Past-paper walk-through

Emission and Absorption Spectra ▪ 15.3

eXercise

Questions in this set

- 2026 Q2
- 2022 Q3
- 2016 Q2

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 2

2026 ▪ Q2

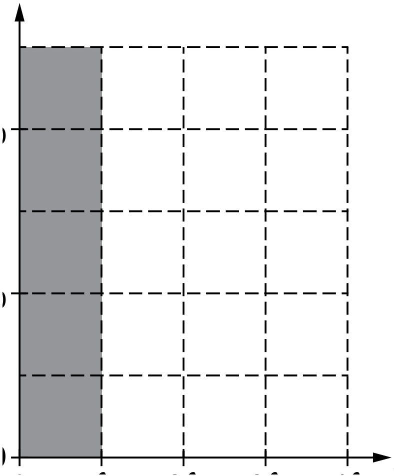
Figure 1 represents the energy levels and their corresponding states for a hypothetical atom.

[Figure 1: An energy-level diagram with two columns, "Energy" and "State". Three horizontal levels are drawn: the topmost level is labelled $-2E_0$ on the left and $n = 3$ on the right; the middle level is labelled $-3E_0$ on the left and $n = 2$ on the right; the bottom level (drawn noticeably lower, with extra vertical spacing below $n = 2$) is labelled $-5E_0$ on the left and $n = 1$ on the right.]

(a) Part A

On Figure 1, **draw** arrows to represent all possible atomic transitions that could result in the emission of a photon.

Question 2



Question 2

2026 ▪ Q2

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(b) Part B

Derive an expression for the wavelength of the highest-energy photon that can be emitted from the atom. Express your answer in terms of E_0 and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

The following information applies to parts C and D.

Question 2

A device can emit monochromatic electromagnetic radiation. The wavelength λ of the radiation can be varied over a continuous range of wavelengths.

Question 2

2026 ▪ Q2

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(c) Part C

On Figure 2, **sketch** the energy E of emitted photons from the device as a function of λ for $\lambda_0 < \lambda < 4\lambda_0$. Photons with wavelength λ_0 have energy $4E_0$. Sketches made in the shaded region will not be scored.

[Figure 2: A set of axes with vertical axis E labelled with gridlines at $2E_0$ and $4E_0$, and horizontal axis λ labelled with gridlines at 0, λ_0, $2\lambda_0$, $3\lambda_0$, $4\lambda_0$. The region from $\lambda = 0$

Question 2

to $\lambda = \lambda_0$ is shaded gray (sketches there are not scored); dashed gridlines mark the intersections at $(\lambda_0, 4E_0)$ and other grid points across the unshaded region from λ_0 to $4\lambda_0$. No curve is drawn — to be sketched by the student.]

Question 2

2026 ▪ Q2

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(d) Part D

A student claims that, based on the energy states shown in Figure 1, the atom can emit a photon of wavelength λ_0 and energy $4E_0$ like the device described in part C. **Indicate** whether the claim is correct or incorrect. Briefly **justify** your answer by referencing the representation in part A.

Question 3

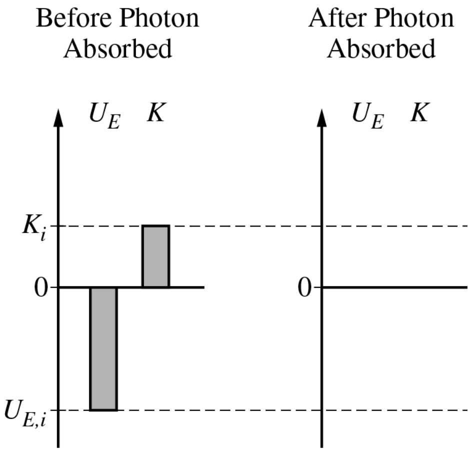
2022 ▪ Q3

[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.

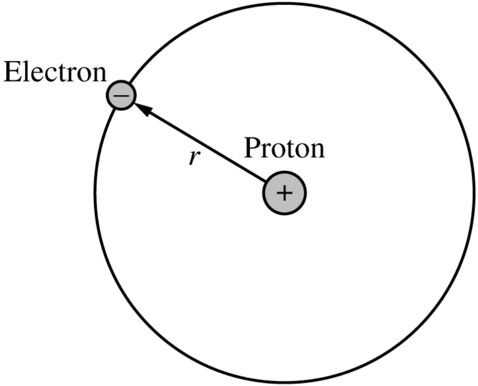
(a) Derive an equation for the speed v of the electron in terms of r and physical constants, as appropriate.

Question 3



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

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.

(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

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

Solution 3

(d)(ii)

Mark scheme

- (1 point) Mass-energy of an electron: $E = mc^2 = (9.11 \times 10^{-31}$ kg$)(3.00 \times 10^{8}$ 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.

Question 2

2016 ▪ Q2

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

(a) A linear graph is to be used to determine the index of refraction of the glass. Indicate the quantities that should be graphed and describe how the graph could be used to determine the index of refraction of the glass.

Question 2

2016 ▪ Q2

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(b) Outline an experimental procedure that could gather the necessary data. Include sufficient detail so that another student could follow your procedure. In addition to the glass block and the hydrogen lamp, the equipment in a typical classroom laboratory is available.

Question 2

2016 ▪ Q2

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

(c) Predict how the path of the light will change as it enters the glass. Support your prediction using a qualitative comparison of the speed of light in glass and the speed of light in air.

Question 2

2016 ▪ Q2

A student is given a glass block that has been specially treated so that the path of light can be seen as the light travels through the glass. The student is asked to design an experiment to measure the index of refraction of the glass. The light source available in the laboratory is a hydrogen lamp that emits red light of a known wavelength.

(d) Describe the process(es) by which red light from the lamp is produced by hydrogen atoms that are initially in the ground state. Draw and label an energy level diagram that supports the atomic process(es) you describe.

Solution 2

(a) Mark scheme

- Graph sin $\theta 1$ (the angle of incidence, measured in air) on one axis versus sin $\theta 2$ (the angle of refraction, measured in the glass) on the other axis — plot the SINES of the angles, not the raw angles. By Snell's law, n1 sin $\theta 1 =$ n2 sin $\theta 2$. Because medium 1 is air, n1 $= 1$, so sin $\theta 1 =$ n2 sin $\theta 2$, meaning a graph of sin $\theta 1$ (vertical axis) vs. sin $\theta 2$ (horizontal axis) is a straight line through the origin whose SLOPE equals n2, the index of refraction of the glass. Full credit needs (1) graphing angles or functions of angles on the axes, (2) plotting the sines of the angles while indicating/implying that the index of refraction of air is 1, and (3) indicating a method (e.g., slope $=$ n2) to determine the glass's index of refraction that is consistent with the graph described.

Solution 2

(b) Mark scheme

- Procedure: Place an aperture or slit in front of the hydrogen lamp so that a single, narrow, well-defined beam of light strikes the glass block (a beam is needed so the entry/exit points and ray paths are unambiguous). Place the glass block on a sheet of paper on the lab table and trace its outline, marking the point where the beam enters the glass and drawing the normal (perpendicular) line to the surface at that point. Direct the beam at the glass block at a chosen angle of incidence and trace the incident ray and the refracted ray inside the glass on the paper. Using a protractor, measure the angle of incidence $\theta 1$ between the incident ray and the normal (in air) and the angle of refraction $\theta 2$ between the refracted ray and the normal (in glass) at the boundary. Repeat this procedure for at least

Solution 2

three (or more) different angles of incidence, recording each ($\theta 1$, $\theta 2$) pair, to obtain enough data points to plot the graph from part (a). Full credit needs (1) indicating the light must be formed into a beam entering the glass, (2) describing a method for measuring angles with a protractor (or equivalent) in both media at the boundary, (3) using angles measured with respect to the normal, and (4) repeating the measurement at three or more different incidence angles.

Solution 2

(c)

Mark scheme

- As the light ray crosses the boundary from air into the glass, it bends TOWARD the normal. This occurs because the speed of light in glass is slower than the speed of light in air (glass is optically denser / has a higher index of refraction); when light slows down entering a medium, its path bends toward the normal at the boundary. Full credit needs (1) indicating the ray bends toward the normal going from air to glass and (2) indicating the speed of light is slower in glass than in air (or an answer consistent with the stated bending direction).

Solution 2

(d) Mark scheme

- Hydrogen atoms in the ground state absorb energy from the electricity delivered to the lamp, which excites the atoms from the ground state up to a higher (excited) energy level. The atoms then spontaneously drop back down to a lower energy level, emitting a photon whose energy equals the difference between the two levels; red light corresponds to a transition whose energy difference equals the energy of a red photon. Energy-level diagram: draw several horizontal lines representing discrete allowed energy levels, with the lowest line labeled 'Ground state'; draw an upward arrow from the ground state to a higher level labeled 'Energy absorption' (showing excitation from the lowest level), and a downward arrow from a higher level to a lower level labeled 'Photon emission' (showing the

Solution 2

atom dropping down and emitting a photon). Full credit needs (1) an appropriate energy-level diagram showing absorption starting from the lowest (ground) level and showing emission, (2) indicating a hydrogen atom can be excited from the ground state to a higher energy state by absorbing energy, and (3) indicating that transitions to lower energy levels cause emission of photons.