

# Chapter 1

## 1.1 Rings, Ideals, Radicals

1. Exercise 1. Show that if  $x$  is nilpotent and  $u$  is a unit,  $x + u$  is a unit.

Exercise 1 solution. Suppose  $x^n = 0$ . First consider  $n = 1$ . We have  $(1 + x)u(1 - x + x^2 - \cdots + (-1)^{n-1}x^{n-1}) = 1 + (-1)^{n-1}x^n = 1$ . Thus  $1 + x$  is a unit. Now for arbitrary  $n$ , we have  $u + x = u(1 + u^{-1}x)$ , and since  $u^{-1}x$  is clearly nilpotent and the unit group is closed under products,  $u + x$  must be a unit as well.

2. Exercise 2. Let  $f = a_0 + a_1x + \cdots + a_nx^n \in A[x]$ . Prove that

- (a)  $f$  is a unit of  $A[x]$  if and only if all the coefficients but the constant term are nilpotents of  $A$  and the constant term is a unit of  $A$ .

Exercise 2a solution. One direction is easy: if  $a_0$  is a unit and  $a_1, \dots, a_n$  are nilpotents, then  $a_1x + \cdots + a_nx^n$  is in the nilradical of  $A[x]$ , and then the previous problem shows that  $f = a_0 + (a_1x + \cdots + a_nx^n)$  is a unit.

In the other direction, let  $f$  be a unit; suppose  $fg = 1$ . Looking at the constant terms, it is clear that  $a_0$  is a unit. Now for the higher-degree terms, it is enough to show  $a_n$  is nilpotent, for if it is, then  $f' = f - a_nx^n$  is a unit by Exercise 1. Then by the same argument it will be true that  $a_{n-1}$ , the next coefficient of  $f'$ , is nilpotent, and so on down the line.

Suppose  $g = b_0 + b_1x + \cdots + b_mx^m$ . Then  $a_nb_m = 0$ . Furthermore,  $a_{n-1}b_m + a_nb_{m-1} = 0$ ; multiplying by  $a_n$ , we find  $a_na_{n-1}b_m + a_n^2b_{m-1} = 0$ . But the first term is zero since  $a_nb_m$  is zero. So  $a_n^2b_{m-1} = 0$  too. Continuing inductively, the coefficient of the term  $x^r$  in the product is  $\sum_{i+j=r} a_ib_j$  (where  $i, j \geq 0$ ), and this is zero if  $k \geq 1$  because  $fg = 1$ . If  $k \geq n$ , writing  $k = m + n - r$  (so  $r \leq m$ ), we can rewrite this sum as

$$\sum_{i=0}^r a_{n-i+r}b_{m-i} = 0$$

provided we define  $a_{n-i+r} = 0$  if  $n - r + i < 0$  (which will happen if  $r > n$ ). This equation is true for all  $r$  satisfying  $r \leq m$ , since this implies  $m + n - r \geq n > 0$ . (There is nothing to prove when  $m = 0$ .) We have shown  $a_nb_m = 0$ , and we contend  $a_n^2b_{m-1}$  is zero for all  $r \leq m$ . We prove it by induction on  $r$ , with the case  $r = 0$  the case just handled. (In fact, we handled  $r = 1$  as an induction of the induction step.) Multiply the above equation by  $a_n^2$ :

$$\sum_{i=0}^r a_n^2 a_{n-i+r}b_{m-i} = 0$$

# Calculus Solution Manual Spivak

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Strauss, Magdalena Daniele Toda, Karl J. Smith, 2014-01-15

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