39.60. **IDENTIFY:** For circular motion, $L = mvr$ and $a = \dfrac{v^2}{r}$. Newton's law of gravitation is $F_g = G\dfrac{mM}{r^2}$, with $G = 6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$.

SET UP: The period T is $2.00\ \text{h} = 7200\ \text{s}$.

EXECUTE: **(a)** $mvr = n\dfrac{h}{2\pi}$. $n = \dfrac{2\pi mvr}{h}$. $v = \dfrac{2\pi r}{T}$ So

$$n = \frac{(2\pi r)^2 m}{hT} = \frac{(2\pi)^2(8.06\times10^6\ \text{m})^2(20.0\ \text{kg})}{(6.63\times10^{-34}\ \text{J.s})(7200\ \text{s})} = 1.08\times10^{46}.$$

(b) $F = ma$ gives $G\dfrac{mm_E}{r^2} = m\dfrac{v^2}{r}$. $\dfrac{Gm_E}{r} = v^2$. The Bohr postulate says $v = \dfrac{nh}{2\pi mr}$ so $\dfrac{Gm_E}{r} = \dfrac{n^2h^2}{4\pi^2m^2r^2}$

$r = \left(\dfrac{h^2}{4\pi^2Gm_Em^2}\right)n^2$. This is in the form $r = kn^2$, with

$$k = \frac{h^2}{4\pi^2Gm_Em^2} = \frac{(6.63\times10^{-34}\ \text{J.s})^2}{4\pi^2(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(5.97\times10^{24}\ \text{kg})^2} = 7.0\times10^{-86}\ \text{m}$$

(c) $\Delta r = r_{n+1} - r_n = k([n+1]^2 - n^2) = (2n+1)k = (2[1.08\times10^{46}]+1)(7.0\times10^{-86}\ \text{m}) = 1.5\times10^{-39}\ \text{m}$

EVALUATE: **(d)** Δr is exceedingly small, so the separation of adjacent orbits is not observable.

(e) There is no measurable difference between quantized and classical orbits for this satellite; either method of calculation is totally acceptable.

39.81. **(a) IDENTIFY** and **SET UP:** $\Delta x\Delta p_x \ge \hbar/2$. Estimate Δx as $\Delta x \approx 5.0\times10^{-15}\ \text{m}$.

EXECUTE: Then the minimum allowed Δp_x is $\Delta p_x \approx \dfrac{\hbar}{2\Delta x} = \dfrac{1.055\times10^{-34}\ \text{J}\cdot\text{s}}{2(5.0\times10^{-15}\ \text{m})} = 1.1\times10^{-20}\ \text{kg}\cdot\text{m/s}$.

(b) IDENTIFY and **SET UP:** Assume $p \approx 1.1\times10^{-20}\ \text{kg}\cdot\text{m/s}$. Use Eq. (37.39) to calculate E, and then $K = E - mc^2$.

EXECUTE: $E = \sqrt{(mc^2)^2 + (pc)^2}$. $mc^2 = (9.109\times10^{-31}\ \text{kg})(2.998\times10^8\ \text{m/s})^2 = 8.187\times10^{-14}\ \text{J}$.

$pc = (1.1\times10^{-20}\ \text{kg}\cdot\text{m/s})(2.998\times10^8\ \text{m/s}) = 3.165\times10^{-12}\ \text{J}$.

$E = \sqrt{(8.187\times10^{-14}\ \text{J})^2 + (3.165\times10^{-12}\ \text{J})^2} = 3.166\times10^{-12}\ \text{J}$.

$K = E - mc^2 = 3.166\times10^{-12}\ \text{J} - 8.187\times10^{-14}\ \text{J} = 3.084\times10^{-12}\ \text{J}\times(1\ \text{eV}/1.602\times10^{-19}\ \text{J}) = 19\ \text{MeV}$.

(c) IDENTIFY and **SET UP:** The Coulomb potential energy for a pair of point charges is given by Eq. (23.9). The proton has charge $+e$ and the electron has charge $-e$.

EXECUTE: $U = -\dfrac{ke^2}{r} = -\dfrac{(8.988\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.602\times10^{-19}\ \text{C})^2}{5.0\times10^{-15}\ \text{m}} = -4.6\times10^{-14}\ \text{J} = -0.29\ \text{MeV}$.

EVALUATE: The kinetic energy of the electron required by the uncertainty principle would be much larger than the magnitude of the negative Coulomb potential energy. The total energy of the electron would be large and positive and the electron could not be bound within the nucleus.