Exercises Quantum Physics (GEMF) – Origin QPh

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1. A 50 kW broadcasting antenna emits radio waves at 98.9 MHz. Calculate the number of photons emitted per second and determine whether the quantum nature of the radiation is important to take into account.

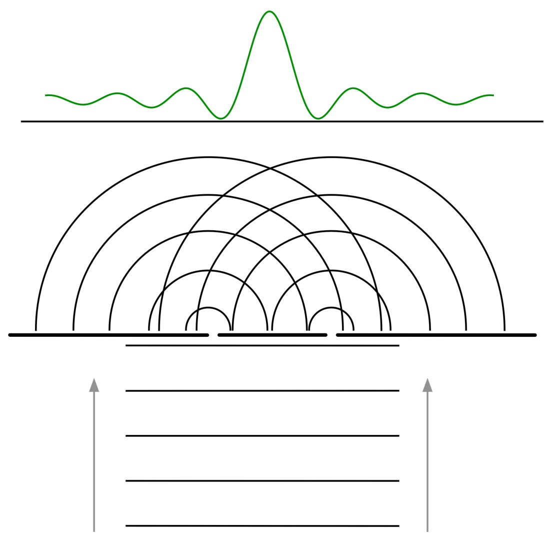
2. An object connected to a spring on a horizontal friction-less table is pulled 25 cm out of equilibrium. The object has a mass of 4 kg and the force constant of the spring is 196 Nm^{-1}. Use classical mechanics to determine the frequency and the energy of the mass-spring system. Next, consider the spring-mass system as a quantum object to calculate the energy difference of two subsequent levels and to calculate the total number of vibrational quanta involved in the movement of the object.

3. After a set of experiments on the photoelectric effect one finds that the minimum electric potential to stop the photoelectron is 2.06 V when the incoming light has a wave length of $\lambda = 3000$ Å, and 1.02 V when $\lambda = 4000$ Å. Compute the threshold frequency and the Planck constant.

4. Calculate the de Broglie wave length of (i) an electron with kinetic energy 54 eV: (ii) a proton of kinetic energy 70 MeV: (iii) a 100 g bullet moving at 1200 m/s.

5. Consider a thermal neutron (moving at speed v corresponding to the average thermal energy) at $T = 300$ K. Calculate the Broglie wave length of the neutron. Can these neutrons be used to unravel the structure of a crystal?

6. Not only the diffraction patterns of electrons and neutrons show that matter has wave character at (sub-)atomic scales, the double-split experiment also provides an excellent confirmation of the hypothesis of de Broglie. When a wave front hits a double split an interference pattern will appear on a screen placed behind the double split. The same happens when electrons are used and one-by-one(!) fired on the double split. In the early 2000s, interference was also detected when C_{60}, the molecular soccer ball, was used. The experiment was performed at 900 K, calculate the wave length associated to the C_{60} molecule. Hint: use the Maxwell-Boltzmann velocity distribution to determine the average velocity of the molecules at this temperature.



Schematic representation of the double spilt experiment. A plane wave hits the wall from below. The wave front is scattered by the two holes in the wall and an interference patterns appears on the screen.

7. A muonium atom is a physical system similar to the hydrogen atom, where the proton is replaced by a positive muon, also known as an antimuon, μ^+. Consider this muonium atom within Bohr's atom model and calculate the radius and the ionization energy of the electron in the ground state. The mass of the muon is 207 times the mass of the electron.

8. Calculate the final size of the wave packet of a free particle after traveling 100 m when the particle is (i) a 25 eV electron with an initial wave packet width of 10^{-6} m; (ii) a 25 eV electron whose wave packet has an initial width of 10^{-8} m; (iii) a 100 MeV electron with an initial width of 10^{-5} m; and (iv) a 1 cm object of 100 g travelling at a speed of 50 ms^{-1}.

9. Calculate the time it takes for case (i) and (iv) of the previous question to increase an initial width of 1 mm to 1 cm.