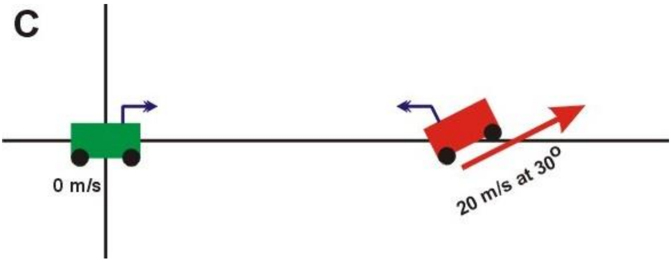
Relative-Motion Test for Unit Reliability



1. Puzzling the Reliability of *m*, *s*, and *m/s* as Scientific Units

Professor Du-Ane Du

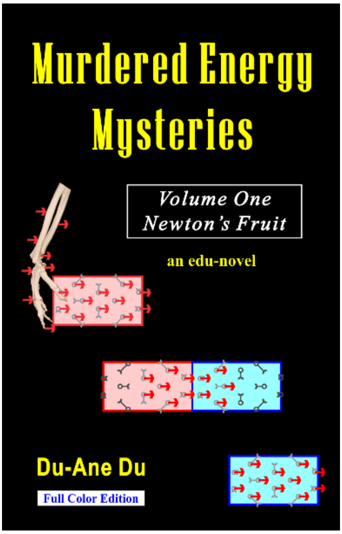
www.Wacky1301SCI.com, *"Looking at serious science, sideways!"*

The first of three puzzle sets that use relative motion to deduce which units are not reliable for scientific comparisons: **(1) the reliability of *m, s, m/s***, (2) the unreliability of joules of kinetic energy and work-done, (3) the reliability of ρ [kgm/s] of impulse and momentum. (1st month of a physics class.)
—By Du-Ane Du, Author of *Murdered Energy Mysteries*, (Amazon, Kindle, ebook 2018, paperback 2021).

In the 1800's there was a rush to standardize units of measurement. Unfortunately, in the hurry to standardize, little effort was made to verify if the units were legitimate in all mathematical situations. Recent research shows that some common units are not mathematically stable in all situations.

This is the first of three puzzle sets that use basic relativity to test the reliability of common scientific units. (This approach is appropriate for presenting in the first month of high school physics, and it is a good way to show the importance of relativistic thinking.)

Here, we will examine the mathematical nature of velocity and make certain that meters, seconds, and meters-per-second are valid units of measure. We can do this by using a technique associated with special relativity:



Relativity

In the early 1900's Albert Einstein developed an extensive set of theories around a concept called relativity. Special Relativity involves the relationships between two or more moving objects [ie. 2 or more spaceships]. It focuses on how observers traveling in the two objects view one another, and it is based on three fundamental premises:

1) There are no fixed reference points, and each observer can only see the single object being observed,
2) Either one object, or both are moving,
3) An observer will always perceive him/herself as being stationary and the observed object as moving.

The phrase **relative to** is used to identify the position of the observer and to establish a frame of reference from which measurements are based.

Relative Motion

To understand the importance of relative motion mathematics, let's examine a couple of scenarios involving Ricky Right and Laura Left:

Laura Left pilots an airplane, and Ricky Right drives a truck. Each vehicle is equipped with a Doppler-laser speed-detector.

A Doppler laser emits a narrow pulse of light, and it examines the frequency change of the light after the light pulse reflects off of another object. Doppler mathematics is used to detect the speed of the object as it moves toward or away from the laser. Doppler lasers cannot measure sideways motion.

The two Doppler lasers are arranged so that they measure velocities up and down the X-axis of a huge graph. In keeping with Einstein's special-relativity premise, Laura Left and Ricky Right cannot perceive the existence of the graph.

In the first experiment, Laura's airplane is parked on the origin of the X-Y axis, which gives it a velocity of 0 m/s. Laura's Doppler laser beam is pointed to the right, along the positive X-axis.

Ricky Right's truck has a fixed speed of 20.0 m/s, and it will begin in various places on the positive side of the X-axis. Ricky Right's Doppler laser is pointed along the X-axis, toward Laura Left's airplane.

Let's see how the two Doppler lasers interpret relative motion:

Scenario 1A: Ricky Right's vehicle begins on the positive side of the X-axis , and it rolls along the X-axis with a velocity of 20.0 m/s at 0° (going to the right). The two Doppler lasers send out a measurement pulse and each vehicle registers the instantaneous velocity of the other vehicle.

What is Laura Left's measurement of Ricky's velocity? Clearly Laura's Doppler laser will measure that Ricky is traveling at 20.0 m/s, moving away.

What is Ricky Right's measurement of Laura's velocity? Ricky cannot perceive his own motion; therefore Ricky's Doppler Laser will measure that Laura has an instantaneous velocity of 20.0 m/s, also moving away.

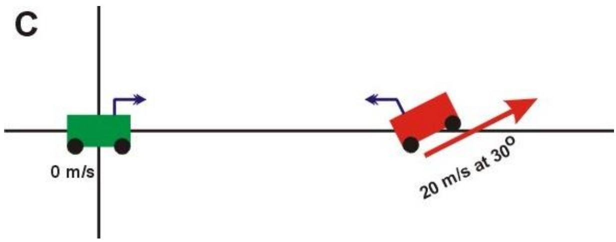
Already we have verified Einstein's premise that each observer will perceive that the other is moving.

Scenario 1B: Next, Ricky Right rotates his vehicle so that it travels along the X-axis in the opposite direction. He drives at a constant velocity of 20.0 m/s at 180° relative to the positive X-axis. The two Doppler lasers send out a measurement pulse, and each records the other's velocity.

What measurement does Laura Left record? Obviously Laura will record that Ricky is traveling at 20.0 m/s moving toward, or –20.0 m/s.

What measurement does Ricky Right record? Once again, Ricky cannot perceive his own motion, so his Doppler laser will record that Laura has an instantaneous velocity of 20.0 m/s moving toward, or –20.0 m/s. (Recall that a positive velocity means moving away, because the distance between the vehicles is increasing; while negative velocity means moving toward, because the distance between the vehicles is decreasing.)

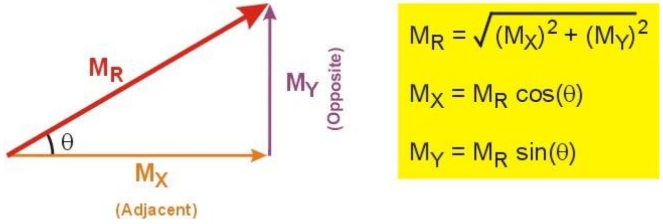
Scenario 1C: Ricky Right turns left and loops around to the south side of the X-axis. Ricky straightens his path so his vehicle rolls at a constant velocity of 20.0 m/s at 30° relative to the positive X-axis. As Ricky crosses the X-axis, both of the Doppler lasers emit a measurement pulse and take readings of one another's instantaneous velocity.



Using vector analysis, we can calculate the measurement from Laura Left's perspective. We first recall that a Doppler laser can only measure motion that is going toward it or away from it. The lasers cannot detect sideways motion, and they are pointed directly along the X-axis. Therefore, Laura can only detect the portion of the velocity that occurs in the X-direction.

When an object is traveling at an angle, it behaves like a resultant vector. The Pythagorean Theorem can be used to combine an X-displacement vector and a Y-displacement vector into a resultant vector. The X-component and the Y-component behave like the legs of a right triangle, and the resultant behaves like a hypotenuse.

Since the word for size is magnitude, we can identify the three sides of the vector triangle as M_R (Magnitude of Resultant), M_Y (Magnitude of Y-component) and M_X (Magnitude of X-component.) The angle is identified with the symbol Θ.



The X-component and the Y-component can be combined to make the resultant. In our current situation, the single velocity vector needs to be split into its X- and Y-components using sine and cosine.

Ricky Right's vehicle is traveling with a velocity vector of 20.0 m/s at 30°. To calculate the components of this motion, we use the trigonometric equations for sine and cosine:

$$Y\text{-}component = M_{Resultant} \times sin(\emptyset)$$
$$M_Y = (20.0\frac{m}{s})sin(30°)$$
$$M_Y = 10\ m/s$$
$$X\text{-}component = M_{Resultant} \times cos(\emptyset)$$
$$M_X = (20.0\frac{m}{s})cos(30°)$$
$$M_X = 17.3\ m/s$$

These calculations show that Ricky Right has a velocity of 17.3 m/s in the X-direction, and a velocity of 10.0 m/s in the Y-direction.

The question at hand was, what is Laura Left's measurement of Ricky's velocity? Our answer is, Laura can only measure motion in the X-direction, therefore

Laura will record that Ricky has a velocity of 17.3 m/s moving away.

Now, when the two Doppler lasers flashed, what did Ricky Right record as Laura's velocity? According to Einstein's premise, Ricky is incapable of perceiving his own motion. Therefore, Ricky's Doppler laser will record that Laura has a velocity of 17.3 m/s moving away, meaning the distance between them was increasing.

Parallax Range

So far, we have been alternating between three different frames of reference, the measurements began from the perspective of the graph itself, then we examined the situation from the perspective of Laura Left's Doppler laser, and finally from the perspective of Ricky Right's Doppler laser. Each perspective was a different frame of reference.

Special relativity and relative motion are all about observing things from a variety of observation points—any of which can be moving.

However, we have also established the maximum and minimum velocities that can be observed from either vantage point. This maximum and minimum can be called the **parallax range.** <u>Angular motion will always produce a value that is within the parallax range</u>.

Angular motion can never produce an answer that is greater than the parallax range. Therefore, the parallax range can be very useful in determining the reliability of measurement units such as meters-per-second.

We can develop a deeper understanding of the mathematics of relative motion by exploring the implications of the current parallax range. The mathematical definition of parallax range is, plus-or-minus one-half of the difference between the maximum and minimum values:

$$\textit{parallax range} = \pm(½(max - min))$$

So far we have determined that Laura Left will observe Ricky Right as having a maximum velocity of +20.0 m/s and a minimum velocity of –20.0 m/s—which is parallax a range of $\pm$20. But will this range hold true if both vehicles are moving when the lasers take their measurements?

Parallax/Relative-Motion
Test of Unit Reliability

The rules of the Parallax/Relative-Motion Test of Unit Reliability state *a unit of measure can only be considered reliable if it produces the same parallax range when viewed from a wide variety of reasonable inertial reference frames*.

The term **inertial** refers to the fact that the observer is not accelerating. A person standing in a room is in an inertial reference frame as long as the earth does not stop rotating. Similarly, a person sitting in a moving vehicle is in an inertial reference frame as long as the vehicle does not accelerate or slow down.

The term *reasonable* should include any reference frame that a scientist might conceivably interact with.

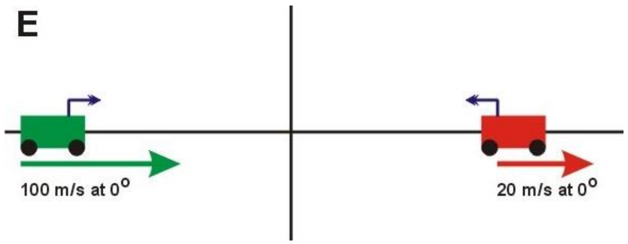
Why is the unit reliability test important? If a policeman is riding in a car, his use of a Doppler laser to detect the velocity of an oncoming car should be just as accurate as if he were standing still on the side of a road. Similarly, a high speed aircraft needs to be able to measure the velocity of a boat moving on the ocean with the same level of accuracy as the measurements made by a nearby aircraft carrier.

Before we can perform the parallax/relative-motion unit reliability test on the units *m*, *s*, and *m/s*, we first need to choose some reasonable velocities to test. Consider the following. The earth rotates at a speed of about

464 m/s. The earth orbits the sun at a speed of about 30,000 m/s. The solar system orbits the Milky Way Galaxy at about 230,000 m/s.

While it is unlikely that an airplane will ever fly at a speed of 230,000 m/s, we do need to know that the measurement of 20 m/s is a reliable measurement. We also we need to know that pilots flying at high speeds will be able to accurately identify when a vehicle below them is traveling at a speed of 20 m/s.

Scenario 2A: To test for m/s unit reliability, we allow Laura Left to fly her airplane far down the left side of the X-axis. Laura turns around and begins flying at a velocity of 100 m/s at 0° relative to the X-axis. Next, Ricky Right drives his truck on the right side of the X-axis, moving at a constant velocity of 20 m/s at 0°.



When the lasers send out measurement pulses, we would expect that Laura Left will record that Ricky is moving closer at a velocity of 80 m/s. This is because:

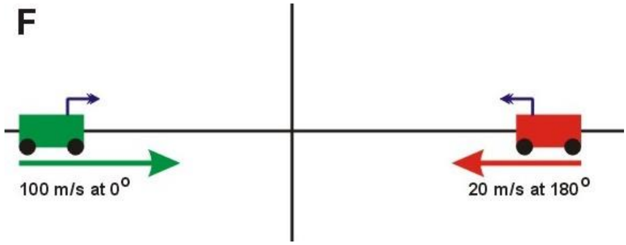
net velocity = (Ricky Right) – (Laura Left)

net velocity = $(+20\frac{m}{s}) - (+100\frac{m}{s})$

net velocity = $\boldsymbol{-80\frac{m}{s}}$***, or*** $\boldsymbol{80\frac{m}{s}}$ ***moving closer***

Similarly, we would expect that Ricky Right will record that Laura is moving closer at a velocity of 80 m/s.

Scenario 2B: Ricky Right turns his vehicle around, so that Ricky moves at a velocity of 20 m/s at 180° relative to the X-axis:



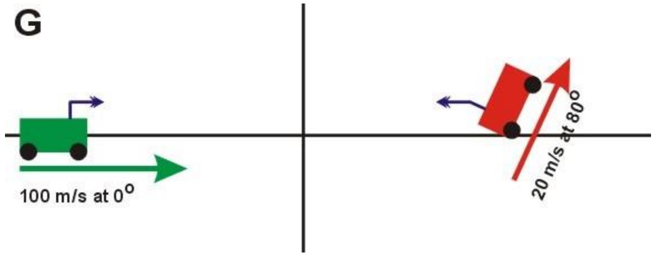
When the lasers send out measurement pulses, we would expect that Laura Left will record that Ricky is moving closer at a velocity of 120 m/s. This is because:

net velocity = (Ricky Right) – (Laura Left)

net velocity = $(-20\frac{m}{s}) - (+100\frac{m}{s})$

$$\textbf{\textit{net velocity}} = -120\frac{m}{s}$$

Scenario 2C: Ricky Right loops his vehicle round so it is moving at a velocity of 20 m/s at 80° relative to the X-axis:



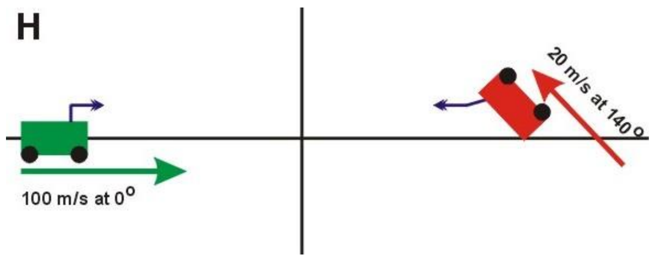
This relative motion situation involves velocity vectors that are moving at angles to one another. The lasers cannot measure sideways motion. So before we can calculate the result, we first need to find the X-component of Ricky's velocity.

$$Y\text{-}component = M_{Resultant} \times sin(\emptyset)$$
$$M_Y = (20.0\frac{m}{s})sin(80°)$$
$$M_Y = 19.7\ m/s$$
$$X\text{-}component = M_{Resultant} \times cos(\emptyset)$$
$$M_X = (20.0\frac{m}{s})cos(80°)$$
$$\mathbf{M_X = 3.47\ m/s}$$

Now we can calculate the approach velocity as seen from the perspective of Laura Left:

$$net\ velocity = (Ricky\ Right) - (Laura\ Left)$$
$$net\ velocity = \left(3.47\frac{m}{s}\right) - \left(+100\frac{m}{s}\right)$$
$$\mathbf{net\ velocity = -96.53\frac{m}{s}}$$

Scenario 2D: Ricky Right rotates his vehicle so it moves at a velocity of 20 m/s at 140° relative to the X-axis:



Once again, the velocity vectors are at angles to one another. Therefore we must begin by finding the X-component of Ricky's velocity.

$$X\text{-}component = M_{Resultant} \times cos(\emptyset)$$
$$M_X = \left(20.0\frac{m}{s}\right)cos(140°)$$
$$\mathbf{M_X = -15.3\frac{m}{s}}$$

Now we can calculate the approach velocity as seen from the Laura's perspective:

$$net\ velocity = (Ricky\ Right) - (Laura\ Left)$$
$$net\ velocity = \left(-15.3\frac{m}{s}\right) - \left(+100\frac{m}{s}\right)$$
$$\mathbf{net\ velocity = -115.3\frac{m}{s},\ or\ 115.3\frac{m}{s}\ closer.}$$

Initial Conclusions: Finally, we can place the data into a comparison table:

Ricky Right's relative velocities as viewed by Laura Left			I
Laura Left is moving at 0 $\frac{m}{s}$.		Laura Left is moving at 100 $\frac{m}{s}$, 0°.	
	Ricky's Velocity		**Ricky's Velocity**
Scenario 1A	$+20\,\frac{m}{s}$	Scenario 2A	$-80\,\frac{m}{s}$
Scenario 1B	$-20\,\frac{m}{s}$	Scenario 2B	$-120\,\frac{m}{s}$
Scenario 1C	$+17.3\,\frac{m}{s}$	Scenario 2C	$-96.53\,\frac{m}{s}$
		Scenario 2D	$-115.3\,\frac{m}{s}$
Parallax Range		**Parallax Range**	
$\pm 1/2(max - min)$ $\pm 1/2(20 - {}^{-}20)$		$\pm 1/2(max - min)$ $\pm 1/2({}^{-}80 - {}^{-}120)$	
$\pm \mathbf{20}\,\frac{\boldsymbol{m}}{\boldsymbol{s}}$		$\pm \mathbf{20}\,\frac{\boldsymbol{m}}{\boldsymbol{s}}$	

In both cases, when we subtract the maximum and minimum values, and then divide by two; we find a parallax range of ± 20 m/s. *Notice that the parallax ranges match*. While one set of experiments is not enough to decisively prove that *me-*

ters per second is a reliable unit for use in scientific measurement, advertising, and commerce; this single test does suggest that further investigation may lead to a deeper understanding.

PUZZLES FOR FURTHER RESEARCH AND UNDERSTANDING

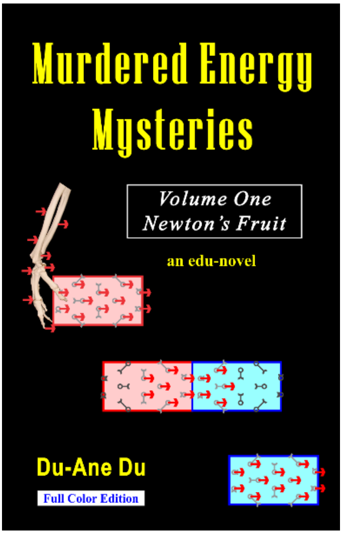
Please help us verify the reliability of *meters per second* as a unit of measure by calculating the parallax range for the following scenarios:

1) **Scenario 3:** Laura Left is moving at a velocity of 500 m/s at 0° relative to the X-axis.
    a. Ricky Right has a velocity of 20 m/s at 0°
    b. Ricky Right has a velocity of 20 m/s at 180°
    c. Ricky Right has a velocity of 20 m/s at 90°
    d. Ricky Right has a velocity of 20 m/s at 75°
2) **Scenario 4:** Laura Left is moving at a velocity of –1,000 m/s at 0° relative to the X-axis.
    a. Ricky Right has a velocity of 20 m/s at 0°
    b. Ricky Right has a velocity of 20 m/s at 180°
    c. Ricky Right has a velocity of 20 m/s at 40°
    d. Ricky Right has a velocity of 20 m/s at 135°

3) **Scenario 5:** Laura Left is moving at a velocity of 5,000 m/s at 0° relative to the X-axis.
   a. Ricky Right has a velocity of 20 m/s at 0°
   b. Ricky Right has a velocity of 20 m/s at 180°
   c. Ricky Right has a velocity of 20 m/s at 60°
   d. Ricky Right has a velocity of 20 m/s at 170°
4) **Scenario 6:** Laura Left is moving at a velocity of –200 m/s at 0° relative to the X-axis.
   a. Ricky Right has a velocity of 20 m/s at 0°
   b. Ricky Right has a velocity of 20 m/s at 180°
   c. Ricky Right has a velocity of 20 m/s at 15°
   d. Ricky Right has a velocity of 20 m/s at 115°
5) Develop a comparison table for Scenarios 1 to 6.
6) Would Ricky Right's measurements be the same or different from the measurements made by Laura Left?
7) Einstein's theory of special relativity states that absent stationary reference points, both observers will view themselves as stationary and the other as moving. Does your conclusion support or contrast with Einstein's theory?
8) Examine your comparison table. Does the parallax range for each inertial frame of reference match the original range of ±20 m/s?
9) Based on your calculations, does the unit of *meters per second* produce results that are reliable under a wide range of moving fields of reference?

10) Based on your calculations, would you recommend *meters per second* as a unit of measure for use during scientific experiments and studies?
11) Based on your calculations, would you recommend *meters per second* as a unit of measure for advertising and commerce?

*   *   *



Examine or purchase at Amazon.com

Murdered Energy Mysteries seeks to increase understanding of the various forms of momentum and momentum transfer, as well as the various forms of energy and energy transfer. The lack of understanding on the part of the scientific community is substantial, and more research needs to be done.

—Du-Ane Du, author of the edu-novel *Murdered Energy Mysteries* (Amazon, Kindle, e-book 2018, paperback 2021.)

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