

Photoelectrons, reduced mass and atomic excitation

GRE undergraduate preparation · local supported objectives

Choose the physical question

Reasoning

Repeated equally spaced current dips can represent repeated losses of the same excitation energy, rather than a sequence of different atomic levels. 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

Choose the system and model

Reasoning

Photoelectric maximum kinetic energy is $K_{\max} = h\nu - \phi$ for photon frequency above threshold $\nu_0 = \phi/h$. A stopping-potential magnitude satisfies $eV_s = K_{\max}$, so V_s is linear in ν above threshold. Increasing intensity at fixed frequency increases the available photon count and usually photocurrent, not maximum photoelectron energy. Below threshold the simple one-photon model emits no photoelectrons regardless of intensity. Work function is a property of the surface, not proportional to the illumination frequency.

Use the governing relation

Reasoning

Characteristic X rays result when an electron fills an inner-shell vacancy, emitting a photon equal to the shell energy difference. Their sharp lines depend on target atoms. Bremsstrahlung arises from deceleration of energetic electrons in nuclear electric fields and produces a continuous background, with an energy endpoint set by the incident electron energy. A continuous background and discrete lines can appear together; the existence of one does not exclude the other. These mechanisms differ from visible fluorescence, phonon scattering and particle capture.

Apply the conditions

Reasoning

For a hydrogen-like two-body atom, replace electron mass by reduced mass $\mu = m_e M / (m_e + M)$. In the simple Coulomb model, level energies scale as $-\mu Z^2 / n^2$, so spectral frequencies scale as μZ^2 and wavelengths inversely. For positronium $M = m_e$, $\mu = m_e / 2$ and its Rydberg constant is half the infinite-nuclear-mass value. For a heavy nucleus μ approaches m_e . In many-electron atoms, use orbital filling and Hund's rule rather than the hydrogen model: degenerate orbitals are occupied singly with parallel spins before pairing. Carbon's $2p^2$ gives two unpaired electrons and total spin $S=1$; oxygen's $2p^4$ has two unpaired electrons and also $S=1$. Filled pairs contribute zero net spin.

Check the conclusion

Reasoning

In Franck–Hertz experiments, accelerated electrons lose energy through inelastic excitation once they reach an atomic threshold. Repeated current-dip or peak spacing in accelerating voltage can therefore identify the same excitation energy lost one, two or more times. A spacing ΔV corresponds to energy $e\Delta V$; peaks at 4, 8, 12 V need not represent three separate excited-level energies. Contact potentials and retarding fields can shift absolute peak positions, so use the spacing and stated apparatus conditions. If the excited atom returns by one photon of that energy, wavelength is $hc/(e\Delta V)$.

Worked reasoning 1

Reasoning

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

Worked relation 2

Reasoning

Apply this relation only under the conditions just stated.

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

Worked reasoning 3

Reasoning

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

Worked relation 4

Reasoning

Apply this relation only under the conditions just stated.

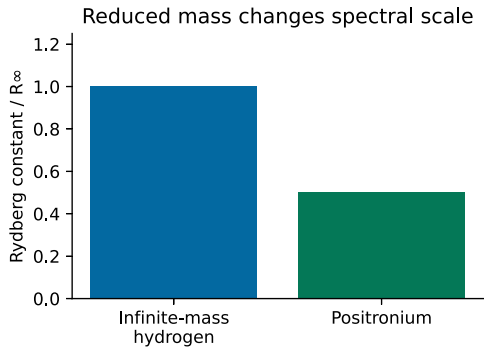
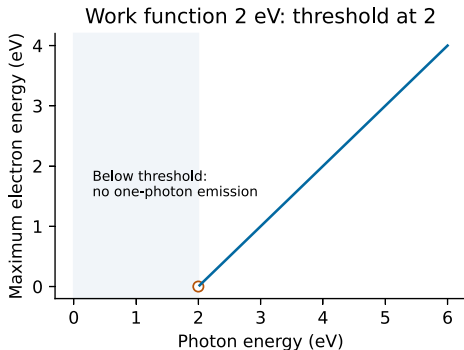
$$K_{\max} = E_{\gamma} - \phi = 4.5 \text{ eV} - 2.0 \text{ eV} = 2.5 \text{ eV}.$$

Worked reasoning 5

Reasoning

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

Read the original diagram



- Original GRE teaching diagram: Photoelectrons, reduced mass and atomic excitation
- Identify the axes, units, directions and the stated model.

Independent transfer · attempt

Reasoning

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]**

Independent transfer · reasoning

Reasoning

$\mu = m_e M / (m_e + M)$ 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.

Check assumptions and limits

Reasoning

Current intensity and stopping voltage answer different questions. Include reduced mass and orbital degeneracy, and use Franck–Hertz spacing rather than treating every peak as a new energy level.

Keep the technical distinctions

Reasoning

work function : Minimum energy required to remove an electron from the specified surface.
reduced mass : Two-body effective mass $m_1 m_2 / (m_1 + m_2)$ for relative motion.

Check yourself

- Define work function and give its condition of use.
- Define reduced mass and give its condition of use.
- Redo the original transfer with a changed parameter; check a limiting case.