LHC Related Problems

P1. Constant Velocity Problems

1. The MINOS experiment fires a beam of neutrinos from the Fermilab near Chicago to the Soudan Mine in northern Minnesota. The distance the neutrinos travel is 735 km and they do this at the speed of light. How much time does it take?

2. How far does a photon go in one millionth of a second?

3. How much time does it take a proton to travel once around the LHC. The proton travels at the speed of light and the LHC has a radius of 4.3 km.

P2. Force & Acceleration Problems

1. It is found that Olympic champion Usain Bolt's final velocity is 9.2 m/s after accelerating for 20m at a rate of 1.6 m/s^2.

   a. What was his initial velocity?__________

   b. How long did it take him to accelerate for this distance?_________

   c. Accelerating at this rate from rest, how long would it take to reach 9.2 m/s?_________

2. The first accelerator in the CERN accelerator chain is a Cockcroft-Walton. A proton enters the accelerator with almost no velocity and exits with a velocity that is 4 percent of the speed of light. The acceleration time is 0.16 μs,
   a. Calculate the average acceleration of the proton and compare it to the acceleration due to gravity.____________________
   b. Calculate the force on the proton._________________
   c. If the electric field can be approximated as being constant and uniform, what is the length of the acceleration region?__________________

   d. How far does in travel in this time?______________

3. A muon with a mass of 1.88×10^{-28}kg experiences a force of 5.00×10^{-12}N when passing through a particle detector. What is the magnitude of its acceleration?__________

P3. Circular Motion Problems

1. The Fermilab accelerator is designed to accelerate protons in a circular orbit with radius 1.0 km and to a momentum p. The LHC accelerator accelerates protons to a momentum seven times that of the Fermilab accelerator. If the radius of circular motion followed by a proton in the LHC is 4.3 km, calculate the ratio of the magnetic field of the Tevatron to the LHC.

2. In a particle accelerator, a proton moves through a magnetic field of 0.10 T at a speed of 3.0×10^7m/s.

   a. If the proton is moving perpendicular to the field, how much force acts on it?_______

   b. What is the radius of curvature of the proton's path?_____________

P4. Magnetic Field Problems

1. The magnetic field of a cyclotron magnet is 1.2T. The accelerated particles are extracted when at a radius of 60cm. What is the energy of the particles if they are:

   a. protons?_____________

   b. deuterons (*$q=e$; $m=3.34 \times 10^{-27}$kg*)?________________

2. How fast should a proton travel at right angles to a magnetic field of 1.0G so that the magnetic force just balances the gravitational force? If the direction of motion of the proton is to the north, what should the direction of the magnetic field be?

3. What is the value of e/m for a particle that moves in a circle of radius 8.0 mm in a 0.46 T magnetic field that is crossed by a 200 V/m electric field that makes the path straight?

4. Protons move in a circle of radius 5.20 cm in a 0.465 T magnetic field. What value of electric field could make their paths straight? In what direction must it point?

5. What is the velocity of a beam of electrons that go undeflected when passing through crossed electric and magnetic fields of magnitude 8.85×10^3 V/m and 4.5×10^{-3}T respectively? What is the radius of the electron orbit if the electric field is turned off?

P5. Gravitational & Electric Forces Problems

1. The hydrogen atom contains a proton and an electron. The average distance between them is 5.3×10^{-11}m. The charge of the proton is the same size, opposite sign of an electron.
   a. What is the magnitude of the electrostatic attraction between them?_________

   b. What is the magnitude of the gravitational attraction between them?_________

   c. How do the magnitudes of the two forces compare?____________

2. A charged particle of -6μC exerts an attractive force of 65N on a second charge that is 5.0cm away. What is the magnitude of the second charge?___________

3. The Sun is part of the Milky Way Galaxy and rotates around the center of the galaxy. The Sun's radius of orbit is about 2.0×10^{20}m and its period is about 6.3×10^{15}s. If our Sun has a mass of about 2.0×10^{30}kg, calculate the number of similar suns (stars) that make up the mass of the Milky Way Galaxy._________

P6. Energy & Conservation Problems

1. What is the total energy of a proton whose kinetic energy is 15 GeV? What is its wavelength?

2. How does the unit of a Joule compare to the unit of a GeV?

3. What is the wavelength of a 400GeV proton?

4. How much kinetic energy does a common housefly possess when moving through your bedroom? How does this compare the energy of a proton in the LHC?

P7. Relativity Problems

1. Your friend is in a spaceship and travels past you at a high speed. She tells you that her ship is 20 m long and that the identical ship you are sitting in is 19 m long. According to your observations:
   a. How long is your ship?
   b. How long is her ship?
   c. What is the speed of your friend's ship?

2. Imagine an astronaut on a trip to Sirius, which is eight light-years from Earth. On arrival at Sirius, the astronaut finds that the trip lasted six years. If the trip was made at a constant speed of 0.8 c, how can the eight light-year distance be reconciled with the six-year duration?

3. Some distant star-like objects, called quasars, are receding from us at half the speed of light or greater. What is the speed of light we receive from these quasars? Explain.

4. An unstable high-energy particle enters a detector and leaves a track 1.05 mm long before it decays. Its speed relative to the detector was 0.992 c. What is its proper lifetime? That is, how long would the particle have lasted before its decay in its own reference frame (at rest relative to the detector)?

5. A pi-meson has an average lifetime in its own frame of reference of 2.6×10^{-8} seconds. (This is the proper lifetime.) If the meson moves with a speed of 0.95 c, what is its mean lifetime as measured by an outside observer, and the average distance it travels before decaying?

<u>LHC Related Questions</u>

Q1. LHC Questions

1. Where is it located ?

2. What is it?

3. What two methods do scientists use to study particles?

4. What is the Standard Model? Give examples. (What are quarks? What are leptons? What are mediating particles?)

5. List in order the devices used to accelerate the particles.

6. How is the linear accelerator different from the LHC?

7. What is CMS?

8. What is ATLAS?

9. What two ways do detectors identify particles?

10. Describe how particle physics assists cosmology.

11. List thee new questions as a result of completing this assignment.

Q2. Conceptual Physics Questions

1. Describe a cathode ray.

2. A fast moving electron enters a magnetic field. Describe what happens to the electron during this interaction. Use the words: *magnetic field, perpendicular, path and force*.

3. Explain Millikan's oil drop experiment. Use at least three sentences and include the words: *charge, force, gravity, electric*.

4. In an early set of experiments (1911), Millikan observed that the following measured charges, among others, appeared at different times on a single drop of oil. Each of these drops of oil had a different mass. What value of elementary charge can be deduced from these data?
   a. 6.563 x 10-19C
   b. 11.5 x 10-19C
   c. 13.13 x 10-19C
   d. 22.89 x 10-19C
   e. 26.13 x 10-19C
   What does this elementary charge represent?

5. Draw a force diagram of an electron falling in the Millikan experiment.

6. What forces were applied on the cathode ray in J. J. Thompson's experiment?
   Draw a force diagram for the electron in Thompson's experiment when the electron is traveling in a straight path.

Q3. Relativity Questions

1. You are on a speedboat on a lake. Ahead of you, there is a wavefront, left by another boat that is moving away from you. You accelerate, catch up with, and pass the wavefront. Is this scenario possible if you are in a rocket and you detect a wavefront of light ahead of you? Explain.

2. You are packing for a trip to another star, to which you will be traveling at 0.99 c. Should you buy smaller sizes of clothing, because you will be skinnier on the trip? Can you sleep in a smaller cabin than usual, because you will be shorter when you lie down? Explain.

3. Two identically constructed clocks are synchronized. One is put in orbit around the Earth and the other remains on Earth. Which clock runs more slowly? When the moving clock returns to Earth, will the two clocks still be synchronized? Explain.

Q4. Dark Matter and Dark Energy Questions

1. Students may explore, at their own pace or as directed by the teacher, the questions that are posed at the following website: http://aether.lbl.gov/

2. How is the presence of dark matter detected?

3. How much more material is there in clusters of galaxies than we would expect from the galaxies and hot gas we can see?

4. Students may explore, at their own pace or as directed by the teacher, the following website: http://cosmology.berkeley.edu/Education/IUP/Big_Bang_Primer.html

Q5. Elementary Particle Questions

1. What would be the charge of a particle that is made up of three up quarks?

2. Anti-quarks carry the opposite charge of quarks. A pion is composed of an anti-down quark and an up quark. What is its charge?

3. Determine the charge on these pions based upon their composition as given
    a. up and anti-up quarks
    b. down and anti-up quarks
    c. down and anti-down quarks

4. Discuss what could occur if an anti-you (i.e. somebody exactly like you except composed of anti-protons, anti-neutrons, and positrons) ran into you.

LHC Related Activities

A1. The Quark Zoo

Goal:

Practice your ability to observe patterns as you interact with your new colleagues.

Procedure:

1. Determine the rules by which quarks join with other quarks.
2. Record any other observations.
3. Record any questions your group may have as a result of your observations.

Allowed Quark Groups:

u u d	$\bar{u}$ d	$\bar{u}$ s	$\bar{u}$ $\bar{d}$ $\bar{d}$	$\bar{d}$ c
$\bar{u}$ s	$\bar{u}$ $\bar{u}$ $\bar{d}$	u d b	u $\bar{b}$	$\bar{u}$ $\bar{u}$ $\bar{c}$
$\bar{d}$ $\bar{s}$ $\bar{c}$	u d s	u d d	u $\bar{d}$	

Rules:

Observations:

Questions:

The Quark Zoo
Teacher's Notes & Set-up

<u>Instructions for teacher to give to students:</u>

Many rules or discoveries in science result from the observation of patterns. At Fermilab, scientists energized protons and then smashed them into energized antiprotons. The energy that results from this collision reorganizes into different particles. These particles are groups of quarks (one of the smallest building blocks of matter).

Study the groups of quarks these scientists have seen. . . .

<u>Materials:</u>

Each group is given a Quark Zoo worksheet. You may also want to prepare a set of cards with each allowed quark group written on a card so that students could sort and categorize them during the activity.

Results:

- 5 different quarks
- "Bar" only joins with an "antibar" or with two other "bars"
- u & d quarks are very common

Teacher Comments:

- There are six…u&d….s&c…b&t *(NOTE: T is missing; discuss with students why it is hard to find; it's not common.)*

A2. Applying Ohm's Laws

Applying Ohm's Laws	
Quarknet Center:	Hampton University
Contact:	Ken Cecire, ken.cecire@hamptonu.edu
Activity Description:	In summer 1999, QuarkNet teacher Rick Dower studied voltage-current relationships in silicon vertex detectors for the upgrade of D-Zero. After establishing a LabView interface to test voltage and current, Dr. Dower moved the apparatus to the small accelerator at the University of Massachussets at Lowell for testing under neutron radiation. All data was recorded and delivered in graphical form as a D-Zero Note. In this lesson, students analyze V vs I graphs to determine the extent to which the silicon vertices are or are not ohmic and to determine the effect that neutron radiation has on a semiconductor device.
Activity URL:	http://quarknet.fnal.gov/projects/ohms/
Content Area	Electricity and Magnetism, Particle Physics
Type	web-based

A3. Bubble Chamber Simulation

Bubble Chamber Simulation	
Quarknet Center:	University of Mississippi
Contact:	Peter Sonnek, peter@phy.olemiss.edu
Activity Description:	This Java-script program simulates events in a Bubble Chamber. It will simulate one particle, the decay $K^- + p \rightarrow \Lambda\ \pi^+\ \pi^-$ ($\Lambda \rightarrow p\pi^-$), and a Higgs decay in a Collider experiment (See Properties, under File). It also allows changes to the momentum and magnetic field, as well as track identification and momentum calculation. It downloads in a zip file. To start the simulation either Double-Click on the file **Bubble1.01.jar** or from within that directory type **java -jar Bubble1.01.jar**. It needs Java 5 (JRE 1.5) or greater. The Current version is 1.01.
Activity URL:	http://www.phy.olemiss.edu/HEP/QuarkNet/bubble3.html
Content Area	Particle Physics
Type	computer-based

A4. Building Accelerator Analogs

Buiding Accelerator Analogs	
Quarknet Center:	Lawrence Berkeley National Laboratory
Contact:	Kris Whelan, kkwhelan@lbl.gov
Activity Description:	Some QuarkNet centers have built accelerators. No, they are not real but can be used as analogs to real particle accelerators. The real learning comes, of course, when you plan and experiment on your own, but this may give you some starting points.
Activity URL:	http://quarknet.fnal.gov/toolkits/new/accelerators.html
Content Area	Particle Physics
Type	longer term project

A5. Catching Some Z's

Quarknet Center:	Fermilab
Contact:	Tom Jordan, Jordant@fnal.gov
Activity Description:	This project allows learners to access Monte Carlo particle physics data. The data represent calorimetry (energy) and tracking (momentum) information for decay products from interactions in an electron positron collider. We also provide test-beam data so that one can understand detector response prior to reducing the data. Learners can apply conservation of momentum and energy to data and determine the mass of a particle that the machine did not directly observe.
Activity URL:	http://quarknet.fnal.gov/projects/summer00/Main/
Content Area	Particle Physics, Conservation Laws
Type	web-based

A6. Relativity

Relativity	
Quarknet Center:	Fermilab
Contact:	Tom Jordan, jordant@fnal.gov
Activity Description:	This is a great way to learn about relativity.
Activity URL:	http://www-ed.fnal.gov/data/phy_sci/relativity/index.shtml
Content Area	Relativity, Particle Physics
Type	2-4 hour project

A7. Run to Discovery – Analyze the Data

Quarknet Center:	Fermilab
Contact:	Tom Jordan, jordant@fnal.gov
Activity Description:	In this series of investigations students analyze real Fermilab data. In the first two investigations students learn how to identify B mesons and W bosons and find the W mass. They can also calculate B lifetime as a special project. Students use the ideas of conservation of energy and momentum, the effects of magnetic fields on charged particles, relativistic effects and ways to analyze large amounts of data. What the students learn from the first two investigations culminates in the search for the Higgs boson. That investigation uses Monte Carlo (simulated) data mixed with real background data to predict where in the mass range the experimental results may lie. The data is presented in Excel spreadsheets and as event pictures. Students hone their Excel skills creating equations, filling in data and creating and plotting histograms.
Activity URL:	http://quarknet.fnal.gov/run2/run2_teacher.shtml
Content Area	Conservation Laws, Particle Physics
Type	web-based

A8. Particle Adventure

A wealth of information exists on ParticleAdventure.org. Students can explore at their own pace or as directed by the teachers

Additional Resources

These can be found at: http://www.particleadventure.org/other/othersites.html. The possibilities are endless…have fun!!