# Problem sheet on Modern Physics

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### Relativity

1. A galaxy in the constellation Ursa Major is receding from the earth at 15,000 km/s. If one of the characteristic wavelengths of the light the galaxy emits is 550 nm, what is the corresponding wavelength measured by astronomers on the earth? [Ans: 578 nm]

2. A spacecraft receding from the earth emits radio waves at a constant frequency of $10^9$ Hz. If the receiver on earth can measure frequencies to the nearest hertz, at what spacecraft speed can the difference between the relativistic and classical Doppler effects be detected? For the classical effect, assume the earth is stationary.

3. An astronaut whose height on the earth is exactly 6 ft is lying parallel to the axis of a spacecraft moving at 0.90$c$ relative to the earth. What is his height as measured by an observer in the same spacecraft? By an observer on the earth? [Ans: 2.6 ft and $3.32 \times 10^{-8}$ s]

4. How much time does a meter stick moving at 0.10$c$ relative to an observer take to pass the observer? The meter stick is parallel to its direction of motion.

5. A spacecraft antenna is at an angle of $10^\circ$ relative to the axis of the spacecraft. If the spacecraft moves away from the earth at a speed of 0.70$c$, what is the angle of the antenna as seen from the earth?                                        [Ans: 14°]

6. A woman leaves the earth in a spacecraft that makes a round trip to the nearest star, 4 light-year distant, at a speed of 0.9c. How much younger is she upon her return than her twin sister who remained behind? [5 yr]

7. Dynamite liberates about 5.4 x $10^6$ J/kg when it explodes. What fraction of its total energy content is this? [Ans: $6.0 \times 10^{-11}$]

8. At what speed does the kinetic energy of a particle equal its rest energy? [Ans: $2.60 \times 10^8$ m/s]

9. What is the speed of a particle if its kinetic energy is 1% larger than its rest energy ?

10. An electron has a kinetic energy of 0.100 MeV. Find its speed according to classical and

    relativistic mechanics. [Ans: $1.88 \times 10^8$ m/s and $1.64 \times 10^8$ m/s]

11. An observer detects two explosions, one that occurs near her at a certain time and another that occurs 2.00 ms later 100 km away. Another observer finds that the two explosions occur at the, same place. What time interval separates the explosions to the second observer? [Ans: 1.97 ms]

12. A particle has a kinetic energy 20 times its rest energy. Find the speed of the particle in terms of c. [Ans: 0.9989c]

13. A man on the moon sees two spacecraft, A and B, coming toward him from opposite directions at the respective speeds of 0.800c and 0.900c. (a) What does a man on A measure for the speed with which he is approaching the moon? For the speed with which he is approaching B? (b) What does a man on B measure for the speed with which he is approaching the moon? For the speed with which he is approaching A ? [Ans: (a) 0.800c and 0.988c, (b) 0.900 c and 0.988 c]

14. The Apollo 11 spacecraft that landed on the moon in 1969 traveled there at a speed relative to the earth at 1.08x$10^4$ m/s. To an observer on the earth, how much longer was the trip?

15. An astronaut whose height on the earth is exactly 6.0 ft is lying parallel to the axis of the spacecraft moving at 0.9c relative to the earth. What is his height as measured by an observer in the same spacecraft? What is his height as measured by an observer on the earth?

16. A woman leaves the earth in a spacecraft that makes a round trip to the nearest star, 4 light-years distant at a speed of 0.9c. How much younger is she upon her return than her twin sister who remained behind?

17. At what speed does the kinetic energy of a particle equal its rest mass?

18. Find the momentum (in MeV/c) of an electron whose speed is 0.600c. [Ans: 0.383 MeV/c]

19. Find the momentum of an electron whose kinetic energy equals its rest energy of 511 keV. [Ans: 1.94 GeV/c]

20. What is the percentage increase in the mass of a proton accelerated to a kinetic energy of 500 MeV?

21. Find the total energy of a neutron ($Mo=0.940$ GeV/c$^2$) whose momentum is 1.20 GeV/c.

22. How much work (in MeV) must be done to increa se the speed of an electron from $1.2 \times 10^8$ m/s to 2.4 X 108 m/s? [Ans: 0.294 MeV]

23. Prove that $\frac{1}{2}\gamma mv^2$, does not equal the kinetic energy of a particle moving at relativistic speeds.

24. Find the speed and momentum (in GeV/c) of a proton whose total energy is 3.500 GeV. [Ans: 0.963c and 3.37 GeV/c]

25. A particle has a kinetic energy of 62 MeV and a momentum of 335 MeV/c. Find its mass (in MeV/c$^2$) and speed (as a fraction of c). [874 MeV/c$^2$ and 0.36c

26. In its own frame of reference, a proton takes 5 min to cross the Milky Way galaxy, which is about $10^5$ light-years in diameter. (a) What is the approximate energy of the proton in electronvolts?. (b) About how long would the proton take to cross the galaxy as measured by an observer in the galaxy's reference frame? [$10^{19}$ eV]