Quantum Physics

Basic Problems

1. Calculate the respective energy and momentum of photons in radio waves with frequency 104 MHz and in X-ray radiation with wavelength 12 pm.
2. Electromagnetic radiation is considered to be dangerous if the photons carry enough energy to ionise atoms (*ionising radiation*). Calculate the maximum wavelength allowing the ionisation of hydrogen atoms (ionisation energy 13.6 eV). Which types of electromagnetic waves can cause ionisation?
3. How many photons per second are emitted by the sun? Assume a constant wavelength of 550 nm.
4. A copper plate is irradiated with UV light (wavelength 110 nm). Calculate the maximum kinetic energy and speed of electrons ejected from the surface of the plate.
5. Calculate the threshold frequency for light to eject electrons from the surface of a tungsten plate. Does this work with visible light?
6. Calculate the de Broglie wavelength and frequency for 500 keV protons. Does the product of wavelength and frequency have the same physical meaning as for light?
7. What is the wavelength of a photon with the same momentum as an electron with a de Broglie wavelength of 5.3 pm? What are the respective frequencies?
8. Estimate the de Broglie wavelength for a hurdler. Why has no one ever observed the diffraction of a hurdler on one of the hurdles?

Supplementary Problems

9. Calculate the velocity change experienced by a dust particle with mass 2 ng when it absorbs a photon of light with wavelength 550 nm.
10. Electrons are accelerated in an electron tube with an acceleration voltage of 5.2 kV. The current carried by the electrons is 1.1 mA. The electron beam has a cross section of 1.2 mm².
    a) Calculate the electrons' de Broglie wavelength.
    b) How many electrons per second hit the target?
11. Show that the wavelength of a photon scattered on a free electron (a phenomenon known as *Compton scattering*) increases by

$$\Delta\lambda = \lambda_C \sin^2(\vartheta/2),$$

    where $\lambda_C = 2\ h/(m_e\ c)$ is the *Compton wavelength* of an electron and ϑ the scattering angle, i.e. the angle by which the photon is deflected from its initial direction.
    Hint: As a reference you can find a derivation on Wikipedia.

    Calculate the wavelength shift for a photon scattered by 90 °. Why is this effect investigated with X rays and not with visible light?

Numerical Solutions: 1. 0.43 µeV, 100 keV; 2. 91 nm (UV); 3. 10^{45}; 4. 6.5 eV, 0.005 *c*; 5. $1.1 \cdot 10^{15}$ Hz, no; 6. $2.3 \cdot 10^{23}$ Hz, 41 fm, no; 7. 5.3 pm, $5.7 \cdot 10^{19}$ Hz, $1.4 \cdot 10^{20}$ Hz; 8. $8 \cdot 10^{-37}$ m; 9. $6 \cdot 10^{-19}$ m/s; 10. 17 pm, $6.9 \cdot 10^{15}$; 11. 4.9 pm