PHYSICS 1020

Homework set 10

19 February 1997

[**10.4**] Velma bicycles northward at 4 m/s. She throws a ball northward at 10 m/s relative to herself. What is the ball's speed and direction of motion relative to Mort, who is standing beside the road? What if Velma had instead thrown the ball southward at 10 m/s? What if she had thrown the ball southward at 4 m/s?

Answer:

Since the speeds involved are rather small, we can use Galilean addition of velocities. The *velocity of the ball, as seen by Mort,* = *the velocity of the ball relative to Velma plus the velocity of Velma relative to Mort.* Since velocity is a vector, we have to keep track of direction. Let's define the positive direction for north-south motion to be the northern direction, i.e velocitiy components are counted positive for northward motion, and negative for southward motion. When the ball is thrown northward at 10 m/s, the velocity components in the northern direction add, and we get 14 m/s northward. When the ball is thrown southward at 10 m/s, the velocity component northward seen by Mort = (- 10 + 4) m/s = -6 m/s, i.e. 6 m/s southward. (We had to put - 10 m/s because the ball was thrown southward, i.e. opposite to the northern direction which we have defined to be the direction in which we count velocities positive.) When the ball is thrown at 4 m/s southward, the velocity in the northward direction seen by Mort = (-4 + 4) m/s = 0, i.e. as seen by Mort, the ball falls straight down.

[**10.5**] A desperado riding on top of a freight-train car fires a gun pointed forward. Compare the speed of the bullet as observed by a passenger on the train and as observed by the sheriff standing beside the tracks. What if the desperado instead points his gun backward toward the rear of the train?

Answer:

The passenger, being at rest relative to the gun, observes the bullet's velocity to be the same as the muzzle velocity (= the bullet's velocity relative to the gun). For the sheriff, the *bullet's velocity* = *the bullet's velocity relative to the train* + *the train's velocity relative to him.* Therefore, if the gun is pointed in the direction of the train's motion, the sheriff sees the bullet move faster than the muzzle velocity, but he sees the bullet move slower than the muzzle velocity when the gun is fired backwards, opposite to the direction of the train's motion. For the passenger who is riding in the train and therefore at rest with respect to the gun, the bullet's speed is always the same.

[**10.6**] In the preceding question, suppose that the gun's muzzle velocity (speed of the bullet relative to the gun) is 500 m/s and that the freight-train's speed is 40 m/s. What is the bullet's speed and direction of motion as observed by the sheriff if the desperado fires the gun forward? What if he instead fires toward the rear of the train?

Answer:

When the gun is fired forward, the velocity seen by the sheriff = (500 + 40) m/s = 540 m/s in the direction of the train; when the gun is fired backward, the bullet's velocity seen by the sheriff is = (-500 + 40) m/s = -460 m/s, i.e. 460 m/s in the direction opposite to the direction of motion of the train.

[**10.15**] A desperado riding on top of a freight-train car fires a laser gun pointed forward (compare this with exercise [10.5]). What is this gun's "muzzle velocity"? Suppose the train is moving at 40 m/s (0.04 km/s). How fast does the tip of the laser beam move relative to the sheriff, who is standing on the ground beside the train? What answer would Galilean theory of relativity give to this question?
Answer:
The laser gun's muzzle velocity is the velocity of light, $c = 300\ 000$ km/s. The sheriff standing on the ground sees the light coming out of the laser gun also moving with the same speed, $c = 300\ 000$ km/s (this is because of the principle of the constancy of the speed of light, i.e. its independence of the state of motion of source or observer). According to Galilean relativity, on the other hand, the two velocities would add, i.e. the sheriff would see the laser light move with velocity $= c + v_{train} = 300\ 000.04$ km/s.

[**10.16**] Earth orbits the sun at a speed of about 30 km/s. If we assume that ether fills all space and that the sun is at rest in the ether, then it follows that Earth is moving at about 30 km/s through the ether. If these assumptions are true, then what speed will the observer in figure 10.8 observe for light beam A? For light beam B?
Answer:
According to the ether theory, light is a wave propagating through ether, with a speed which is constant with respect to the ether. Light beam A of Fig.10.8 is emitted by a light source behind Earth. Therefore the observer on Earth is moving away from the source, and so the velocity of light perceived by an observer on Earth is smaller than it would be for an observer at rest relative to the ether:

$$v_A = c - v_E = (300000 - 30)\text{km/s} = 299970 \text{ km/s}.$$

For light beam B, the observer on Earth is movimg towards the source, and therefore the velocity of the light perceived in this case is larger than for an observer at rest with respect to the ether:

$$v_B = c + v_E = (300000 + 30)\text{km/s} = 300030\text{km/s}.$$

[**10.17**] Michelson and Morley measured the difference between the speeds of two light beams moving in different directions. Under the assumptions stated in the preceding exercise, what would be the difference between the speeds of the two light beams in figure 10.8? Express your answer as a fraction of c.
Answer:
The difference between the velocities of the two lightbeams B and A is

$$(c + v_E) - (c - v_E) = 2v_E = 60\text{km/s}.$$

As a fraction of c, this is $= 60/300000 = 2 \cdot 10^{-4} = 0.00002$.

[**10.26**] Your extraordinarily fantastic rocketship moves at 99% of lightspeed. If you took off, moved at this speed for 24 hours as measured by you, and returned to Earth, by how much would your clock differ from Earth-based clocks? Would you have aged more or less than people on Earth? By how much?
Answer:

Time T as measured by observers on Earth is related to time $T_\circ$ as measured by you in your spaceship by

$$T = \gamma \cdot T_\circ, \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}, \quad \beta = \frac{v}{c}$$

For $\beta = \frac{v}{c} = 0.99$, this gives $\gamma = 7.09$ (See also table 10.1). This means that for every day that passes for you on your rocketship, 7.1 days pass for the observers on Earth. When you return after one of your days, 7.1 days have passed for the observers on Earth. Thus, you have aged by one day, while the observers on Earth have aged by 7.1 days, i.e. by 6.1 days more than you.