

Chapter 13, Problem 14. Show that the nilpotent elements of a commutative ring form a subring.

**Solution:** Let  $S$  be the set of nilpotent elements of a commutative ring. Since  $0 \in S$ ,  $S$  is nonempty. So, suppose  $a, b \in S$ , then there exist positive integers  $h$  and  $k$  with  $a^h = b^k = 0$ . Notice that if  $b^k = 0$ ,  $(-b)^k = 0$  since for even  $k$  the two are equal and for odd  $k$ , they are additive inverses (and the additive inverse of 0 is 0). Now, consider  $(a - b)^{h+k}$ :

$$\begin{aligned} (a - b)^{h+k} &= \sum_{i=0}^{h+k} \binom{h+k}{i} a^{h+k-i} (-b)^i \\ &= \sum_{i=0}^h \binom{h+k}{i} a^{h+k-i} (-b)^i + \sum_{i=k+1}^{h+k} \binom{h+k}{i} a^{h+k-i} (-b)^i \end{aligned}$$

Since  $a^h = 0$  and  $(-b)^k = 0$ , and each term in the first summation is the product of  $a^h$  with some other ring element, and each term in the second summation is the product of  $(-b)^k$  with some other ring element, each term in each sum is equal to 0, as is this sum. Hence,  $(a - b) \in S$ .

Now, let  $a$  and  $b$  be as above. Since  $R$  is a commutative ring, we can write  $(ab)^h = a^h b^h = 0 \cdot b^h = 0 = b^h \cdot 0 = b^h a^h = (ba)^h$ , hence  $ba = ab \in S$ . So, by the subring test,  $S$  is a subring of  $R$ .

Chapter 13, Problem 42. Let  $R$  be a commutative ring with unity 1 and prime characteristic. If  $a \in R$  is nilpotent, prove that there is a positive integer  $k$  such that  $(1 + a)^k = 1$ .

**Solution:** Let  $R$  be as specified above, and let  $p$  be the characteristic of  $R$ . Let  $a$  be a nilpotent element of  $R$  with  $a^n = 0$ . Since  $p$  is prime,  $p > 1$ , and so we can find some positive integer  $i$  with  $p^i > n$ . Then, by Problem 41 part b) we have  $(1 + a)^{p^i} = 1^{p^i} + a^{p^i} = 1 + a^n a^{p^i - n} = 1 + 0 = 1$ .

Chapter 14, Problem 34. Let  $R$  be a ring and let  $I$  be an ideal of  $R$ . Prove that the factor ring  $R/I$  is commutative if and only if  $rs - sr \in I$  for all  $r$  and  $s$  in  $R$ .

**Solution:** ( $\Rightarrow$ ) Suppose  $R/I$  is a commutative ring. Let  $r, s \in R$ . Then  $rs + I = (r + I)(s + I) = (s + I)(r + I) = sr + I$ , and adding the additive inverse of  $sr$  to both sides, we have  $rs - sr + I = sr - sr + I = 0 + I = I$ . Hence,  $rs - sr \in I$ .

( $\Leftarrow$ ) Let  $r + I$  and  $s + I$  be arbitrary elements of  $R/I$ . Now, suppose  $rs - sr \in I$ . Then  $rs - sr + I = I$ , and  $rs + I = sr + I$ . But  $rs + I = (r + I)(s + I)$  and  $sr + I = (s + I)(r + I)$ , so we have  $(r + I)(s + I) = (s + I)(r + I)$  for these arbitrary elements of the ring  $R/I$ , hence  $R/I$  is commutative.

Chapter 14, Problem 42. Let  $R$  be a commutative ring and let  $A$  be any ideal of  $R$ . Show that the nil radical of  $A$ ,  $N(A) = \{r \in R \mid \exists n \in \mathbb{Z} \text{ s.t. } r^n \in A\}$ , is an ideal of  $R$ .

**Solution:** Notice that any element of  $A$  will be an element of  $N(A)$ , hence  $N(A)$  is nonempty. Now, suppose  $a, b \in N(A)$ . Then there exist positive integers  $h$  and  $k$  with  $a^h, b^k \in A$ . Notice

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