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 3.92×10^{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 __________.

Homework

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 9.11×10^{-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 1.67×10^{-27} kg. (OpenStax 28.44) $\mathbf{1.503 \times 10^{-10}}$ **J, 939 MeV**
6. A supernova explosion of a 2.00×10^{31} kg star produces 1.00×10^{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) $\mathbf{1.11 \times 10^{27}}$ **kg,** $\mathbf{5.556 \times 10^{-5}}$
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) $\mathbf{1 \times 10^{16}}$ **kg,** $\mathbf{1 \times 10^{13}}$ **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 γ 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 6.80×10^{-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) $\mathbf{1.64 \times 10^{-13}}$ **J, 0.0467c, 0.943c**