Exam Papers Practice

Structure of the Atom

Mark Schemes

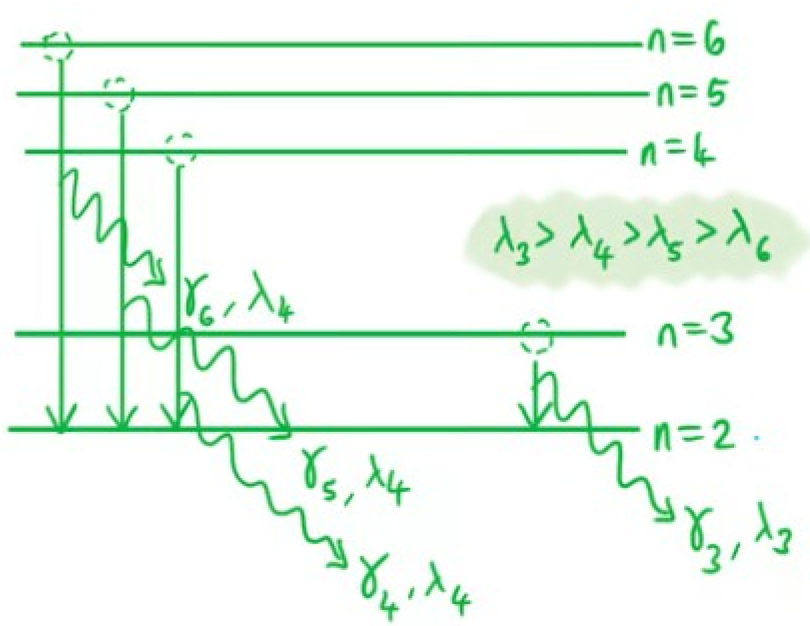
Course	HL IB Physics
Section	Nuclear & Quantum Physics
Topic	Structure of the Atom
Difficulty	Medium

To be used by all students preparing for HL IB Physics
Students of other boards may also find this useful

1

The correct answer is **B** because:

- Energy levels $n = 4$, $n = 5$, and $n = 6$ exist above the energy level $n = 3$ in the hydrogen atom
- Each of these energy levels provide transitions for excited electrons down to the $n = 2$ energy level
  - Hence, these levels contribute to the visible light spectrum for hydrogen
- By inspection, the photon emitted during an electron transition from $n = 4$, 5 or 6 down to $n = 2$ will have a **greater frequency** than the photon emitted during an electron transition from $n = 3$ to $n = 2$
  - This is because the energy gap is larger for such transitions
  - Therefore, since the energy of photons emitted $E = hf$, then larger energy transitions produce photons with a greater frequency
- Since the speed of each photon c is related to its frequency f by the speed equation $c = f\lambda$, then:
  - Photons with larger frequency must have a shorter wavelength
  - Hence, each of the photons emitted during transitions from $n = 4$, 5, or 6 to $n = 2$ have a shorter wavelength than that emitted from $n = 3$ to $n = 2$
- This is shown below:



- Hence, each of the additional spectral lines corresponding to visible light must have a **shorter wavelength** than the line corresponding to the transition from $n = 3$ to $n = 2$
  - This eliminates options **C** and **D**
- The size of the gaps between energy levels gets smaller as n increases
  - Therefore, the correct answer is **B**

A is incorrect as the spectral lines according to transitions to $n = 2$, from $n = 4$, 5 and 6, are equally spaced. Energy level gaps should decrease as n increases. Hence, spectral lines should be closer together for shorter wavelengths (higher frequency photon emission).

C is incorrect as all three spectral lines according to transitions to $n = 2$, from $n = 4$, 5 and 6, are shown as having a **larger** wavelength than the transition $n = 3$ to $n = 2$. This cannot be true: the photons emitted due to transitions from higher energy levels have a greater energy, greater frequency, and hence shorter wavelengths.

D is incorrect as one of the spectral lines is shown as having a **longer** wavelength than the transition $n = 3$ to $n = 2$. This cannot be true: the photons emitted due to transitions from any of the higher energy levels must have a greater energy, greater frequency, and hence shorter wavelengths.

2

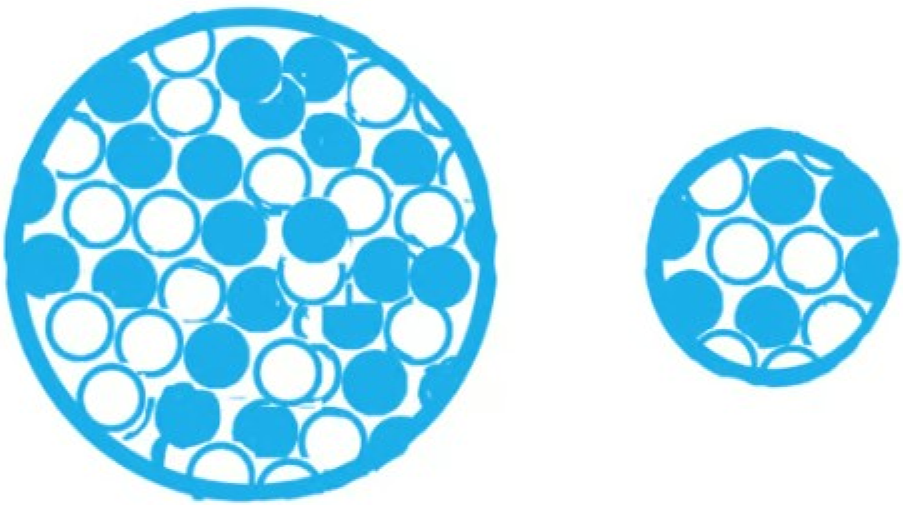
The correct answer is **C** because:

- The density of nuclei is a constant value because it is independent of the radius and the mass
  - Therefore, all the other ratios are incorrect and only **C** can be the right answer

How long did you spend solving this question? Some concepts in Physics can feel surprising, such as the fact that all nuclei have the same density.

This can be proven by calculation, which shows that the nuclear density,

- $\rho = \dfrac{3u}{4\pi R_0^{\ 3}}$, where u is the atomic mass unit (a constant value), and R_o is the constant of proportionality.



However many nuclides a nucleus contains, they always pack together with the same density, so nuclei with more nuclides are simply larger!

3

The correct answer is **B** because:

- Most α-particles pass through the gold foil without deflection. This is because:
  - The empty space in an atom has a radius 10 000 times larger than the radius of the nucleus
  - Therefore, the nucleus is only a tiny fraction of the 'target' atom
  - Most alpha particles travel through the gold atom with no, or only a small amount of, deflection
  - The charge on the nucleus causes this deflection
- A very small number of alpha particles were deflected by a large angle. This is because:
  - The ratio of the size of the nucleus to the size of the atom is inferred from this experiment
  - The ratio of large angle deflections to total particles fired is directly related to the size ratio

A is incorrect as the statements refer to atoms being small rather than nuclei, but it is the charge on the nucleus that causes the deflection.

C is incorrect as the small positive charges on the nucleus and the alpha particle cause the deflection. Although the charges are small they are both positive and so repel each other.

D is incorrect as the small positive charges on the nucleus and the alpha particle cause the deflection. Although the charges are small if the α-particle is moving directly, or nearly directly, towards the nucleus then the deflection will be directly, or nearly directly, away from it. This is large-angle deflection.

4

The correct answer is **C** because

- The question asks for the **best** estimate of nuclear radius
- Two methods are well-understood: Electron diffraction, and closest approach of alpha-particles to the nuclei of metals (Rutherford's original experiment)
- Electron diffraction is the most accurate method because:
  - It gives a direct measurement of the radius of a nucleus
  - Electrons are leptons and so do not interact with nucleons in the nucleus through the strong nuclear force
- The method using closest approach will always overestimate nuclear radius for several reasons:
  - It measures the nearest distance the alpha particle can get to the gold nucleus, not the radius of it
  - Alpha particles are hadrons which are affected by the strong nuclear force as they approach the nucleus, which changes their motion
  - The gold nucleus will recoil as the alpha particle approaches

A is incorrect because this method can be used but is not the most precise choice, for the reasons outlined above.

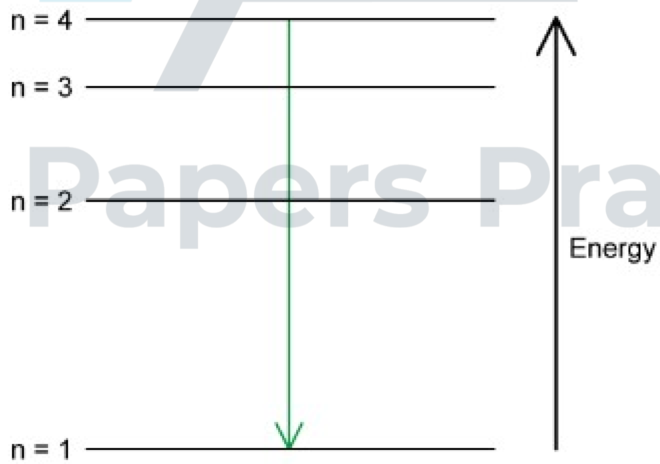
B is incorrect because the emission of photoelectrons provides evidence for the particle-like behaviour of light.

D is incorrect because ionisation by alpha-particles occurs due to the momentum of the particles and so may be indirectly linked to their radii but does not help in estimating the size of the particle.

5

The correct answer is **A** because:

- The wavelength of each emitted photon is linked to a discrete energy change according to the following equation:
  - $\Delta E = \frac{hc}{\lambda}$
- The electron transition with the largest energy change corresponds to the shortest wavelength of the emitted photon
  - If the overall value of the fraction (ΔE) is larger, the denominator of the fraction (λ) must be small
- The transition between n = 4 and n = 1 gives the largest energy change which corresponds to the shortest wavelength



B is incorrect as this is the largest transition between consecutive energy levels, but transitions across multiple energy levels are possible, and several of these have a larger energy difference than the transition from n = 2 to n = 1.

C is incorrect as not only is this transition the smallest energy difference, but n = 3 to n = 4 is an excitation process. This involves the absorption of a photon, not the emission of one.

D is incorrect as this transition has the smallest energy change, which would result in the emission of a photon with the largest wavelength of all the transitions shown.

Confusion in questions like these can often arise from assuming that a large energy means a large wavelength. It is often helpful to consider more familiar forms of electromagnetic radiation to remind yourself of the inverse proportionality between energy and wavelength.

Remember:

- Gamma rays transfer a **large** amount of energy, and they have a **very short** wavelength
- Radio waves transfer a **small** amount of energy, and they have the **longest** wavelength

6

The correct answer is **B** because:

- The difference between the higher energy levels is 3.40 – 0.85 = 2.55, so the energies given must represent a transition from the lowest energy level, n = 1
- No transition from n = 1 has an energy difference of exactly 12.29 eV
- In addition, 12.29 eV is less than 13.6 eV, so it is not a large enough energy to completely ionise the electron
  - Therefore, this photon would **not** be absorbed

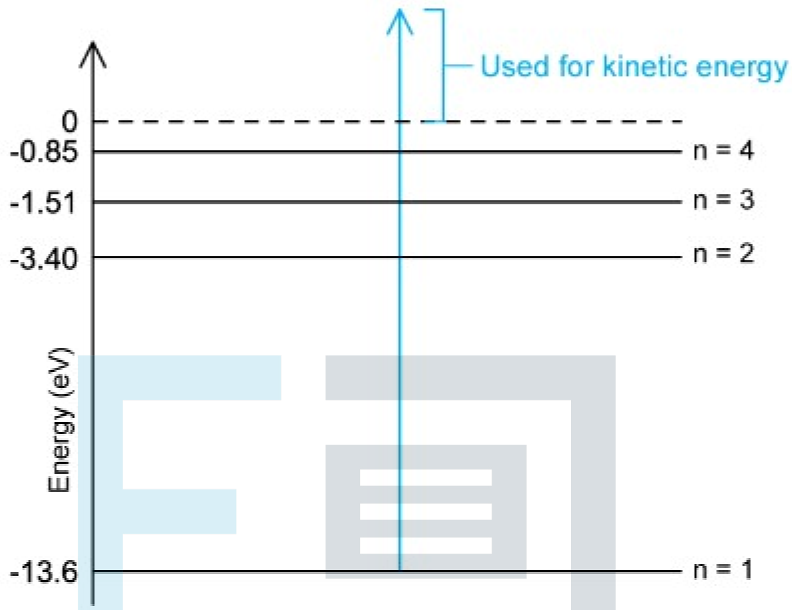
A is incorrect as this is the exact energy difference between n = 1 to n = 2, 13.6 – 3.4 = 10.2 eV, so this photon will cause an excitation.

C is incorrect as this is the exact energy difference between n = 1 and n = 4, 13.6 – 0.85 = 12.75 eV, so this photon will cause an excitation.

D is incorrect as15 eV may not match a specific transition, but since it is more than 13.6 eV, this energy is enough to cause complete ionisation of the electron.

An atom will only absorb a photon if it has exactly the right energy to match a transition between discrete energy levels.

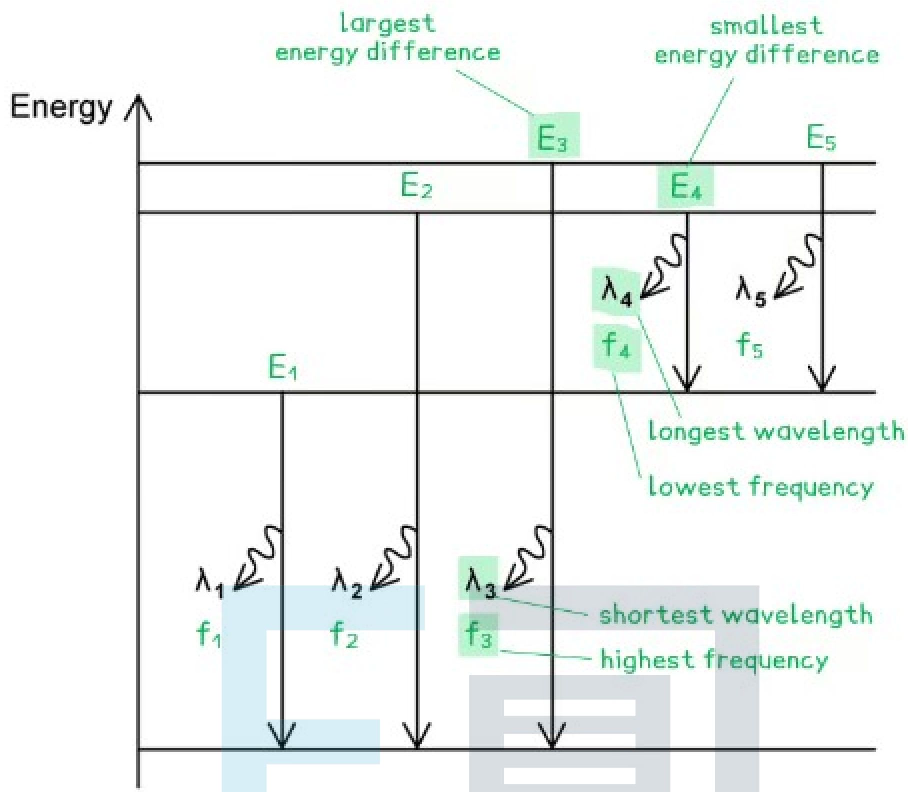
The only exception to this is **ionisation**. If a photon's energy is equal to or more than an atom's ionisation energy (13.6 eV in this case), an electron will be completely removed. Any excess energy from the photon will result in the electron having kinetic energy.



7

The correct answer is **D** because:

- Photon energy is equal to the difference between two energy levels of a transition: $\Delta E = hf = \frac{hc}{\lambda}$
- This means that ΔE is directly proportional to f and inversely proportional to λ, i.e. $\Delta E \propto f \propto \frac{1}{\lambda}$
    - The **largest energy gap** represents the largest energy difference, the highest frequency and the shortest wavelength
    - The **smallest energy gap** represents the smallest energy difference, the lowest frequency and the longest wavelength



- This means that
  - $E_3 > E_2 > E_1 > E_5 > E_4$
  - $f_3 > f_2 > f_1 > f_5 > f_4$
  - $\lambda_4 > \lambda_5 > \lambda_1 > \lambda_2 > \lambda_3$

A is incorrect as the E_5 and E_1 are the wrong way around

B is incorrect as this is the wrong way around, f_4 is the smallest frequency and f_3 is the largest frequency since f is proportional to the difference between the energy levels

C is incorrect as this is the wrong way around, λ_4 has the largest wavelength and λ_3 is the smallest wavelength since λ is inversely proportional to the difference between the energy levels