

$$\text{e.g. } \psi(r) = \left(\frac{1}{2\pi a_0^3} \right)^{1/4} e^{-r^2/4a_0^2}$$

$$\Delta t = \frac{2a_0}{c} = \frac{2\hbar^2}{mc^2} = \frac{2\hbar^2}{mc^2 c} \quad \text{electron}$$

$$e^2 = \frac{\hbar c}{137} \quad \hbar c = 197 \text{ MeV-fm}$$

$$m = 0.511 \frac{\text{MeV}}{c^2}$$

$$\Delta t = \frac{2\hbar}{mc^2 c} \frac{c^2}{c^2} = \frac{2(\hbar c)^2}{mc^2 \frac{\hbar c}{137}} = \frac{2\hbar c}{mc^2 c} 137$$

$$= \frac{2 \cdot 137 \cdot 197 \text{ MeV-fm}}{0.511 \text{ MeV} \times 3 \times 10^8 \times 10^{15} \text{ fm/s}}$$

$$\Delta t = 3.521 \times 10^{-19} \text{ s}$$

$$\sigma = \frac{2m\sigma^2}{\hbar} = \Delta t \quad \text{Eq. 6.48 in Liboff}$$

$$\sigma^2 = \frac{\hbar \Delta t}{2m} \frac{c^2}{c^2}$$

$$= \frac{\hbar c \Delta t c}{2mc^2}$$

$$= \frac{(197 \text{ MeV-fm})(3.521 \times 10^{-19} \text{ s}) \times (3 \times 10^8 \times 10^{15} \text{ fm/s})}{2(0.511 \text{ MeV}) c^2}$$

$$\sigma^2 = 2.036 \times 10^{-7} \text{ fm}^2 \times \left(\frac{10^{-15} \text{ m}}{\text{fm}} \right)^2$$

$$\sigma = 4.51 \times 10^{-18} \text{ m}$$