

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

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

provided we define $a_{n-i+r} = 0$ if $n - i + r < 0$ (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 :

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

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Dan Clegg



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