

## Conservation of Energy and Momentum Worksheet

<p><b>Recall the basic relations:</b></p> $E_i = E_f$ $P_i = P_f$ $\Delta E \Delta t \geq \frac{h}{2\pi}$ $\Delta p \Delta x \geq \frac{h}{2\pi}$	<p><b>Equations:</b></p> <ol style="list-style-type: none"> <li>1. <math>E = K + U + mc^2</math> (usually <math>U = 0</math>)</li> <li>2. <math>E = \sqrt{(pc)^2 + (mc^2)^2}</math> for all particles</li> <li>3. <math>E = hf</math> (for a photon)</li> <li>4. <math>p = mv</math> (for a massive particle at low speeds)</li> <li>5. <math>p = \frac{E}{c}</math> (for a massless particle)</li> </ol>
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**Constants:**

$$h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s} = 4.14 \times 10^{-21} \text{ MeV} \cdot \text{s}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

$$\text{Mass of electron} = \text{mass of positron} = 9.1 \times 10^{-31} \text{ kg} = .511 \text{ MeV} / c^2$$

$$\text{Mass of hydrogen atom} = 1.67 \times 10^{-27} \text{ kg}$$

**Example 1:**

A gamma ray photon has energy equal to 5 MeV. What is its:

- a. momentum (in kg-m/s)?
- b. momentum (in MeV/c)?
- c. frequency (in  $\text{s}^{-1}$ )?

**Example 2:**

An electron and positron are at rest in a particular frame of reference. What is their:

- a. total energy (in J)?
- b. total energy (in MeV)?

**Example 3**

A 5 MeV gamma ray turns into an electron-positron pair moving in the same direction as the gamma ray. What is:

- a. the total momentum of the electron and positron (in MeV/c)?
- b. the total energy of the electron and positron (in MeV) using energy conservation?
- c. the total energy of the electron and positron using Equation 2 (above) (in MeV)?
- d. the difference in energy between the results of (b) and (c)?

**Example 4:**

Using the result (d) from Example 3, and the uncertainty principle, for how much time can the electron-positron pair exist before they must annihilate (turn back into a gamma ray)?