Mass-energy relation

Einstein linked not only space and time but also mass and energy. A piece of matter, even at rest and not interacting with anything else, has an "energy of being". This is called its *rest energy.* Einstein concluded that it takes energy to make mass and that energy is released if mass disappears. Mass of an object is also a relativistic quantity.
According to the special theory of relativity, the mass of an object increases as its speed increases, and the relativistic mass is

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} = \gamma m_0$$

where m_0 represents the mass of the object measured in a frame of reference in which it is at rest, and it is called the **rest mass** of the object; *m* represents the mass of the object measured in a frame of reference in which it moves at speed *v*.
A consequence of Einstein's special theory of relativity is that objects cannot keep on increasing their speed to or past the speed of light, i.e. $v < c$. As $v \to c, m \to \infty$. To accelerate an object to speed *c* would require an infinite amount of energy, and so is impossible.

This linkage has resulted in the term mass-energy.
The **mass-energy** of any object is given by $E = mc^2$. With mass-energy, a moving body has kinetic energy and rest energy. $\therefore E = E_k + E_{rest}$

$$\therefore mc^2 = E_k + m_0c^2$$
$$\therefore E_k = mc^2 - m_0c^2$$

Substituting $m = m_0\gamma$

$$\therefore E_k = m_0\gamma c^2 - m_0c^2$$
$$\therefore E_k = (\gamma - 1)m_0c^2$$

When particles are travelling at high speeds (particularly greater than 10% of *c*) the KE is given by **$E_k = (\gamma - 1)m_0c^2$**, where m_0 = rest mass.

Mass and energy are equivalent. For this idea to have any practical meaning, then mass ought to be convertible to energy and vice versa, just as the different types of energy are interconvertible. This has been experimentally confirmed in nuclear and elementary particle processes.
Energy released = Difference in total rest energy before and after process.

Our Sun
In 1 second, 4.5 million tonnes of mass are converted into radiant energy in the sun. The sun is so massive, however, that in 1 million years only one ten millionth of the sun's mass will have been converted to radiant energy.

Combining Atoms – Nuclear Fusion
Nuclear fusion is the process of fusing two atoms together and creating a larger atom.

The energy from the Sun (heat and light) originates from this **nuclear fusion process** that is occurring inside the core of the Sun. The specific type of fusion that occurs inside of the Sun is known as **proton-proton fusion**.

Inside the Sun, this process begins with protons (a lone hydrogen nucleus) and through a series of steps, these protons fuse together and are turned into helium.

The main conceptual difficulty in this subtopic is understanding that mass-energy relation $E = mc^2$ is the sum of the rest energy and kinetic energy.

General approach is that $E = E_{rest} + E_k \ \ and\ so\ E_k = E - E_{rest}$,

$$W = \Delta E, so\ W = \Delta E_k$$

$$E = mc^2\ E_{rest} = m_0 c^2$$

As some students have difficulties with rearranging the formulas it is a good idea to have 'pre-arranged' formulas like

$$\gamma = \frac{E_k}{m_0 c^2} + 1$$