{x^{k+1} + y^{k+1}}{y} > \frac{z}{y} > \frac{\ln z}{\ln y}$$

1.2 By part (a) of this Lemma, we know that  $x^{k+1} + y^{k+1} > z^{k+1}$  and thus we get the left-hand inequality of (2), hence of (1).

1.3 For all  $u, v > e$  (the base of the natural logarithms), if  $u < v$  then  $(\ln u)/u > (\ln v)/v$ .

*Proof:*

We show that, for all  $w > e$ , the base of the natural logarithms, the derivative of  $(\ln w)/w$  is negative.

By the basic rule for the derivative of a fraction,

$$\frac{d\left(\frac{\ln w}{w}\right)}{dw} = \frac{w\left(\frac{d(\ln w)}{dw}\right) - (\ln w)\left(\frac{dw}{dw}\right)}{w^2} = \frac{w\left(\frac{1}{w}\right) - (\ln w)}{w^2} = \frac{1 - (\ln w)}{w^2}$$

The rightmost term is negative because the natural logarithm of all  $w > 3$  is  $> 1$ .  $\square$

1.4 Therefore, since  $e < y < z$ , it follows that  $(\ln y)/y > (\ln z)/z$ , hence  $z/y > (\ln z)/(\ln y)$ , and we have the left-hand inequality and the right-hand inequality of (2), hence of (1).  $\square$

2. In (1), cross-multiply  $z^k$  in the denominator of the left-hand term, with  $\ln z$  in the numerator of the right-hand term, yielding  $z^k (\ln z)$  in the numerator of the right-hand term.

In (1), cross-multiply  $\ln y$  in the denominator of the right-hand term with the numerator of the left-hand term, yielding

$$(x^k)(x (\ln y)/y) + y^k (\ln y)$$

But since, by step 1.3,  $y/x > \ln y/\ln x$ ,  $\ln x > (x(\ln y))/y$ , and so, from what we have established in this step, we can write

$$(x^k)(\ln x) + y^k (\ln y) > z^k (\ln z), \text{ which implies that}$$

$$(x^k)(\ln x) + y^k (\ln y) - z^k (\ln z) > 0, \text{ which is the desired result. } \square$$

**Proof of Lemma 1.5 (g)**

By part (f) of this Lemma,  $x^k + y^k - z^k < x^{k+1} + y^{k+1} - z^{k+1}$  for all  $k, 1 \leq k \leq p-2$ . Since, by "Lemma 0.2" in Part (1) of this paper, on the web site [occampress.com](http://occampress.com),  $x + y - z = Kdef$ , the result follows.  $\square$

**Proof of Lemma 1.5 (h)**

Since by "Lemma 1.0." in Part (1) of this paper, on the web site [occampress.com](http://occampress.com),  $x < y < z$ , it must be that  $x^k < y^k < x^k + y^k < 2y^k < 2z^k$ . That  $z^k < x^k + y^k$  is established by part (a) of this Lemma.  $\square$

**Proof of Lemma 1.5 (i)**

We know that  $U(k, x, y, z)$  is negative for all  $k > p$  (Lemma 1.95 in Part (1) of this paper, on [occampress.com](http://occampress.com)). Now if  $x^k + y^k - z^k < 0$ , then multiplying both sides of the inequality by  $\ln z$ , a positive number, we get  $x^k(\ln z) + y^k(\ln z) - z^k(\ln z) < 0$ . Since  $x < y < z$ ,  $\ln x$  and  $\ln y$  (both positive numbers) are each less than  $\ln z$ . And so we can write  $x^k(\ln x) + y^k(\ln y) - z^k(\ln z) < 0$ . But the left-hand side of this inequality is the derivative of the function  $x^k + y^k - z^k$ , and so, since the derivative is always negative, we can conclude that  $x^{k+1} + y^{k+1} - z^{k+1} < x^k + y^k - z^k$  for all  $k \geq p$ .

**Proof of Lemma 1.5 (j)**

Follows directly from Parts (f) and (i).

**Lemma 1.95. Statement and Proof**

Let  $x, y, z$ , be elements of the minimum counterexample  $x^p + y^p = z^p$ . Then for all  $k > p$ ,  $x^k + y^k < z^k$ .

**Proof of Lemma 1.95:**

1. We use proof by induction.

*Basis step*

1. Assume that

$$(1) x^p + y^p = z^p .$$

2. Then

$$(x^p + y^p)^{(p+1)/p} = ((z^p)^{(p+1)/p} = z^{p+1} ) .$$

3. But then it must be the case that

$$x^{p+1} + y^{p+1} < z^{p+1} .$$

*Inductive step*

4. Assume that for all  $j, p < j \leq k, x^j + y^j < z^j$ .

2. Then

$$(x^k + y^k)^{(k+1)/k} < ((z^k)^{(k+1)/k}) = z^{k+1}.$$

3. But then it must certainly be the case that

$$x^{k+1} + y^{k+1} < z^{k+1}. \quad \square$$

We can establish more regarding the ratios

$$\frac{x^k + y^k}{z^k}$$

when  $k > p = n + 1$  as will be seen in the next lemma.

**Lemma 1.97<sup>1</sup>: Statement and Proof**

Let  $x, y, z$ , be elements of a counterexample  $x^{(p=n+1)} + y^{(p=n+1)} = z^{(p=n+1)}$  to FLT, where  $p = n + 1$  is the smallest such exponent. Then

$$\lim_{k \rightarrow \infty} \frac{x^k + y^k}{z^k} = 0$$

**First (and Simplest) Proof of Lemma 1.97:**

1. By Lemma 1.0,  $x < y < z$ .

2. Therefore  $(x/z)^k$  can be made arbitrarily small for sufficiently large  $k$ , and similarly for  $(y/z)^k$ . Thus

$$\lim_{k \rightarrow \infty} \left( \frac{x^k}{z^k} + \frac{y^k}{z^k} = \frac{x^k + y^k}{z^k} \right) = 0$$

□

1. A young mathematician has written us that Lemma 1.97 “bears a major resemblance to what is known as the ABC Conjecture, ... a long unsolved problem in additive number theory... The ABC Conjecture almost proves FLT in the sense that if ABC is true, then for all  $n$  sufficiently large,  $x^n + y^n = z^n$  has no integer solutions. See for instance [mathworld.wolfram.com/abcconjecture.html](http://mathworld.wolfram.com/abcconjecture.html).”

**Second Proof of Lemma 1.97:**

1. If we can prove that

$$\lim_{k \rightarrow \infty} \frac{y^k + y^k}{(y + 1)^k} = \left( \lim_{k \rightarrow \infty} \frac{2y^k}{y^k + \binom{k}{1}y^{k-1} + \binom{k}{2}y^{k-2} + \dots + \binom{k}{k}} \right) = 0$$

we will have our proof of the Lemma, since the leftmost term in the leftmost equation above, in which  $x = y$ , and  $z = (y + 1)$ , is the most unfavorable case for our Lemma.

2. The first term in the denominator on the right-hand side of the leftmost equation is always  $y^k$ .

The coefficient of the second term, as is well-known, increases with increasing  $k$ , so eventually a  $k$  will be reached such that the coefficient is  $\geq y$  and will remain  $\geq y$  for all larger  $k$ .

So then the denominator is  $\geq 2y^k$  and remains so for all larger  $k$ .

But eventually a  $k$  will be reached such that the coefficient of the second term is  $\geq 2y$  and will remain  $\geq 2y$  for all larger  $k$ .

So then the denominator is  $\geq 3y^k$  and remains so for all larger  $k$ .

Etc. The result follows.  $\square$

**Remark on Second Proof**

The rate of convergence is actually faster than the above proof indicates, since we can include more terms in step 2. Thus, e.g., in the case of the coefficient of the third term, eventually an  $n$  will be reached such that the coefficient is  $\geq y^2$  and will remain  $\geq y^2$  for all larger  $k$ . Etc.

**Lemma 2.0. Statement and Proof**

$z < 2y$ .

**Proof of Lemma 2.0.**

$x^n + y^n < 2y^n < (2y)^n$ , so  $z$  cannot be  $\geq 2y$ .  $\square$

**Lemma 3.0. Statement and Proof**

See “Appendix A — Lemma 3.0” in.

**Lemma 4.0. Statement and Proof**

*Assume a counterexample  $x^p + y^p = z^p$  exists. Then  $p$  cannot be a member of a certain infinite set*



of primes.

**Proof of Lemma 4.0**

1. Assume a counterexample  $x^p + y^p = z^p$  exists. By “Definition of ‘Minimum Counterexample’” in Part (1) of this paper, on the web site [occampress.com](http://occampress.com),  $p$  is the smallest such prime.

2. As proved under “Lemma 0.0: Statement and Proof” in, it is not possible that  $x + y = z$ .

3. Let  $q$  be a prime such that  $(x, q) = (y, q) = (z, q) = 1$  and  $x + y, z < q$ . Such a prime must exist because there are an infinite number of primes and only a finite number of prime factors, total, in  $x, y,$  and  $z$ .

4. By (1.92),  $(q - 1)$  defines a set of  $(q - 1)$  residue classes mod  $(q - 1)$ . For the class whose minimum element is 1, we have, by step 2,

$$(1.95) \quad x^{1+k(q-1)} + y^{1+k(q-1)} \text{ is not } \equiv z^{1+k(q-1)} \pmod{q},$$

where  $k \geq 0$ .

5. Dirichlet’s celebrated Theorem states that the infinite series  $\{a + v b\}, (a, b) = 1, v \geq 0$ , contains an infinity of primes, and since  $(1, (q - 1)) = 1$ , this means that for an infinity of  $k$  in (1.95),  $1 + k(q - 1)$  is prime. By (1.95) and (1.91) (c),  $p$  cannot be one of these primes.  $\square$

We see here how the fact (which followed from our assumption of a counterexample) that

$$x + y \neq z$$

and the fact that there exists a prime  $q$  such that  $x + y$  and  $z$  are both less than  $q$ , led to an infinity of facts, namely the non-congruences expressed by (1.95), which in turn gave us another infinity of facts, namely, that the prime  $p$  in the assumed counterexample could not be one of the infinity of primes required by Dirichlet’s Theorem.

A young mathematician stated and proved the following, stronger version of Lemma 4.0. (The proof given here is a slightly edited version of the original. Any errors are entirely our responsibility.)

**Lemma 4.0.5: Statement and Proof**

*Assume a counterexample  $x^p + y^p = z^p$  exists. Then  $p$  can be at most one prime  $p$ .*

**First Proof of Lemma 4.0.5**

We will be using the fact that for positive numbers  $a$  and  $b$  and an exponent  $r > 1: a^r + b^r < (a + b)^r$ .

1. Let us assume there are *two* primes  $p < q$  for which:

$$x^p + y^p = z^p;$$

$$x^q + y^q = z^q.$$

2. Let  $(r = q/p) > 1$ . By the above fact, with  $x^p$  and  $y^p$  playing the role of  $a$  and  $b$ :

$$x^q + y^q = (x^p)^r + (y^p)^r < (x^p + y^p)^r = (z^p)^r = z^q = x^q + y^q,$$

which is a contradiction. Therefore there cannot be two  $p$  which yield counterexamples for given  $x, y, z$ .  $\square$

### Second Proof of Lemma 4.0.5:

“The Fermat curves  $C_m: X^m + Y^m = 1$  intersect trivially.” (A reader)  $\square$

### Lemma 6.0. Statement and Proof

See “Appendix D — Proof of Lemma 6.0” in.

### Lemma 10.0: Statement and Proof

Let  $u, v, w$  each be less than  $m$ , and let  $(u, m) = (v, m) = (w, m) = 1$ . If for all  $j$ , where  $1 \leq j \leq \varphi(m)$ ,  $C_{u, v, w, j, m}$  is non-congruent, then  $\langle x^p + y^p, z^p \rangle$  is not an element of the  $\mathbf{C}$ -set.

#### Proof:

The exponent  $p$  must be congruent to a  $j$  in the range  $1 \leq j \leq \varphi(m)$ . But the element  $\langle x^p + y^p, z^p \rangle$  must be congruent, whereas, by hypothesis each  $C_{u, v, w, j, m}$  is non-congruent, and therefore can contain no counterexample element.  $\square$

### Lemma 12.0: Statement and Proof

Let  $q$  be an odd prime such that  $(x, q) = (y, q) = (z, q) = 1$ , and  $x, y, z > q$  (see “Lemma 30.0: Statement and Proof” in). Let  $k \geq 1$ . Let  $\mathbf{K}$  be the set of all  $\mathbf{C}$ -sets mod  $q^k$  such that  $1 \leq j \leq \varphi(q^k)$ , where  $j$  is the exponent of terms in the base element. In other words,  $\mathbf{K}$  contains all  $\mathbf{C}$ -sets mod  $q^k$ . Let  $\mathbf{K}'$  be the subset of  $\mathbf{K}$  consisting of all  $\mathbf{C}$ -sets such that  $1 \leq j \leq k$ . Then each  $\mathbf{C}$ -set in  $\mathbf{K}'$  is non-congruent.

#### Proof:

We know that if  $x^j + y^j$  and  $z^j$  are each less than  $q^k$  then  $x^j + y^j \neq z^j$ . Hence the  $\mathbf{C}$ -set of which  $x^j + y^j$  and  $z^j$  constitute the base element must be a non-congruent  $\mathbf{C}$ -set and can contain no counterexample element.

If  $x^j + y^j \equiv z^j \pmod{q^k}$  then by definition of congruence, there exists an  $h$  such that  $x^j + y^j + hq^k = z^j$ , where  $h \neq 0$ . (It is not possible that  $h = 0$  because we are assuming that  $p$  is greater than  $\varphi(q^k)$  and all our  $j$ 's are less than  $\varphi(q^k)$  (step 1).)

We know that  $x^j + y^j > z^j$  and  $x^j + y^j - z^j < x^j$  ( see Lemma 1.5 in Part (1) of this paper, on the web site [occampress.com](http://occampress.com)) so  $z^j < x^j + y^j < z^j + x^j$ . Thus the difference between  $z^j$  and  $x^j + y^j$  is less than  $x^j$ . But by our assumption regarding  $q$  in step 1,  $x^i < q^i$  for all  $i \geq 1$ . Therefore, in particular,  $x^k < q^k$ . And thus there does not exist an  $h \neq 0$  such that  $x^j + y^j + hq^k = z^j$ . Thus (1) is proved.

**Lemma 30.0: Statement and Proof**

*There exists a prime  $q$ , hence a smallest prime  $q$ , such that  $(x, q) = (y, q) = (z, q) = 1$  and such that at least one of  $x, y, z$  is greater than  $q$ , and therefore such that our assumed minimum counterexample  $x^p + y^p = z^p > q$ .*

We provide four proofs. In the first, we prove that the desired prime  $q$  is less than  $y$ , which, by Lemma 1.0 in Part (1) of this paper, on the web site [occampress.com](http://occampress.com), is less than  $z$ .

**First Proof**

1. We know that  $x$  is the product of one or more primes. If there is a prime  $q < x$  that is relatively prime to  $x, y,$  and  $z$ , then we are done:  $q$  is the desired modulus.

2. So assume that at least one prime less than  $x$  and relatively prime to  $x$  is a factor of  $y$  or  $z$ . A basic result of number theory states that each of the primes that are factors of  $y$  is less than or equal to  $\sqrt{y}$ . If we can prove that there is a prime  $q$  such that

(1)

$$\sqrt{y} < \sqrt{z} < q < 2 \cdot \sqrt{z} < y.$$

then we will have our desired  $q$ . For by Bertrand’s Postulate, which states that for all positive integers  $n$ , there exists a prime between  $n$  and  $2n$ , we know that there is a prime  $q$  between  $\sqrt{z}$  and  $2 \cdot \sqrt{z}$  (we take the smallest integer greater than or equal to  $\sqrt{z}$  as the value of  $\sqrt{z}$ , since the Postulate is stated for integers only). Since  $\sqrt{y} < \sqrt{z} < q$  we know that  $q$  cannot be a factor of either  $y$  or  $z$ .

3. We now must prove that  $2 \cdot \sqrt{z} < y$ . By part (b) of Lemma 1.0 in Part (1) of this paper, on the web site [occampress.com](http://occampress.com), we know that  $z < 2y$ . Therefore  $z/2 < y$ . So we must prove that  $2 \cdot \sqrt{z} < z/2$ , or that

(2)

$$4 \cdot \sqrt{z} < z.$$

It is easy to show that (2) is true for all  $z > 16$ . We must therefore show that no counterexample can exist if  $z \leq 16$ . Since, by part (a) of Lemma 1.0 in Part (1) of this paper, on the web site [occampress.com](http://occampress.com),  $p < x < y < z$ , we could easily test each possibility for a counterexample. But this is unnecessary, since long before Wiles’ proof it was known that  $p > 125,000$ .

Thus we have proved that (1) holds, and we have our result.  $\square$

**Second Proof**

1. "Lucas proved...in 1891:  $y, z$  have at least two prime factors."<sup>1</sup> We assume this means that  $y, z$  each have at least two prime factors.

Let  $P$  denote all the primes  $\leq z$ . Let the primes in  $P$  be listed in order of increasing magnitude, and let them be designated  $p_1 = 2, p_2 = 3, p_3 = 5, \dots, p_t =$  the largest prime in  $P$ . If all the primes in  $x, y, z$  do not exhaust all the primes in  $P$ , then we have our  $q$ : it is simply the smallest prime in  $P$  that is not a factor of  $x, y$ , or  $z$ .

2. Therefore we must assume that  $x, y$ , and  $z$  contain all primes in  $P$ . If  $p_t$  is a factor in a product  $H$  of two or more primes  $p_j$ , where  $2 \leq p_j \leq p_t$ , then there exists a prime  $p'$  such that  $p_t < p' < 2p_t$ , by "Bertrand's Postulate" in Part (1) of this paper, on the web site [occampress.com](http://occampress.com). Clearly,  $p' < H$ , since all primes are  $\geq 2$ .

Thus we have our  $q$  (namely  $p'$ ) if  $p_t$  is a factor in a product  $H$ . Therefore, we must assume that  $p_t = x$ . We now ask if  $p_{t-1}$  is a factor of  $y$ . By Bertrand's Postulate, we know that  $p_{t-1} < p_t < 2p_{t-1}$ , and that therefore there is a prime  $p''$ ,  $2p_{t-1} < p'' < 4p_{t-1}$ . So if

$$y = p_{t-1}2^k, k > 1, \text{ or if}$$

$$y = p_{t-1}2J, \text{ where } J \text{ is a single prime } \geq 3, \text{ or a product of primes } \geq 3, \text{ or if}$$

$$y = p_{t-1}K, \text{ where } K \text{ is a product of at least two odd primes,}$$

then again we have our  $q$ , namely,  $p''$ .

So, if our desired  $q$  is not to exist, it must be the case that

$$y = p_{t-1}2 \text{ or}$$

$$y = p_{t-1}3.$$

But then  $z$  contains as factors all primes in  $P$  except  $p_t, p_{t-1}$ , and 2 or 3. But this is impossible, because if  $x$  is a prime, then, as Jonquières proved<sup>2</sup> in 1884,  $z$  must equal  $y + 1$ .

It was known, as of 1990, that the exponent  $p$  in a counterexample must be greater than about 125,000. By Lemma 1.0 in Part (1) of this paper, on the web site [occampress.com](http://occampress.com), we know that  $p < x < y < z$ .

Since by the Prime Number Theorem<sup>3</sup> there are more than 10,000 primes less than 125,000, and all of these must be factors of  $z$  by step 3, it is clear that  $z$  is far too large to equal  $y + 1$ . Thus  $q$  exists.  $\square$

1. Ribenboim, Paulo, *13 Lectures on Fermat's Last Theorem*, Springer-Verlag, N.Y., 1970, p. 64.

2. *ibid.*, p. 64.

3. This theorem asserts: if  $\pi(x)$  denotes the number of primes that do not exceed  $x$ , then  $\pi(x)$  is asymptotic to  $x/(\log x)$ .

### Third Proof

The above proof uses several results that were almost certainly unknown to Fermat. The question arises, Is there a proof of the Lemma that requires fewer of these results? The following proof requires only Bertrand's Postulate and Lemma 1.0 in Part (1) of this paper, on the web site occampress.com, which states that  $p < x < y < z$ . The Postulate was only proved in the 19th century (by Tschebyschef)<sup>1</sup> and requires a quite sophisticated argument. So the proof was probably unknown to Fermat. On the other hand he might have assumed the Postulate was true based on his own empirical results. (Bertrand verified the Postulate for  $n = 2$  to  $n = 6,000,000$  before it was proved for all  $n$ .<sup>2</sup>)

Lemma 1.0 is easy to prove, as the reader can see by looking at the proof in this Appendix, so we can reasonably assume that Fermat had a proof if in fact he used this Lemma.

1. Let  $P$  = the set of all primes that are factors of  $x$ ,  $y$ , and  $z$  and assume that  $P$  consists of the first  $t$  primes, where  $t \geq 1$ . Furthermore assume that  $P$  contains all primes  $\leq z$ . (Otherwise, if  $P$  did not contain one or more primes  $\leq z$ , the least of these would be our desired prime  $q$ .) Let the primes in  $P$  be designated  $p_1 = 2, p_2 = 3, p_3 = 5, \dots, p_t$  = the largest prime in  $P$ .

2. "Lemma 45.0: Statement and Proof" in states:

*Let  $n$  be a positive integer greater than 1. Then there are at least  $k$  primes between  $n$  and  $2^k n$ , where  $k \geq 1$ .*

It follows that neither  $x$ ,  $y$ , nor  $z$  can contain the product  $Up_t$ , where  $U$  is a product of primes in  $P$ . For, suppose  $w$  contained such a product, where  $w$  is  $x$ ,  $y$ , or  $z$ . Then by Lemma 45.0 there would be a prime between  $p_t$  and  $w$ , contrary to the definition of  $P$  and  $p_t$ .

Furthermore it follows that neither  $x$ ,  $y$ , nor  $z$  can contain the product  $U'p_{t-1}$ , where  $U'$  is a product of primes in  $P$  whose value  $\geq 2^2$ . For, suppose  $w$  contained such a product, where  $w$  is  $x$ ,  $y$ , or  $z$ . Then by Lemma 45.0 there would be two primes between  $p_{t-1}$  and  $w$ . One of these would be  $p_t$ . The second would contradict the definition of  $P$  and  $p_t$ .

Finally, it follows that neither  $x$ ,  $y$ , nor  $z$  can contain the product  $U''p_{t-2}$ , where  $U''$  is a product of primes in  $P$  whose value  $\geq 2^3$ . The reason is similar to that for the previous two cases.

3. By Lemma 1.5 in Part (1) of this paper, on the web site occampress.com which asserts that  $(x, y) = (y, z) = (x, z) = 1$ , we have that:

one of  $x, y, z = p_{t-2}$  or  $2p_{t-2}$  or  $3p_{t-2}$  or  $2^2p_{t-2}$  or  $6p_{t-2}$ .  
another of  $x, y, z = p_{t-1}$  or  $2p_{t-1}$  or  $3p_{t-1}$ ;  
the third of  $x, y, z = p_t$ ;

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1. Niven, Ivan, and Zuckerman, H. S., *An Introduction to The Theory of Numbers*, Fourth Edition, John Wiley & Sons, N.Y., 1972, p. 224.

2. *ibid.*, p. 224.

By definition of  $P$ , then,  $P = \{2, 3, 5, 7\}$ , where

$p_{t-3} = 2$  (a 2 factor is required by (1.8): see “(1.8): Statement and Proof” in);

$p_{t-2} = 3$ ;

$p_{t-1} = 5$ ;

$p_t = 7$ .

4. We can therefore write, for possible values of  $x, y$ , and  $z$ , with no suggestion being made here as to which values apply to which of  $x, y, z$ :

(1)

2,  $2^2$ ,  $2^3$ ; ( $2^4$  is not a candidate because there is a  $q$ , namely 11 or 13, that is less than  $2^4$ );

3, 6, 9, 12, 18;

5, 10, 15;

7

5. We could now make a table of all legitimate assignments of the numbers in (1) to  $x, y, z$  and show that for each of these, there is a prime  $q$  meeting the requirements of the Lemma. The reader can determine for him- or herself that most of the possible assignments will be illegitimate. For example, since, by Lemma 0.0 in Part (1) of this paper, on the web site [occampress.com](http://occampress.com), in a counterexample,  $x + y > z$ , the following are all illegitimate assignments:

**Table 1:**

<b><math>x</math> candidate</b>	<b><math>y</math> candidate</b>	<b><math>z</math> candidate</b>
2	3	5
3	4	7
4	5	9
5	9	14

So are all assignments in which  $x + y < z$ , such as:

<b><math>x</math> candidate</b>	<b><math>y</math> candidate</b>	<b><math>z</math> candidate</b>
2	3	7
5	7	18

Unfortunately, there is at least one assignment, namely,  $x = 7$ ,  $y = 9$  and  $z = 10$ , that is legitimate but does not give us the desired  $q$ . But this, and all assignments having the same property, do not constitute an obstacle, since Lemma 1.0 guarantees us that  $p < x < y < z$  and so in these cases we can simply compute  $x^p + y^p$  and  $z^p$  and see if inequality holds. It does in all cases<sup>1</sup>. (For example,  $7^5 + 9^5 \neq 10^5$ , and similarly  $7^3 + 9^3 \neq 10^3$ .)

Among legitimate assignments, for example:  $x = 4$ ,  $y = 5$ , and  $z = 7$  yields 3 as our desired  $q$ ;  $x = 4$ ,  $y = 7$ , and  $z = 9$  yields 5 as our desired  $q$ .

And so we have our result.  $\square$

#### Fourth Proof

Follows from the “Smaller Prime” Lemma in Part (1) of this paper, on [occampress.com](http://occampress.com).

#### Lemma 45.0: Statement and Proof

Let  $n$  be a positive integer greater than 1. Then there are at least  $k$  primes between  $n$  and  $2^k n$ , where  $k \geq 1$ .

##### Proof:

Follows directly from “Bertrand’s Postulate” in Part (1) of this paper, on the web site [occampress.com](http://occampress.com), which states that if  $n$  is a positive integer, then there is at least one prime between  $n$  and  $2n$ . Hence there is at least one prime between  $2n$  and  $4n$ , and at least one prime between  $4n$  and  $8n$ , etc.  $\square$

#### Lemma 50.0: Statement and Proof

Let  $1 < a < b$ , where  $a, b$  are integers and  $(a, b) = 1$ . Let  $p$  be an odd prime, and let  $(a, p) = (b, p) = 1$ . Let the largest power of  $p$  that divides  $a + b$  be  $p^k$ , where  $k \geq 1$ . By the binomial theorem we know that  $(a + b)^p = a^p + H + b^p$ . Then  $p^{k+1}$ , but no larger power of  $p$ , divides  $H$ .

##### Proof:

The following proof is a slightly-edited version of a proof by a mathematics graduate student. All errors are entirely our own.

1. Let  $a + b = p^k M$ , where  $(M, p) = 1$ . Then  $b = p^k M - a$ .

2. By the binomial theorem

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1. All these cases could easily have been checked by Fermat. In passing, we mention that by 1850, thanks to the efforts of E. E. Kummer, FLT was known to be true for all primes less than 100 except for 37, 59, and 67. — Ribenoim, op. cit., p 9.

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$$b^p = (p^k M - a)^p = ((-a) + p^k M)^p = (-a)^p + p(-a)^{p-1} p^k M + (p(p-1)/2)((-a)^{p-2} p^{2k} M^2 + \dots \quad (1)$$

3. The third term on the right-hand side of (1) is divisible by  $p^{2k+1}$  and therefore, since  $k \geq 1$ , by  $p^{k+2}$ . Furthermore, each term in the ellipsis, “...”, is divisible by  $p^{3k}$  and hence by  $p^{k+2}$ . Thus

$$b^p = (-a)^p + (-a)^{p-1} p^{k+1} M + p^{k+2} N, \text{ for some integer } N.$$

It follows that

$$b^p + a^p = (-a)^{p-1} p^{k+1} M + p^{k+2} N,$$

and we have

$$(a + b)^p - a^p - b^p = p^{pk} M^p - (-a)^{p-1} p^{k+1} M - p^{k+2} N. \quad (2)$$

4. Each term on the right-hand side of (2) is divisible by  $p^{k+1}$ . The first term is divisible by  $p^{k+2}$  (since  $p \geq 3$  and  $k \geq 1$ ) and the last term is divisible by  $p^{k+2}$ . However, the middle term is not divisible by  $p^{k+2}$  (since  $p$  does not divide  $a$  or  $M$ ). Thus,  $p^{k+2}$  does not divide  $H = (a + b)^p - a^p - b^p$ .  $\square$

**Lemma 55.0: Statement and Proof**

*Let  $1 < a < b$ , where  $a, b$  are integers and  $(a, b) = 1$ . Let  $p$  be an odd prime, and let  $(a, p) = (b, p) = 1$ . Let the largest power of a prime  $q$ , where  $q \neq p$ , that divides  $a + b$  be  $q^k$ , where  $k \geq 1$ . By the binomial theorem we know that  $(a + b)^p = a^p + H + b^p$ . Then  $q^k$ , but no larger power of  $q$ , divides  $H$ .*

**Proof:**

The following proof is a slightly-edited version of a proof by a mathematics graduate student. All errors are entirely our own.

$$\begin{aligned} 1. \text{ Let } a + b &= cq^k, \text{ where } (c, q) = 1. \text{ Then } (a + b)^p - a^p - b^p = H = (cq^k)^p - a^p - (cq^k - a)^p \\ &= (cq^k)^p - a^p - (cq^k)^p + a^p + \sum_{i=1}^{p-1} \binom{p}{i} (-1)^{p-i+1} a^{p-i} (cq^k)^i = \\ &\sum_{i=1}^{p-1} \binom{p}{i} (-1)^{p-i+1} a^{p-i} (cq^k)^i. \end{aligned}$$

2. The largest power of  $q$  that divides the  $i = 1$  term in the above summation is  $k$ , since  $q$  does



not divide any of the other factors in the term. The largest power of  $q$  that divides each of the other terms in the summation is greater than  $q^k$ , since the exponents in those terms are integral multiples of  $k$ . Therefore the largest power of  $q$  that divides  $H$  is  $q^k$ .  $\square$

**Lemma 60.0: Statement and Proof**

Assume a counterexample  $x^p + y^p = z^p$  exists.

Let  $q$  be a prime. Let  $S_k = \{ \langle a^r, b^r, c^r \rangle \mid a^r \equiv x^k, b^r \equiv y^k, c^r \equiv z^k \pmod{q} \}$ . We say that each triple  $\langle a^r, b^r, c^r \rangle$  is congruent to the triple  $\langle x^k, y^k, z^k \rangle$ . We observe that there are two ways that a triple  $\langle a^r, b^r, c^r \rangle$  can be an element of  $S_k$ .

One is via Fermat's Little Theorem (see Part (4) of this paper), which implies that if

$$r \equiv k \pmod{q-1},$$

$$\text{then } x^r \equiv x^k, y^r \equiv y^k, z^r \equiv z^k \pmod{q}.$$

The other is via (1.91)(c) in Part (4) of this paper, which implies that if

$$a \equiv x \pmod{q}, \text{ and } b \equiv y \pmod{q}, \text{ and } c \equiv z \pmod{q}, \text{ and if}$$

$$x^r + y^r \equiv z^r \pmod{q}, \text{ then}$$

$$a^r + b^r \equiv c^r \pmod{q}.$$

For all  $k \geq 1$ , and for all positive integers  $k, a, b, c$ , such that  $\langle a^r, b^r, c^r \rangle$  is congruent to the triple  $\langle x^k, y^k, z^k \rangle$ , let  $U(k, a, b, c) = a^k + b^k - c^k$ . (Note that  $k, a, b, c$  can equal  $p, x, y, z$ , respectively.)

Then:

(a) the  $U(k, a, b, c)$  are partitioned into  $q-1$  sets, each set a proper subset of a residue class mod  $q$ . The  $U(k, a, b, c)$  in exactly one of these sets, namely, the set containing  $U(p, x, y, z)$ , are all multiples of  $q$ .

(b) (This part has been removed because it was not correct.)

(c) Each  $U(k, a, b, c)$  is a multiple of 2.

(d) For each prime  $q$ , if  $U(k, a, b, c)$  is a multiple of  $q$ , then at least one of  $a^k, b^k$ , must be greater than  $q$ .

**Proof:**

Part (a)

1. By assumption of a counterexample,  $U(p, x, y, z) = 0$ . It follows that for each triple  $\langle a^r, b^r, c^r \rangle$  that is congruent to the triple  $\langle x^k, y^k, z^k \rangle$ ,  $U(r, a, b, c)$  must be congruent to  $U(p, x, y, z)$ . Since  $U(p, x, y, z) = 0$ , it follows, by a basic fact of elementary congruence theory, that  $U(r, a, b, c)$  is a multiple of  $q$ .

Part (c)

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Let  $q = 2$ . Then  $q - 1 = 1$  and our set of exponents is  $p \pm j$ , where  $j$  is a positive integer such that  $p - j$  is not negative. Then by part (a), each  $U(k, a, b, c)$  is a multiple of 2. But since our set of exponents is all exponents such that  $p - j$  is not negative, there cannot be any other  $U(k, a, b, c)$ , and so we have our result.  $\square$

*Part (d)*

Seeking a contradiction, assume that both  $a^k$  and  $b^k$ , are less than or equal to  $q$ . Then since  $c^k$  is greater than or equal to 1,  $a^k + b^k - c^k$  is less than  $2q$ , contradicting part (c).  $\square$