Unit 23 · Quantization of Energy

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 32

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Spot the error

ANSWER U · 3

He forgot to square the n's: the formula is $\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$. His working gives the $2 \to 1$ line.

Correctly, $\frac{1}{\lambda} = 1.097 \times 10^7\left(1 - \frac{1}{16}\right) = 1.028 \times 10^7\ \text{m}^{-1}$, so $\lambda = \mathbf{9.72 \times 10^{-8}\ m}$ (97.2 nm, ultraviolet, Lyman).

MARKING SCHEME

- ✓ The error: the n's are not squared.
- ✓ $1/\lambda = R(1 - 1/16)$.
- ✓ $\lambda = 97.2$ nm.

2 Read the data

ANSWER A · 4

(The readings are made up, for planes 2.82 Å apart.)

i. $d = \frac{n\lambda}{2\sin\theta}$: $1.54 \div (2 \times 0.272) = 2.83$ Å; $3.08 \div (2 \times 0.546) = 2.82$ Å; $4.62 \div (2 \times 0.819) = 2.82$ Å.

ii. **d = 2.82 Å**.

iii. For n = 4, $\sin\theta = 4 \times 1.54 \div (2 \times 2.82) =$ **1.09**, more than 1: no angle gives it.

MARKING SCHEME

- ✓ $d = n\lambda/(2\sin\theta)$.
- ✓ 2.83, 2.82, 2.82 Å.
- ✓ d = 2.82 Å.
- ✓ $\sin\theta = 1.09 > 1$ for n = 4.

3 Predict, then explain

MARKING SCHEME U · 3

- ✓ Voltage controls the quality: λmin halves.
- ✓ Filament current controls the intensity: more photons, same λmin.
- ✓ Explained with $\lambda_{\text{min}} = hc/eV$ and more electrons from a hotter filament.

4 Show that

MARKING SCHEME A · 3

- ✓ $1/\lambda_L = 3R/4$.
- ✓ $1/\lambda_B = 5R/36$.
- ✓ Ratio 5/27; the Lyman line is shorter.

5 Estimate it

ANSWER A · 3

$\Delta p = \frac{h}{2\pi\Delta x} = \frac{6.63 \times 10^{-34}}{2\pi \times 10^{-10}} = 1.1 \times 10^{-24}$ kg m/s, so $\Delta v = \Delta p/m \approx \mathbf{1.2 \times 10^6\ m/s}$. That is about **half** the speed itself: the electron's speed and place can't both be known well enough to speak of a sharp orbit with a definite speed. Bohr's orbits are only a picture.

MARKING SCHEME

- ✓ $\Delta p \approx 1.1 \times 10^{-24}$ kg m/s.
- ✓ $\Delta v \approx 1.2 \times 10^6$ m/s, about half the orbital speed.
- ✓ So a sharp orbit with an exact speed can't be known.

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6 Which explanation fits?

MARKING SCHEME U · 2

- ✓ B.
- ✓ A cool gas absorbs its own emission wavelengths: an absorption spectrum shows hydrogen is present.

7 Correct the misconceptions

ANSWER U · 3

1. In a stationary orbit the electron gives out **no** light; it radiates only when it jumps to a lower level.
2. The shortest wavelength depends only on the **voltage**: $\lambda_{\min} = hc/eV$.
3. $\lambda = h/mv$: at the same speed the heavier proton has the **shorter** wavelength.

MARKING SCHEME

- ✓ No radiation in a stationary orbit; only on a jump.
- ✓ λmin depends on the voltage only.
- ✓ The proton's wavelength is shorter ($\lambda = h/mv$).

8 Work backwards

ANSWER A · 3

$E = \dfrac{hc}{\lambda} = \dfrac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{1282 \times 10^{-9}} = 1.55 \times 10^{-19}$ J = **0.97 eV**. Trying levels: $E_5 - E_3 = -0.544 - (-1.511) = 0.967$ eV. So the jump is **n = 5 to n = 3**, in the **Paschen** series (infrared).

MARKING SCHEME

- ✓ E = 0.97 eV.
- ✓ $E_5 - E_3 = 0.967$ eV, so $5 \to 3$.
- ✓ Paschen series (infrared).

9 Compare

ANSWER HA · 4

i. $p = \dfrac{h}{\lambda} = \dfrac{6.63 \times 10^{-34}}{1.0 \times 10^{-10}} = \mathbf{6.6 \times 10^{-24}\ kg\ m/s}$.

ii. $E = pc = 1.99 \times 10^{-15}$ J = **12 400 eV**.

iii. $E_k = \dfrac{p^2}{2m} = \dfrac{(6.63 \times 10^{-24})^2}{2 \times 9.1 \times 10^{-31}} = 2.4 \times 10^{-17}$ J = **151 eV**.

iv. The **electron**: at the same wavelength it carries about 80 times less energy, so it can show the same detail while doing less damage.

MARKING SCHEME

- ✓ p = 6.6×10^{-24} kg m/s.
- ✓ Photon 12 400 eV.
- ✓ Electron 151 eV.
- ✓ The electron, with far less energy.

10 What if?

ANSWER HA · 2

$r_n \propto 1/m$: the atom would be **half as big** (radius 0.27 Å). $E_n \propto m$: every level twice as deep, so the ionization energy would **double**, to 27.2 eV, and every line's photons would carry twice the energy.

MARKING SCHEME

- ✓ Radius halves (r ∝ 1/m).
- ✓ Ionization energy doubles to 27.2 eV (E ∝ m).

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11 Make your own

ANSWER HA · 2

For example: “An X-ray tube works at 49.7 kV. Find the shortest wavelength of its X-rays.”

$\lambda_{\text{min}} = \dfrac{hc}{eV} = \dfrac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{1.6 \times 10^{-19} \times 49\,700} = 2.5 \times 10^{-11}$ m $= 0.25$ Å. Any voltage of about 50 kV is right.

MARKING SCHEME

✓ A sensible X-ray tube problem.

✓ Solved correctly to 0.25 Å with $\lambda_{\text{min}} = hc/eV$.

See it at Science Playground

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- **Plasma Ball** (exhibit): The glowing gas gives an emission spectrum: excited atoms drop to lower levels, giving out only their own wavelengths, each gas its own color.
- **The Spectroscope** (exhibit): Look at different light sources through it: a hot filament or sunlight gives a continuous band; a fluorescent tube’s glowing gas adds bright lines of its own.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	11	13	8	**32**

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