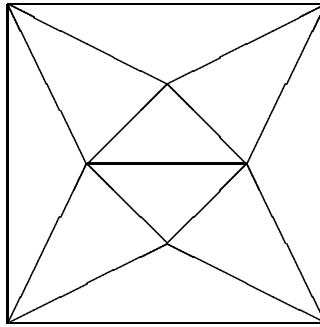


18.S34 PROBLEMS #11

Fall 2002

109. [1] Can the following figure be drawn without lifting one's pencil from the paper or retracing any lines?



110. A *covering congruence* is a finite set $(a_1, m_1), \dots, (a_k, m_k)$ of ordered pairs of integers, where $0 < m_1 < \dots < m_k$, such that every integer can be written in at least one of the forms $m_i x + a_i$, where x is an integer.
- (a) [1] Find a covering congruence with $m_1 > 1$.
- (b) [5] Does there exist a covering congruence with m_1 arbitrarily large? (The largest known value which m_1 can have is 20.)
- (c) [5] Does there exist a covering congruence with each m_i odd?
- (d) [1.5] Show that in a covering congruence,

$$\frac{1}{m_1} + \dots + \frac{1}{m_k} \geq 1.$$

- (e) [2.5] Show that in a covering congruence,

$$\frac{1}{m_1} + \dots + \frac{1}{m_k} > 1.$$

This is equivalent [why?] to saying that there does not exist a covering congruence where every integer can be written *uniquely* in the form $m_i x + a_i$. In other words, the set \mathbb{Z} of integers cannot be written as a *disjoint* union of arithmetic progressions, all with different differences.

111. (a) [2] Evaluate the infinite product

$$\prod_{n=0}^{\infty} (1 + x^{2^n}), \quad |x| < 1.$$

- (b) [3.5] Consider the Taylor series expansion

$$\prod_{n=0}^{\infty} (1 + x^{2^n} + x^{2^{n+1}}) = a_0 + a_1x + \dots$$

The sequence (a_0, a_1, \dots) begins

$$(1, 1, 2, 1, 3, 2, 3, 1, 5, 3, 5, 2, 5, 3, 4, 1, 5, 4, 7, 3, 8, \dots).$$

Show that every positive rational number occurs exactly once among the fractions a_{i+1}/a_i , and moreover these fractions are in lowest terms.

- (c) [3] Let $f(x) = 1/(1 + 2[x] - x)$, and define a sequence x_0, x_1, \dots by $x_0 = 1$ and $x_{n+1} = f(x_n)$ for $n \geq 0$. Show that $x_n = a_{n+1}/a_n$.
112. [1]–[3.5] Color the (x, y) -plane in two colors, i.e., color every point in the plane either red or blue, say. Will there always exist two points at distance one which are the same color? What about three colors? Four colors? Etc.
113. [2.5] Let $f(n)$ be a nonconstant polynomial with integer coefficients. Show that $f(n)$ is composite for infinitely many values of n . (NOTE: It is not known whether there exists a polynomial $g(n)$ of degree greater than one with integer coefficients such that $g(n)$ is prime for infinitely many values of n . However, many polynomials, such as $n^2 + 1$, are conjectured to have this property.)
114. [2.5] What positive real numbers a have the following property? For every continuous function $f(x)$ on the closed interval $[0, 1]$ satisfying $f(0) = f(1) = 0$, there is some value of x for which $f(x) = f(x + a)$.
115. [2.5] Person A writes down one positive real number on each of two slips of paper, so that one of the numbers is twice the other. Person A then turns the slips face down and asks person B to choose a slip. A

agrees to pay B the amount on the slip (in dollars) which B has chosen. After B picks his slip and turns it over, showing a number x , A then says that B if he wants can choose the other slip instead. B reasons as follows: There is a 50% chance that the number on the other slip is $2x$, and a 50% chance it is $x/2$. Therefore the expected amount of money B will receive if he chooses the other slip is $.5x + .5(x/2) = 5x/4 > x$. Thus B should always choose the other slip. Is there a flaw in this reasoning?

116. [3.5] Let x be a positive real number. Show that a square can be tiled with finitely many rectangles similar to a $1 \times x$ rectangle if and only if x is algebraic (satisfies a polynomial equation with integer coefficients) and all its conjugates (the other roots of the polynomial of least degree satisfied by x) have positive real part. For instance, $x = \sqrt{2}$ and $x = 1 + \sqrt{2}$ cannot be done, since the conjugates are $-\sqrt{2} < 0$ and $1 - \sqrt{2} < 0$. However, $x = 2 + \sqrt{2}$ is possible since $2 - \sqrt{2} > 0$.