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On the negative Pell equation $y^2 = 42x^2 - 6$

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Abstract
The binary quadratic equation represented by the negative Pellian $y^2 = 42x^2 - 6$ is analyzed for its distinct integer solutions. A few interesting relations among the solutions are given. Further, employing the solutions of the above hyperbola, we have obtained solutions of other choices of hyperbolas, parabolas and special Pythagorean triangle.

Keywords: Binary quadratic, hyperbola, parabola, integral solutions, pell equation

1. Introduction

Diophantine equation of the form $y^2 = Dx^2 + 1$, where D is a given positive square-free integer is known as Pell equation and is one of the oldest Diophantine equation that has interesting mathematicians all over the world, since antiquity, J.L. Lagrange proved that the positive Pell equation $y^2 = Dx^2 + 1$ has infinitely many distinct integer solutions whereas the negative Pell equation $y^2 = Dx^2 - 1$ does not always have a solution. In [1], an elementary proof of a ceriterium for the solvability of the Pell equation $x^2 - Dy^2 = -1$ where D is any positive non-square integer has been presented. For examples the equations $y^2 = 3x^2 - 1$, $y^2 = 7x^2 - 4$ have no integer solution whereas $y^2 = 54x^2 - 1$, $y^2 = 202x^2 - 1$ have integer solutions. In this context, one may refer [2-17]. More specifically, one may refer "The on-line encyclopaedia of integer sequences" (A031396, A130226, A031398) for values of D for which the negative Pell equation $y^2 = Dx^2 - 1$ is solvable. In this communication, we present a problem of binary quadratic equation represented by the negative Pellian $y^2 = 42x^2 - 6$ is analyzed for its distinct integer solutions. A few interesting relations among the solutions are given. Further, employing the solutions of the above hyperbola, we have obtained solutions of other choices of hyperbolas, parabolas and special Pythagorean triangle.

Method of analysis

The negative Pell equation representing hyperbola under consideration is

$$y^2 = 42x^2 - 6 \tag{1}$$

Whose smallest positive integer solution is $x_0 = 1, y_0 = 6$.

To obtain the other solutions of (1), consider the pell equation $y^2 = 42x^2 - 6$ whose solution is given by

$$\tilde{x}_n = \frac{1}{2\sqrt{42}} g_n$$

$$\tilde{y}_n = \frac{1}{2} f_n$$

Where,

$$f_n = \left(13 + 2\sqrt{42}\right)^{n+1} + \left(13 - 2\sqrt{42}\right)^{n+1}$$

$g_n = \left(13+2\sqrt{42}\right)^{n+1} - \left(13-2\sqrt{42}\right)^{n+1}$

Applying Brahamagupta Lemma between (x_0, y_0) and $(\tilde{x}_n, \tilde{y}_n)$, the other integer solutions of (1) are given by

$$x_{n+1} = \frac{1}{2} f_n + \frac{3}{\sqrt{42}} g_n,$$

$$y_{n+1} = 3 f_n + \frac{21}{\sqrt{42}} g_n, \text{ where n= -1,0,1,…..}$$

The recurrence relations satisfied by the solutions x and y are given by

$$26x_{n+2} - x_{n+1} - x_{n+3} = 0,$$

$$26y_{n+2} - y_{n+1} - y_{n+3} = 0.$$

Some numerical examples of x and y satisfying (1) are given in the table1 below:

Table 1: Examples

N	x_n	y_n
0	1	6
1	25	162
2	649	4206
3	16849	109194

From the above table, we observe some interesting relations among the solutions which are presented below.

1) Both the values of x_n and y_n are odd &even.
2) Each of the following expressions is a nasty number.

- $162x_{2n+2} - 6x_{2n+3} + 12$
- $\frac{2103x_{2n+2} - 3x_{2n+4} + 156}{13}$
- $4206x_{2n+3} - 162x_{2n+4} + 12$
- $\frac{2100x_{n+2} - 12y_{2n+3} + 156}{13}$
- $\frac{9086x_{2n+2} - 2y_{2n+4} + 4044}{337}$
- $2100x_{2n+3} - 324y_{2n+3} + 12$
- $\frac{84x_{2n+3} - 324y_{2n+2} + 26}{13}$
- $\frac{54516x_{2n+3} - 324y_{2n+4} + 156}{13}$
- $54516x_{2n+4} - 8412y_{2n+4} + 12$
- $y_{2n+3} - 25y_{2n+2} + 12$
- $\frac{252x_{2n+4} - 25236y_{2n+3} + 2022}{1011}$
- $\frac{6300y_{2n+4} - 25236y_{2n+3} + 468}{39}$
- $\frac{6y_{2n+4} - 3894y_{2n+2} + 1872}{156}$
- $\frac{3150y_{2n+4} - 81774y_{2n+3} + 1512}{126}$

3) Each of the following expressions is a cubical integer:

- $(27x_{3n+3}-x_{3n+4})+3(27x_{n+1}-x_{n+2})$
- $676(701x_{3n+3}-x_{3n+5})+2028(701x_{n+1}-x_{n+3})$
- $338(175x_{3n+3}-y_{3n+4})+1014(175x_{n+1}-y_{n+2})$
- $227138(4543x_{3n+3}-y_{3n+5})+68144(4543x_{n+1}-y_{n+3})$
- $36(4206x_{3n+4}-162x_{3n+5})+108(4206x_{n+2}-162x_{n+3})$
- $169(14x_{3n+4}-54y_{3n+3})+507(14x_{n+2}-54y_{n+1})$
- $(350x_{3n+4}-54y_{3n+4})+3(350x_{n+2}-54y_{n+2})$
- $169(9086x_{3n+4}-54y_{3n+5})+507(9086x_{n+2}-54y_{n+3})$
- $1022121(42x_{3n+5}-4206y_{3n+3})+3066363(42x_{n+3}-4206y_{n+1})$
- $1521(1050x_{3n+5}-4206y_{3n+4})+4563(1050x_{n+3}-4206y_{n+2})$
- $(9086x_{3n+5}-1402y_{3n+5})+3(9086x_{n+3}-1402y_{n+3})$
- $36(y_{3n+4}-25y_{3n+3})+108(y_{n+2}-25y_{n+1})$
- $24336(y_{3n+5}-649y_{3n+3})+73008(y_{n+3}-649y_{n+1})$
- $15876(525y_{3n+5}-13629y_{3n+4})+47628(525y_{n+3}-13629y_{n+2})$

4) Relations among the solutions:

- $2x_{n+3}=52x_{n+2}-2x_{n+1}$
- $6y_{n+1}=3x_{n+2}-39x_{n+1}$
- $6y_{n+2}=39x_{n+2}-3x_{n+1}$
- $6y_{n+3}=1011x_{n+2}-39x_{n+1}$
- $312x_{n+2}=12x_{n+1}+12x_{n+3}$
- $156y_{n+1}=3x_{n+3}-1011x_{n+1}$
- $156y_{n+2}=39x_{n+3}-39x_{n+1}$
- $156y_{n+3}=1011x_{n+3}-3x_{n+1}$
- $78x_{n+2}=6x_{n+1}-12y_{n+2}$
- $78x_{n+3}=78x_{n+1}-312y_{n+2}$
- $39y_{n+1}=3y_{n+2}-252x_{n+1}$
- $39y_{n+3}=252x_{n+1}+1011y_{n+2}$
- $2022x_{n+2}=78x_{n+1}+12y_{n+3}$
- $2022x_{n+3}=6x_{n+1}+312y_{n+3}$
- $1011y_{n+1}=3y_{n+3}-6552x_{n+1}$
- $6y_{n+1}=39x_{n+3}-1011x_{n+2}$
- $6y_{n+2}=3x_{n+3}-39x_{n+2}$
- $6y_{n+3}=39x_{n+3}-3x_{n+2}$
- $78x_{n+1}=6x_{n+2}-12y_{n+1}$
- $78x_{n+3}=2022x_{n+2}+12y_{n+1}$
- $39y_{n+2}=252x_{n+2}+3y_{n+1}$
- $39y_{n+3}=3065039y_{n+1}-729048x_{n+2}$
- $6x_{n+3}=12y_{n+2}+78x_{n+2}$
- $3y_{n+3}=252x_{n+2}+39y_{n+2}$
- $6x_{n+1}=2022x_{n+2}-12y_{n+3}$

- $78x_{n+3} = 12y_{n+3} + 6x_{n+2}$
- $39y_{n+1} = 39y_{n+3} - 6552x_{n+2}$
- $2022x_{n+1} = 78x_{n+3} - 8100y_{n+1}$
- $2022x_{n+2} = 2022x_{n+3} - 210288y_{n+1}$
- $1011y_{n+2} = 6552x_{n+3} - 681411y_{n+1}$
- $1011y_{n+3} = 170100x_{n+3} - 17690439y_{n+1}$
- $39y_{n+1} = 1011y_{n+2} - 252x_{n+3}$
- $39y_{n+3} = 252x_{n+3} + 3y_{n+2}$
- $6x_{n+1} = 52494x_{n+3} - 8100y_{n+3}$
- $6x_{n+2} = 1362822x_{n+3} - 210288y_{n+3}$
- $3y_{n+1} = 170100x_{n+3} - 26247y_{n+3}$
- $3y_{n+2} = 4416048x_{n+3} - 681411y_{n+3}$
- $2184x_{n+1} = y_{n+3} - 337y_{n+1}$
- $2184x_{n+3} = 337y_{n+3} - y_{n+1}$
- $2184x_{n+2} = 13y_{n+3} - 13y_{n+1}$
- $1092y_{n+2} = 42y_{n+3} + 42y_{n+1}$
- $84x_{n+1} = y_{n+2} - 13y_{n+1}$
- $84x_{n+2} = 13y_{n+2} - y_{n+1}$
- $2x_{n+3} = 337y_{n+2} - 13y_{n+1}$
- $42y_{n+3} = 1092y_{n+2} - 42y_{n+1}$
- $252x_{n+3} = 39y_{n+3} - 3y_{n+2}$
- $126y_{n+1} = 3276y_{n+2} - 126y_{n+3}$

Remarkable observations

1. Employing linear combinations among the solutions of (1), one may generate integer solutions for other choices of hyperbolas which are presented in the table 2 below.

Table 2: Hyperbolas

S. No	(X,Y)	Hyperbola
1	$(x_{n+2} - 25x_{n+1}, 27x_{n+1} - x_{n+2})$	$6Y_n^2 - 7X_n^2 = 24$
2	$(x_{n+3} - 649x_{n+1}, 701x_{n+1} - x_{n+3})$	$36Y_n^2 - 42X_n^2 = 97344$
3	$(y_{n+2} - 162x_{n+1}, 175x_{n+1} - y_{n+2})$	$6Y_n^2 - 7X_n^2 = 1014$
4	$(y_{n+3} - 4206x_{n+1}, 4543x_{n+1} - y_{n+3})$	$36Y_n^2 - 42X_n^2 = 4088484$
5	$(25x_{n+3} - 649x_{n+2}, 4206x_{n+2} - 162x_{n+3})$	$Y_n^2 - 42X_n^2 = 144$
6	$(25y_{n+1} - 6x_{n+2}, 14x_{n+2} - 54y_{n+1})$	$9Y_n^2 - 42X_n^2 = 6084$
7	$(25y_{n+2} - 162x_{n+2}, 350x_{n+2} - 54y_{n+2})$	$Y_n^2 - 42X_n^2 = 36$
8	$(25y_{n+3} - 4206x_{n+2}, 9086x_{n+2} - 54y_{n+3})$	$9Y_n^2 - 42X_n^2 = 6084$
9	$(6x_{n+3} - 649y_{n+1}, 42x_{n+3} - 4206y_{n+1})$	$Y_n^2 - 42X_n^2 = 4088484$
10	$(649y_{n+2} - 162x_{n+3}, 1050x_{n+3} - 4206y_{n+2})$	$Y_n^2 - 42X_n^2 = 6084$
11	$(4206x_{n+3} - 649y_{n+3}, 9086x_{n+3} - 1402y_{n+3})$	$9Y_n^2 - 42X_n^2 = 36$
12	$(701y_{n+1} - y_{n+3}, y_{n+3} - 649y_{n+1})$	$49Y_n^2 - 42X_n^2 = 4769856$
13	$(27y_{n+1} - y_{n+2}, y_{n+2} - 25y_{n+1})$	$6Y_n^2 - 7X_n^2 = 24$
14	$(2103y_{n+2} - 81y_{n+3}, 525y_{n+3} - 13629y_{n+3})$	$Y_n^2 - 42X_n^2 = 63504$

2. Employinglinear combinations among the solutions of (1), one may generate integer solutions for other choices of parabolas which are presented in the table 2 below.

Table 3: Parabolas

S. No	(X,Y)	Parabola
1	$\left(x_{n+2}-25x_{n+1}, 27x_{2n+2}-x_{2n+3}\right)$	$6Y_n - 7X_n^2 = 12$
2	$\left(x_{n+3}-649x_{n+1}, 701x_{2n+2}-x_{2n+4}\right)$	$936Y_n - 42X_n^2 = 48672$
3	$\left(y_{n+2}-162x_{n+1}, 175x_{2n+2}-y_{2n+3}\right)$	$234Y_n - 42X_n^2 = 3042$
4	$\left(y_{n+3}-4206x_{n+1}, 4543x_{2n+2}-y_{2n+4}\right)$	$1011Y_n - 7X_n^2 = 340707$
5	$\left(25x_{n+3}-649x_{n+2}, 4206x_{2n+3}-162x_{2n+4}\right)$	$6Y_n - 42X_n^2 = 72$
6	$\left(25y_{n+1}-6x_{n+2}, 14x_{2n+3}-54y_{2n+2}\right)$	$117\,Y_n - 42\,X_n^2 = 3042$
7	$\left(25y_{n+2}-162x_{n+2}, 350x_{2n+3}-54y_{2n+3}\right)$	$Y_n - 42X_n^2 = 18$
8	$\left(25y_{n+3}-4206x_{n+2}, 9086x_{2n+3}-54y_{2n+4}\right)$	$117Y_n - 42X_n^2 = 3042$
9	$\left(6x_{n+3}-649y_{n+1}, 42x_{2n+4}-4206y_{2n+3}\right)$	$1011Y_n - 42X_n^2 = 2044242$
10	$\left(649y_{n+2}-162x_{n+3}, 1050x_{2n+4}-4206y_{2n+3}\right)$	$Y_n - 42X_n^2 = 6084$
11	$\left(4206x_{n+3}-649y_{n+3}, 9086x_{2n+4}-1402y_{2n+4}\right)$	$9Y_n - 42X_n^2 = 18$
12	$\left(701y_{n+1}-y_{n+3}, y_{2n+4}-649y_{2n+2}\right)$	$7644Y_n - 42X_n^2 = 2384928$
13	$\left(27y_{n+1}-y_{n+2}, y_{2n+3}-25y_{2n+2}\right)$	$7Y_n - X_n^2 = 84$
14	$\left(2103y_{n+2}-81y_{n+3}, 525y_{2n+4}-13629y_{2n+3}\right)$	$126Y_n - 42X_n^2 = 31752$

3. Consider $m = x_{n+1} + y_{n+1}, n = x_{n+1}$, observe that $m > n > 0.$ Treat m, n as the generators of the pythagorean triangle T (α, β, γ),

$\alpha = 2mn$, $\beta = m^2 - n^2$, $\gamma = m^2 + n^2$.

Then the following interesting relations are observed.

a) $\alpha - 21\beta + 20\gamma = 6$

b) $22\alpha - \gamma + 84\dfrac{A}{P} = 6$

c) $\dfrac{2A}{P} = x_{n+1}y_{n+1}$

Conclusion

In this paper, we have presented infinitely many integer solutions for all hyperbola represented by the negative pell equation $y^2 = 42x^2 - 6$. As the binary quadratic Diophantine equations are rich in variety, one may search for the other choices of negative pell equations and determine their integer solutions along with suitable properties.

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