

PHY 221 LAB 05-1: Particle Energy

Particle Energy

A *fundamental particle* is an object that is simple and structureless—not made of anything smaller. Physicists have developed a theory that explains what all objects are made of and what holds everything together. This theory is called the *standard model* and explains the hundreds of known particles and how they interact. The fundamental particles of the standard model are:

- 6 quarks
- 6 leptons
- force carrier particles

All known particles are composed of quarks and leptons and interact via the exchange of force carrier particles.

The everyday use of the term *particle*, however, is much simpler and more general. The everyday definition of a *particle* is a single unit of matter (i.e. energy) that is NOT composed of smaller particles.

You can treat large objects as particles. For example, you can treat a skydiver, car, airplane, etc. as particles. For large objects that you treat as a particle, the position of the particle is considered to be the position of the center of mass of the object. The *center of mass* is the weighted average of the mass distribution of the object.

The following equation for the energy of a particle was developed by Albert Einstein in his Theory of Special Relativity. Later, this was shown to be correct experimentally. The energy of a particle is

$$E = \frac{mc^2}{\sqrt{1 - v^2/c^2}} \quad (1)$$

where m is the mass of the particle and c is the speed of light, 3×10^8 m/s. This equation calculates THE energy of a particle. A particle has NO other kind of energy.

Background

Eq. (1) is THE energy of a particle. Nonetheless, for convenience in calculations we can break it into two parts:

$$E = E_{rest} + E_{motion}$$

To find E_{rest} , substitute $v = 0$ into Equation 1.

$$E_{rest} = mc^2 \quad (2)$$

To find E_{motion} , take the total energy and subtract the rest energy.

$$E_{motion} = E - E_{rest}$$

We call energy of motion *kinetic energy*, K . Thus,

$$K = E - E_{rest} \quad (3)$$

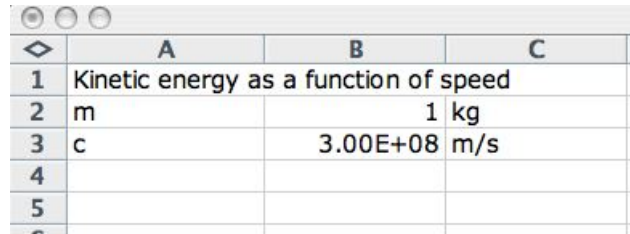
$$K = \frac{mc^2}{\sqrt{1 - v^2/c^2}} - mc^2$$

$$K = mc^2 \left(\frac{1}{\sqrt{1 - v^2/c^2}} - 1 \right)$$

Procedure

In this exercise, you will use Excel to calculate and graph the kinetic energy of a particle as a function of its speed.

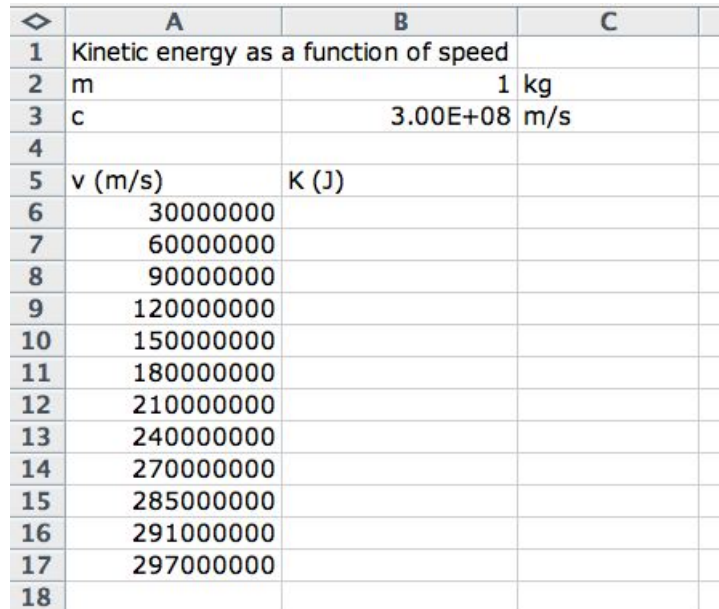
1. Open Excel.
2. Enter a mass of 1 kg into one cell, and enter the speed of light $3e8$ m/s into another cell. Be sure that you type the units in a separate cell from the value. When typing your formula to calculate kinetic energy, you will use the constants for mass and speed of light, respectively. See the example in Figure ??.



| | A | B | C |
|---|---------------------------------------|----------|-----|
| 1 | Kinetic energy as a function of speed | | |
| 2 | m | 1 | kg |
| 3 | c | 3.00E+08 | m/s |
| 4 | | | |
| 5 | | | |

Figure 1: Enter constants such as mass and the speed of light.

3. Enter the data shown below, starting in row 5. Use the first row for cell headings, speed and kinetic energy, as shown in Figure ?. Always include units in the labels for the columns.



| | A | B | C |
|----|---------------------------------------|----------|-----|
| 1 | Kinetic energy as a function of speed | | |
| 2 | m | 1 | kg |
| 3 | c | 3.00E+08 | m/s |
| 4 | | | |
| 5 | v (m/s) | K (J) | |
| 6 | 30000000 | | |
| 7 | 60000000 | | |
| 8 | 90000000 | | |
| 9 | 120000000 | | |
| 10 | 150000000 | | |
| 11 | 180000000 | | |
| 12 | 210000000 | | |
| 13 | 240000000 | | |
| 14 | 270000000 | | |
| 15 | 285000000 | | |
| 16 | 291000000 | | |
| 17 | 297000000 | | |
| 18 | | | |

Figure 2: High speed data.

4. Type the formula for kinetic energy into cell B6. For *mass*, type $\$B\2 , and for *speed of light*, type $\$B\3 . The $\$$ symbol is used for an absolute reference. That is, when a value in a cell is a constant, then the cell reference must use a $\$$ symbol.
5. Graph the kinetic energy vs speed. To use Excel to plot the graph, highlight the data including the column headings and click the chart wizard. Alternatively, you can copy and paste the data into Logger Pro.

Results

You can see from the graph that the function asymptotically approaches infinity at a certain speed. At what speed does the kinetic energy approach infinity?

Kinetic energy at low speeds

In most of the situations that we will analyze in this class, particles are moving at speeds much less than the speed of light. In this exercise, determine the kinetic energy of a particle as a function of speed for speeds less than $0.1c$. Some sample data is shown in Figure ???. Note enter the speeds and calculate kinetic energy with a formula in Excel.

| v (m/s) | K (J) |
|---------|-------------|
| 10 | 59.95204333 |
| 20 | 199.8401444 |
| 40 | 799.3605777 |
| 80 | 3217.426325 |
| 160 | 12809.75326 |
| 320 | 51199.045 |
| 640 | 204816.164 |
| 1280 | 819204.7041 |
| 2560 | 3276798.832 |
| 5120 | 13107215.31 |
| 10240 | 52428801.3 |
| 20480 | 209715205.2 |

Figure 3: Low speed data.

1. Open Logger Pro.
2. Graph the low-speed data for kinetic energy as a function of speed.
3. Fit a function to the curve.

What is the function of the best-fit curve for kinetic energy as a function of speed for low speeds?

Upon analyzing the units and looking at the value of the constant, what does the constant (of the v^2 term) represent?

