Physics 330, Spring 2009
Final Exam
100 points

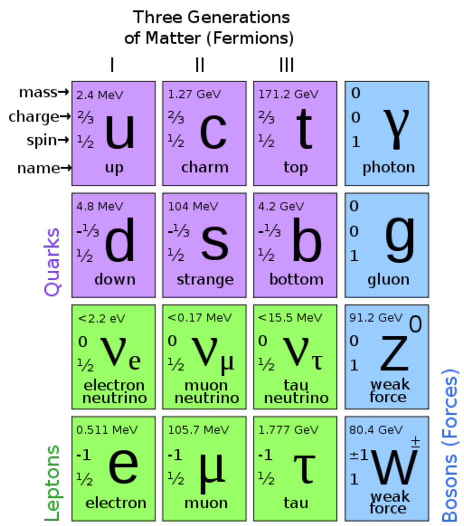
1. **Problem 1 (20 points)** Sodium (Na) has $Z = 11$.
   (a) (5 pts) Write the electron configuration of the ground state.
   (b) (5 pts) Estimate the ionization energy. Write your answer in terms of fundamental constants, then give an approximate value in eV.
   (c) (5 pts) If spin-orbit coupling is ignored (ignore fine-structure energy level splitting), what are the possible values of j for the ground state of Na?
   (d) (5 pts) Describe what gives the fine-structure energy level splitting.

2. **Problem 2 (20 points)** For the 1-dimensional infinite square well:
   (a) (5 pts) Write the equations for the time-independent wave functions corresponding to the ground and first excited state.
   (b) (5 pts) Sketch the above wave functions with respect to the potential well.
   (c) (5 pts) If two fermions trapped in the potential must have have the same spin state (because of a large applied magnetic field, for example), write the equation for the wave function corresponding to the lowest energy state.
   (d) (5 pts) What is the energy of the above two particle state? Would the result be different if the particles were bosons? Explain.

3. **Problem 3 (20 points)** Two atoms of mass m form a diatomic molecule with a separation of d. At what temperature is it equally likely to find the molecule in the ground or first excited rotational state? Hint: These states have different degeneracies.

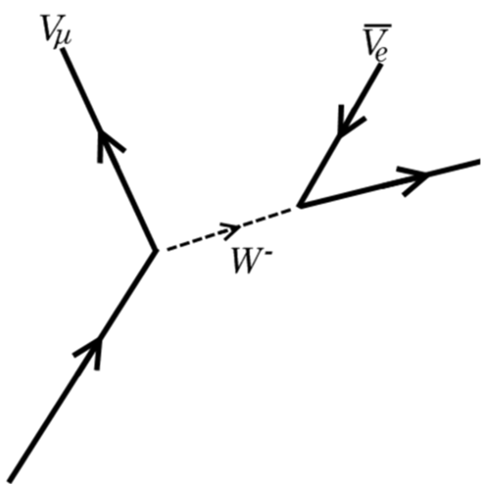
4. **Problem 4 (20 points)** An electron neutrino is generated in a neutron decay $n \rightarrow p + \bar{\nu}_e + e^-$ and the produced electron immediately annihilates with a positron giving 2 photons. This occurs 200,000 light years from earth. The upper limit for the mass of the electron neutrino is ≈ 2 eV. The masses of the proton, neutron and electron are $m_p = 938.27$ MeV/c^2, $m_n = 939.57$ MeV/c^2, and $m_e = 0.511$ MeV/c^2. Assume all of the energy of the neutron decay is carried away by the neutrino. Make an estimate for γ (the relativistic quantity related to the speed, momentum and energy of the neutrino.) If both the photon and the neutrino reach earth, estimate the delay between the photon arrival and neutrino arrival. Hint: Write $v = c - \epsilon$ and discard small terms. There are 3×10^7 seconds in a year. Clearly explain your approach.

PROBLEM 5 IS ON THE BACK OF THIS SHEET!

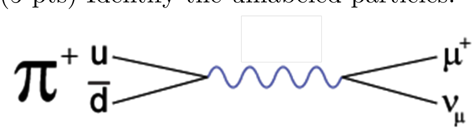


5. **Problem 5 (20 points)** Reproduce diagrams on your answer sheet.

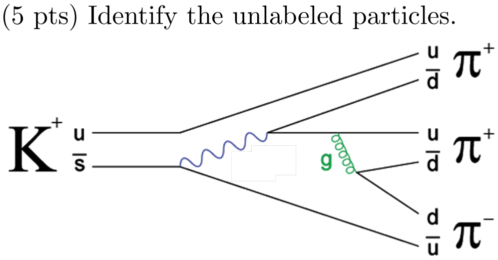
(a) (5 pts) Identify the unlabeled particles.



(b) (5 pts) Identify the unlabeled particles.



(c) (5 pts) Identify the unlabeled particles.



(d) (5 pts) Draw a diagram showing elastic scattering between an electron and a neutrino.