15.4: Speed is Relative - The Fundamental Postulate of Special Relativity

You are sitting in a railway carriage (or a railroad car, if you prefer the term). The windows and curtains are closed and you cannot see outside. You are asked to measure the constant speed of the carriage along its tracks. You try a number of experiments. You measure the period of a simple pendulum. You slide a puck and roll a ball down an inclined plane. You throw a ball vertically up in the air and catch it as it comes down. You throw it up at an angle and you watch it describe a graceful parabola. You cause billiard balls to collide on the billiards table thoughtfully provided in your carriage. You experiment with a torsion pendulum. You stand a pencil on its end and you watch it as it falls to a horizontal position.

All your careful work is to no avail. None of them tells you what speed you are moving at, or even if you are moving at all. After exhausting all mechanical experiments you can think of, you are led to the conclusion:

> *It is impossible to determine the speed of motion of a uniformly-moving reference frame by means of any mechanical experiment performed within that frame.*

Frustrated, you open a curtain on one side of the carriage. You look out and you see that there is another train on the line next to you. It appears to be moving backwards. Or are you moving forwards? Or are you both moving in the same direction but at different speeds? You still can't tell.

You move to the other side of the carriage and open the curtain there. This time you see the station platform, and the station platform is moving backwards. Or are you moving forwards? (Those of you who have not done much travel by train may not appreciate just how very strong the impression can be that the platform is moving.) What does it mean, anyway, to say that it is you that is moving rather than the platform?

The following story is not true, but it ought to be. (It is an "apocryphal" story.) Einstein was travelling by train across Canada. Halfway across the Prairies he leant across and tapped on the knee of his fellow passenger and asked: "Excuse me, mein Herr, bitte, but does Regina stop at this train?"

You are about to conclude that it is not possible by any means, whether by experiment or by observation, to determine the speed of your reference frame, or even whether it is moving or stationary.

But not so hasty! I am about to invent a speedometer, which I intend to patent and to use to make myself rich. I am going to use my invention to measure the speed of our train – without even looking out of the window!

We shall set up two long parallel glass rods in the middle of the corridor, parallel to the railway lines and to the velocity of the train. We shall suspend the rods horizontally, side by side from a common support, and we shall rub each of them with a silken handkerchief, so that each of them bears an electrostatic charge of λCm^{-1}. They will repel each other with an electrostatic force per unit length of

$$F_e = \frac{\lambda^2}{4\pi\epsilon_0 r} Nm^{-1}, \tag{15.4.1}$$

where r is their distance apart, and consequently they will hang out of the vertical – see figure XV.4.

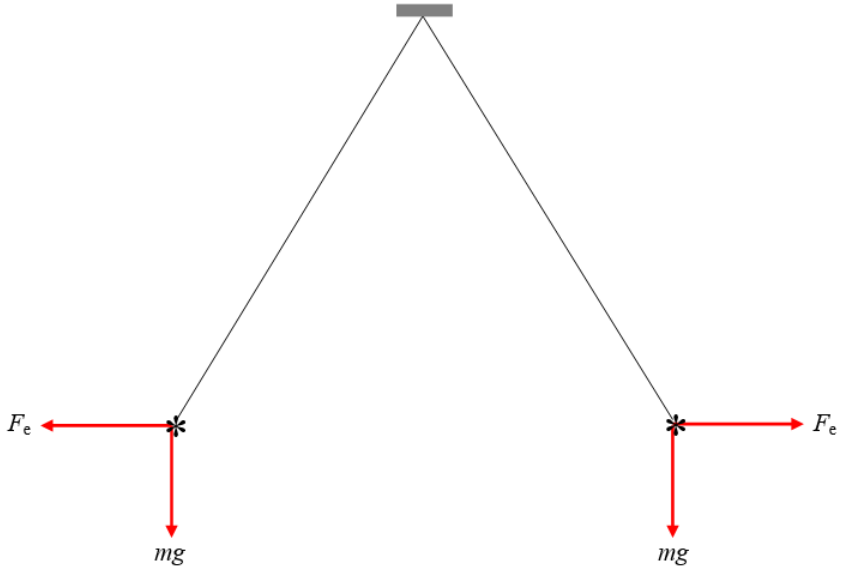

FIGURE XV.4

Now see what happens when the train moves forward at speed ν. Each rod, bearing a charge λ per unit length, is now moving forward at speed ν, and therefore each rod constitutes an electric current $\lambda\nu A$. Therefore, by Ampère's law, in addition to the Coulomb repulsion, they will experience a magnetic attraction per unit length equal to

$$F_m = \frac{\mu_0 \lambda^2 \nu^2}{4\pi r} Nm^{-1} \tag{15.4.2}$$

The net repulsive force per unit length is now

$$\frac{\lambda^2}{4\pi\epsilon_0 r^2}(1 - \mu_0\epsilon_0\nu^2). \tag{15.4.3}$$

This is a little less than it was when the train was stationary, so the angle between the suspending strings is a little less, as shown in figure XV.5. It might be noted that the force between the strings is reduced to zero (and the angle also becomes zero) when the train is travelling at a speed $\frac{1}{\sqrt{\mu_0\epsilon_0}}$. We remember from electromagnetic theory that the permeability of free space is $\mu_0 = 4\pi$ % 10^{-7} H m^{-1} and that the permittivity ϵ_0 is 8.8542 % 10^{-12} F m^{-1}; consequently the force and the angle drop to zero and the strings hang vertically, when the train is moving at a speed of 2.998 % 10^8 m s^{-1}.

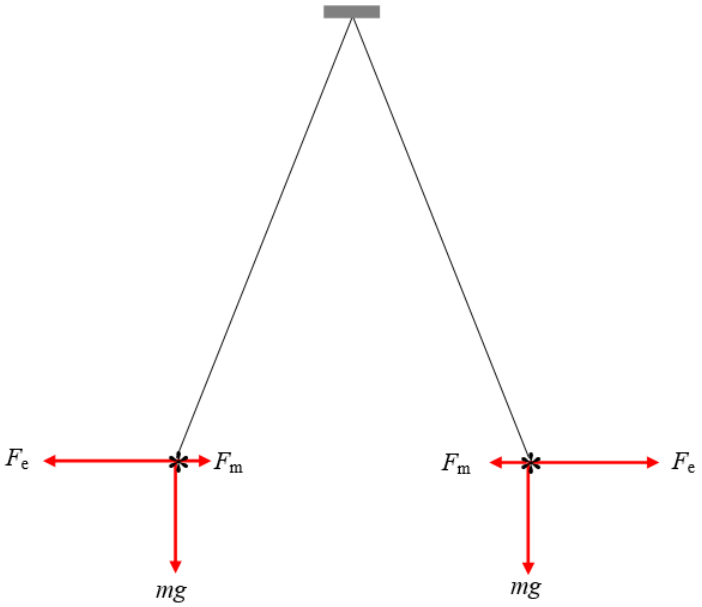

FIGURE XV.5

To complete my invention, I am now going to attach a protractor to the instrument, but instead of marking the protractor in degrees, I am going to calibrate it in miles per hour, and my speedometer is now ready for use (figure XV.6).

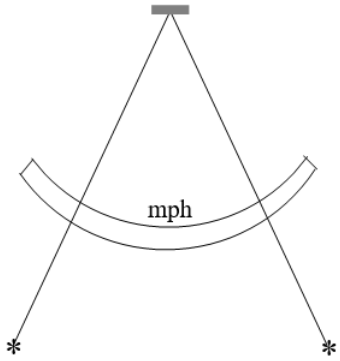

FIGURE XV.6

You now have a choice. Either:

i. You can choose to believe that the speedometer will work and you can accompany me to the patent office to see if they will grant a patent for this invention, which will measure the speed of a train without reference to any external reference frame. If you choose to believe this, there is no need for you to read the remainder of the chapter on special relativity.

or

ii. You can say that it defies common sense to believe that it is possible to determine whether a given reference frame is moving or stationary, let alone to determine its speed. Common sense dictates that

It is impossible to determine the speed of motion of a uniformly-moving reference frame by any means whatever, whether by a mechanical or electrical or indeed any experiment performed entirely or partially within that frame, or even by reference to another frame.

Your common sense, then, leads you – as it should – to the fundamental principle of special relativity. Whereas some people protest that relativity "defies common sense", in fact relativity *is* common sense, and its predictions (such as your prediction that my speedometer will not work) are exactly what common sense would lead you to expect.