

23.1 Photoelectrons, reduced mass and atomic excitation

Name: _____ Class: _____ Date: _____

Total: 10 marks

KEY WORDS work function • reduced mass

Objective

Distinguish photoelectric thresholds and characteristic X rays; Apply reduced-mass spectral scaling and many-electron spin filling; Interpret Franck–Hertz energy spacing without inventing new levels. Original public practice; not an ETS paper.

1 Key knowledge and worked examples

In the one-photon photoelectric model, $K_{\max} = h\nu - \phi$ above threshold $\nu_0 = \phi/h$ and $eVs = K_{\max}$. Increasing intensity at fixed frequency changes available electron count/current, not maximum energy. Below threshold there is no one-photon emission; work function belongs to the surface.

Characteristic X rays are discrete photons from filling inner-shell vacancies. Bremsstrahlung is a continuous background from electron deceleration in nuclear fields; its endpoint follows incident energy. Both can appear together. Do not substitute phonon scattering or electron capture for the characteristic-line mechanism.

Hydrogen-like energies scale as $-\mu Z^2/n^2$, with $\mu = m_e M/(m_e + M)$; wavelengths scale inversely with μZ^2 . Positronium has $\mu = m_e/2$. Many-electron spin needs orbital filling/Hund's rule: occupy degenerate orbitals singly with parallel spins before pairing. Carbon $2p^2$ and oxygen $2p^4$ each have two unpaired electrons and $S=1$.

Franck–Hertz spacing ΔV reveals repeated losses of excitation energy $e\Delta V$, not necessarily distinct levels at every peak. Contact/retarding potentials can shift absolute positions. If one return photon carries that energy, $\lambda = hc/(e\Delta V)$; use the spacing and stated apparatus conditions.

■ Worked method

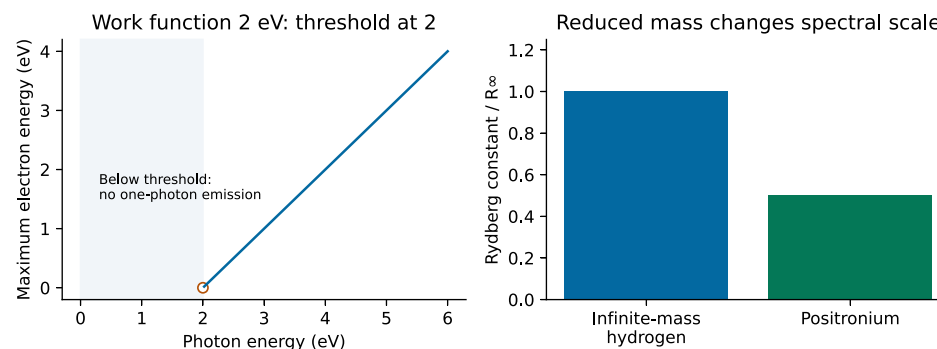
In the one-photon photoelectric effect _____, use the surface work function ϕ .

$$K_{\max} = h\nu - \phi, \quad eV_s = K_{\max}.$$

For photon energy 4.5 eV and $\phi = 2.0$ eV,

$$K_{\max} = E_\gamma - \phi = 4.5 \text{ eV} - 2.0 \text{ eV} = 2.5 \text{ eV}.$$

The stopping-potential magnitude is 2.5 V. Higher intensity at the same frequency changes the available electron rate, not this maximum energy.



2 Practice

2.1 Choose one answer. At fixed above-threshold frequency, increasing light intensity in the one-photon photoelectric model mainly changes: [1]

- A The surface work function
- B Maximum electron kinetic energy
- C The photon frequency
- D Available photoelectron count/current
- E Planck's constant

2.2 Choose one answer. For neutral oxygen ground configuration $1s^2 2s^2 2p^4$, Hund filling gives total electronic spin: [1]

- A 0
- B $1/2$
- C 1
- D $3/2$
- E 2

2.3 Positronium reduced mass divided by electron mass equals _____ (decimal). Show your relation and units. [2]

2.4 Decide whether this claim is true. Justify it: Equally spaced Franck–Hertz features necessarily identify a different atomic excitation energy at each successive feature. [2]

3 Exam-style questions

3.1 Compare the same hydrogenic transition for nuclear masses $M = 10m_e$ and $M = 20m_e$, with equal Z . Find the ratio of photon frequencies and wavelengths using reduced mass. Explain the infinite-nuclear-mass limit. [4]

Solutions

2.1 D More photons can emit more electrons; $h\nu - \phi$ remains the same.

Compare the rejected options: The surface work function; Maximum electron kinetic energy; The photon frequency; Planck's constant. Use the stated model and conditions.

2.2 C Three p orbitals fill singly first, then one pair; two unpaired parallel electrons give $S=1$.

Compare the rejected options: 0; 1/2; 3/2; 2. Use the stated model and conditions.

2.3 0.5. $m_e^2/(2m_e) = m_e/2$.

2.4 False. Successive collisions can lose the same excitation energy repeatedly.

3.1 $\mu = m_e M / (m_e + M)$ gives $\mu_1 = 10m_e/11$ and $\mu_2 = 20m_e/21$. $\nu_2/\nu_1 = \mu_2/\mu_1 = 22/21$ and $\lambda_2/\lambda_1 = 21/22$. For $M \rightarrow \infty$, $\mu \rightarrow m_e$ from below. Award reduced masses, frequency ratio, inverse wavelength ratio and limit. Values describe a model, not real isotopes.