Neutrino Questions (revised Aug 2008 by: Steve Pullar)
Place answers in you notebook for turn in later.

1. The MINOS detector is constructed of two ½ inch steel plates welded together with crossed seams, making one plane, attached to each set of steel plates is a 1.0 cm wide layer of scintillator material (figure 1). The MINOS detector contains 486 planes of steel and 484 planes of scintillator. There is also a combined 12.8 meters of air gap between all of the plates. The detector has an octagon shape like a stop sign, and each plane/scintillator is hung on a rack just like a file folder.

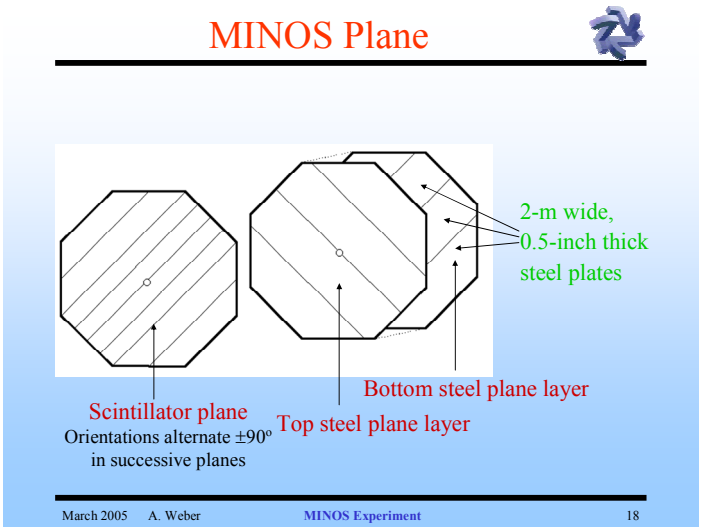
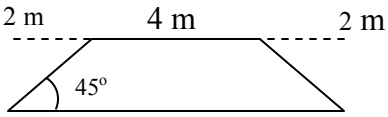


Figure 1

a) If we only consider the top three sides of the octagon, what is the total top surface area of the detector?
b) On the surface one muon cosmic ray hits a square centimeter every minute. How many would hit the detector each second if it were on the surface?
c) By what approximate factor is the rock above the detector shielding, if the detector is hit by a cosmic muon every 2.08 seconds?



This shielding is why the detector was built 713.5m (2341 ft) underground!

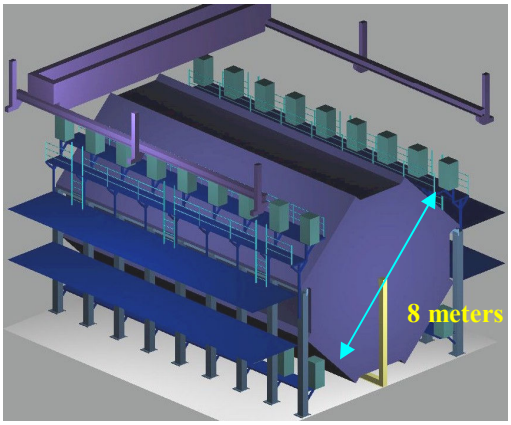


Figure 2

2. How likely is a neutrino to hit the nucleus of an atom? Let's first consider the hydrogen atom. We know the radius of the first energy level is the Bohr radius at 5.29 X 10^{-11} meters. a) How many hydrogen atoms end to end would cross the width of the dot at the end of this sentence (0.5 mm)? b) Calculate the circular surface area of the atom (not the spherical!). This is not the circular area of the nucleus, that's much smaller! The

equation used to find the radius of the nucleus is $r = R_o A^{1/3}$, where $R_o = 1.2 \times 10^{-15}$m and A is the number of nucleons (protons and neutrons) in the nucleus. Hydrogen has only one nucleon, so "A" is one. c) Calculate the radius of a hydrogen atom (proton). d) how many times smaller is the area of the nucleus of hydrogen than the atom of hydrogen?

3. The Far Detector at Soudan uses iron atoms as the neutrino target. A typical iron atom has a radius of 1.26×10^{-10}m repeat the calculations for 2b) through 2d) for iron. What can you say about atoms??!! A neutrino is estimated to be about 100,000 times smaller than a proton, and the neutrino must have a direct interaction with the nucleus. It is no wonder it takes many trillions of neutrinos passing through the detector to get one interaction.

4. The detector is made of 5500 tons of iron. Use the following information to estimate the numbers of atoms of iron in the detector. 1 ton = 2000 lbs; on the planet Earth, one kilogram of mass has a weight of 2.2 lbs; the molar mass of iron is 55.8 g/mol, and one mole is 6.02×10^{23} atoms. Even with trillions of neutrinos sent every 2.2 seconds, only 2 – 12 events caused by beam neutrino/iron nuclei interaction happens each DAY!

5. MINOS and other experiments have estimated the mass of an electron neutrino to be about 3 electron volts (eV). How can mass be measured in VOLTS!! Well, 1 eV is the same energy as 1.6×10^{-19} J. Once we convert eV to joules we are set up for the famous Einstein equation which fell out of his work on special relativity, $E = mc^2$. Try this. The rest mass of an electron is 0.511MeV find its mass in kilograms. Now fill in the table:

Flavor (name)	Mass in eV	Mass in kilograms
Electron neutrino	Less than 3eV	
Muon neutrino	Less than 170KeV	
Tau neutrino	Less than 18.2 MeV	

6. We know the nucleus is made of protons and neutrons, but these are not fundamental particles (smallest possible) they are made of smaller particles held together with the strong nuclear force. They belong to a class of particles called hadrons. They also belong to a subclass called baryon particles. Baryons are made up of three fundamental particles called quarks. Another subclass of hadrons are mesons, like pions and kaons, which are made up of two quarks. There are six different quarks; up, down, top, bottom, and my favorites, charm and strange. And remember every particle has its alter ego of antimatter, that makes 12 quarks total. Protons and neutrons are made of different combinations of up and down quarks, the two smallest. An up quark has a +2/3 charge and a down has a -1/3 charge complete the following table.

	Particle charge	1st quark	2nd quark	3rd quark
Proton	+1			
Neutron	zero			

Solutions to questions:

1. By multiplying the thickness of the steel plates (2.54 cm) by 486 and adding 484 cm (from the scintillator) you get a length of 17.2 meters then adding the 12.8 meters of air space we get 30.0 m. Then treating each of the three plates as rectangles we get 283cm X 3000cm X 2 + 400cm X 3000cm = 2898000cm^2. Which equates to 2898000 cosmic muons per minute at the surface or 48300 muons per second. Down in the mine one muon per 2.08 second (reciprocal) equates to about 0.481 muons per second.

$$\frac{48300 \text{ mu/s}}{(1/2.08)} = \text{about 100,000 times fewer cosmic rays!}$$

2. a) 4.7 million! b) 8.79 X $10^{-21}m^2$ c) 1.2 X 10^{-15} m, it would take 208 billion hydrogen nuclei lined up to cross a period as in a) above! d) the circular area is 4.52 X $10^{-30}m^2$, therefore, it is 1.9 billion times smaller area.

3. Atoms are mostly EMPTY SPACE!!!

4. 5.5 X 10^{30} atoms of iron

5. 9.1 X 10^{-31}kg, in order, 1.25 X 10^{-44}, 5.3 X 10^{-40}, 5.3 X 10^{-38}.

6. up, up, down, up, down, down