5.7: Virtual Pair Production (Project)

The Heisenberg Uncertainty Principle allows for short-term violations of the law of energy conservation. The amount of energy "borrowed" from empty space (ΔE) and the elapsed time (Δt) before the energy must be "repaid" are related by

$$(\Delta E)(\Delta t) \approx \frac{\hbar}{2} \tag{5.7.1}$$

These fluctuations in energy often take the form of matter/antimatter pairs of particles spontaneously "popping" into existence from otherwise empty space. These pairs of particles, called virtual particles, travel finite distances through space during their brief lifetimes and have repercussions that may influence the ultimate fate of the universe. In this activity, you will develop a spreadsheet that calculates the maximum distance these particles can travel as a function of their rest mass and kinetic energy.

I. Constructing the Spreadsheet

Construct a spreadsheet that has the following general form. (The template VirtualParticles is available in the PHY 262 course folder.)

Virtual Particle Production
your name:
your name:

rest energy = MeV

$$\text{Kinetic Energy (MeV)} \quad \Delta t(s) \text{gamma Velocity } (c) \quad \text{Distance (m)} \tag{5.7.2}$$

The spreadsheet should allow you to enter the rest energy of one of the pair of particles produced (its antimatter partner has the same rest energy). Then, for kinetic energies ranging from 0 to the rest energy of the particle, in 20 even increments, and from the rest energy to 20 times the rest energy, in 20 even increments, the spreadsheet should complete the above table of values.

The spreadsheet should then construct a graph of distance traveled vs. kinetic energy.

II. Using the Spreadsheet

A. Testing your Spreadsheet

An electron and positron, each with kinetic energy 1.0 MeV, spontaneously appear from the vacuum. Calculate below the distance each particle can travel before disappearing.

If your spreadsheet does not agree with your calculation above, correct your spreadsheet (or your calculation) before continuing!

B. Electron/positron pair production

1. What is the maximum distance a virtually produced electron or positron can travel? How does this distance compare to the size of an atom? The size of a nucleus?

2. At what kinetic energy (in MeV) does the pair travel a maximum distance?

3. What is this kinetic energy as a fraction of the rest energy of the particle?

C. Proton/antiproton pair production

1. What is the maximum distance a virtually produced proton or antiproton can travel? How does this distance compare to the size of an atom? The size of a nucleus?

2. At what kinetic energy (in MeV) does the pair travel a maximum distance?

3. What is this kinetic energy as a fraction of the rest energy of the particle?

You should notice that the graph of distance traveled vs. kinetic energy has the same functional shape regardless of rest energy, with the maximum distance traveled always occurring for the same kinetic energy value (expressed as a fraction of rest energy).

D. Neutrino/antineutrino pair production

The least massive (non-zero mass) particle known to exist is the electron neutrino, with rest energy of approximately 0.05 eV. Print the graph of distance vs. kinetic energy, and your evaluated spreadsheet, for this pair production. Attach your printouts to the end of this activity.
