Physics 125 Midterm

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Open book, notes. Express answers in symbolic form first, and then, when asked, in numerical form. Give numbers to two significant figures.

1. A point particle of infinite mass with one unit of positive electric charge, e sits at the origin. For this problem, use the Bohr atom, and in your symbolic answer, eliminate the electric charge e in favor of the fine-structure constant $\alpha = e^2/(4\pi\epsilon_0\hbar c)$. Some constants: $\hbar c = 200\,\text{MeV-fm}$, $m_e c^2 = 0.51\,\text{MeV}$, $\alpha = 1/140$, $c = 3.0\times 10^8\,\text{m/s} = 3.0\times 10^{23}\,\text{fm/s}$.

   (a) A particle of mass M and negative electric charge $-e$ is in the ground state orbit ($n = 1$). The radius of the orbit is $r = 1\,\text{fm}$, which happens to be the characteristic size of a nucleon. Determine the mass of the particle, both in symbolic form *and* in numerical form.

   (b) An electron, initially at rest and not bound to the positive charge, falls into the ground state, and emits a single photon. Determine the ratio of the wavelength of the photon to the diameter of the ground state, both in symbolic form *and* in numerical form.

2. A beam of particles penetrates through the earth along a diameter. The mean number of interactions with the earth's nucleons experienced by a penetrating particle is 1. The radius of the earth is $R_\oplus = 6.4\times 10^6\,\text{m}$, the mass of the earth is $M_\oplus = 6.0\times 10^{24}\,\text{kg}$, the mass of a nucleon is $m_N = 1.7\times 10^{-27}\,\text{kg}$, and Newton's constant is $G_N = 6.7\times 10^{-11}\,\text{m}^3\text{kg}^{-1}\text{s}^{-2}$.

   (a) What is the cross section for the interaction of one of the particles with a nucleon, both symbolically *and* numerically?

   (b) What is the probability that a particle will pass through a diameter of the earth and experience no interaction at all, both symbolically *and* numerically?

3. The Λ_b^0 is a baryon that consists of the quarks udb. The branching ratio for the decay $\Lambda_b^0 \to \Lambda_c^+ e^- \overline{\nu}$ is 10%. Symbolically and numerically, what is the branching ratio for the decay $\Lambda_b^0 \to p e^- \overline{\nu}$. The CKM matrix elements are $V_{ud} = V_{cs} = 0.97$, $V_{us} = V_{cd} = 0.22$, $V_{tb} = 1.0$, $V_{cb} = V_{ts} = 0.04$, $V_{ub} = 0.004$, and $V_{td} = 0.009$.

4. Suppose the coupling strength of the quark-gluon vertex is still $\sqrt{\alpha_s/2}$, but suppose that there are only two colors, instead of three. Can like quarks can still attract, if they are in the right color eigenstate? In that state, what is the eigenvalue of the product of strong charge couplings?

5. A beam of silver atoms goes into a Stern-Gerlach magnet; the direction of the beam, and the long axis of the Stern-Gerlach, is denoted y. The axis of the magnetic field, perpendicular to y, is denoted the z direction. At the end of the magnet, only those atoms with $s_z = -\hbar/2$ are allowed out of the magnet. The surviving beam is then fed into a second Stern-Gerlach magnet with its magnetic axis rotated 60° with respect to that of the first magnet. What is the intensity of the beam that exists the second Stern-Gerlach magnet with spin component along the second magnetic axis of $+\hbar/2$? You can quote the intensity at the exit of the second magnet *relative* to the intensity at the entrance of that magnet.