

Chapter 9. Problem 58. Suppose that a group G has a subgroup of order n . Prove that the intersection of all subgroups of G of order n is a normal subgroup of G .

Solution: Let G be a group with a subgroup of order n , and let $\{H_\alpha\}$ be the collection of all such subgroups. Let $N = \cap_\alpha H_\alpha$. Then from previous work, we know $N \leq G$. Now, let $x \in G$ and consider the set $x^{-1}Nx$. For each x , this is the inner automorphism of G induced by x^{-1} , acting on the subgroup N . Being an automorphism, $x^{-1}H_\alpha x$ will be another subgroup of G of order n . So we have $x^{-1}Nx = x^{-1}(\cap_\alpha H_\alpha)x = \cap_\alpha (x^{-1}H_\alpha x)$, and since for each $x^{-1}H_\alpha x$, $x^{-1}H_\alpha x \in \{H_\alpha\}$, we know $\cap_\alpha (x^{-1}H_\alpha x) \supseteq N$. That is $x^{-1}Nx \supseteq N$. Multiplying through on the left by x and on the right by x^{-1} , we have $N \supseteq xNx^{-1}$, so by the normal subgroup test, $N \triangleleft G$.

Chapter 10. Problem 6. Let G be the group of all polynomials with real coefficients under addition. For each f in G , let $\int f$ denote the antiderivative of f that passes through the point $(0, 0)$. Show that the mapping $f \mapsto \int f$ from G to G is a homomorphism. What is the kernel of this mapping? Is this mapping a homomorphism if $\int f$ denotes the antiderivative of f that passes through $(0, 1)$?

Solution: Let f and h be polynomials with real coefficients. Since $\int f$ and $\int h$ each pass through the point $(0, 0)$, their sum will also pass through $(0, 0)$: let $F = \int f$ and $H = \int h$. Then $F(0) = 0$ and $H(0) = 0$, so $(F + H)(0) = 0$. We know from calculus that the antiderivative of $f + h$ is the same as the sum of the antiderivatives of f and h . That is, $\int f + h = F + H$, since we have already seen that $F + H$ passes through $(0, 0)$. Let f_0 denote the zero polynomial ($f_0(x) = 0 \forall x$). Then the kernel of this map is $\ker \int = \{f \in G : \int f = f_0\} = \int^{-1}(f_0) = \{\frac{d}{dx} f_0\} = \{f_0\}$, since $\int^{-1} = \frac{d}{dx}$.

Now, consider the image of the zero polynomial, f_0 , under the mapping where $\int f$ denotes the antiderivative of f that passes through $(0, 1)$. Then $\int f_0 = 1$, the constant function. But $f_0 + f_0 = f_0$, so if this map were a homomorphism, we would have $\int f_0 = \int(f_0 + f_0) = \int f_0 + \int f_0$. That is, $1 = 1 + 1 = 2$, which is obviously not true. Since this map does not preserve the operation, it is not a homomorphism.

Chapter 10. Problem 40. (Third Isomorphism Theorem) If M and N are normal subgroups of G and $N \leq M$, prove that $(G/N)/(M/N) \cong G/M$.

Solution: First, define the map $\phi : G/N \rightarrow G/M$ by $\phi(gN) = gM$. We will show that ϕ is a well defined homomorphism, that $\phi(G/N) = G/M$ (i.e., that ϕ is onto), and that $\ker \phi = M/N$.

Now, let $g, g' \in G$ with $gN = g'N$. Then $N = g^{-1}g'N$, hence $g^{-1}g' \in N$. Since $N \leq M$, this means $g^{-1}g' \in M$, as well. So, $\phi(g^{-1}g'N) = g^{-1}g'M = M$. Then, multiplying through by g , we have $g'M = gM$, or $\phi(g'N) = \phi(gN)$. Hence, ϕ is well defined.

Let $g_1N, g_2N \in G/N$. Then $\phi(g_1Ng_2N) = \phi(g_1g_2N) = g_1g_2M = g_1Mg_2M = \phi(g_1N)\phi(g_2N)$, hence ϕ is a homomorphism.

Let $g \in G$, then $gM \in G/M$. We know that there is a coset of N in G containing g , and that we can call this coset gN . By the definition of our map, we have $\phi(gN) = gM$, hence ϕ is onto. That is, $\phi(G/N) = G/M$.

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