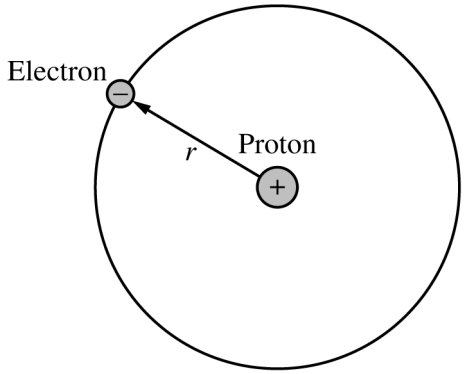
Begin your response to **QUESTION 3** on this page.



Note: Figure not drawn to scale.

3. (12 points, suggested time 25 minutes)

A hydrogen atom can be modeled as an electron in a circular orbit of radius r about a stationary proton, as shown above. The gravitational force between the proton and electron is negligible compared to the electrostatic force between them.

(a) Derive an equation for the speed v of the electron in terms of r and physical constants, as appropriate.

(b) Derive an equation for the total energy of the atom in terms of r and physical constants, as appropriate.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(c) When the hydrogen atom absorbs a photon, the electron moves to an orbit with a larger radius and the total energy of the atom increases. Is your equation for the energy derived in part (b) consistent with this description of the model of a hydrogen atom absorbing a photon? Explain why the equation is or is not consistent.

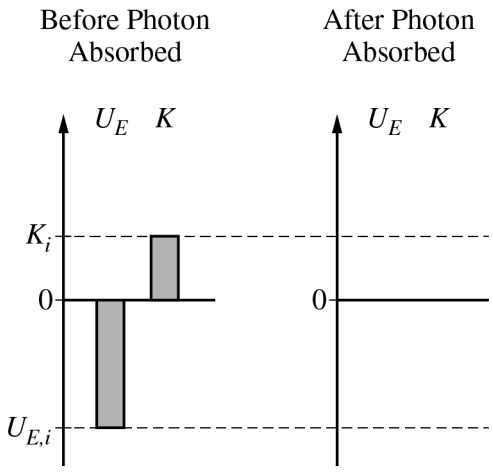
(d) Experiments show that a hydrogen atom can absorb a photon of frequency 3.2×10^{15} Hz.

i. Calculate the energy of a photon with this frequency.

ii. A student claims that when a hydrogen atom absorbs a photon at this frequency, the energy could be converted into mass, adding an electron to the atom. Calculate the amount of energy needed to create a particle with the mass of an electron and determine whether or not there is sufficient energy gained by the atom to add another electron.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.



iii. The left bar chart in the figure above is complete and represents the initial electric potential energy $U_{E,\,i}$ of the atom and the initial kinetic energy K_i of the electron before the photon is absorbed. In the space provided on the right, draw a bar chart to represent a possible final electric potential energy of the atom and final kinetic energy of the electron.

GO ON TO THE NEXT PAGE.

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

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

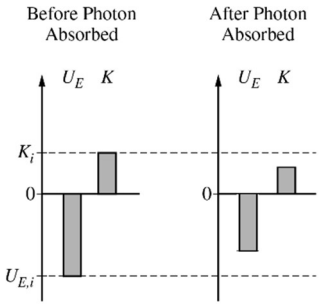
For a correct expression for kinetic energy of the electron, including a substitution consistent with the expression from part (a) to eliminate speed from the equation — **1 point**

Example Response

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

(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