forces acting on the post due to its contact with the ground and the gravitational force exerted on the post by the earth, we will restrict our attention to the horizontal component of the third force. Let $\vec{\mathbf{F}}_3$ denote the sum of the forces due to the ropes. Then we can write the vector $\vec{\mathbf{F}}_3$ as

$$\vec{\mathbf{F}}_3 = (F_{1x} + F_{2x})\,\hat{\mathbf{i}} + (F_{1y} + F_{2y})\,\hat{\mathbf{j}} = (70\text{ N} + -30\text{ N})\,\hat{\mathbf{i}} + (20\text{ N} + 40\text{ N})\,\hat{\mathbf{j}}$$
$$= (40\text{ N})\,\hat{\mathbf{i}} + (60\text{ N})\,\hat{\mathbf{j}}$$

Therefore the horizontal component of the third force of the post must be equal to

$$\vec{\mathbf{F}}_{hor} = -\vec{\mathbf{F}}_3 = -(\vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2) = (-40\text{ N})\,\hat{\mathbf{i}} + (-60\text{ N})\,\hat{\mathbf{j}}\,.$$

The magnitude is $\left|\vec{\mathbf{F}}_{hor}\right| = \sqrt{(-40\text{ N})^2 + (-60\text{ N})^2} = 72\text{ N}$. The horizontal component of the force makes an angle

$$\theta = \tan^{-1}\left[\frac{60\text{ N}}{40\text{ N}}\right] = 56.3^\circ$$

as shown in the figure above.

7.1.1 Mass Calibration

So far, we have only used the standard body to measure force. Instead of performing experiments on the standard body, we can calibrate the masses of all other bodies in terms of the standard mass by the following experimental procedure. We shall refer to the mass measured in this way as the **inertial mass** and denote it by m_{in}.

We apply a force of magnitude F to the standard body and measure the magnitude of the acceleration a_s. Then we apply the same force to a second body of unknown mass m_{in} and measure the magnitude of the acceleration a_{in}. Since the same force is applied to both bodies,

$$F = m_{in}\,a_{in} = m_s\,a_s\,, \tag{1.7}$$

Therefore the ratio of the inertial mass to the standard mass is equal to the inverse ratio of the magnitudes of the accelerations,

$$\frac{m_{in}}{m_s} = \frac{a_s}{a_{in}}\,. \tag{1.8}$$

Therefore the second body has inertial mass equal to

$$m_{in} \equiv m_s \frac{a_s}{a_{in}}. \tag{1.9}$$

This method is justified by the fact that we can repeat the experiment using a different force and still find that the ratios of the acceleration are the same. For simplicity we shall denote the inertial mass by m.

7.2 Newton's First Law

The First Law of Motion, commonly called the "Principle of Inertia," was first realized by Galileo. (Newton did not acknowledge Galileo's contribution.) Newton was particularly concerned with how to phrase the First Law in Latin, but after many rewrites Newton perfected the following expression for the First Law (in English translation):

> *Law 1: Every body continues in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it.*
>
> *Projectiles continue in their motions, so far as they are not retarded by the resistance of air, or impelled downwards by the force of gravity. A top, whose parts by their cohesion are continually drawn aside from rectilinear motions, does not cease its rotation, otherwise than as it is retarded by air. The greater bodies of planets and comets, meeting with less resistance in freer spaces, preserve their motions both progressive and circular for a much longer time.*[4]

The first law is an experimental statement about the motions of bodies. When a body moves with constant velocity, there are either no forces present or there are forces acting in opposite directions that cancel out. If the body changes its velocity, then there must be an acceleration, and hence a total non-zero force must be present. We note that velocity can change in two ways. The first way is to change the magnitude of the velocity; the second way is to change its direction.

After a bus or train starts, the acceleration is often so small we can barely perceive it. We are often startled because it seems as if the station is moving in the opposite direction while we seem to be still. Newton's First Law states that there is no physical way to distinguish between whether we are moving or the station is, because there is essentially no total force present to change the state of motion. Once we reach a constant velocity, our minds dismiss the idea that the ground is moving backwards because we think it is impossible, but there is no actual way for us to distinguish whether the train is moving or the ground is moving.

[4] Ibid. p. 13.