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Exercise 6.8

Q1. Find an equation of each of the following curves with respect to new parallel axis obtained by shifting the origin to the indicated point.

i. $\mathbf{x^2 + 16y - 16 = 0}$ $\mathbf{O'(0,1)}$

Solution

Equation of transformation are

$$x = x + 0, \quad y = y + 1$$

Substituting these values of x,y into above we have

$$x^2 + 16(y + 1) - 16 = 0$$

$$x^2 + 16y + 16 - 16 = 0$$

$$x^2 + 16y = 0$$

ii. $\mathbf{4x^2 + y^2 + 16x - 10y + 37 = 0}$ $\mathbf{O'(-2,5)}$

Solution

$$4x^2 + y^2 + 16x - 10y + 37 = 0$$

Equation of transformation are

$$x = x - 2, \quad y = y + 5$$

Substituting these values of x,y into above we have

$$4(x - 2)^2 + (y + 5)^2 + 16(x - 2) - 10(y + 5) + 37 = 0$$

$$4(x^2 - 4x + 4) + (y^2 + 10y + 25) + 16x - 32 - 10y - 50 + 37 = 0$$

$$4x^2 - 16x + 16 + y^2 + 10y + 25 + 16x - 10y - 45 = 0$$

$$4x^2 + y^2 - 4 = 0$$

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iii. $\mathbf{9x^2 + 4y^2 + 18x - 16y - 11 = 0}$ $\mathbf{O'(-1, 2)}$

Solution

$$9x^2 + 4y^2 + 18x - 16y - 11 = 0$$

Equation of transformation are

$$x = x - 1, \quad y = y + 2$$

Substituting these values of x,y into above we have

$$9(x-1)^2 + 4(y+2)^2 + 18(x-1) - 16(y+2) - 11 = 0$$

$$9(x^2 - 2x + 1) + 4(y^2 + 4y + 4) + 18x - 18 - 16y - 32 - 11 = 0$$

$$9x^2 - 18x + 9 + 4y^2 + 16y + 16 + 18x - 16y - 61 = 0$$

$$49 + 4y^2 - 36 = 0$$

iv. $\mathbf{x^2 - y^2 + 4x + 8y - 11 = 0}$ $\mathbf{O'(-2, 4)}$

Solution

$$x^2 - y^2 + 4x + 8y - 11 = 0$$

Equation of transformation are

$$x = x - 2, \quad y = y + 4$$

Substituting these values of x,y into above we have

$$(x-2)^2 - (y+4)^2 + 4(x-2) + 8(y+4) - 11 = 0$$

$$(x^2 - 4x + 4) - (y^2 + 8y + 16) + 4x - 8 + 8y + 32 - 11 = 0$$

$$x^2 - 4x + 4 - y^2 - 8y - 16 + 4x + 8y + 13 = 0$$

$$x^2 - y^2 + 1 = 0$$

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v. $9x^2 - 4y^2 + 36x + 8y - 4 = 0 \qquad O'(-2, 1)$

Solution

$$9 - 4y^2 + 36x + 8y - 4 = 0$$

Equation of transformation are

$$X = x - 2,$$

$$y = y + 1$$

Substituting these values of x,y into above we have

$$9(x-2)^2 - 4(y+1)^2 + 36(x-2) + 8(y+1) - 4 = 0$$

$$9(x^2 - 4x + 4) - 4(y^2 + 2y + 1) + 36x - 72 + 8y + 8 - 4 = 0$$

$$9x^2 - 36x + 36 - 4y^2 - 8y - 4 + 36x - 72 + 8y - 4 = 0$$

$$9x^2 - 4y^2 - 36 = 0$$

Q2. Find coordinates of the new origin (axis remaining parallel) so that first degree terms are removed from the transformed equation of each 0f the following also find the transformed equations.

i. $3x^2 - 2y^2 + 24x + 12y + 24 = 0$

Solution

Let the coordinates of the new origin $O'(h, k)$ equations of transformation are

$$X = x + h, \quad y = y + k$$

Substituting these values of x,y into above we have

$$3(x+h)^2 - 2(y+k)^2 + 24(x+h) + 12(y+k) + 24 = 0$$

$$3(x^2 + 2hx + h^2) - 2(y^2 + 2yk + k^2) + 24x + 24h + 12y + 12k + 24 = 0$$

$$3x^2 + 6xh + 3h^2 - 2y^2 - 4yk - 2k^2 + 24x + 24h + 12y + 12k + 24 = 0$$

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$$3x^2 - 2y^2 + x(6h + 24) - y(4k - 12) + 3h^2 - 2k^2 + 24h + 12k + 24 = 0$$

(h, k) to be chosen that first degree terms are removed from the transformed equation

$$6h + 24 = 0 \qquad 4k - 12 = 0$$

$$h + 4 = 0 \qquad k - 3 = 0$$

$$h = -4 \qquad k = 3$$

thus $(h, k) = (-4,3)$

putting (h, k) into above, the transformed equation

$$3x^2 - 2y^2 + x(0) - y(0) + 3(-4)^2 - 2(3)^2 + 24(-4) + 12(3) + 24 = 0$$

$$3x^2 - 2y^2 + 48 - 18 - 96 + 36 + 24 = 0$$

$$3x^2 - 2y^2 - 6 = 0$$

ii. $\mathbf{25x^2 + 9y^2 + 50x - 36y - 164 = 0}$

Solution

Let the coordinates of the new origin $O'(h, k)$ equations of transformation are

$$X = x + h, \quad y = y + k$$

Substituting these values of x,y into above we have

$$25(x + h)^2 + 9(y + k)^2 + 50(x + h) - 36(y + k) - 164 = 0$$

$$25(x^2 + 2hx + h^2) + 9(y^2 + 2yk + k^2) + 50x + 50h - 36y - 36k - 164 = 0$$

$$25x^2 + 50xh + 25h^2 + 9y^2 + 18yk + 9k^2 + 50x + 50h - 36y - 36k - 164 = 0$$

$$25x^2 + 9y^2 + x(50h + 50) + y(18k - 36) + 25h^2 + 9k^2 + 50h - 36k - 164 = 0$$

(h, k) to be chosen that first degree terms are removed from the transformed equation

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$50h + 50 = 0$ $\qquad$ $18k - 36 = 0$

$h + 1 = 0$ $\qquad$ $k - 2 = 0$

$h = -1$ $\qquad$ $k = 2$

thus $(h, k) = (-1,2)$

putting (h, k) into above, the transformed equation is

$$25x^2 + 9y^2 + x(0) - y(0) + 25(-1)^2 + 9(2)^2 + 50(-1) - 36(2) - 164 = 0$$

$$25x^2 + 9y^2 + 25 + 36 - 50 - 72 - 164 = 0$$

$$25x^2 + 9y^2 - 225 = 0$$

iii. $\mathbf{x^2 - y^2 - 6x + 2y + 7 = 0}$

Solution

Let the coordinates of the new origin $O'(h, k)$ equations of transformation are

$$X = x + h, \quad y = y + k$$

Substituting these values of x,y into above we have

$$(x + h)^2 - (y + k)^2 - 6(x + h) + 2(y + k) + 7 = 0$$

$$(x^2 + 2hx + h^2) - (y^2 + 2yk + k^2) - 6x - 6h + 2y + 2k + 7 = 0$$

$$x^2 - y^2 + x(2h - 6) - y(2k - 2) + h^2 - k^2 - 6h + 2k + 7 = 0$$

(h, k) to be chosen that first degree terms are removed from the transformed equation

$2h - 6 = 0$ $\qquad$ $2k - 2 = 0$

$h - 3 = 0$ $\qquad$ $k - 1 = 0$

$h = 3$ $\qquad$ $k = 1$

thus $(h, k) = (3,1)$

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putting (h, k) into above, the transformed equation

$$x^2 - y^2 + x(0) - y(0) + (3)^2 - (1)^2 - 6(3) + 2(1) + 7 = 0$$

$$x^2 - y^2 + 9 - 1 - 18 + 2 + 7 = 0$$

$$x^2 - y^2 - 1 = 0$$

Q3. In each of the following, find an equation of the curve referred to the new axis obtained by rotation of axis about the origin through the given angle.

i. $\mathbf{xy = 1}$ $\mathbf{\theta = 45°}$

Solution

Equation o transformation are

$$x = x\cos\theta - y\sin\theta = x\cos 45° - y\sin 45°$$

$$= x\left(\frac{1}{\sqrt{2}}\right) - y\left(\frac{1}{\sqrt{2}}\right) = \frac{x-y}{2}$$

$$y = x\sin\theta + y\cos\theta = x\sin 45° + y\cos 45°$$

$$= x\left(\frac{1}{\sqrt{2}}\right) - y\left(\frac{1}{\sqrt{2}}\right) = \frac{x+y}{2}$$

Substituting these expressions for x and y into (1), we have

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

$\Rightarrow$ $x^2 - y^2 = 2$ is the required equation.

ii. $\mathbf{7x^2 - 8xy + y^2 - 9 = 0}$ $\mathbf{\theta = \arctan 2}$

Solution

$$7x^2 - 8xy + y^2 - 9 = 0 \qquad \text{----------} (1)$$

$\Rightarrow$ $\tan\theta = 2$ $\sin\theta = \frac{2}{\sqrt{5}}$ $\cos\theta = \frac{1}{\sqrt{5}}$

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Equation of transformation are

$$x = x\cos\theta - y\sin\theta = x\left(\frac{1}{\sqrt{5}}\right) - y\left(\frac{2}{\sqrt{5}}\right) = \frac{x-2y}{\sqrt{5}}$$

$$y = x\sin\theta + y\cos\theta = x\left(\frac{2}{\sqrt{5}}\right) - y\left(\frac{1}{\sqrt{5}}\right) = \frac{2x+y}{\sqrt{5}}$$

Substituting these expressions for x and y into (1), we have

$\Rightarrow \quad 7(\frac{x-2y}{\sqrt{5}})^2 - 8(\frac{x-2y}{\sqrt{5}})(\frac{2x+y}{\sqrt{5}}) + (\frac{2x+y}{\sqrt{5}})^2 - 9 = 0$

$\Rightarrow \quad \frac{7}{5}(x^2 - 4xy + 4y^2) - \frac{8}{5}(2x^2 + xy - 4xy - 2y^2) + \frac{1}{5}(4x^2 + 4xy + y^2) - 9 = 0$

$\Rightarrow \quad 7x^2 - 28xy + 28y^2 - 16x^2 + 24xy + 16y^2 + 4x^2 + 4xy + y^2 - 45 = 0$

$\Rightarrow \quad -5x^2 + 45y^2 - 45 = 0$

$\Rightarrow \quad x^2 - 9y^2 + 9 = 0$ is the required equation.

iii. $\mathbf{9x^2 + 12xy + 4y^2 - x - y = 0} \qquad \mathbf{\theta = \arctan\frac{2}{3}}$

Solution

$$9x^2 + 12xy + 4y^2 - x - y = 0 \qquad \text{---------- (1)}$$

$\Rightarrow \quad \tan\theta = \frac{2}{3} \quad \sin\theta = \frac{2}{\sqrt{13}} \qquad \cos\theta = \frac{3}{\sqrt{13}}$

Equation of transformation are

$$x = x\cos\theta - y\sin\theta = x\left(\frac{3}{\sqrt{13}}\right) - y\left(\frac{2}{\sqrt{13}}\right) = \frac{3x-2y}{\sqrt{13}}$$

$$y = x\sin\theta + y\cos\theta = x\left(\frac{2}{\sqrt{13}}\right) - y\left(\frac{3}{\sqrt{13}}\right) = \frac{2x+3y}{\sqrt{13}}$$

Substituting these expressions for x and y into (1), we have

$\Rightarrow \quad 9(\frac{3x-2y}{\sqrt{13}})^2 + 12\left(\frac{3x-2y}{\sqrt{13}}\right)\left(\frac{2x+3y}{\sqrt{13}}\right) + 4\left(\frac{2x+3y}{\sqrt{13}}\right)^2 - (\frac{3x-2y}{\sqrt{13}}) - (\frac{2x+3y}{\sqrt{13}}) = 0$

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$$\frac{9}{13}(9x^2 - 12xy + 4y^2) + \frac{12}{13}(6x^2 + 9xy - 4xy - 6y^2) + \frac{4}{13}(4x^2 + 12xy + 9y^2) - \frac{2x + 3y}{\sqrt{13}} - \left(\frac{3x - 2y}{\sqrt{13}}\right) = 0$$

$$81x^2 - 108xy + 36y^2 + 72x^2 + 60xy - 72y^2 + 16x^2 + 48xy + 36y^2 - 3\sqrt{13}x + 2\sqrt{13}y - 2\sqrt{13}x - 3\sqrt{13}y = 0$$

$$169x^2 - 5\sqrt{13}x - \sqrt{13}y = 0$$

Divide by $\sqrt{13}$

$\Rightarrow$ $13\sqrt{13}x^2 - 5x - y = 0$ is the required equation.

iv. $\mathbf{x^2 - 2xy + y^2 - 2\sqrt{2}x - 2\sqrt{2}y + 2 = 0}$ $\qquad$ $\mathbf{\theta = 45°}$

Solution

$$x^2 - 2xy + y^2 - 2\sqrt{2}x - 2\sqrt{2}y + 2 = 0 \quad \text{---------- (1)}$$

$\Rightarrow$ $\theta = 45°$ $\quad \sin\theta = \frac{1}{\sqrt{2}}$ $\qquad$ $\cos\theta = \frac{1}{\sqrt{2}}$

Equation of transformation are

$$x = x\cos\theta - y\sin\theta = x\left(\frac{1}{\sqrt{2}}\right) - y\left(\frac{1}{\sqrt{2}}\right) = \frac{x-y}{\sqrt{2}}$$

$$y = x\sin\theta + y\cos\theta = x\left(\frac{1}{\sqrt{2}}\right) - y\left(\frac{1}{\sqrt{2}}\right) = \frac{x+y}{\sqrt{2}}$$

Substituting these expressions for x and y into (1), we have

$\Rightarrow$ $$\left(\frac{x-y}{\sqrt{2}}\right)^2 - 2\left(\frac{x-y}{\sqrt{2}}\right)\left(\frac{x+y}{\sqrt{2}}\right) + \left(\frac{x+y}{\sqrt{2}}\right)^2 - 2\sqrt{2}\left(\frac{x-y}{\sqrt{2}}\right) - 2\sqrt{2}\left(\frac{x+y}{\sqrt{2}}\right) + 2 = 0$$

$$\frac{1}{2}(x^2 - 2xy + y^2) - (x^2 - y^2) + \frac{1}{2}(x^2 + 2xy + y^2) - 2(x - y) - 2(x + y) + 2 = 0$$

$$x^2 - 2xy + y^2 - x^2 + 2y^2 + x^2 + 2xy + y^2 - 4x + 4y - 4x - 4y + 4 = 0$$

$\Rightarrow$ $4y^2 - 8x + 4 = 0$

$\Rightarrow$ $y^2 - 2x + 1 = 0$ is the required equation.

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Q4. Find measure of the angle through which the axis by stated so that the product of term xy is removed from the transformed equation. Also find the transformation equation.

i. $2x^2 + 6xy + 10y^2 - 11 = 0$

Solution

Let the axis be stated through an angle θ. Equations of transformation are

$$x = x\cos\theta - y\sin\theta, \qquad y = x\sin\theta + y\cos\theta$$

substituting into the given equation, we get

$\Rightarrow \quad 2(x\cos\theta - y\sin\theta)^2 + 6(x\cos\theta - y\sin\theta)(x\sin\theta + y\cos\theta) + 10(x\sin\theta + y\cos\theta)^2 - 11 = 0$

$2(x^2\cos^2\theta - 2xy\sin\theta\cos\theta + y^2\sin^2\theta) + 6(x^2\cos\theta\sin\theta + xy\cos^2\theta - xy\sin^2\theta - y^2\sin\theta\cos\theta) + 10(x^2\sin^2\theta + 2xy\sin\theta\cos\theta + y^2\cos^2\theta) - 11 = 0$ ---------- (1)

Since this equation is to be free the product term xy, the coefficient of xy is zero. i.e.

$\Rightarrow \quad -4\sin\theta\cos\theta + 6(\cos^2\theta - \sin^2\theta) + 20\sin\theta\cos\theta = 0$

$\Rightarrow \quad 6\cos 2\theta + 16\sin\theta\cos\theta = 0$

$\Rightarrow \quad 6\cos 2\theta + 8\sin 2\theta = 0$

$\Rightarrow \quad 6\cos 2\theta = -8\sin 2\theta$

$\Rightarrow \quad \tan 2\theta = -\frac{3}{4} \qquad \frac{2\tan\theta}{1-\tan^2\theta} = -\frac{3}{4}$

$\Rightarrow \quad 8\tan\theta = -3(1 - \tan^2\theta) \qquad 8\tan\theta = -3 + 3\tan^2\theta$

$\Rightarrow \quad 3\tan^2\theta - 8\tan\theta - 3 = 0$

$\Rightarrow \quad 3\tan^2\theta - 9\tan\theta + \tan\theta - 3 = 0$

$\Rightarrow \quad 3\tan\theta(\tan\theta - 3) + (\tan\theta - 3) = 0$

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$\Rightarrow \quad (\tan\theta - 3)(3\tan\theta + 1) = 0$

$\Rightarrow \quad (\tan\theta - 3) = 0 \qquad 3\tan\theta + 1 = 0$

$\Rightarrow \quad \tan\theta = 3 \qquad \tan\theta = -\frac{1}{3}$

since θ lies in the first quadrant,

$\tan\theta = -\frac{1}{3}$ is not admissible

$\tan\theta = 3 \quad \Rightarrow \sin\theta = \frac{3}{\sqrt{10}}, \qquad \cos\theta = \frac{1}{\sqrt{10}}$

substituting the values in (1), the transformed equation is.

$$2(x^2\left(\frac{1}{\sqrt{10}}\right)^2 + y^2\left(\frac{3}{\sqrt{10}}\right)^2) + 6(x^2(\frac{1}{\sqrt{10}})(\frac{3}{\sqrt{10}}) - y^2(\frac{3}{\sqrt{10}})(\frac{1}{\sqrt{10}})) + 10(x^2(\frac{3}{\sqrt{10}})^2 + y^2(\frac{1}{\sqrt{10}})^2) - 11 = 0$$

$$2(\frac{1}{10}x^2 + \frac{9}{10}y^2) + 6(\frac{3}{10}x^2 - \frac{3}{10}y^2) + 10(\frac{9}{10}x^2 + \frac{1}{10}y^2) - 11 = 0$$

$$\Rightarrow \quad \frac{2}{10}x^2 + \frac{18}{10}y^2 + \frac{18}{10}x^2 - \frac{18}{10}y^2 + \frac{90}{10}x^2 + \frac{10}{10}y^2 - 11 = 0$$

$$\left(\frac{2}{10} + \frac{18}{10} + \frac{90}{10}\right)x^2 + \left(\frac{18}{10} - \frac{18}{10} + \frac{10}{10}\right)y^2 - 11 = 0$$

$$\Rightarrow \quad \frac{110}{10}x^2 + y^2 - 11 = 0$$

$$\Rightarrow \quad 11x^2 + y^2 - 11 = 0$$

ii. $\mathbf{xy + 4x - 3y - 10 = 0}$

Solution

Let the axis be stated through an angle θ. Equations of transformation are

$$x = x\cos\theta - y\sin\theta, \qquad y = x\sin\theta + y\cos\theta$$

Substituting into the given equation, we get

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$(x\cos\theta - y\sin\theta)(x\sin\theta + y\cos\theta) + 4(x\cos\theta - y\sin\theta) - 3(x\sin\theta + y\cos\theta) - 10 = 0$

$(x^2\cos\theta\sin\theta + xy\cos^2\theta - xy\sin^2\theta - y^2\sin\theta\cos\theta) + 4x\cos\theta - 4y\sin\theta - 3x\sin\theta - 3y\cos\theta - 10 = 0$ ---------- (1)

Since this equation is to be free the product term xy, the coefficient of xy is zero.
i.e.

$\Rightarrow \quad \cos^2\theta - \sin^2\theta = 0 \qquad \cos^2\theta = \sin^2\theta$

$\Rightarrow \quad \tan^2\theta = 1 \qquad \tan\theta = 1$

$\Rightarrow \quad \theta = 45°$

putting value in (1), the transformed equation is

$(x^2\cos 45°\sin 45° - y^2\sin 45°\cos 45°) + 4x\cos 45° - 4y\sin 45° - 3x\sin 45° - 3y\cos 45° - 10 = 0$

$x^2\left(\frac{1}{\sqrt{2}}\right)\left(\frac{1}{\sqrt{2}}\right) - y^2\left(\frac{1}{\sqrt{2}}\right)\left(\frac{1}{\sqrt{2}}\right) + 4x\left(\frac{1}{\sqrt{2}}\right) - 4y\left(\frac{1}{\sqrt{2}}\right) - 3x\left(\frac{1}{\sqrt{2}}\right) - 3y\left(\frac{1}{\sqrt{2}}\right) - 10 = 0$

$\frac{1}{2}x^2 - \frac{1}{2}y^2 + x\left(\frac{1}{\sqrt{2}}\right) - y\left(\frac{7}{\sqrt{2}}\right) - 10 = 0$

$x^2 - y^2 + \sqrt{2}x - 7\sqrt{2}y - 20 = 0$

iii. $\mathbf{5x^2 - 6xy + 5y^2 - 8 = 0}$

Solution

Let the axis be stated through an angle θ. Equations of transformation are

$x = x\cos\theta - y\sin\theta, \qquad y = x\sin\theta + y\cos\theta$

substituting into the given equation, we get

$\Rightarrow \quad 5(x\cos\theta - y\sin\theta)^2 - 6(x\cos\theta - y\sin\theta)(x\sin\theta + y\cos\theta) + 5(x\sin\theta + y\cos\theta)^2 - 8 = 0$

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$5(x^2\cos^2\theta - 2xy\sin\theta\cos\theta + y^2\sin^2\theta) - 6(x^2\cos\theta\sin\theta + xy\cos^2\theta - xy\sin^2\theta - y^2\sin\theta\cos\theta) + 5(x^2\sin^2\theta + 2xy\sin\theta\cos\theta + y^2\cos^2\theta) - 8 = 0$ ---------- (1)

Since this equation is to be free the product term xy, the coefficient of xy is zero.

i.e.

$$-10\sin\theta\cos\theta + 6(\cos^2\theta - \sin^2\theta) + 10\sin\theta\cos\theta = 0$$

$$\text{Cos}^2\theta - \sin^2\theta = 0 \qquad \cos^2\theta = \sin^2\theta$$

$$\tan^2\theta = 1 \qquad \tan\theta = 1$$

$$\Rightarrow \quad \theta = 45°$$

putting value in (1), the transformed equation is

$\Rightarrow \quad 5(x^2\cos^2 45° + y^2\sin^2 45°) - 6(x^2\cos 45°\sin 45° - y^2\sin 45°\cos 45°) + 5(x^2\sin^2 45° + y^2\cos^2 45°) - 8 = 0$

$$5\left[x^2\left(\frac{1}{2}\right) + y^2\left(\frac{1}{2}\right)\right] - 6\left[x^2\left(\frac{1}{2}\right) - y^2\left(\frac{1}{2}\right)\right] + 5\left[x^2\left(\frac{1}{2}\right) + y^2\left(\frac{1}{2}\right)\right] - 8 = 0$$

$$\frac{5}{2}x^2 + \frac{5}{2}y^2 - \frac{6}{2}x^2 + \frac{6}{2}y^2 + \frac{5}{2}x^2 + \frac{5}{2}y^2 - 8 = 0$$

$$\left(\frac{5}{2} - \frac{6}{2} + \frac{5}{2}\right)x^2 + \left(\frac{5}{2} + \frac{6}{2} + \frac{5}{2}\right)y^2 - 8 = 0$$

$$\left(\frac{5-6+5}{2}\right)x^2 + \left(\frac{5+6+5}{2}\right)y^2 - 8 = 0$$

$$\frac{4}{2}x^2 + \frac{16}{2}y^2 - 8 = 0$$

$$2x^2 + 8y^2 - 8 = 0$$

$$x^2 + 4y^2 - 4 = 0$$

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