

## Axioms of the integers $\mathbb{Z}$ .

The word “integer” is our undefined term (sometimes referenced as the “primitive” term) for this section. The set  $\mathbb{Z}$  is the set of all integers (Axiom D3 implies that  $\mathbb{Z}$  has at least two elements, so I am grammatically correct in using the plural). The set  $\mathbb{Z}$  satisfies the following axioms.

The usual rules (axioms) of logic are to be used to prove theorems from these axioms. As needed these rules will be discussed and stated. As a first such, following are the properties of the equality symbol.

- i.) [Reflexive]  $x = x$  for all  $x$ .
- ii.) [Symmetric] If  $x = y$  then  $y = x$ .
- iii.) [Transitive] If  $x = y$  and  $y = z$  then  $x = z$ .
- iv.) [Uniqueness of function values] If  $f$  is a function and  $x = y$  then  $f(x) = f(y)$ .

Axioms about addition and multiplication: There exists two operations on the integers: addition denoted by “+” and multiplication denoted by “·”. [Strictly speaking “+” is a map from the cross product of the integers with itself into the integers with certain properties as defined by the axioms, and similarly for multiplication “·”. Cross products of sets will be more formally defined later in the semester.] Note that  $a \cdot b$  is usually written as  $ab$ . It is this functional definition and properties of the = symbol that yields the following (axioms) which will be needed for our proofs and which you may assume as part of our logic system.

$$\text{If } a = b \text{ and } c = d \text{ then } a + c = b + d.$$

$$\text{If } a = b \text{ and } c = d \text{ then } a \cdot c = b \cdot d.$$

[Observation: the symbols  $\wedge$  and  $\vee$  also satisfy these properties.]

### Axioms about addition.

A1. If  $a \in \mathbb{Z}$  and  $b \in \mathbb{Z}$  then  $a + b \in \mathbb{Z}$ . [Closure.]

A2. If  $a \in \mathbb{Z}$  and  $b \in \mathbb{Z}$  then  $a + b = b + a$ . [Commutativity.]

A3. If  $a \in \mathbb{Z}$ ,  $b \in \mathbb{Z}$  and  $c \in \mathbb{Z}$  then  $a + (b + c) = (a + b) + c$ . [Associativity.]

A4. There exists an element  $0 \in \mathbb{Z}$  so that if  $a \in \mathbb{Z}$  then  $a + 0 = a$ . [Additive Identity element.]

A5. If  $a \in \mathbb{Z}$  then there exists an element in  $\mathbb{Z}$  denoted by  $-a$  so that  $-a + a = 0$ . [Additive inverse.]

Definition:  $a - b$  means  $a + (-b)$ .

### **Axioms about multiplication.**

B1. If  $a \in \mathbb{Z}$  and  $b \in \mathbb{Z}$  then  $a \cdot b \in \mathbb{Z}$ . [Closure.]

B2. If  $a \in \mathbb{Z}$  and  $b \in \mathbb{Z}$  then  $a \cdot b = b \cdot a$ . [Commutativity.]

B3. If  $a \in \mathbb{Z}$ ,  $b \in \mathbb{Z}$  and  $c \in \mathbb{Z}$  then  $a \cdot (b \cdot c) = (a \cdot b) \cdot c$ . [Associativity.]

B4. There exists an element  $1 \in \mathbb{Z}$  so that if  $a \in \mathbb{Z}$  then  $a \cdot 1 = a$ . [Multiplicative Identity element.]

B5. If  $a \in \mathbb{Z}$ ,  $b \in \mathbb{Z}$ ,  $c \in \mathbb{Z}$  with  $c \neq 0$  and  $ac = bc$  then  $a = b$ . [Cancellation rule.]

### **Axiom on the relationship between addition and multiplication.**

C1. If  $a \in \mathbb{Z}$ ,  $b \in \mathbb{Z}$  and  $c \in \mathbb{Z}$  then  $a \cdot (b + c) = a \cdot b + a \cdot c$ . [Distributive law.] (Note the assumption that the order of operation is to perform  $\cdot$  first then  $+$ . In other words  $ab + cd$  means  $(ab) + (cd)$ .)

### **Axioms on order.**

There exists an order relation " $<$ " so that:

D1. If each of  $a$  and  $b$  is an integer then exactly one of the following is true:

$$a < b, \quad a = b, \quad b < a.$$

D2. If each of  $a$ ,  $b$  and  $c$  is an integer  $a < b$  and  $b < c$ , then  $a < c$ .

D3.  $0 < 1$ .

D4. If each of  $a$ ,  $b$  and  $c$  is an integer and  $a < b$ , then  $a + c < b + c$ .

D5. If each of  $a$ ,  $b$  and  $c$  is an integer  $a < b$  and  $0 < c$ , then  $a \cdot c < b \cdot c$ .

Definition. The integer  $p$  is said to be positive if and only if  $0 < p$ ;  
 $\mathbb{N} = \{n \in \mathbb{Z} \mid 0 < n\}$ .

D6. If  $n$  is an integer then exactly one of the following is true [Trichotomy Law.]:

$$n \in \mathbb{N}, \quad n = 0, \quad -n \in \mathbb{N}.$$

**Induction axiom.**

E1. Suppose that  $S$  is a subset of  $\mathbb{N}$  containing 1 such that if  $n \in S$  then  $n + 1 \in S$ . Then  $S = \mathbb{N}$ .