

Problems are on two pages! You can gain a total of 30 + 2 pts.

1. How far does light travel in 1 μs ? Give your result in meters. **(1 pt)**
2. Write down the Lorentz transformations from a system \mathcal{S} with coordinates (x, y, z, t) to a system \mathcal{S}' with coordinates (x', y', z', t') , for the case that \mathcal{S}' moves with velocity v in the z -direction (not the x -direction!). **(2 pts)**
3. What is the length L of a stick, measured by an observer \mathcal{O} , if the stick has proper length L_0 , propagates along its extended direction, and passes \mathcal{O} with velocity v ? Expand the length L , seen by the observer, for small values $v^2/c^2 \ll 1$ to lowest non-vanishing order in a Taylor expansion. **(2 pts)**
4. Two spaceships approach each other, each moving with the *same* speed as measured by an observer on Earth. If their *relative* speed is v_{rel} , what is the speed of each spaceship? **(3 pts)**
5. The pion has an average lifetime of $t_0 = 26$ ns when at rest. For it to travel $\Delta x = 10.0$ m on average, how fast must it move? Give first the formula in terms of velocity v , distance Δx and lifetime t_0 , then put in numbers. **(3 pts)**
6. An object disintegrates into two fragments. One of the fragments has mass m_1 and momentum p_1 in the positive x -direction. The other fragment has mass m_2 and momentum p_2 in the positive y -direction. Find mass, speed and direction of the original object. **(4 pts)**
7. A radium isotope decays to a radon isotope, ^{222}Rn , by emitting an α particle (a helium nucleus) according to the decay scheme $^{226}\text{Ra} \rightarrow ^{222}\text{Rn} + ^4\text{He}$. The masses of the atoms are 226.0254 (Ra), 222.0175 (Rn), and 4.0026 (He). How much energy is released as the result of this decay? Give your result in MeV. **(2 pts)**
8. Calculate the energy of a photon whose wavelength is 500 nm. Express your answer in electron volts **(1 pt)**
9. A plate of 10 cm \times 10 cm is kept on a temperature $T = 1000$ Kelvin. Assume that this plate radiates as a blackbody.
 - (a) What is the wavelength λ_{max} at which the maximum energy is emitted? **(1 pt)**
 - (b) What is the total energy emitted in 1 min? **(1 pt)**
 - (c) Assume that an observer \mathcal{O} approaches this plate with high velocity v . At which wavelength λ'_{max} will \mathcal{O} observe the maximum of the radiated spectrum? Express your result as a formula, but do not put in numbers. **(2 pts)**
10. Which features of the photoelectric effect cannot be described by classical electrodynamics? (give your answer in key words, at most three or four lines of prose) **(1 pt)**
 Light of wavelength 500 nm is incident on a metallic surface. If the stopping potential for the photoelectric effect is 0.45 V, find (a) the maximum energy of the emitted electrons in eV, (b) the work function which determines the 'binding' energy of the electron in the metall, and (c) the cutoff wavelength above which no photoelectric effect is seen. **(3 pts)**

11. What is the relation between the momentum of a particle and its (de Broglie) wavelength? **(1 pt)**.

Assume that a neutron has a de Broglie wavelength of $\lambda_n = 0.1$ nm. What is the kinetic energy of this neutron (Hint: work with the non-relativistic formula for the kinetic energy E_{kin} and argue finally why this is justified. Express E_{kin} in terms of the neutron momentum.). **(1 pt)**

The inter-atomic distance of Ni-atomes is $d = 2.15$ Angstrom. For a beam of neutrons with de Broglie wavelength $\lambda_n = 0.1$ nm, incident on a Ni plate, calculate the Bragg angle under which a maximum of the number of recoiling neutrons is seen. **(2 pts)**

12. Ask yourself an *interesting* question, in which Planck's constant h and Boltzmann's constant k_B appear. Then give the correct solution to your question. (up to **2 extra pts**).