Past-paper walk-through

Fission, Fusion, and Nuclear Decay ▪ 15.7

eXercise

Questions in this set

- 2022 Q3

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 3

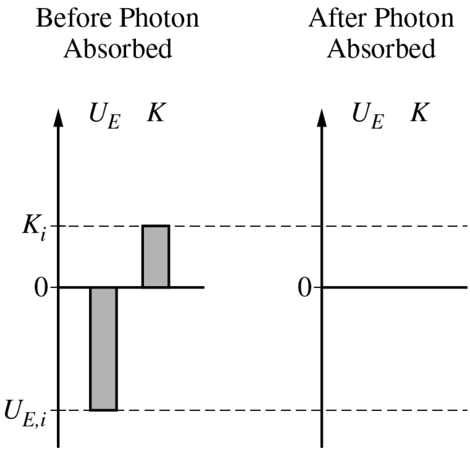
2022 ▪ Q3

[Diagram: A circle representing the electron's circular orbit of radius r around a stationary proton at the center. The electron, labeled with a minus sign, is on the circle at upper left, with an arrow pointing along the circle indicating its direction of motion; a line labeled r connects the electron to the central proton, labeled with a plus sign. Note: Figure not drawn to scale.]

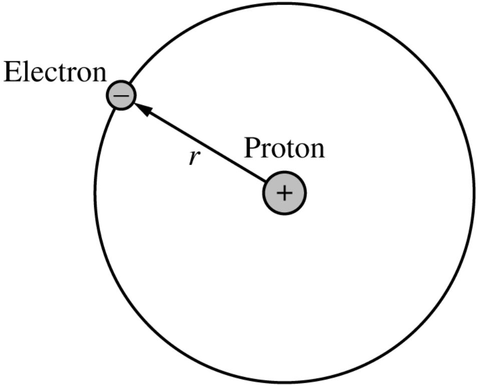
A hydrogen atom can be modeled as an electron in a circular orbit of radius r about a stationary proton, as shown above. The gravitational force between the proton and electron is negligible compared to the electrostatic force between them.

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

Question 3


Before Photon Absorbed
After Photon Absorbed
U_E
K
U_E
K
K_i
0
$U_{E,i}$
0

Question 3



Note: Figure not drawn to scale.

Question 3

2022 ▪ Q3

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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.

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

Question 3

2022 ▪ Q3

[Diagram: A circle representing the electron's circular orbit of radius r around a stationary proton at the center. The electron, labeled with a minus sign, is on the circle at upper left, with an arrow pointing along the circle indicating its direction of motion; a line labeled r connects the electron to the central proton, labeled with a plus sign. Note: Figure not drawn to scale.]

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.

(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.

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[Diagram: A circle representing the electron's circular orbit of radius *r* around a stationary proton at the center. The electron, labeled with a minus sign, is on the circle at upper left, with an arrow pointing along the circle indicating its direction of motion; a line labeled *r* connects the electron to the central proton, labeled with a plus sign. Note: Figure not drawn to scale.]

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.

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

Calculate the energy of a photon with this frequency.

(d)(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.

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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.

(d)(iii) [Diagram: Two bar charts side by side, titled "Before Photon Absorbed" and "After Photon Absorbed." Each chart has a vertical axis with two bars labeled U_E and K. In the left ("Before") chart, a dashed horizontal line marks a positive level K_i and a dashed horizontal line below zero marks a negative level $U_{E,i}$; the U_E bar extends from 0 down to $U_{E,i}$ (negative), and the K bar extends from 0 up to K_i (positive). The right ("After") chart shows only the zero line, with both bars blank for the student to draw.] 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

Question 3

represent a possible final electric potential energy of the atom and final kinetic energy of the electron.

Solution 3

(a) Mark scheme

- (1 point) Set the electrostatic (Coulomb) force equal to the net (centripetal) force on the electron: $\Sigma F = ma \Rightarrow F_E = F_C \Rightarrow \frac{kq^2}{r^2} = \frac{mv^2}{r}$ (an incorrect mass label is still acceptable for this point). (1 point) Use these expressions, with mass and charge consistently referring to the electron (m_e, e; q_e/q_p notation also acceptable), to solve for speed: $\frac{ke^2}{r^2} = \frac{m_e v^2}{r} \Rightarrow v^2 = \frac{ke^2}{m_e r} \Rightarrow v = \sqrt{\frac{ke^2}{m_e r}}$.

Solution 3

(b) Mark scheme

- (1 point) Electric potential energy, using charges consistent with part (a): $U = -\dfrac{ke^2}{r}$. (1 point) Kinetic energy of the electron, substituting the speed from part (a) to eliminate v: $K = \frac{1}{2}m_e v^2 = \frac{1}{2}m_e\left(\dfrac{ke^2}{m_e r}\right) = \frac{1}{2}\dfrac{ke^2}{r}$. (1 point) Indicate the total energy of the atom is the sum of potential and kinetic energy: $E = U + K = -\dfrac{ke^2}{r} + \frac{1}{2}\dfrac{ke^2}{r} = -\dfrac{ke^2}{2r}$.

Solution 3

(c) Mark scheme

- (1 point) Correctly indicate that the equation from part (b), $E = -\dfrac{ke^2}{2r}$, is consistent with the given description, with an explanation that references that equation. (1 point) Correctly address the functional dependence: as the orbital radius r increases, E becomes less negative — i.e. the total energy increases — which matches the description that absorbing a photon increases both the orbit radius and the atom's total energy. Model 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."

Solution 3

(d)(i)

Mark scheme

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

Solution 3

(d)(ii)

Mark scheme

- (1 point) Mass-energy of an electron: $E = mc^2 = (9.11 \times 10^{-31}\ \text{kg})(3.00 \times 10^{8}\ \text{m/s})^2 = 8.20 \times 10^{-14}$ J. (1 point) Compare this to the photon energy from part (d)(i) (2.12×10^{-18} J), in matching units (J to J, or eV to eV), and correctly conclude the photon energy is negligible compared to the electron's mass-energy — so there is NOT enough energy to create a new electron (the student's claim is incorrect). An answer consistent with the student's own (d)(i)/(d)(ii) numbers also earns this point.

Solution 3

(d)(iii)

Mark scheme

- On the "After Photon Absorbed" bar chart relative to "Before": (1 point) the electric potential energy bar U_E is drawn smaller in magnitude but still negative (shorter than $U_{E,i}$, still below zero). (1 point) the kinetic energy bar K is drawn smaller in magnitude but still positive (shorter than K_i, still above zero). This reflects that as r increases, both $|U| = ke^2/r$ and $K = \frac{1}{2}ke^2/r$ decrease in magnitude while U stays negative and K stays positive.