# The 69th William Lowell Putnam Mathematical Competition Saturday, December 6, 2008

- A1 Let  $f : \mathbb{R}^2 \to \mathbb{R}$  be a function such that f(x, y) + f(y, z) + f(z, x) = 0 for all real numbers x, y, and z. Prove that there exists a function  $g : \mathbb{R} \to \mathbb{R}$  such that f(x, y) = g(x) - g(y) for all real numbers x and y.
- A2 Alan and Barbara play a game in which they take turns filling entries of an initially empty 2008 × 2008 array. Alan plays first. At each turn, a player chooses a real number and places it in a vacant entry. The game ends when all the entries are filled. Alan wins if the determinant of the resulting matrix is nonzero; Barbara wins if it is zero. Which player has a winning strategy?
- A3 Start with a finite sequence a<sub>1</sub>, a<sub>2</sub>,..., a<sub>n</sub> of positive integers. If possible, choose two indices j < k such that a<sub>j</sub> does not divide a<sub>k</sub>, and replace a<sub>j</sub> and a<sub>k</sub> by gcd(a<sub>j</sub>, a<sub>k</sub>) and lcm(a<sub>j</sub>, a<sub>k</sub>), respectively. Prove that if this process is repeated, it must eventually stop and the final sequence does not depend on the choices made. (Note: gcd means greatest common divisor and lcm means least common multiple.)
- A4 Define  $f : \mathbb{R} \to \mathbb{R}$  by

$$f(x) = \begin{cases} x & \text{if } x \leq e \\ xf(\ln x) & \text{if } x > e. \end{cases}$$

Does  $\sum_{n=1}^{\infty} \frac{1}{I(n)}$  converge?

- A5 Let n ≥ 3 be an integer. Let f(x) and g(x) be polynomials with real coefficients such that the points (f(1), g(1)), (f(2), g(2)),..., (f(n), g(n)) in R<sup>2</sup> are the vertices of a regular n-gon in counterclockwise order. Prove that at least one of f(x) and g(x) has degree greater than or equal to n − 1.
- A6 Prove that there exists a constant c > 0 such that in every nontrivial finite group G there exists a sequence of length at most c ln |G| with the property that each element of G equals the product of some subsequence.

(The elements of G in the sequence are not required to be distinct. A subsequence of a sequence is obtained by selecting some of the terms, not necessarily consecutive, without reordering them; for example, 4, 4, 2 is a subsequence of 2, 4, 6, 4, 2, but 2, 2, 4 is not.)

- B1 What is the maximum number of rational points that can lie on a circle in R<sup>2</sup> whose center is not a rational point? (A rational point is a point both of whose coordinates are rational numbers.)
- B2 Let  $F_0(x) = \ln x$ . For  $n \ge 0$  and x > 0, let  $F_{n+1}(x) = \int_0^x F_n(t) dt$ . Evaluate

$$\lim_{n\to\infty} \frac{n! F_n(1)}{\ln n}.$$

- B3 What is the largest possible radius of a circle contained in a 4-dimensional hypercube of side length 1?
- B4 Let p be a prime number. Let h(x) be a polynomial with integer coefficients such that h(0), h(1),...,h(p² 1) are distinct modulo p². Show that h(0), h(1),...,h(p³ 1) are distinct modulo p³.
- B5 Find all continuously differentiable functions f: R → R such that for every rational number q, the number f(q) is rational and has the same denominator as q. (The denominator of a rational number q is the unique positive integer b such that q = a/b for some integer a with gcd(a, b) = 1.) (Note: gcd means greatest common divisor.)
- B6 Let n and k be positive integers. Say that a permutation σ of {1,2,...,n} is k-limited if |σ(i) − i| ≤ k for all i. Prove that the number of k-limited permutations of {1,2,...,n} is odd if and only if n ≡ 0 or 1 (mod 2k + 1).

# **Mathematical Literacy Ppreparation Examination 2008**

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