

Algebra I  
Winter 2020



WAYNE STATE  
UNIVERSITY

## CHAPTER 1 INTEGERS

### 1.1 Divisors

1. Let  $m, n, r, s \in \mathbb{Z}$ . If  $m^2 + n^2 = r^2 + s^2 = mr + ns$ , prove that  $m = r$  and  $n = s$ .

**Joe Starr**

We select  $m, n, r, s \in \mathbb{Z}$ , given  $m^2 + n^2 = r^2 + s^2 = mr + ns$  which can write as  $m^2 + n^2 - mr - ns = r^2 + s^2 - mr - ns$ . From here we can simplify:

$$m^2 + n^2 - mr - ns = r^2 + s^2 - mr - ns \Rightarrow m(m - r) + n(n - s) = r(r - m) + s(s - n)$$

$$\Rightarrow m(m - r) + n(n - s) - r(r - m) - s(s - n) = 0$$

$$\Rightarrow m(m - r) + r(m - r) + n(n - s) + s(n - s) = 0$$

$$\Rightarrow (m - r)(m + r) + (n - s)(n + s) = 0$$

from here we can see that in order for  $(m - r)(m + r) + (n - s)(n + s) = 0$  to be true

$m = r$  and  $n = s$ .



5. Use the Euclidean algorithm to find the following greatest common divisors

a (6643, 2873)

d (6540, 1206)

b (7684, 4148)

e (12091, 8439)

c (26460, 12600)

**Joe Starr**

(a) (6643, 2873)

$$6643 = 2873 * 2 + 897$$

$$2873 = 897 * 3 + 182$$

$$897 = 182 * 4 + 169$$

$$182 = 169 * 1 + 13$$

$$169 = 13 * 13$$

(b) (7684, 4148)

$$7684 = 4148 * 1 + 3536$$

$$4148 = 3536 * 1 + 612$$

$$3536 = 612 * 5 + 476$$

$$612 = 476 * 1 + 136$$

$$476 = 136 * 3 + 68$$

$$136 = 68 * 2$$

(c) (26460, 12600)

$$26460 = 12600 * 2 + 1260$$

$$12600 = 1260 * 10$$





9. let  $a, b, c$  be integers such that  $a + b + c = 0$ . Show that if  $n$  is an integer which is a divisor of two of the three integers, then it is also a divisor of the third.

**Joe Starr**

Select  $a, b, c \in \mathbb{Z}$  to satisfy  $a + b + c = 0$ , WLOG let  $n \in \mathbb{Z}$  such that  $n|a$  and  $n|b$ . Since  $(a + b) + c = 0$  it must be that  $(a + b) = -c$ . From here we must show  $n|(a + b)$ , or  $a + b = nq$ . Since  $n|a$  and  $n|b$  we may write  $a = nq_1$  and  $b = nq_2$ , yielding,  $nq_1 + nq_2 = n(q_1 + q_2) = nq$  thus  $n|c$ , as desired.  $\square$

13. Show that if  $n$  is any integer, then  $(10n+3, 5n+2) = 1$

**Joe Starr**

We begin with the Euclidean algorithm,

$$10n + 3 = (5n + 2) 1 + (5n + 1)$$

$$5n + 2 = (5n + 1) 1 + 1$$

from here we have  $(10n + 3, 5n + 2) = (5n + 2, 5n + 1) = 1$ , as desired.



15. For what positive integers  $n$  is it true that  $(n, n + 2) = 2$ ? Prove your claim.

**Joe Starr**

The conjecture is that the statement is true for even values of  $n$ . We begin with rewriting  $n$  in terms of  $k$ ,  $n = 2k$  the Euclidean algorithm,

$$(2k) + 2 = (2k) 1 + (2)$$

$$2k = (2) k$$

from here we have  $(n + 2, n) = (2k + 2, 2k) = 2$ , as desired.

17. Show that the positive integer  $k$  is the difference of two odd squares if and only if  $k$  is divisible by 8.

**Joe Starr**

We begin by writing  $k = a^2 - b^2$ , since  $a$  and  $b$  are odd we can write,

$$a = 2r + 1$$

$$b = 2s + 1$$

from here we have  $a^2 - b^2 = 4(r + s + 1)(r - s)$ . Since  $k > 0$  we must consider two cases  $r - s = 2m + 1$  and  $r - s = 2m$ .

$$r - s = 2m:$$

In this case we have  $a^2 - b^2 = 4(r + s + 1)2m = 8(r + s + 1)m$  and we are done.

$$r - s = 2m + 1:$$



## 1.2 Primes

1. Find the prime factorizations of each of the following numbers, and use them to compute the greatest common divisor and least common multiple of the given pairs of numbers.

(a) (35, 14)

(c) (252, 11)

(e) (6643, 2873)

(b) (15, 11)

(d) (7684, 4148)

Joe Starr			
(a) (35, 14)	14 : 2, 7	(d) (7684, 4148)	4148 : 2, 2, 17, 61
35 : 5, 7	gcd: 7	7684 : 2, 2, 17, 113	gcd: 68
	lcm: 70		lcm: 468724
(b) (15, 11)	11 : 11	(e) (6643, 2873)	2873 : 13, 13, 17
15 : 3, 5	gcd: 1	6643 : 7, 13, 73	gcd: 13
	lcm: 165		lcm: 1468103
(c) (252, 180)	180 : 2, 2, 3, 3, 5		
252 : 2, 2, 3, 3, 7	gcd: 36		
	lcm: 1260		

2. US the sieve of Eratosthenes to find all prime numbers less than 200.

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	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110
111	112	113	114	115	116	117	118	119	120
121	122	123	124	125	126	127	128	129	130
131	132	133	134	135	136	137	138	139	140
141	142	143	144	145	146	147	148	149	150
151	152	153	154	155	156	157	158	159	160
161	162	163	164	165	166	167	168	169	170
171	172	173	174	175	176	177	178	179	180
181	182	183	184	185	186	187	188	189	190
191	192	193	194	195	196	197	198	199	200



4. Find all positive integers less than 60 and relatively prime to 60.

**Joe Starr**

60 : 2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 49, 53, 59

9. (a) For which  $n \in \mathbb{Z}^+$  is  $n^3 - 1$  a prime number?

(b) For which  $n \in \mathbb{Z}^+$  is  $n^3 + 1$  a prime number?

(c) For which  $n \in \mathbb{Z}^+$  is  $n^2 - 1$  a prime number?

(d) For which  $n \in \mathbb{Z}^+$  is  $n^2 + 1$  a prime number?

**Joe Starr**

(a) We can factor  $n^3 - 1$  into  $(n - 1)(n^2 + n + 1)$ . We have then  $n - 1 | n^3 - 1$ , for  $n^3 - 1$  to be prime  $n - 1$  must be 1. This happens only for  $n = 2$ .

(b) We can factor  $n^3 + 1$  into  $(n + 1)(n^2 - n + 1)$ . We have then  $(n^2 - n + 1) | n^3 + 1$ , for  $n^3 + 1$  to be prime  $(n^2 - n + 1)$  must be 1. This happens only for  $n = 1$ .

(c) We can factor  $n^2 - 1$  into  $(n - 1)(n + 1)$ . We have then  $(n - 1) | n^2 - 1$ , for  $n^2 - 1$  to be prime  $(n - 1)$  must be 1. This happens only for  $n = 2$ . For which  $n \in \mathbb{Z}^+$  is  $n^2 - 1$  a prime number?

(d) ????



11. Prove that  $n^4 + 4^n$  is composite if  $n > 1$ .

**Joe Starr**

We are presented with two potability's,  $n$  is even or  $n$  is odd.

$n$  even

It's obvious that  $n^4 + 4^n$  is an even not 2 and can't be prime.

$n$  odd

We begin by completing the square

$$\begin{aligned}n^4 + 4^n &= n^4 + 4^n \\&= (n^2)^2 + (2^n)^2 \\&= (n^2 + 2^n)^2 - 2n^2 2^n\end{aligned}$$

We from here we observe that  $2^n 2 = 2^{n+1}$ , since  $n$  is odd  $n + 1$  is even yielding  $2^{n+1} = 2^{2k}$ . We can see we have a difference of squares

$$\begin{aligned}(n^2 + 2^n)^2 - 2n^2 2^n &= (n^2 + 2^n)^2 - (2^n n)^2 \\&= (n^2 + 2^n + 2^n n) (n^2 + 2^n - 2^n n)\end{aligned}$$

since we are restricted to  $n > 1$  we can see that both  $(n^2 + 2^n + 2^n n) > 1$  and  $(n^2 + 2^n - 2^n n) > 1$  for all  $n$ . Making  $n^4 + 4^n$  composite as desired.

13. Let  $a, b, c$  be positive integers, and let  $d = (a, b)$ . Since  $d|a$ , there exists an integer  $h$  with  $a = dh$ . Show that  $a|bc$ , then  $h|c$ .

**Joe Starr**

We will proceed with a transitive proof:

$$a|abc \rightarrow a|(a, b) c$$

$$\rightarrow a|dc$$

$$\rightarrow dh|dc$$

$$\rightarrow h|c$$

14. Show that  $a\mathbb{Z} \cap b\mathbb{Z} = [a, b]$ .

**Joe Starr**

Let  $x \in (a\mathbb{Z} \cap b\mathbb{Z})$ , since  $x \in a\mathbb{Z}$  we have  $x = aq_1$ , similarly since  $x \in b\mathbb{Z}$  we have  $x = bq_2$ .

We can see that  $x = abq$ , this means  $x$  is a multiple of  $[a, b]$  putting  $x \in [a, b]$ . Next, we

let  $x \in [a, b] \mathbb{Z}$ , this means  $x$  is of the form  $x = [a, b] q$ . We can see that  $a|x$  and  $b|x$  since

$a|[a, b]$ , This makes  $x \in a\mathbb{Z}$  and  $x \in b\mathbb{Z}$ , as desired.

17. Let  $a, b$  be nonzero integers. Prove  $(a, b) = 1$  if and only if  $(a + b, ab) = 1$ .

**Joe Starr**

$\Rightarrow$  We let  $(a, b) = 1$ , then consider the  $(a + b, ab)$ . We assume  $(a + b, ab) = d$ , with  $d > 1$ . Since  $d > 1$  there must exist  $p$  a prime such that  $p|d$ . This means that  $p|a + b$  and  $p|ab$ . Consequently, either  $p|a$  or  $p|b$ . WOLOG we have  $p|a$ , and since  $p|a + b$  it must be that  $p|b$ . Finally, since  $p|a$  and  $p|b$ ,  $p|(a, b)$  a contradiction. So  $(a + b, ab) = 1$ .

$\Leftarrow$  We let  $(a + b, ab) = 1$ , then consider the  $(a, b)$ . We assume  $(a, b) = d$ , with  $d > 1$ . Since  $d > 1$  there must exist  $p$  a prime such that  $p|d$ . This means that  $p|a$  and  $p|b$ , further  $p|ab$ . Since  $p$  divides  $a$  and  $b$ , we have  $p|a + b$ . Finally, since  $p|ab$ , and  $p|a + b$ ,  $p|(a + b, ab)$ , a contradiction so  $(a, b) = 1$ .

18. Let  $a, b$  be nonzero integers with  $(a, b) = 1$ . Compute  $(a + b, a - b)$ .

**Joe Starr**

We know that  $d = (a + b, a - b)$ , this means that  $d|a + b$  and  $d|a - b$ . From here we have that  $d|(a + b) + (a - b) \rightarrow d|2a$  and  $d|(a + b) - (a - b) \rightarrow d|2b$ . Since  $d$  divides both  $2a$  and  $2b$ ,  $d$  must also divide  $2(a, b)$ . Since  $(a, b) = 1$  we have  $(a + b, a - b) = 2$ .

19. Let  $a$  and  $b$  be positive integers, and let  $m$  be an integer such that  $ab = m(a, b)$ . Without using the prime factorization theorem, prove that  $(a, b)[a, b] = ab$  by verifying that  $m$  satisfies the necessary properties of  $[a, b]$ .

**Joe Starr**

We let  $d = (a, b)$ , this means that  $ab = md$ . We first show  $a|m$  and  $b|m$ ,

$$ab = md \rightarrow a(dq) = md$$

$$\rightarrow adq - md = 0$$

$$\rightarrow d(aq - m) = 0 \quad (\text{by def } d > 0)$$

$$\rightarrow aq = m$$

$$\rightarrow a|m$$

similarly for  $b$ .

Next we will show that if  $a|c$  and  $b|c$  then  $m|c$ . We have that  $c = aq_1 = bq_2$  or  $c^2 = abq$ .

We can multiply  $ab = md$  by  $q$  giving  $abq = mdq$ , this means we have  $c^2 = mdq$ , which is true only if  $c = mdq$ ,  $m|c$  as desired.

20. A positive integer  $a$  is called a square if  $a = n^2$  for some  $n \in \mathbb{Z}$ . Show that the integer  $a > 1$  is a square if and only if every exponent in its prime factorization is even.

**Joe Starr**

Let  $a \in \mathbb{Z}$  be a square. Since  $a$  is a square by definition there exists a  $n$  such that  $nn = a$ . Now by the fundamental theorem of arithmetic we know  $n$  has a prime factorization, written  $p_1^{n_1} \cdots p_k^{n_k}$ . If we consider  $nn$ , we have  $nn = (p_1^{n_1} \cdots p_k^{n_k})(p_1^{n_1} \cdots p_k^{n_k})$ , by combining terms we can see that  $nn = (p_1^{2n_1} \cdots p_k^{2n_k})$ , as desired.

23. Let  $p$  and  $q$  be prime numbers. Prove that  $pq + 1$  is a square if and only if  $p$  and  $q$  are twin primes.

**Joe Starr**

We begin by letting selecting  $p$  a prime and  $q$  a prime such that  $q = p + 2$ . Now we consider  $pq$ ,

$$\begin{aligned}pq &\rightarrow p(p + 2) \\&\rightarrow p^2 + p2\end{aligned}$$

We now consider  $p + 1$ , if we take  $(p + 1)^2$ , we get  $p^2 + 2p + 1$ . It's obvious that  $pq + 1 = p^2 + p2 + 1 = (p + 1)^2$ , so  $pq + 1$  is a square when  $p$  and  $q$  are twin primes.

We can now consider  $p$  a prime, and  $q$  a prime such that  $q = p + n$  with  $n > 2$ . If we calculate  $pq$  we see that,

$$\begin{aligned}pq &\rightarrow p(p + n) \\&\rightarrow p^2 + pn\end{aligned}$$

we then have that  $pq + 1 = p^2 + pn + 1$  with  $n > 2$ , this is not a square, showing when  $p$  and  $q$  aren't twin primes  $pq + 1$  is not a square.



26. Prove that if  $a > 1$ , then there is a prime  $p$  with  $a < p \leq a! + 1$ .

**Joe Starr**

We observe that  $a! + 1$  is either prime or composite, if  $a! + 1$  is prime we are done, if  $a! + 1$  is composite we know by the fundamental theorem of arithmetic that  $a! + 1$  has prime factors. Now if all prime factors  $p$  are such that  $p \leq a$  since  $p|a!$  we see that if we divide  $a! + 1$  by any of these we get a remainder of 1, a contradiction so there must be a prime factor  $p$  with  $a < p$ .

*Note: this is basically the same argument as euclid's proof of infinite primes*

29. Show that  $\log 2 / \log 3$  is not a rational number.

**Joe Starr**

We observe this is an application of the change of base formula, making  $\frac{\log 2}{\log 3} = \log_3 2$ .

From here we have  $x = \log_3 2 \rightarrow 3^x = 2$ , if  $x$  is rational then there exist  $m$  and  $n$  such that  $\frac{m}{n} = x$ . We now have  $3^{\frac{m}{n}} = 2 \rightarrow 3^m = 2^n$ , a contradiction since there is no  $m$  and  $n$  that satisfy this equivalence, making  $\log 2 / \log 3$  irrational as desired.

## CHAPTER 2 FUNCTIONS

### 2.1 Functions

1. In each of the following parts, determine whether the given function is 1:1 and whether it is onto.

(a)  $f : \mathbb{R} \rightarrow \mathbb{R}; f(x) = x + 3$

(b)  $f : \mathbb{C} \rightarrow \mathbb{C}; f(x) = x^2 + 2x + 1$

(c)  $f : \mathbb{Z}_n \rightarrow \mathbb{Z}_n; f([x]_n) = [mx + b]_n$ , where  $m, b \in \mathbb{Z}$

(d)  $f : \mathbb{R}^+ \rightarrow \mathbb{R}; f(x) = \ln x$

**Joe Starr**

(a) We can see that  $f(x) = x + 3$  then  $f^{-1}(x) = x - 3$ ,  $f(f^{-1}(x)) = (x - 3) + 3 = x$ .

Showing  $f$  is a bijection.

(b) 1:1:

Assume  $f(x) = 25 = f(y)$ , we can see that if  $x = 4$ ,  $f(x) = 25$ , and  $y = -6$ ,

$f(y) = 25$ , showing  $f$  not injective.

onto:

Let  $y \in \mathbb{C}$  we must now show there exists a  $x \in \mathbb{C}$  such that  $f(x) = y$ .





4. For each 1:1 and onto function in Exercise 2, find the inverse of the function

(a)  $f : \mathbb{R} \rightarrow \mathbb{R}; f(x) = x^2$

(b)  $f : \mathbb{C} \rightarrow \mathbb{C}; f(x) = x^2$

(c)  $f : \mathbb{R}^+ \rightarrow \mathbb{R}^+; f(x) = x^2$

(d)  $f : \mathbb{R}^+ \rightarrow \mathbb{R}^+; f(x) = \begin{cases} x & \text{if } x \text{ is rational} \\ x^2 & \text{if } x \text{ is irrational} \end{cases}$

**Joe Starr**

(a) Not a bijection

(b) Not a bijection

(c)  $f^{-1}(x) = +\sqrt{x}$

(d)  $f : \mathbb{R}^+ \rightarrow \mathbb{R}^+; f^{-1}(x) = \begin{cases} x & \text{if } x \text{ is rational} \\ +\sqrt{x} & \text{if } x \text{ is irrational} \end{cases}$

13. Let  $f : A \rightarrow B$  be a function, and let  $f(A) = \{f(a) \mid a \in A\}$  be the image of  $f$ . Show that  $f$  is onto if and only if  $f(A) = B$ .

**Joe Starr**

Let  $f(A) = B$ , select  $y \in B$ , since  $y \in B$  we have  $y \in f(A)$ , that means there exists  $a \in A$  such that  $f(a) = y$ . Showing  $f$  surjective. Let  $f(A) \neq B$ , let  $y \in B$ , such that  $y \notin B \cap f(A)$ . Since we have  $y \notin f(A)$  we have no  $a \in A$  that maps to  $y$  showing  $f$  not surjective, as desired.

15. Let  $f : A \rightarrow B$  and  $g : B \rightarrow C$  be functions. Prove that if  $g \circ f$  is 1:1, then  $f$  is 1:1, and that if  $g \circ f$  is onto  $g$  is onto.

**Joe Starr**

Let  $g \circ f$  be injective, but  $f$  not injective. Since  $f$  is not injective  $\exists a, x \in A$  such that  $a \neq x$  but  $f(x) = f(a)$ . We consider  $g \circ f(a)$  and  $g \circ f(x)$ , since  $f(x) = f(a)$  it must be that  $g(f(x)) = g(f(a))$ . This means that with  $a \neq x$ ,  $g(f(x)) = g(f(a))$ , making  $g \circ f$  not injective a contradiction so  $f$  injective.

Let  $g \circ f$  be surjective, but  $g$  not surjective. Since  $g$  not surjective there exists some  $c \in C$  such that  $g(b) \neq c$  for all  $b \in B$ . However since  $g \circ f$  surjective there exists  $g \circ f(a) = c$  a contradiction, making  $g$  surjective.







## 2.2 Equivalence Relations

## 2.3 Permutations

1. Consider the following Permutations in  $S_7$ .

$$\sigma = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 \\ 3 & 2 & 5 & 4 & 6 & 1 & 7 \end{pmatrix} \quad \tau = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 \\ 2 & 1 & 5 & 7 & 4 & 6 & 3 \end{pmatrix}$$

(a)  $\sigma\tau$

(b)  $\tau\sigma$

(c)  $\tau^2\sigma$

(d)  $\sigma^{-1}$

(e)  $\sigma\tau\sigma^{-1}$

(f)  $\tau^{-1}\sigma\tau$

**Joe Starr**

(a)  $\sigma\tau$

(b)  $\tau\sigma$

(c)  $\tau^2\sigma$

(d)  $\sigma^{-1}$

(e)  $\sigma\tau\sigma^{-1}$



2. Write each of the permutations  $\sigma\tau, \tau\sigma, \tau^2\sigma, \sigma^{-1}, \sigma\tau\sigma^{-1}$ , and  $\tau^{-1}\sigma\tau$  in Exercise 1 as a product of disjoint cycles. Write  $\sigma$  and  $\tau$  as products of transpositions.

**Joe Starr**

(a)  $\sigma\tau$

(b)  $\tau\sigma$

(c)  $\tau^2\sigma$

(d)  $\sigma^{-1}$

(e)  $\sigma\tau\sigma^{-1}$

(f)  $\tau^{-1}\sigma\tau$

3. Write  $\begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 \\ 3 & 4 & 10 & 5 & 7 & 8 & 2 & 6 & 9 & 1 \end{pmatrix}$  as the product of disjoint cycles and as a product of transpositions. Construct its associated diagram, find its inverse, and find its order.

**Joe Starr**





5. Let  $3 \leq m \leq n$ . Calculate  $\sigma\tau^{-1}$  for cycles  $\sigma = (1, 2, \dots, m-1)$  and  $\tau = (1, 2, \dots, m-1, m)$  in  $S_n$ .

**Joe Starr**

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## CHAPTER 3 SECTION

I <3 my Wayne State Libraries! Do you?

### 3.1 A Subsection

## CHAPTER 4 SECTION

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### 4.1 A Subsection

## CHAPTER 5 SECTION

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### 5.1 A Subsection

## CHAPTER 6 SECTION

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### 6.1 A Subsection

## CHAPTER 7 SECTION

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### 7.1 A Subsection

## CHAPTER 8 SECTION

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### 8.1 A Subsection

## CHAPTER 9 SECTION

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### 9.1 A Subsection



## CHAPTER 10 SECTION

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### 10.1 A Subsection