

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 $(1 + a)^{p^i} = 1^{p^i} + a^{p^i} = 1 + a^{p^i} a^{p^i - n} = 1 + 0 = 1$.

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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Julia Schneider



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