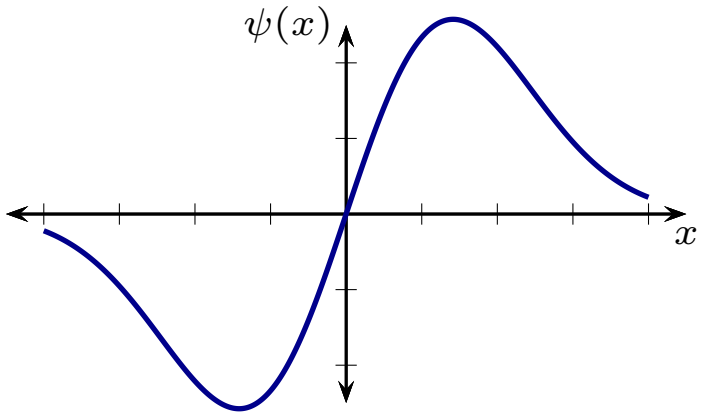
Question 1

A possible antisymmetric energy eigenstate for the harmonic oscillator is as illustrated.



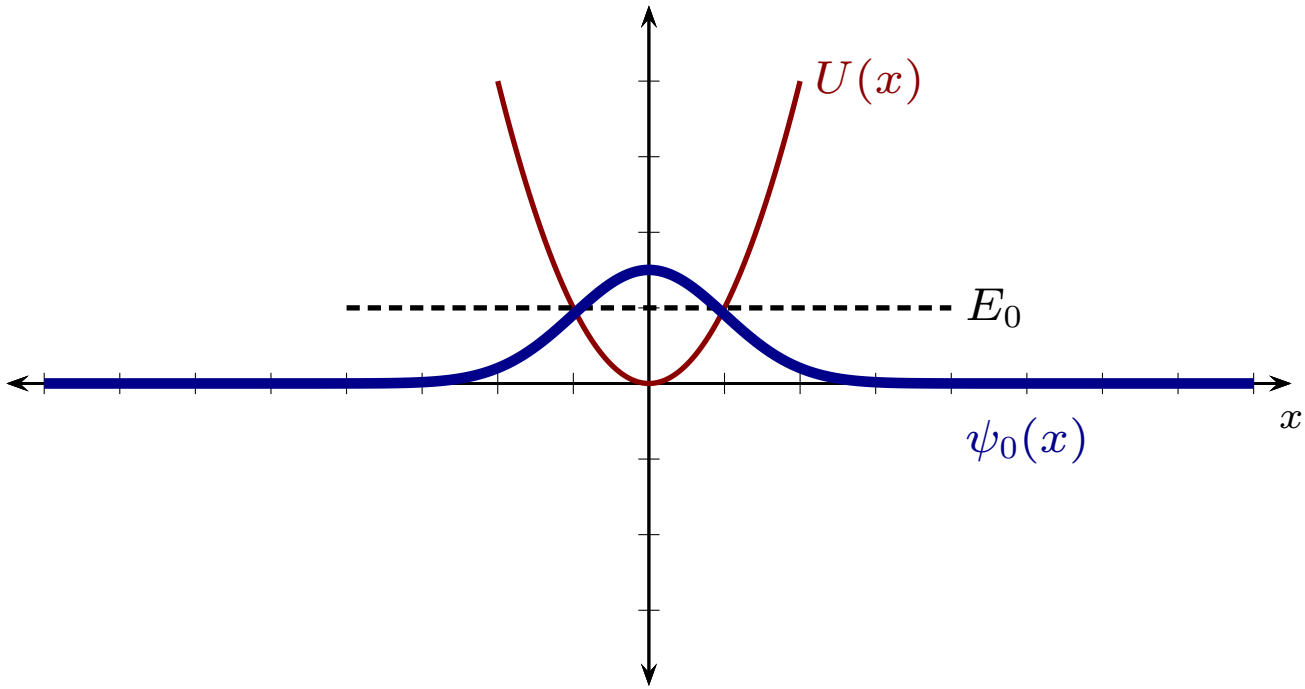
Which of the following is true?

1. $\langle x \rangle = 0$
2. $\langle x \rangle > 0$
3. $\langle x \rangle < 0$

Harmonic Oscillator Ground State

- Ground state energy and wavefunction

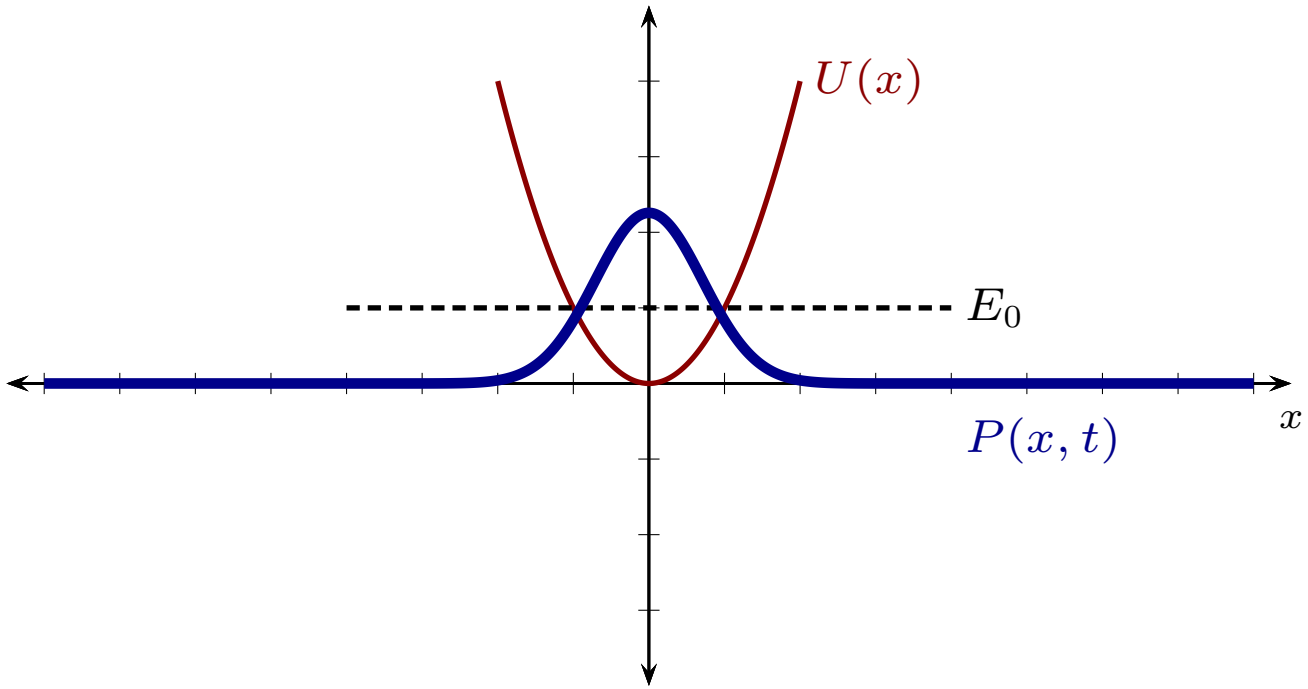
$$E_0 = \hbar\omega/2 \qquad \psi_0(x) = \left(\frac{m\omega}{\pi\hbar}\right)^{1/4} e^{-m\omega x^2/2\hbar}$$



Harmonic Oscillator Ground State Probability Density

- Ground state probability distribution for position measurement outcomes:

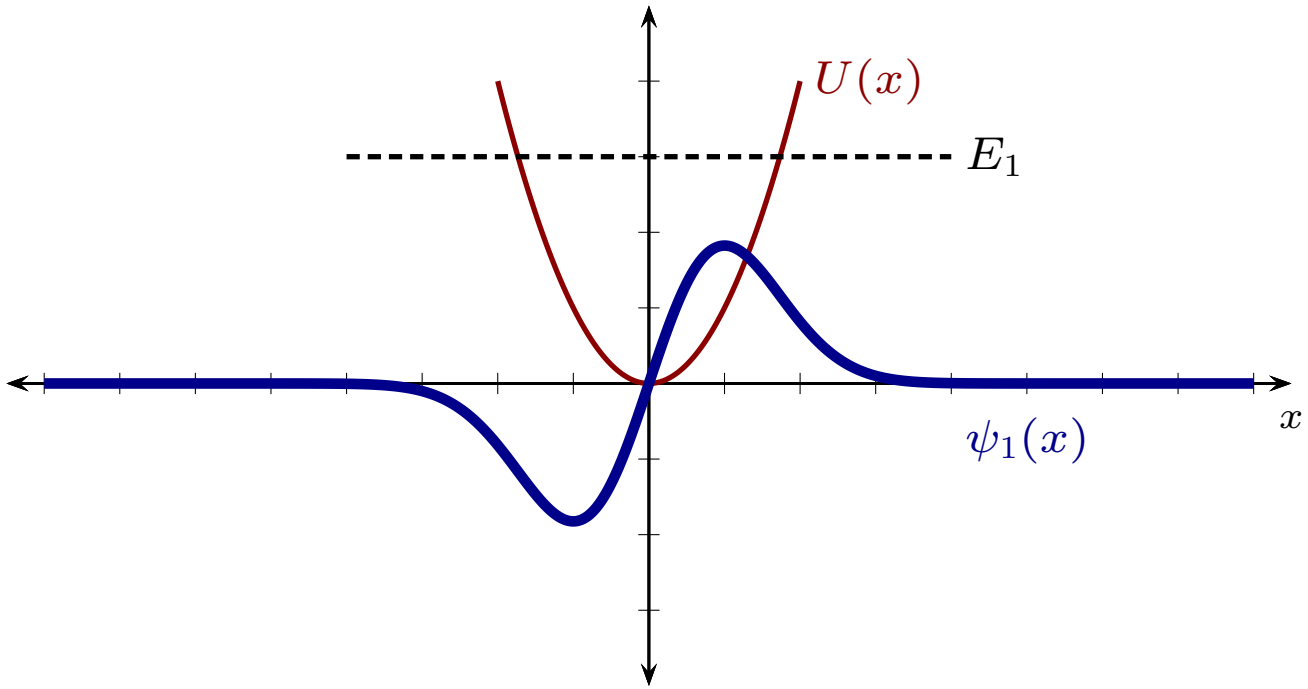
$$P(x,t) = |\psi_0(x)|^2 = \left(\frac{m\omega}{\pi\hbar}\right)^{1/2} e^{-m\omega x^2/\hbar}$$



Harmonic Oscillator First Excited State

- First excited state ($n = 1$) energy and wavefunction

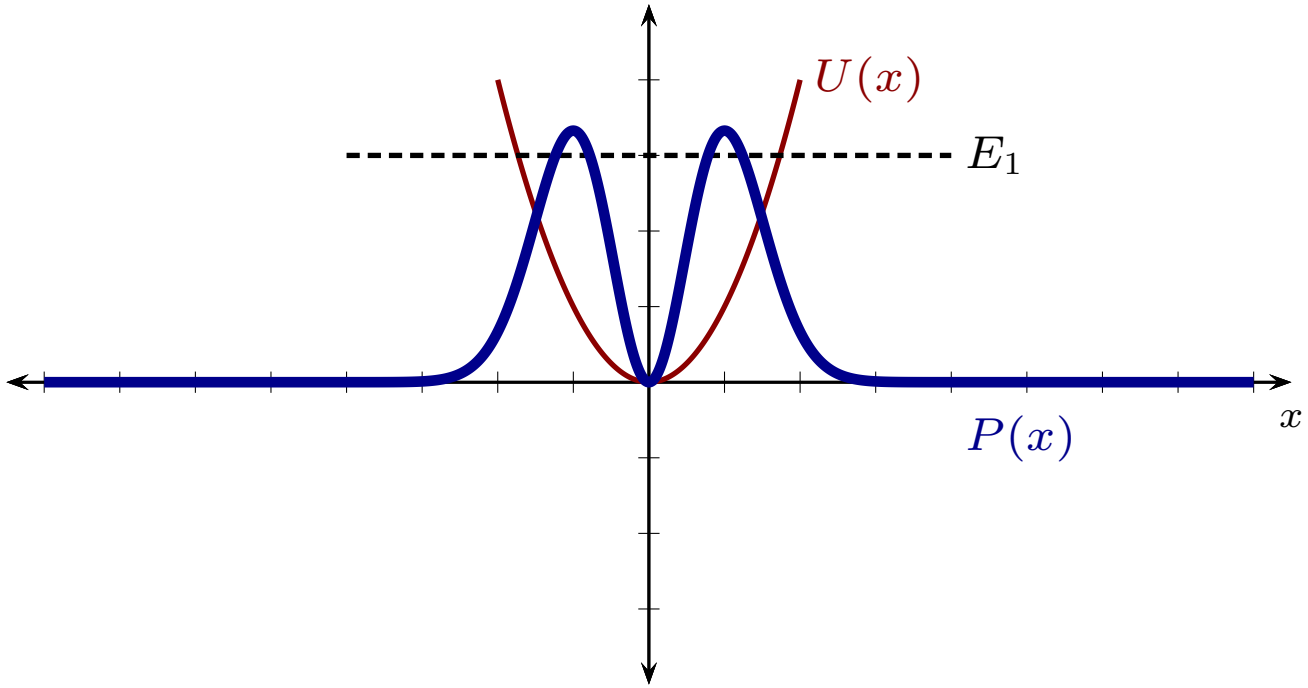
$$E_1 = \frac{3}{2}\hbar\omega \qquad \psi_1(x) = 2\sqrt{\frac{m\omega}{\hbar}}xe^{-m\omega x^2/2\hbar}$$



Harmonic Oscillator First Excited State Probability Density

- First excited state probability distribution for position measurement outcomes:

$$P(x,t) = |\psi_1(x)|^2 = \frac{4m\omega}{\hbar} x^2 \, e^{-m\omega x^2/\hbar}$$



Question 2

Consider a quantum harmonic oscillator with frequency ω_0.

Which of the following is true regarding the lowest frequency light emitted by the oscillator?

1. Frequency is $\omega_0/2\pi$; only occurs for $n = 1 \rightarrow n = 0$.
2. Frequency is $\omega_0/2\pi$; only occurs for $n = 2 \rightarrow n = 1$.
3. Frequency is $\omega_0/2\pi$; many ways that this can occur.
4. Frequency is $\omega_0/4\pi$; only occurs for $n = 1 \rightarrow n = 0$.
5. Frequency is $\omega_0/4\pi$; only occurs for $n = 2 \rightarrow n = 1$.

Question 3

Let

$$\psi(x) = Ax^2 - Bx$$

where A and B are positive constants.

Which of the following best represents $\hat{p}\psi$?

1. $p\,(Ax^2 - Bx)$.
2. $-i\hbar p(Ax^2 - Bx)$.
3. $2Ax - B$.
4. $i\hbar(2Ax - B)$.
5. $-i\hbar(2Ax - B)$.