Name Date

22b. We can't ignore relativity, that is the main trick. Kinetic energy, relativistically:

$$KE = (\gamma - 1)mc^2 = E_{\text{total}} - E_{\text{rest}} = \sqrt{p^2c^2 + (mc^2)^2} - mc^2$$

We made use of the fact that the total energy for a free particle is the kinetic energy plus the rest energy. You need the last expression, relating kinetic energy to momentum.

For an electron, the rest energy mc^2 is 511 keV, so the equation above isn't as bad as it looks. We can get p from de Broglie:

$$\lambda = \frac{h}{p}$$

First find p, using $h = 4.14 \times 10^{-15}\,\text{eV}\cdot\text{s}$ to get the right units, then calculate $\sqrt{p^2c^2 + (mc^2)^2} - mc^2$ in eV, using the rest mass of the electron as $m_ec^2 = 511\,\text{keV}$.

24b. First, use position-momentum uncertainty to find the minimum possible momentum. The proton is confined to a diameter of 10^{-15} m, so that is Δx. Solve for Δp, and plug that into the expression for kinetic energy. At the end, you will have an answer in J if you use conventional units for the constants - divide that by e to get the answer in eV.

$$\begin{aligned}
\Delta x \Delta p &= (10^{-15})\Delta p \geq \frac{h}{4\pi} \\
\Delta p &\geq \frac{h}{4\pi 10^{-15}} \\
KE &= \frac{p^2}{2m} \geq \frac{(\Delta p)^2}{2m_p} \\
KE &\geq \approx 5\,\text{MeV}
\end{aligned}$$

Careful with the units.