Photoelectrons, reduced mass and atomic excitation

GRE undergraduate preparation · local supported objectives

Photoelectrons, reduced mass and atomic excitation

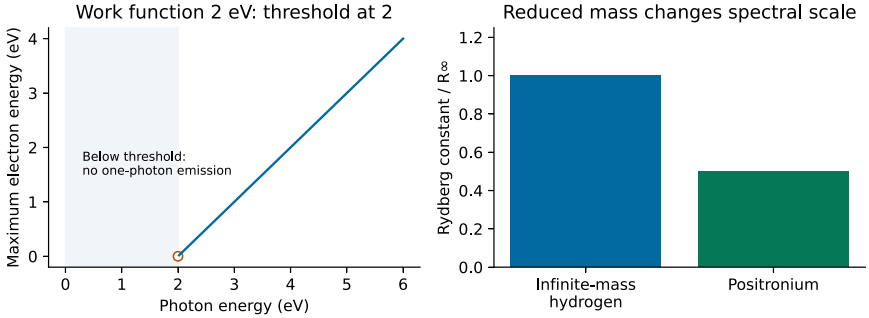
- Use the photoelectric equation with the **work function 逸出功** and **stopping potential 遏止电压**.
- Read X-ray spectra: **characteristic X-rays 特征 X 射线** and **bremsstrahlung 韧致辐射**.
- Use **reduced mass 约化质量** for two-body atoms.
- Interpret Franck–Hertz spacings.

The photoelectric effect

- Below the **threshold frequency** 截止频率 $\nu_0 = \phi/h$, no electrons come out, however bright the light.
- Brighter light at a fixed frequency gives more electrons (more current), not faster ones.
- In 1916 Robert Millikan plotted V_s against ν and found a straight line of slope h/e.

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

Figure: The photoelectric effect



- Identify the axes, units, directions and the stated model.

X-ray spectra

- Characteristic lines: an electron knocks out an inner electron, and an outer one falls into the gap. The lines are sharp and set by the target. For the K_α line, $E \approx 10.2\,\text{eV} \times (Z-1)^2$ (Moseley's law).
- Bremsstrahlung: electrons slowing in the target give a continuous spectrum. It ends at the tube energy eV, so $\lambda_{\min} = hc/eV$.

Reduced mass

- Energy levels scale as μZ^2. Deuterium's lines are slightly shorter in wavelength than hydrogen's.
- Positronium (an electron and a positron): $\mu = m_e/2$, so its energies are halved and its wavelengths doubled.

$$\mu = \frac{m_e M}{m_e + M}$$

Spin pairing and Hund's rule

- Carbon ($2p^2$) and oxygen ($2p^4$) both have two unpaired electrons and total spin $S = 1$.
- Nitrogen ($2p^3$) has three unpaired electrons: $S = 3/2$.

Franck–Hertz spacings

- Use the spacing, not the position of the first dip: contact potentials shift every dip by the same amount.
- The excited atom returns to the ground state by emitting a photon of $\lambda = 1240/(e\Delta V \text{ in eV})$ nm.

Worked example: a photocell

- Photon energy: $h\nu = 3.31$ eV.
- $K_{\max} = 3.31 - 2.0 = 1.31$ eV, so $V_s = 1.31$ V.
- Threshold: $\nu_0 = 2.0/(4.14 \times 10^{-15}) = 4.8 \times 10^{14}$ Hz.

Worked example: X-rays from copper

- K_α: $E \approx 10.2 \times 28^2 = 8.0$ keV, close to the measured 8.05 keV.
- Shortest bremsstrahlung wavelength: $\lambda_{\min} = 1240/30{,}000 = 0.041$ nm.
- Positronium's Lyman-alpha line is twice hydrogen's 122 nm: 243 nm.

Common errors

- Thinking brighter light gives faster photoelectrons.
- Reading the energy from the first Franck–Hertz dip instead of the spacing.
- Confusing characteristic lines with the bremsstrahlung continuum.

Common errors (2)

- Using the electron mass for positronium.
- Pairing electrons before every degenerate orbital has one.

Key terms

- **work function**: The least energy needed to free an electron from a metal surface.
- **stopping potential**: The reverse voltage that just stops the fastest photoelectrons.
- **threshold frequency**: The lowest light frequency that frees electrons.
- **characteristic X-rays**: Sharp X-ray lines from inner-shell transitions, set by the element.

Check yourself

- The light on a photocell doubles in intensity at the same frequency. What happens to $K_{\max}$ and the current?
- What is the shortest X-ray wavelength from a 50 kV tube?
- Franck–Hertz dips are 4.9 V apart. What wavelength do the excited atoms emit?