

## 2.59: The Wigner Distribution for the 3p State of the 1D Hydrogen Atom

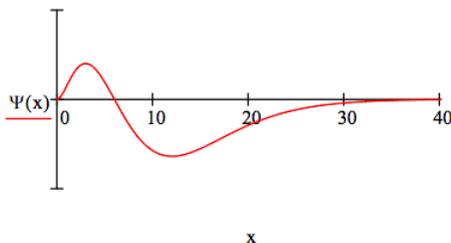
This tutorial presents three pictures of the 3p state of the one-dimensional hydrogen atom using its position, momentum and phase-space representations.

The energy operator for the one-dimensional hydrogen atom in atomic units is:

$$-\frac{1}{2} \frac{d^2}{dx^2} + \frac{L(L+1)}{2x^2} - \frac{1}{x}$$

The 3p wave function is:

$$\Psi(x) = \frac{8}{27\sqrt{6}} \left(1 - \frac{x}{6}\right) x^2 \exp\left(\frac{-x}{2}\right) \quad \int_0^\infty \Psi(x)^2 dx = 1$$

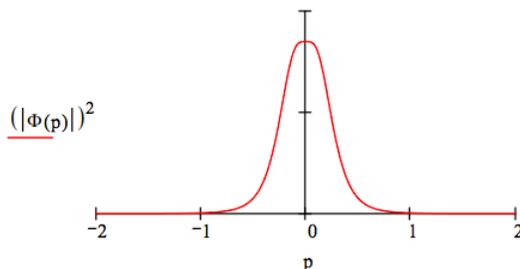


The 3p state energy is  $-0.0556 E_h$ .

$$-\frac{1}{2} \frac{d^2}{dx^2} \Psi(x) + \frac{1}{x^2} \Psi(x) - \frac{1}{x} \Psi(x) = E \Psi(x) \text{ solve, } E \rightarrow \frac{-1}{18} = -0.0556$$

The momentum wave function is generated by the following Fourier transform of the coordinate space wave function.

$$\Phi(p) = \frac{1}{\sqrt{2\pi}} \int_0^\infty \exp(-i p x) \Psi(x) dx \rightarrow \frac{2}{3} 2^{\frac{1}{2}} 6^{\frac{1}{2}} \frac{(-1) + 6i p}{(3i p + 1)^4 \pi^{\frac{1}{2}}}$$

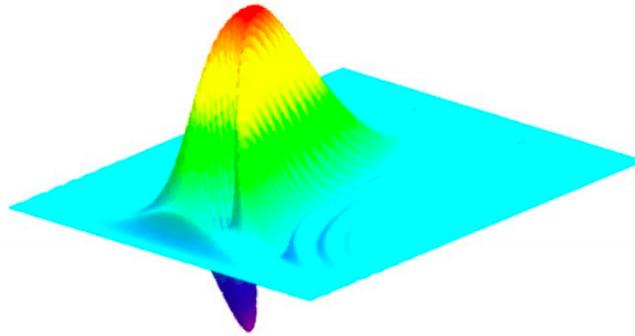


The Wigner function (phase-space representation) for the 3p state is generated using the momentum wave function.

$$W(x, p) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \overline{\Phi\left(p + \frac{s}{2}\right)} \exp(-i s x) \Phi\left(p - \frac{s}{2}\right) ds$$

The Wigner distribution is displayed graphically.

$$N = 150 \quad i = 0..N \quad x_i = \frac{35i}{N} \quad j = 0..N \quad p_j = -2 + \frac{4j}{N} \quad \text{Wigner}_{i,j} = W(x_i, p_j)$$



Wigner

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