Ph 406

PROBLEM SET 2. DUE FEB. 17, 1993

(1) An experiment on proton decay is to be carried out using a large cubical tank of water as the proton source, and the possible decay mode $p \to e^+ + \pi^0$ is to be detected by the Čerenkov light emitted when the electromagnetic showers from the decay products traverse the water. How big should the water tank be in order to contain such showers? Estimate the total track-length integral (TLI) of the showers in a decay event and hence the total number of photons emitted in the visible region ($\lambda = 400$–700 nm). The light is to be detected by an array of photomultipliers placed at the water surfaces. If the optical transmission of the water is 20% and the photocathode efficiency is 15%, what fraction of the surface must be covered by photocathode to give an energy resolution of 10%? NOTE: THE π^0 DECAYS TO $\gamma\gamma$ (2 PHOTONS) WITH $\tau \sim 10^{-16}$ s

(2) PROBLEMS 8.2 & 13.5 OF COTTINGHAM & GREENWOOD

8.2 Neutron detectors register individual neutrons by their production of charged, ionising particles in a nuclear reaction. One method, appropriate to thermal neutrons ($E < 0.1$ eV) uses the reaction

$n + {}^3_2\mathrm{He} \to p + {}^3_1\mathrm{H} + 0.73$ MeV.

The cross-section for this reaction, which dominates at low energies, follows the $(1/v)$ law,

$\sigma = 0.039(c/v)$ b.

The mean distance a neutron travels through ^{3}He gas before it interacts is $l = 1/(\rho_{He}\sigma)$, where ρ_{He} is the number density of helium atoms (Appendix A). What detector thickness is needed, using ^{3}He gas at a pressure of 10 bars (which gives $\rho_{He} = 2.4 \times 10^{26}\ \mathrm{m}^{-3}$) in order that at least 90% of incident neutrons with energy 0.1 eV produce ionisation?

13.5 In a neutron detector of the type described in Problem 8.2, estimate roughly the number of ion pairs produced in the helium gas per neutron interaction and the distance over which the ionisation is deposited.

PROBLEMS (1) & (2) OFFER THE OPPORTUNITY TO WORK OUT THE KINEMATICS OF TWO-BODY DECAY. THE PRINCIPLE IS THAT ENERGY AND MOMENTUM ARE CONSERVED. PROB (1) REQUIRES USE OF RELATIVITY: MOST ELEGANTLY, $1 \to 2 + 3 \Rightarrow P_1 = P_2 + P_3 \Rightarrow P_3^2 = m_3^2 = (P_1 - P_2)^2 = \ldots$

WHERE P IS A 4-VECTOR.

(3) A MAGNETIC MONOPOLE WITH MAGNETIC CHARGE g, MASS M, AND VELOCITY $\beta = v/c$ PASSES THRU A MATERIAL WITH ELECTRON DENSITY N/cm^3. CALCULATE THE ENERGY LOSS PER UNIT PATH LENGTH, dE/dx, ASSUMING $\beta \sim 1$. YOU MAY WISH TO COMPARE THE RESULT TO THE dE/dx FOR CHARGED PARTICLES SUPPOSING THE MONOPOLE SATISFIES THE DIRAC QUANTIZATION CONDITION $eg = \hbar c/2$. (JACKSON, CLASSICAL ELECTRODYNAMICS, 2ND ED, GIVES A SEMI-CLASSICAL DISCUSSION OF THIS CONDITION.)

(4) FOR MAGNETIC MONOPOLES WITH $\beta \sim 10^{-3}$, AS MIGHT BE CONSISTENT WITH EXTRA GALACTIC ORIGIN, THE ABOVE RESULT FOR dE/dx SHOULD BE MODIFIED. CONSIDER ENERGY LOSS IN A METAL PLATE OF RESISTIVITY ρ DUE TO JOULE HEATING FROM THE EDDY CURRENTS INDUCED BY THE CHANGING MAGNETIC FLUX AS THE MONOPOLE PASSES THRU THE PLATE AT NORMAL INCIDENCE. YOU MAY ASSUME β REMAINS CONSTANT. NOTE THAT YOU MUST ESTIMATE ($\Rightarrow$ DISCUSS BRIEFLY ALSO) SOME PROPERTY OF THE MATERIAL OF THE PLATE NOT SPECIFIED ABOVE.