

The 66th William Lowell Putnam Mathematical Competition
Saturday, December 3, 2005

A-1 Show that every positive integer is a sum of one or more numbers of the form $2^r 3^s$, where r and s are nonnegative integers and no summand divides another. (For example, $23 = 9 + 8 + 6$.)

A-2 Let $\mathbf{S} = \{(a, b) \mid a = 1, 2, \dots, n, b = 1, 2, 3\}$. A rook tour of \mathbf{S} is a polygonal path made up of line segments connecting points p_1, p_2, \dots, p_{3n} in sequence such that

- (i) $p_i \in \mathbf{S}$,
- (ii) p_i and p_{i+1} are a unit distance apart, for $1 \leq i < 3n$,
- (iii) for each $p \in \mathbf{S}$ there is a unique i such that $p_i = p$. How many rook tours are there that begin at $(1, 1)$ and end at $(n, 1)$?

(An example of such a rook tour for $n = 5$ was depicted in the original.)

A-3 Let $p(z)$ be a polynomial of degree n , all of whose zeros have absolute value 1 in the complex plane. Put $g(z) = p(z)/z^{n/2}$. Show that all zeros of $g'(z) = 0$ have absolute value 1.

A-4 Let H be an $n \times n$ matrix all of whose entries are ± 1 and whose rows are mutually orthogonal. Suppose H has an $a \times b$ submatrix whose entries are all 1. Show that $ab \leq n$.

A-5 Evaluate

$$\int_0^1 \frac{\ln(x+1)}{x^2+1} dx.$$

A-6 Let n be given, $n \geq 4$, and suppose that P_1, P_2, \dots, P_n are n randomly, independently and uniformly, chosen points on a circle. Consider the convex n -gon whose vertices are P_i . What is the probability that at least one of the vertex angles of this polygon is acute?

B-1 Find a nonzero polynomial $P(x, y)$ such that $P(\lfloor a \rfloor, \lfloor 2a \rfloor) = 0$ for all real numbers a . (Note: $\lfloor v \rfloor$ is the greatest integer less than or equal to v .)

B-2 Find all positive integers n, k_1, \dots, k_n such that $k_1 + \dots + k_n = 5n - 4$ and

$$\frac{1}{k_1} + \dots + \frac{1}{k_n} = 1.$$

B-3 Find all differentiable functions $f : (0, \infty) \rightarrow (0, \infty)$ for which there is a positive real number a such that

$$f' \left(\frac{a}{x} \right) = \frac{x}{f(x)}$$

for all $x > 0$.

B-4 For positive integers m and n , let $f(m, n)$ denote the number of n -tuples (x_1, x_2, \dots, x_n) of integers such that $|x_1| + |x_2| + \dots + |x_n| \leq m$. Show that $f(m, n) = f(n, m)$.

B-5 Let $P(x_1, \dots, x_n)$ denote a polynomial with real coefficients in the variables x_1, \dots, x_n , and suppose that

$$\left(\frac{\partial^2}{\partial x_1^2} + \dots + \frac{\partial^2}{\partial x_n^2} \right) P(x_1, \dots, x_n) = 0 \quad (\text{identically})$$

and that

$$x_1^2 + \dots + x_n^2 \text{ divides } P(x_1, \dots, x_n).$$

Show that $P = 0$ identically.

B-6 Let S_n denote the set of all permutations of the numbers $1, 2, \dots, n$. For $\pi \in S_n$, let $\sigma(\pi) = 1$ if π is an even permutation and $\sigma(\pi) = -1$ if π is an odd permutation. Also, let $\nu(\pi)$ denote the number of fixed points of π . Show that

$$\sum_{\pi \in S_n} \frac{\sigma(\pi)}{\nu(\pi) + 1} = (-1)^{n+1} \frac{n}{n+1}.$$