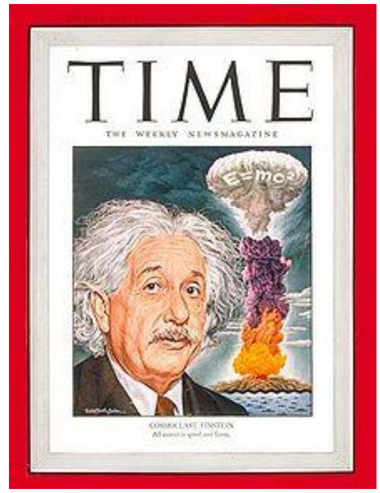
# Mass-Energy Equivalence




## Mass-Energy Equivalence

In 1905 Einstein wrote a series of revolutionary papers that changed physics and the way we look at the universe forever. One of those papers (which had no references) contained his now most famous equation. This paper originally was generally ignored. It was not until the second world war and research carried out by a group of scientists in Germany that finally realized the potential behind the equation. These scientists performed the first transmutation (nuclear reactions) on heavy atoms. In their work they were looking to add neutrons to an atom and increase the mass of it and thus create a new atom with a greater mass. They consistently found that they were instead getting two or more smaller atoms and energy. The mass of the original atom was more than the sum of the product atoms. The difference (and the energy) released matched exactly with Eintein's $E=mc^2$ equation. The atom had been split and the race for the bomb began.

Einstein's famous equation states that **mass and energy are one in the same**. They can be converted between each other. Mass can become energy and energy can become mass. The link is the speed of light squared. The speed of light squared is a massive ($9.0 \times 10^{16}$) number; thus the energy released when even a small amount of mass is converted into energy is very large.

$$\boxed{E = \gamma mc^2}$$

Where, $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

This means that the rest mass-energy equivalence (when $v = 0$) is $E = mc^2$. The amount of energy stored in an object as it starts to move increases. You can see that if you allow v→ c then the energy approaches infinity. Hence you cannot reach the speed of light as it would take an infinite amount of energy.

## Energy Change Associated with Mass Loss

**Example:** Determine the rest energy of a 0.05 kg pencil. Using the following conversion to determine the amount of energy that would be released is this mass turned completely into energy. Compare this to a nuclear bomb yield (1 kiloton of TNT is 4.184 TJ and 1TJ = 1 million million Joules = $10^{12}$)

Use: $$\Delta E = \Delta mc^2$$

## Relativistic Kinetic Energy

Objects moving at speeds close to the speed of light must account for the increase in mass that occurs and thus the kinetic energy of the particle or object is not the same as the classical kinetic energy.

### Classical (v<<c):

$$E_k = \frac{1}{2}mv^2$$

### Relativistic (v→ c):

$$\boxed{E_k = E_{total} - E_{rest} = \gamma mc^2 - mc^2}$$

**Example:** Determine the relativistic kinetic energy of an electron moving at 0.9c.

## Electron Volts

Since the energy associated with mass loss is often with small systems the energies are typically small and thus we invoke a new measurement of energy called the **Electron Volt**.

$$\boxed{1.60 \times 10^{-19} J = 1 eV}$$

As a result we can express mass units in terms of Einstein's equations and electron volts.

## Nuclear Reactions

During nuclear reactions the mass of the products is always a little less than the mass of the reactants (mass is NOT conserved). **The mass is converted into energy!**