1 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 $x^m = 0$. First consider $u = 1$. We have $(1+x)[1-x+x^2-\cdots+(-x)^{m-1}] = 1+(-1)^{m-1}x^m = 1$. Thus $1+x$ is a unit. Now for arbitrary u, 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, $u+x$ cannot 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 $a_1, \ldots, a_n$ 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 lead coefficient of f', is nilpotent, and so on shows the fact.

   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-1} we find $a_{n-1}a_nb_m + a_{n-1}^2b_{m-1} = 0$. But the first term is zero since a_nb_m is zero. So $a_{n-1}^2b_{m-1} = 0$ too. Continuing inductively: the coefficient of the term x^k in the product is $\sum_{i+j=k} a_ib_j$ (where $i, j \geq 0$), and this is zero if $k \geq 1$ because $fg = 1$. If $k \geq m$, writing $k = m + n - r$ (so $r \leq m$), we can rewrite this sum as

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

   provided we define $a_{n-r+i} = 0$ 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 $n + m - r \geq n > 0$. (There is nothing to prove when $n = 0$.) We have shown $a_nb_m = 0$, and we contend $a_n^cb_{m-r}$ is zero for all $r \leq m$. We prove it by induction on r, with the case $r = 0$ the one just handled. (In fact, we handled $r = 1$ as an intermediate of the induction step.) Multiply the above equation by a_n^c:

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

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Richard K. Gardner,Phyllis Grumm

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