# On the photoelectric effect

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## Warm-up problems

1. Draw a labelled diagram of the structure of a metal, and refer to it to explain two properties of metals.
2. Give the definition of 'a quantum', and explain how light is quantized.
3. Write down an equation which gives the maximum kinetic energy of electrons escaping from a metal surface via the photoelectric effect, and explain each term carefully.

## Regular problems

4. Calculate the energies of these photons.
   (a) A radio photon carrying a transmission of Test Match Special on BBC Radio 4 LW (which has a frequency of 198 kHz). What is its wavelength?
   (b) A visible photon emitted by the transition of an electron in a sodium atom (this is the brilliantly bright yellow light, familiar from street lamps, caused by the 'D-lines'[1] in the emission spectrum of sodium) at a wavelength of 589.0 nm.
   (c) A gamma photon detected in a PET (Positron Emission Tomography) scanner which has a wavelength of $2.43 \times 10^{-12}$ m.
5. Explain the following
   (a) Electrons can be emitted from the surface of zinc when ultraviolet light falls on it, but not visible.
   (b) Electrons will be emitted from the surface of potassium even with visible light.
   (c) The electrons emitted from potassium have a greater kinetic energy than those from zinc do when they are illuminated with the same ultraviolet light.

[1] There are actually two lines, very close together, at 589.0 nm and 589.6 nm, due to fine structure caused by the relativistic effect of spin-orbit coupling between L and S. This particular line, at 589.0 nm, is due to the transition from $3P_{3/2} - 3S_{1/2}$.

6. Ultraviolet light of wavelength $3.5 \times 10^{-7}$ m falls on a potassium surface. The work function of potassium is $4.4 \times 10^{-19}$ J.

   (a) What is the maximum energy of the photoelectrons?

   (b) Why is this a maximum energy (i.e. why might electrons be emitted with less than this energy)?

7. X-rays with frequency $1.53 \times 10^{16}$ Hz cause the emission of electrons from a material with a maximum kinetic energy of $2.18 \times 10^{-18}$ J. Calculate, for this material,

   (a) the work function,

   (b) the threshold frequency.

8. [AQA PA01 Jan 2002]

   (a) When monochromatic light is incident on a metal plate, electrons are emitted only when the frequency of the light exceeds a certain threshold frequency.

      i. Explain, in terms of energy, why this threshold frequency exists. [3]

   (b) A sodium metal surface is illuminated with incident light of frequency $9.70 \times 10^{14}$ Hz. The maximum kinetic energy of an emitted electron is $2.49 \times 10^{-19}$ J.
   Calculate

      i. the wavelength of the incident light,
      ii. the energy, in J, of each incident photon,
      iii. the work function, in J, of sodium,
      iv. the work function, in eV, of sodium. [7]

## Extension problems

8. The maximum kinetic energy of photoelectrons from aluminium is found experimentally to be 2.3 eV for radiation of $2.00 \times 10^{-7}$ m and 0.90 eV for radiation of $3.13 \times 10^{-7}$ m. Use these experimental data to calculate Planck's constant and the work function for the metal.

9. (a) If the energy flux associated with a beam of light of wavelength $3 \times 10^{-7}$ m is $10\,\mathrm{W\,m^{-2}}$, estimate how long it would take, classically, for sufficient energy to arrive at a potassium atom of radius $2 \times 10^{-10}$ m so than an electron can be ejected. The work function of potassium is $4.4 \times 10^{-19}$ J.

   (b) What would be the average emission rate of photoelectrons if such light fell on a piece of potassium $10^{-3}\,\mathrm{m^2}$ in area?

   (c) Would you expect the average emission rate to be significantly affected by quantum mechanical considerations?