Relativistic Energy

The _________ energy of an _________

\[ E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} \]

If the object is _________ moving, the _________ energy is

\[ E_0 = mc^2 \]

How much energy is in a 5-gram pen at rest?

How long will that run a 60-W light bulb?

If the object is _________, then the total _________ is \( E = E_0 + KE \)

\[ KE = mc^2 \left( \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right) \]

_______ and _________ are the _________

- A change in _________, means a change in the _________.
- For example, you pick up your backpack and increase its _________ _________ _________ energy.
  - Since the _________ increases, the mass must _________.
  - So when you _________ your backpack, it is actually _________ than when it is on the _________.

The sun radiates electromagnetic energy at \( 3.92 \times 10^{26} \) W. How much mass does the sun lose in 1 year?

A _________ consequence

- Objects with _________ cannot reach the _________ of _________.
- This is because it would take an _________ amount of _________.
1. How are the classical laws of conservation of energy and conservation of mass modified by modern relativity?

2. Consider a thought experiment. You place an expanded balloon of air on weighing scales outside in the early morning. The balloon stays on the scales and you are able to measure changes in its mass. Does the mass of the balloon change as the day progresses? Discuss the difficulties in carrying out this experiment.

3. Given the fact that light travels at \( c \), can it have mass? Explain.

4. What is the rest energy of an electron, given its mass is \( 9.11 \times 10^{-31} \) kg? Give your answer in joules and MeV. (OpenStax 28.43) 0.512 MeV

5. Find the rest energy in joules and MeV of a proton, given its mass is \( 1.67 \times 10^{-27} \) kg. (OpenStax 28.44) 1.503 \( \times 10^{-10} \) J, 939 MeV

6. A supernova explosion of a \( 2.00 \times 10^{31} \) kg star produces \( 1.00 \times 10^{44} \) J of energy. (a) How many kilograms of mass are converted to energy in the explosion? (b) What is the ratio \( \frac{\Delta m}{m} \) of mass destroyed to the original mass of the star? (OpenStax 28.47) \( 1.11 \times 10^{27} \) kg, \( 5.56 \times 10^{-5} \)

7. There is approximately \( 10^{34} \) J of energy available from fusion of hydrogen in the world’s oceans. (a) If \( 10^{33} \) J of this energy were utilized, what would be the decrease in mass of the oceans? (b) How great a volume of water does this correspond to? (c) Comment on whether this is a significant fraction of the total mass of the oceans. (OpenStax 28.50) \( 1 \times 10^{16} \) kg, \( 1 \times 10^{13} \) m³, no

8. A muon has a rest mass energy of 105.7 MeV, and it decays into an electron and a massless particle. (a) If all the lost mass is converted into the electron’s kinetic energy, find \( \gamma \) for the electron. (b) What is the electron’s velocity? (OpenStax 28.51) 208, 0.999988c

9. Alpha decay is nuclear decay in which a helium nucleus is emitted. If the helium nucleus has a mass of \( 6.80 \times 10^{-27} \) kg and is given 5.00 MeV of kinetic energy, what is its velocity? (OpenStax 28.54) 0.0511c

10. (a) Beta decay is nuclear decay in which an electron is emitted. If the electron is given 0.750 MeV of kinetic energy, what is its velocity? (b) Comment on how the high velocity is consistent with the kinetic energy as it compares to the rest mass energy of the electron. (OpenStax 28.55) 0.914c

11. A positron is an antimatter version of the electron, having exactly the same mass. When a positron and an electron meet, they annihilate, converting all of their mass into energy. (a) Find the energy released, assuming negligible kinetic energy before the annihilation. (b) If this energy is given to a proton in the form of kinetic energy, what is its velocity? (c) If this energy is given to another electron in the form of kinetic energy, what is its velocity? (OpenStax 28.56) 1.64 \( \times 10^{-13} \) J, 0.0467c, 0.943c