Chapter 28: Special Relativity

# 28.6 Relativistic Energy

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| 43. | *What is the rest energy of an electron, given its mass is ? Give your answer in joules and MeV.* |
| Solution | (according to the number of sig. fig. stated. The exact value is closer to 0.511 MeV.) |
| 44. | *Find the rest energy in joules and MeV of a proton, given its mass is .* |
| Solution |  |
| 45. | *If the rest energies of a proton and a neutron (the two constituents of nuclei) are 938.3 and 939.6 MeV respectively, what is the difference in their masses in kilograms?* |
| Solution | To two digits since the difference in rest mass energies is found to two digits. |
| 46. | *The Big Bang that began the universe is estimated to have released*  *of energy. How many stars could half this energy create, assuming the average star’s mass is ?* |
| Solution |  |
| 47. | *A supernova explosion of a  star produces  of energy. (a) How many kilograms of mass are converted to energy in the explosion? (b) What is the ratio*  *of mass destroyed to the original mass of the star?* |
| Solution | (a)  (b) |
| 48. | *(a) Using data from Table 7.1, calculate the mass converted to energy by the fission of 1.00 kg of uranium. (b) What is the ratio of mass destroyed to the original mass,* *?* |
| Solution | (a) From Table 7.1, the energy released from the nuclear fission of 1.00 kg of uranium is . So, , we get    (b) To calculate the ratio, simply divide by the original mass: |
| 49. | *(a) Using data from Table 7.1, calculate the amount of mass converted to energy by the fusion of 1.00 kg of hydrogen. (b) What is the ratio of mass destroyed to the original mass,* *? (c) How does this compare with*  *for the fission of 1.00 kg of uranium?* |
| Solution | (a)  (b)  (c)  is greater for hydrogen. |
| 50. | *There is approximately*  *of energy available from fusion of hydrogen in the world’s oceans. (a) If*  *of this energy were utilized, what would be the decrease in mass of the oceans? Assume that about 0.08% of the mass of a water molecule is converted to energy during the fusion of hydrogen. (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.* |
| Solution | (a)  (b)  (c) Since approximately 2/3 of the surface of the earth is covered with water, the surface area of water on Earth is:  So the volume of water found in part (b) would be equivalent to a thickness of water of:  Therefore, no, this mass is not a significant fraction of the total mass of the oceans. |
| 51. | *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  for the electron. (b) What is the electron’s velocity?* |
| Solution | (a)  (b)  (six digits used to show difference from *c*.) |
| 52. | *A* *-meson is a particle that decays into a muon and a massless particle. The* *-meson has a rest mass energy of 139.6 MeV, and the muon has a rest mass energy of 105.7 MeV. Suppose the* *-meson is at rest and all of the missing mass goes into the muon’s kinetic energy. How fast will the muon move?* |
| Solution | Solving for  will give us a way of calculating the speed of the muon. From the equation above, we see that:  Now, use  or  so |
| 53. | *(a) Calculate the relativistic kinetic energy of a 1000-kg car moving at 30.0 m/s if the speed of light were only 45.0 m/s. (b) Find the ratio of the relativistic kinetic energy to classical.* |
| Solution | (a)  (b) |
| 54. | *Alpha decay is nuclear decay in which a helium nucleus is emitted. If the helium nucleus has a mass of and is given 5.00 MeV of kinetic energy, what is its velocity?* |
| Solution |  |
| 55. | *(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.* |
| Solution | (a)    (b) The rest mass energy of an electron is 0.511 MeV, so the kinetic energy is approximately 150% of the rest mass energy. The electron should be traveling close to the speed of light. |
| 56. | *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?* |
| Solution | (a)  (b)  (c) |
| 57. | *What is the kinetic energy in MeV of a π-meson that lives*  *as measured in the laboratory, and* *when at rest relative to an observer, given that its rest energy is 135 MeV?* |
| Solution | from the result of Exercise 28.5. Thus, |
| 58. | *Find the kinetic energy in MeV of a neutron with a measured life span of 2065 s, given its rest energy is 939.6 MeV, and rest life span is 900s.* |
| Solution | From Exercise 28.6, we know that = 2.2944, so we can determine the kinetic energy of the neutron: |
| 59. | *(a) Show that . This means that at large velocities . (b) Is*  *when* *, as for the astronaut discussed in the twin paradox?* |
| Solution | (a) , so that  and  (b) Yes: , to within 1 part in , Since |
| 60. | *One cosmic ray neutron has a velocity of  relative to the Earth. (a) What is the neutron’s total energy in MeV? (b) Find its momentum. (c) Is*  *in this situation? Discuss in terms of the equation given in part (a) of the previous problem.* |
| Solution | (a) , where  so  (b)  (c) No. This is true when  which is not the case for this situation. Here . |
| 61. | *What is  for a proton having a mass energy of 938.3 MeV accelerated through an effective potential of 1.0 TV (teravolt) at Fermilab outside Chicago?* |
| Solution | so that |
| 62. | *(a) What is the effective accelerating potential for electrons at the Stanford Linear Accelerator, if  for them? (b) What is their total energy (nearly the same as kinetic in this case) in GeV?* |
| Solution | (a)  (b) |
| 63. | *(a) Using data from Table 7.1, find the mass destroyed when the energy in a barrel of crude oil is released. (b) Given these barrels contain 200 liters and assuming the density of crude oil is , what is the ratio of mass destroyed to original mass,* *?* |
| Solution | (a)  (b)  Therefore, |
| 64. | *(a) Calculate the energy released by the destruction of 1.00 kg of mass. (b) How many kilograms could be lifted to a 10.0 km height by this amount of energy?* |
| Solution | (a)  (b) |
| 65. | *A Van de Graaff accelerator utilizes a 50.0 MV potential difference to accelerate charged particles such as protons. (a) What is the velocity of a proton accelerated by such a potential? (b) An electron?* |
| Solution | (a)  (b)  (Five digits used to show difference from .) |
| 66. | *Suppose you use an average of*  *of electric energy per month in your home. (a) How long would 1.00 g of mass converted to electric energy with an efficiency of 38.0% last you? (b) How many homes could be supplied at the*  *per month rate for one year by the energy from the described mass conversion?* |
| Solution | (a) The monthly energy use is  The energy available is  Thus,  (b) |
| 67. | *(a) A nuclear power plant converts energy from nuclear fission into electricity with an efficiency of 35.0%. How much mass is destroyed in one year to produce a continuous 1000 MW of electric power? (b) Do you think it would be possible to observe this mass loss if the total mass of the fuel is ?* |
| Solution | (a)  (b) This much mass would be measurable, but probably not observable just by looking because it is 0.01% of the total mass. |
| 68. | *Nuclear-powered rockets were researched for some years before safety concerns became paramount. (a) What fraction of a rocket’s mass would have to be destroyed to get it into a low Earth orbit, neglecting the decrease in gravity? (Assume an orbital altitude of 250 km, and calculate both the kinetic energy (classical) and the gravitational potential energy needed.) (b) If the ship has a mass of  (100 tons), what total yield nuclear explosion in tons of TNT is needed?* |
| Solution | (a)  Thus,  (b) |
| 69. | *The Sun produces energy at a rate of* *W by the fusion of hydrogen. (a) How many kilograms of hydrogen undergo fusion each second? (b) If the Sun is 90.0% hydrogen and half of this can undergo fusion before the Sun changes character, how long could it produce energy at its current rate? (c) How many kilograms of mass is the Sun losing per second? (d) What fraction of its mass will it have lost in the time found in part (b)?* |
| Solution | (a)  (b)  (c)  (d) |
| 70. | ***Unreasonable Results*** *A proton has a mass of . A physicist measures the proton’s total energy to be 50.0 MeV. (a) What is the proton’s kinetic energy? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?* |
| Solution | (a) , so that .    (b) The kinetic energy, KE, must be greater than or equal to 0. Here it is negative.  (c) The proton’s total energy must be |

# Test Prep for AP® courses

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| 1. | *Which of the following statements describes the Michelson-Morley experiment?*   1. The speed of light is independent of the motion of the source relative to the observer. 2. The speed of light is different in different frames of reference. 3. The speed of light changes with changes in the observer. 4. The speed of light is dependent on the motion of the source. |
| Solution | (a) |
| 2. | *What happens when velocities comparable to the speed of light are involved in an observation?*   1. Newton’s second law of motion, , governs the motion of the object. 2. Newton’s second law of motion, , no longer governs the dynamics of the object. 3. Such velocities cannot be determined mathematically. 4. None of the above |
| Solution | (b) |
| 3. | *How is the relativistic Doppler effect different from the classical Doppler effect?* |
| Solution | The relativistic Doppler effect takes into account the special relativity concept of time dilation and also does not require a medium of propagation to be used as a point of reference (light does not require a medium for propagation). |
| 4. | *A mass of 50 g is completely converted into energy. What is the energy that will be obtained when such a conversion takes place?* |
| Solution | ] |
| 5. | *Show that relativistic kinetic energy becomes the same as classical kinetic energy when .* |
| Solution | Relativistic kinetic energy is given as  where  Classical kinetic energy is given as  At low velocities , a binomial expansion and subsequent approximation of  gives:  or  Substituting in the expression for gives    Hence, relativistic kinetic energy becomes classical kinetic energy when . |
| 6. | *The relativistic energy of a particle in terms of momentum is given by:*  (a)  (b)  (c)  (d) |
| Solution | (a) |

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