$$W_{\text{п}} = -\frac{k}{r} \tag{1}$$

$$W_{\text{цб}} = \frac{N^2}{2mr^2} \tag{2}$$

$$W_{\text{эфф}} = W_{\text{цб}} + W_{\text{п}} = \frac{N^2}{2mr^2} - \frac{k}{r} \tag{3}$$

$$\varphi(r) = \frac{N}{m} \int \frac{dr}{r^2 \sqrt{\frac{2}{m}(W - W_{\text{эфф}})}} + C \tag{4}$$

Выберем начало отсчета угла так, чтобы $C = 0$.

$$W - W_{\text{эфф}} = W - (\frac{N^2}{2mr^2} - \frac{k}{r}) \tag{5}$$

$$\varphi(r) = \int \frac{d\left(\frac{N}{r}\right)}{\sqrt{2m(W - W_{\text{эфф}})}} \tag{6}$$

$$\varphi(r) = \int \frac{d\left(\frac{N}{r}\right)}{\sqrt{2mW - \left(\frac{N^2}{r^2} - \frac{2mk}{r}\right)}} \tag{7}$$

$$\frac{N^2}{r^2} - \frac{2mk}{r} = \left(\frac{N}{r} - \frac{mk}{N}\right)^2 - \left(\frac{mk}{N}\right)^2 \tag{8}$$

$$\varphi(r) = \int \frac{d\left(\frac{N}{r} - \frac{mk}{N}\right)}{\sqrt{\left(2mW + \left(\frac{mk}{N}\right)^2\right) - \left(\frac{N}{r} - \frac{mk}{N}\right)^2}} \tag{9}$$

$$\beta^2 = 2mW + \left(\frac{mk}{N}\right)^2 \tag{10}$$

$$\alpha^2 = \left(\frac{N}{r} - \frac{mk}{N}\right)^2 \tag{11}$$

$$\varphi(r) = \int \frac{d\alpha}{\sqrt{\beta^2 - \alpha^2}} \tag{12}$$

$$\varphi(r) = \arccos \frac{\frac{N}{r} - \frac{mk}{N}}{\sqrt{2mW + \frac{m^2k^2}{N^2}}} = \arccos \frac{\frac{N^2}{mkr} - 1}{\sqrt{1 + \frac{2WN^2}{mk^2}}} \tag{13}$$

$$p = \frac{N^2}{mk} \tag{14}$$

$$e = \sqrt{1 + \frac{2WN^2}{mk^2}} \tag{15}$$

$$\cos\varphi = \frac{\frac{p}{r} - 1}{e} \tag{16}$$

$$\frac{p}{r} = 1 + e\cos\varphi \tag{17}$$

$$r = \frac{p}{1 + e\cos\varphi} \tag{18}$$