Question 3: Quantitative/Qualitative Translation — 12 points

(a) For indicating that the electrostatic force is equal to the net (centripetal) force on the electron, with a correct expression for each — **1 point**

Example Response

$$\Sigma\vec{F} = m\vec{a}$$
$$F_E = F_C$$
$$\frac{kq^2}{r^2} = \frac{mv^2}{r}$$

Scoring Note: An incorrect mass label is acceptable to earn this point.

For using the expressions for the electrostatic and net forces to determine the speed v of the electron (responses must indicate that the mass in the expression represents the mass of the electron and the charge in the expression represents the charge of the electron) — **1 point**

Example Response

$$\frac{ke^2}{r^2} = \frac{m_e v^2}{r}$$
$$v^2 = \frac{ke^2}{m_e r}$$
$$v = \sqrt{\frac{ke^2}{m_e r}}$$

Scoring Note: q_e and q_p are acceptable.

Total for part (a) — **2 points**

(b) For a correct expression for electric potential energy, using charges consistent with charges from part (a) — **1 point**

Example Response

$$U = -\frac{ke^2}{r}$$

For a correct expression for kinetic energy of the electron, including a substitution consistent with the expression from part (a) to eliminate speed from the equation — **1 point**

Example Response

$$K = \frac{1}{2}m_e\left(\frac{ke^2}{m_e r}\right) = \frac{1}{2}\frac{ke^2}{r}$$

For indicating that the total energy of the atom is the sum of the electric potential energy and the kinetic energy of the electron **1 point**

Example Response

$$E = U + K$$
$$E = -\frac{ke^2}{r} + \frac{1}{2}\frac{ke^2}{r}$$
$$E = -\frac{ke^2}{2r}$$

Total for part (b) 3 points

(c) For correctly indicating consistency between the equation in part (b) and the description with an explanation that references the equation in part (b) **1 point**

For correctly addressing functional dependence of the energy equation from part (b) to the orbital radius of the electron **1 point**

Example Response

The equation from part (b) indicates that as the radius increases, the total energy of the atom becomes less negative, which is an increase in the total energy. This is consistent with the given description of the atom absorbing a photon.

Total for part (c) 2 points

(d)(i) For a correct calculation of the energy of the photon **1 point**

Example Response

$$E = hf$$
$$E = (6.63 \times 10^{-34}\ \text{J} \cdot \text{s})(3.2 \times 10^{15}\ \text{Hz})$$
$$E = 2.12 \times 10^{-18}\ \text{J}$$

(d)(ii) For a correct calculation of the mass-energy of an electron **1 point**

Example Response

$$E = mc^2$$
$$E = (9.11 \times 10^{-31}\ \text{kg})(3.00 \times 10^{8}\ \text{m/s})^2$$
$$E = 8.20 \times 10^{-14}\ \text{J}$$

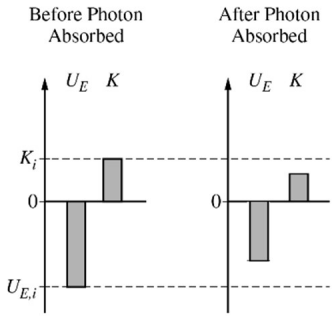
For correctly indicating that the photon energy is negligible compared to the mass energy of the electron (or an answer that is consistent with the energies calculated in part (d)(i) and part (d)(ii)) **1 point**

Scoring Note: The energy comparison must be from the unit of joules to joules or the unit of electron volts to electron volts in order for this point to be earned.

(d)(iii) For U smaller in magnitude but still negative **1 point**

For K smaller in magnitude but still positive **1 point**

Example Response



Total for part (d) 5 points

Total for question 3 12 points