

## Relativity-2: Mass, momentum, energy, Doppler effect & gravity

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1. Deduce the fractional increase of the mass of a particle for velocity  $0.1c$ . [ $5 \times 10^{-3}$ ]
  2. Find the mass and speed of 2 MeV electrons. [2 MeV/ $c^2$ , 0.97 $c$ ]
  3. A particle of mass  $m_0$  moves with speed  $c/2$ . Calculate the mass, the momentum, the total energy and the kinetic energy of the particle. [ $1.15m_0$ ,  $0.58m_0c$ ,  $1.15m_0c^2$ ,  $0.15m_0c^2$ ]
  4. A stationary body explodes into two fragments, each of mass 1 kg. The fragments move apart at speeds of  $0.6c$  relative to the original body. Find the mass of the original body. [2.5 kg]
  5. The mass of a moving electron is 11 times its rest mass. Calculate its kinetic energy and momentum. [5.1 MeV, 5.6 MeV/ $c$ ]
  6. Compute the effective mass of a 5000Å photon. [ $4.4 \times 10^{-36}$  kg]
  7. At what speed would the total energy of a body be twice its rest energy? What is the speed if the kinetic energy is twice the rest energy? [0.87 $c$ , 0.94 $c$ ]
  8. The speed of an electron is doubled from  $0.2c$  to  $0.4c$ . By what ratio does the momentum increase? What is the ratio if the speed is doubled again from  $0.4c$  to  $0.8c$ ? [2.14, 3.06]
  9. With the numerical data of the previous problem, provide similar ratios for the kinetic energy of a proton. [4.33, 7.33]
  10. What is the energy of a photon whose momentum is the same as that of a proton whose kinetic energy is 10 MeV? [139 MeV]
  11. A particle has a kinetic energy of 62 MeV and a momentum of 335 MeV/ $c$ . Find its mass and speed (in terms of  $c$ ). [873 MeV/ $c^2$ , 0.36 $c$ ]
  12. A particle of rest mass  $m_0$  moving with a speed of  $0.8c$  makes a completely inelastic collision with a particle of rest mass  $3m_0$  that is initially at rest. What is the rest mass of the resulting single body? [4.47 $m_0$ ]
  13. A galaxy is receding from the Earth at  $15000 \text{ km s}^{-1}$ . If one of the wavelengths of light emitted by the galaxy is 550 nm, what is the corresponding wavelength measured by astronomers on the Earth? [578 nm]
  14. The frequencies of the spectral lines in the light from a distant galaxy are found to be two-thirds as those of the same lines in the light from nearby stars. Find the recession speed of the distant galaxy. [0.38 $c$ ]
  15. A police radar uses Doppler effect to catch speeding cars. The radar transmits a microwave signal of  $8 \times 10^9 \text{ Hz}$  to an approaching car, from which the signal is reflected back. There are two Doppler shifts in the reflected signal, whose frequency beats against the frequency of the original signal. If the beat frequency is 1600 Hz, what is the speed of an approaching car? [108 km hr $^{-1}$ ]
  16. Estimate the Schwarzschild radius of a star of mass  $10 M_\odot$ . ( $M_\odot = 2 \times 10^{30} \text{ kg}$ ). [30 km]
  17. Einstein predicted a fractional change of  $2 \times 10^{-6}$  for the wavelengths of solar radiation, due to gravitational red shift. Show this to be theoretically true. ( $R_\odot = 7 \times 10^5 \text{ km}$ ).
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