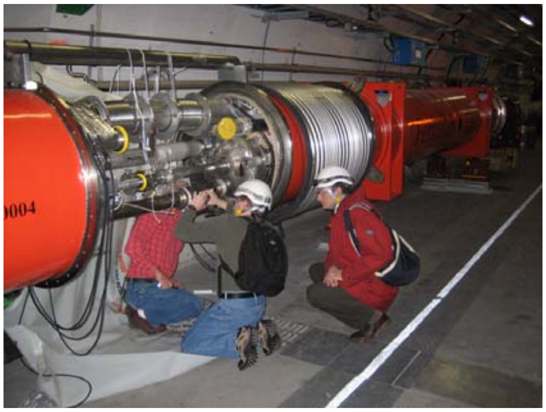

A small section of the LHC (Photo: Peter Limon)

During November, 2009 the Large Hadron Collider experiment at CERN began a slow, step-by-step process of being turned on. Its goal is to accelerate two beams of protons and anti-protons to very high energies, and collide them to form new sub-atomic particles for physicists to discover and study.

Although it is not a NASA research program, it will directly impact the findings of many NASA research satellites such as Chandra and WMAP in searching for Dark Matter and Dark Energy. To understand the operation of LHC, we must first learn how to measure and discuss very small amounts of energy!

The 27-kilometer diameter LHC ring, buried deep underground, uses thousands of magnets to steer two beams of protons so that they collide at specific points along the ring. The beams are no bigger than a human hair in diameter, but contain millions of protons and anti-protons traveling at nearly the speed of light and circulating in the 27-kilometer ring in opposite directions. When these particles collide, their energies combine to create a momentary explosion out of which is created hundreds of particles including electrons, quarks and even more massive particles. Thanks to Albert Einstein's $E=mc^2$, the energy of the two protons can create a burst of new particles, m, literally created out of the raw energy, E, of the collisions.

Physicists use the 'electron volt' as a convenient unit of energy. One 'eV' is the amount of energy that an electron gains as it falls through a voltage difference of exactly 1 volt. This energy is equal to $1.6 \times 10^{-19}$ Joules. Physicists find it far easier to remember and write energy measured in units of eV than in Joules! The following problems exercise your ability to translate between eV units and Joules.

**Problem 1** - The mass of an electron is equivalent to 511,000 eV of energy (also written as 511 keV). How many Joules is this?

**Problem 2** - The mass of a Top Quark is 175 billion eV (or 175 Giga-electron Volts abbreviated as 175 GeV). How many Joules is this?

**Problem 3** - A proton has an energy equivalent to $1.5 \times 10^{-10}$ Joules. How many electron volts is this?

**Problem 4** - A small gnat in flight carries about $1.6 \times 10^{-7}$ Joules of energy. About how many electron Volts is this equivalent to?

**Problem 5** - When the LHC began operation, on November 30, 2009 it achieved an energy of 1.2 trillion electron Volts (1.2 Terra eV or 1.2 TeV). How many Joules of energy is this?

**Problem 6** - When fully operational, the LHC will carry 100 trillion protons along each beam, with each proton carrying an energy of 15 TeV. What is the total energy of each proton beam in the LHC compared to: A) A baseball in flight (120 Joules)? B) A small car traveling at 60 mph (300,000 Joules)? C) A Boeing 767 in flight (4 billion Joules)?

**Problem 1** - The mass of an electron is equivalent to 511,000 eV of energy (also written as 511 keV). How many Joules is this?
Answer: 511,000 eV x (1.6 x $10^{-19}$ Joules/1 eV) = **8.2 x $10^{-14}$ Joules.**

**Problem 2** - The mass of a Top Quark is 175 billion eV (or 175 Giga-electron Volts abbreviated as 175 GeV). How many Joules is this?
Answer: 175,000,000,000 eV x (1.6 x $10^{-19}$ Joules/1 eV) = **2.8 x $10^{-6}$ Joules.**

**Problem 3** - A proton has an energy equivalent to 1.5 x $10^{-10}$ Joules. How many electron volts is this?
Answer; 1.5 x $10^{-10}$ Joules x (1 eV/ 1.6 x $10^{-19}$ Joules) = **938,000,000 eV**
Also written as 938 MeV.

**Problem 4** - A small gnat in flight carries about 1.6 x $10^{-7}$ Joules of energy. About how many electron Volts is this equivalent to?
Answer; 1.6 x $10^{-7}$ Joules x (1 eV/ 1.6 x $10^{-19}$ Joules) = **1,000,000,000,000 eV**
Also written as 1 terra eV or 1 TeV.

**Problem 5** - When the LHC began operation, on November 30, 2009 it achieved an energy of 1.2 trillion electron Volts (1.2 Terra eV or 1.2 TeV). How many Joules of energy is this?
Answer: 1,200,000,000,000 eV x (1.6 x $10^{-19}$ Joules/1 eV) = **1.9 x $10^{-7}$ Joules.**

**Problem 6** - When fully operational, the LHC will carry 100 trillion protons along each beam, with each proton carrying an energy of 15 TeV. What is the total energy of each proton beam in the LHC compared to: A) A baseball in flight (120 Joules)? B) A small car traveling at 60 mph (300,000 Joules)? C) A Boeing 767 in flight (4 billion Joules)?

Answer: Each proton will carry 15,000,000,000,000 eV x (1.6 x $10^{-19}$ Joules/1 eV) = 2.4 x $10^{-6}$ Joules. So the total energy of each beam will be 100 trillion times this or **2.4 x $10^{8}$ Joules!**

A) 2.4 x $10^{8}$ Joules / 120 Joules = **2 million times a baseball in flight**.

B) 2.4 x $10^{8}$ Joules / 300,000 Joules = **800 times a car in motion.**

C) 2.4 x $10^{8}$ Joules / 4,000,000,000 Joules = **1/17 of a passenger jet.**