

**Algebra Ph.D. Qualifying Exams, January 2013**

*Answer all questions. Partial credit will be given.*

1. Let  $p$  be prime and let  $P$  be a group of prime power order  $p^\alpha$  for some  $\alpha \geq 1$ . Prove that the center  $Z(P)$  is nontrivial.
2. Prove that  $x^4 + 4x^3 + 6x^2 + 2x + 1$  is irreducible in  $\mathbb{Z}[x]$ .
3. Let  $p$  be a prime. Compute the Galois group over  $\mathbb{Q}$  for the splitting field of the polynomial  $x^p - 2$ , by describing the action of the elements of the group on generators of the extension.
4. Let  $F$  be a field and let  $V_F$  be a (possibly infinite-dimensional) vector space over  $F$ . Let  $V^* = \text{Hom}(V, F)$  denote the dual space of  $V$ . Consider the map
$$\Phi : V \rightarrow (V^*)^*, \quad v \mapsto E_v,$$
where  $E_v \in (V^*)^* = \text{Hom}(V^*, F)$  is the evaluation map defined by the rule  $E_v(f) = f(v)$  (for each  $f \in V^*$ ). Prove that  $\Phi$  is an injective linear transformation.
5. Show that the alternating group  $A_5$  is simple.
6. Part A: Describe all ring homomorphisms (not necessarily sending  $1 \mapsto 1$ ) from  $\mathbb{Z} \rightarrow \mathbb{Q}$ .  
Part B: Describe all  $\mathbb{Z}$ -module homomorphisms from  $\mathbb{Z} \rightarrow \mathbb{Q}$ .
7. Prove the existence of a non-abelian group of order 20 not isomorphic to  $D_{20}$ .
8. Let  $I$  be an indexing set and let  $R$  be a (commutative) ring with  $1 \neq 0$ . For each  $i \in I$  let  $M_i$  be an  $R$ -module. Also let  $N$  be an  $R$ -module. Prove that there exists an isomorphism:

$$\text{Hom}_R\left(\bigoplus_{i \in I} M_i, N\right) \cong \prod_{i \in I} \text{Hom}(M_i, N).$$

9. Let  $R$  be a noncommutative ring with 1. Assume  $ab = 1$  but  $ba \neq 1$ . Prove that  $a$  has at least two distinct right inverses.
10. Let  $F$  be a field and assume  $\alpha, \beta$  are both algebraic over  $F$ . Prove that  $\alpha + \beta$  is algebraic over  $F$ .

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