Particle Physics at Soudan

These questions will help you prepare for a tour of the Soudan Underground Laboratory, and understand what you may learn here. Have fun with them, and we look forward to seeing you! (edited by Steve Pullar August 2008)

1. **Cosmic Rays.** Cosmic rays are protons and other particles that enter the Earth's atmosphere from outer space. The cosmic ray particle flux on the surface (particles per unit area per second) is about:

$$f_{CR} = 200/m^2s$$

Estimate the number of cosmic rays hitting a typical person (area ½ m^2) each year.

Answer:________________

2. On the surface you have about one muon (these make up a vast majority of cosmic rays) per cm^2 per minute. The rock above the laboratory reduces the number of cosmic rays by 100,000 times.

a. Estimate the number of muons passing through your hand in one minute, (unit: 1/min).

Answer:________________

b. How long would you have to wait to have one pass through your hand in the lab, (unit: days/1) Hint: Use the force, I mean the units, Luke!

Answer:________________

3. Missing Mass. In uniform circular motion, the centripetal acceleration is related to the tangential velocity by:

$$a_c = \frac{v^2}{r}$$

The force responsible is from gravity, which is described by the Universal Gravitational Force Law:

$$F_g = \frac{GMm}{r^2}$$

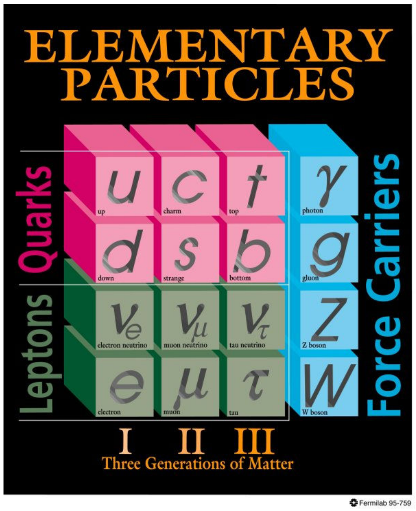
"G" is 6.67×10^{-11} Nm^2/kg^2, but we'll not need its numerical value. Suppose a star of mass *m* orbits the center of a galaxy at radius r and velocity *v*.
Use Newton's second law (F=ma) to find the mass of the galaxy in terms of G, r, and v.

Outer stars are moving too fast!

Astronomical observations consistently show that the mass of galaxies calculated in this way is much greater than the apparent mass of the stars, gas, and dust we can see. The question of the "missing mass" or "dark matter" is the most fundamental problem in astrophysics today.

4. Quarks, Leptons, and WIMOs. Protons and neutrons are made of three quarks. The "up" quark (u) has a charge of +2/3 *e* (two-thirds the elementary electric charge 1.6e-19C), and the down quark (d) has a charge of -1/3 *e*.

Which three quarks make up the proton (charge +e)?



Answer:_____ _____ _____

Which three quarks make up the neutron (zero charge)?

Answer:_____ _____ _____

The electron is not made of quarks, but is a fundamental (indivisible) particle called a *lepton.* It's a lot smaller than a proton or neutron, with:

$m_e = 9.11X10^{-31}$ kg & $m_{p \text{ and } n} = 1.67X10_{-27}$ kg

How many electrons make up the same mass as a proton?

Answer:________________

The *electron neutrino* (ν_e) is a neutral particle partnered with the electron in processes like radioactive decay. The upper mass limit for this $4.5x10^{-36}$kg

How many electron neutrinos (minimum) make up the mass of one proton?

Answer:________________

Another particle called a "WIMP" (Weakly Interacting Massive Particle) could weigh much more than a proton, as much as 10^{16}protons per WIMP! If there is $6.02X10^{23}$ protons in one gram of mass, *how many WIMPs are there in one gram?*

Answers: (1) about 3 billion; (2a). range: 65 – 70, (2b). about one day; (3) $M=v^2r/G$; (4) uud,udd, 1833, 371million, 60 million.