

Note on a diophantine equation

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a distance. Can this be done with as few as $O(n^{1/2})$ points; or with $O(n^{1/3})$ points in one dimension?

Another open problem [1] is given any n points in the plane (not necessarily lattice points) [or in d dimensions], how many can one select so that the distances which are determined are all distinct? P. ERDÖS and R. K. GUY, Budapest

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Note on a Diophantine Equation

SCHINZEL and SIERPIŃSKI [1] have given the general solution of the diophantine equation

$$(x^2 - 1)(y^2 - 1) = \left[\left(\frac{x - y}{2} \right)^2 - 1 \right]^2,$$

and SZYMICZEK [2] has given the general solution of

$$(x^2 - z^2)(y^2 - z^2) = \left[\left(\frac{y - x}{2} \right)^2 - z^2 \right]^2.$$

The purpose of this paper is to obtain a complete solution of the diophantine equation

$$(x^2 + a)(y^2 + a) = \left[a \left(\frac{y - x}{2b} \right)^2 + b^2 \right]^2, \quad (1)$$

where a and b are any two given integers.

Let $X = x - y$, $Y = x + y$; then $X \equiv Y \pmod{2}$ and (1) becomes

$$b^4 (X^2 + 2XY + Y^2 + 4a)(X^2 - 2XY + Y^2 + 4a) = (aX^2 + 4b^4)^2.$$

This equation reduces to

$$b^4 ((Y^2 - X^2)^2 + 8a(Y^2 - X^2) + 16a^2) = (aX^2 + 4b^4)^2 - 16ab^4X^2$$

and we have

$$b^2 (Y^2 - X^2 + 4a) = \pm (aX^2 - 4b^4).$$

At this point it becomes necessary to find the complete solutions of

$$b^2 (Y^2 - X^2 + 4a) = + (aX^2 - 4b^4) \quad (2)$$

and

$$b^2 (Y^2 - X^2 + 4a) = - (aX^2 - 4b^4) . \quad (3)$$

We shall first solve (2).

Let $(a, b^2) = \gamma^2 \delta$, where δ has no square factors; then $a = \gamma^2 \delta \alpha$ and $b = \gamma \delta \beta$, where $(\beta \delta, \alpha) = 1$.

From (2), we must have

$$\delta \beta^2 \mid \alpha X^2$$

or, equivalently, $X = \delta \beta Z$, for some integer Z . On substituting this value for X and re-arranging the terms in (2), we obtain the equation

$$Y^2 - (\delta \beta^2 + \alpha) \delta Z^2 = -4 \gamma^2 (\delta^2 \beta^2 + \delta \alpha) . \quad (4)$$

If we let

$$c_1^2 d_1 = \delta \beta^2 + \alpha , \quad (5)$$

where d_1 has no square factors, then $(d_1, \delta) = 1$ and therefore, $Y = c_1 d_1 \delta W$, for some integer W . Equation (4) reduces to

$$Z^2 - d_1 \delta W^2 = 4 \gamma^2 . \quad (6)$$

Thus the problem of obtaining all solutions of (2) reduces to the solved problem of finding all solutions of (6). It may be shown similarly that if we let

$$c_2^2 d_2 = \delta \beta^2 - \alpha ,$$

where d_2 has no square factor, then the problem of obtaining all solutions of (3) reduces to the problem of obtaining all solutions of

$$z^2 - d_2 \delta w^2 = -4 \gamma^2 .$$

It is evident that part of the solutions of (1) must be of the form

$$x = (\delta \beta Z + c_1 d_1 \delta W)/2 , \quad y = (c_1 d_1 \delta W - \delta \beta Z)/2 ,$$

where (Z, W) is a solution of (6). If $2 \mid \delta$ or $2 \mid d_1$, it is clear that x and y will both be integers. If $2 \nmid \delta$ and $2 \nmid d_1$, then, by (6), Z and W will be of the same parity. If they are both even, then x and y are integers; if they are both odd, we must have, in order that x and y be integers, that $\beta \equiv c_1 \pmod{2}$. But, from (5),

$$c_1 \equiv \beta + \alpha \pmod{2} ;$$

thus, it is necessary that $\alpha \equiv 0 \pmod{2}$.

Hence, if $2 \mid (d_1 \delta \alpha)$, $(c_1 d_1 \delta W \pm \delta \beta Z)/2$ are integers. If $2 \nmid (d_1 \delta \alpha)$, then $(c_1 d_1 \delta W \pm \delta \beta Z)/2$ will be integers if and only if $2 \mid W$ and $2 \mid Z$.

This same discussion may be applied to what must be the forms of the remaining solutions of (1), that is,

$$x = (\delta \beta z + c_2 d_2 \delta w)/2 , \quad y = (c_2 d_2 \delta w - \delta \beta z)/2 .$$

Thus we have proved the following

Theorem. If $(a, b^2) = \gamma^2 \delta$, where δ has no square factors, and

$$c^2 d = \delta \beta^2 \pm \alpha,$$

where

$$\beta = \frac{b}{\gamma \delta},$$

and

$$\alpha = \frac{a}{\gamma^2 \delta},$$

and d has no square factors, then any solution of (1) must be of the form

$$x = (c d \delta W + \delta \beta Z)/2, \quad y = (c d \delta W - \delta \beta Z)/2,$$

where (Z, W) is a solution of

$$Z^2 - d \delta W^2 = \pm 4 \gamma^2$$

and $2 \mid (\alpha \delta d)$; if $2 \nmid (\alpha \delta d)$, then any solution of (1) must be of the form

$$x = c d \delta W + \delta \beta Z, \quad y = c d \delta W - \delta \beta Z,$$

where (Z, W) is a solution of

$$Z^2 - d \delta W^2 = \pm \gamma^2.$$

This theorem has the following

Corollary. The equation

$$(x^2 + a)(y^2 + a) = (az^2 + b^2)^2, \quad (7)$$

where a and b are integers, has integer solutions given by

$$x = b u + c d v, \quad y = b u - c d v, \quad z = u,$$

provided

$$b^2 \pm a = c^2 d,$$

where d has no square factors, and u and v are given by

$$u^2 - d v^2 = \pm 1.$$

It is not known to the author whether there are values of a and b for which the above result provides all the solutions to the equation (7); however, the equation (7) with $a = b = 1$, which was originally suggested to the author by L. J. MORDELL, has no solutions other than those predicted by the foregoing method for all integers x and y , where $1 \leq x \leq 300$ and $1 \leq y \leq x$.

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