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Forces Between Carts: An Exploration of Newton's Third Law

--Manuscript Draft--

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Physics Education Title:

Forces Between Carts: An Exploration of Newton's Third Law

Overview:

In this experiment, we look at various situations involving two interacting objects.

First, we examine the forces that two objects apply to one another while they are colliding. The objects are wheeled carts, which have a variable mass. The point of this experiment is to discover when the force the first cart exerts on the other is the same magnitude as the force the second cart exerts back on the first, and when these two forces have different magnitudes.

Second, we will look at the forces that two objects exert on one another while one cart is pushing or pulling the second one. Again, the focus will be on exploring in what situations the two forces have the same magnitude, and in what situations they have different magnitudes.

Principles:

The primary goal of the experiment is to explore Newton's third law. Newton's third law states that whenever two objects interact, the second object exerts a force on the first object that is equal in magnitude, and opposite in direction, to the force the first object exerts on the second object. This is simple to state, but can be hard to accept, with it often assumed that a larger object will exert a larger force on a smaller object than the smaller object exerts back on the larger object.

Understanding the apparatus

As shown in Figure 1, the apparatus consists of two carts, each with a force sensor mounted on top. The force sensors are connected to a computer via a dedicated computer interface. Each force sensor measures the force exerted on it by the other force sensor during the collision (or, later, during the pushing or pulling situation).

Procedure:

1. Collision Situations

1.1. Screw either a rubber bumper or a hook into each force sensor. For the collision situations, the rubber bumpers (as shown in Figure 1) are used.

1.2. Set each force sensor on the 50 N setting.

1.3. Zero the force sensors before each trial (next to the green arrow that starts data collection, there is a zero button).

1.4. Check to see that the positive direction (to the right) is defined appropriately for each force sensor.

1.4.1. Pushing in on the force sensor mounted on the right of the car should result in a positive force reading. Pushing in on the force sensor mounted on the left of the cart should result in a negative force reading.

1.4.2. If both are wrong, simply reverse the position of the carts.

1.4.3. If only one is wrong, go to the Experiment menu, select "Setup Sensors". Choose the appropriate force sensor and select "Reverse Direction."

1.5. The first collision involves carts of equal mass. Designate one cart to be stationary prior to the collision.

1.6. Give an initial velocity to the second cart toward the stationary cart.

1.7. Predict which cart will experience a larger force in this collision.

1.8. Hit the Collect button (the green arrow), and push one cart toward the other.

1.9. Once completed, the computer will display a graph of "force vs. time" as recorded by each force sensor.

1.10. If the graphs don't show up, reverse the triggering.

1.10.1. After you hit the Collect button, no data is actually recorded until one of the force sensors records a value above (or below) a certain trigger level. However, if the trigger level is set to a positive value and the force sensor is only giving negative force values, or vice versa, the computer will never get the signal telling it to record data.

1.10.2. To check, or reverse, the trigger setting, press the Data Collection icon (immediately to the left of the Zero icon), and select the "Triggering" tab.

1.10.3. The two options we will use in this experiment are Increasing across 0.2 N, or Decreasing across –0.2 N. If one of those settings is not causing the necessary triggering, switch to the other one.

1.11. In the second collision, the stationary cart has 2-3 times the mass of the cart that is moving before the collision. Repeat the process (see steps below).

1.11.1. Designate one cart to be stationary prior to the collision.

1.11.2. Predict which of the carts will experience a larger force in this collision.

1.11.3. Hit the Collect button, and push the lower-mass cart toward the higher-mass cart.

1.11.4. The computer will display the two “force vs. time” graphs.

1.12. In the third collision, the cart that is moving before the collision has 2-3 times the mass of the stationary cart. Repeat the process.

2. Pushing and Pulling Situations

2.1. Replace the rubber bumpers with hooks on each force sensor.

2.2. Hook the carts together. This will allow one cart to push or pull the other cart.

2.3. Reverse the triggering condition, as described in step 1.10.

2.4. Start with carts of equal mass, and make a prediction – for example, in a pulling or pushing situation, which cart will experience a larger force?

2.5. Hit the Collect button.

2.6. Either pull or push one of the carts so it pulls or pushes the other cart, or rock it back and forth so there is both pulling and pushing happening.

2.7. Designate that the cart being pulled and/or pushed has 2-3 times the mass of the other cart. Repeat the process.

2.7.1. Make a prediction about which cart will experience a larger force, and then record “force vs. time” data in a pushing/pulling scenario.

2.8. Designate the cart doing the pulling and/or pushing has 2-3 times the mass of the other cart. Repeat the process.

2.8.1. Make a prediction about which cart will experience a larger force, and then record “force vs. time” data in a pushing/pulling scenario.

Applications:

The concept addressed in this experiment, that in all interactions the force that one object applies to another is equal in magnitude and opposite in direction to the force applied by the second object back on the first, has many applications. A small sample includes:

- The gravitational force the Sun applies to the Earth is equal and opposite to the gravitational force the Earth applies to the Sun.
- The gravitational force the Earth applies to the Moon is equal and opposite to the gravitational force the Moon applies to the Earth.
- The gravitational force the Earth exerts on an apple is equal and opposite to the gravitational force the apple applies to the Earth.
- In a collision, such as that between a car and a truck on the street, or between two football players, the forces are always equal-and-opposite, no matter how the masses compare.
- When you stand on a floor, or sit on a chair, the force exerted on you by the floor or the chair is equal-and-opposite to the force you exert on the floor or chair.

Legend:

Figure 1. The basic setup. Key components of the apparatus are the two wheeled carts, each with a force sensor mounted on top, and a computer interface.

Figure 2. Result of the first collision. The forces experienced by the carts are equal and opposite.

Figure 3. Result of the second collision. The forces experienced by the carts are equal and opposite.

Figure 4. Result of the third collision. The forces experienced by the carts are equal and opposite.

Figure 5. Result of the first pushing and pulling situation. The forces experienced by the carts are equal and opposite.

Figure 6. Result of the second pushing and pulling situation. The forces experienced by the carts are equal and opposite.

Figure 7. Result of the third pushing and pulling situation. The forces experienced by the carts are equal and opposite.

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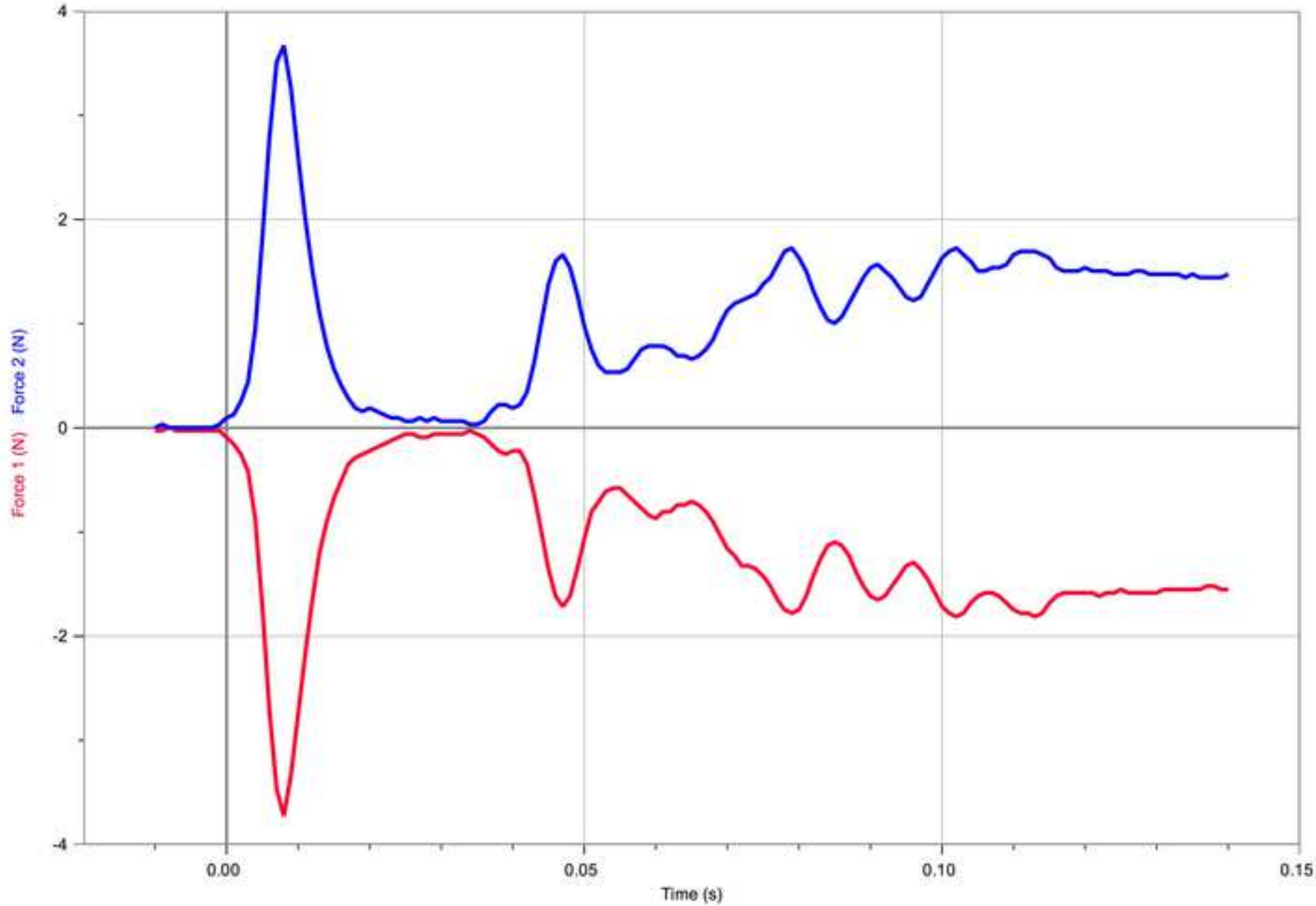

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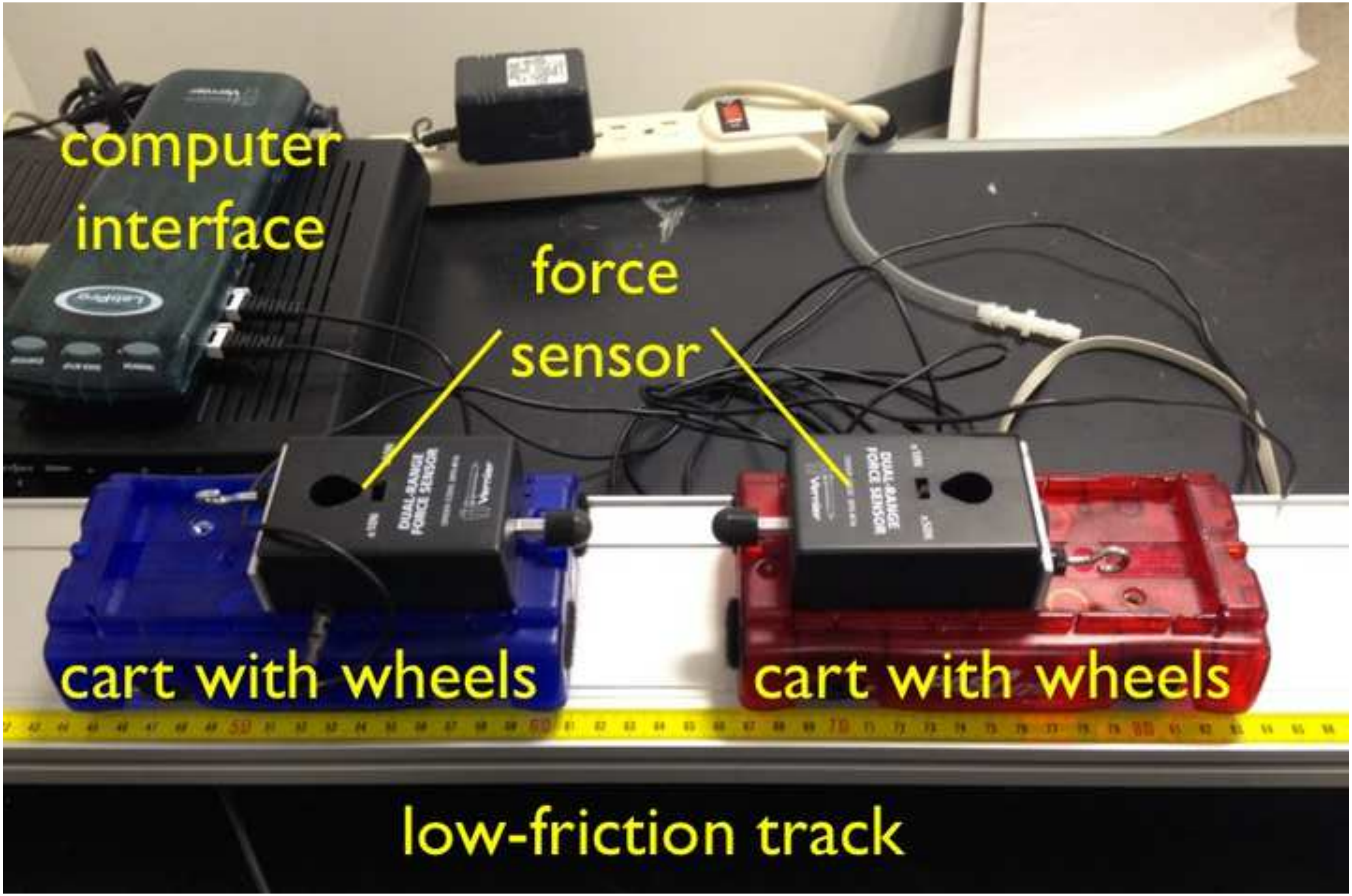

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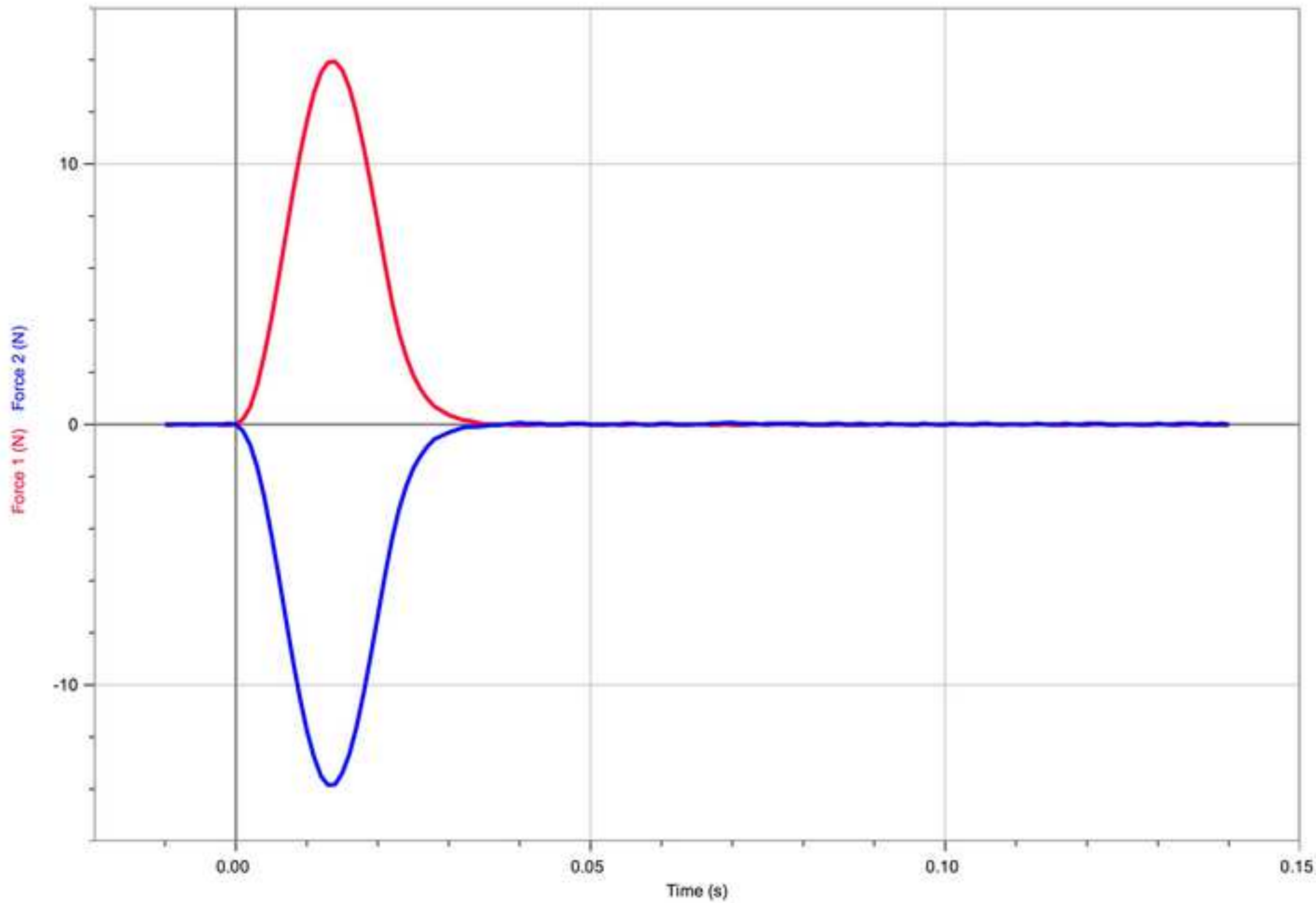

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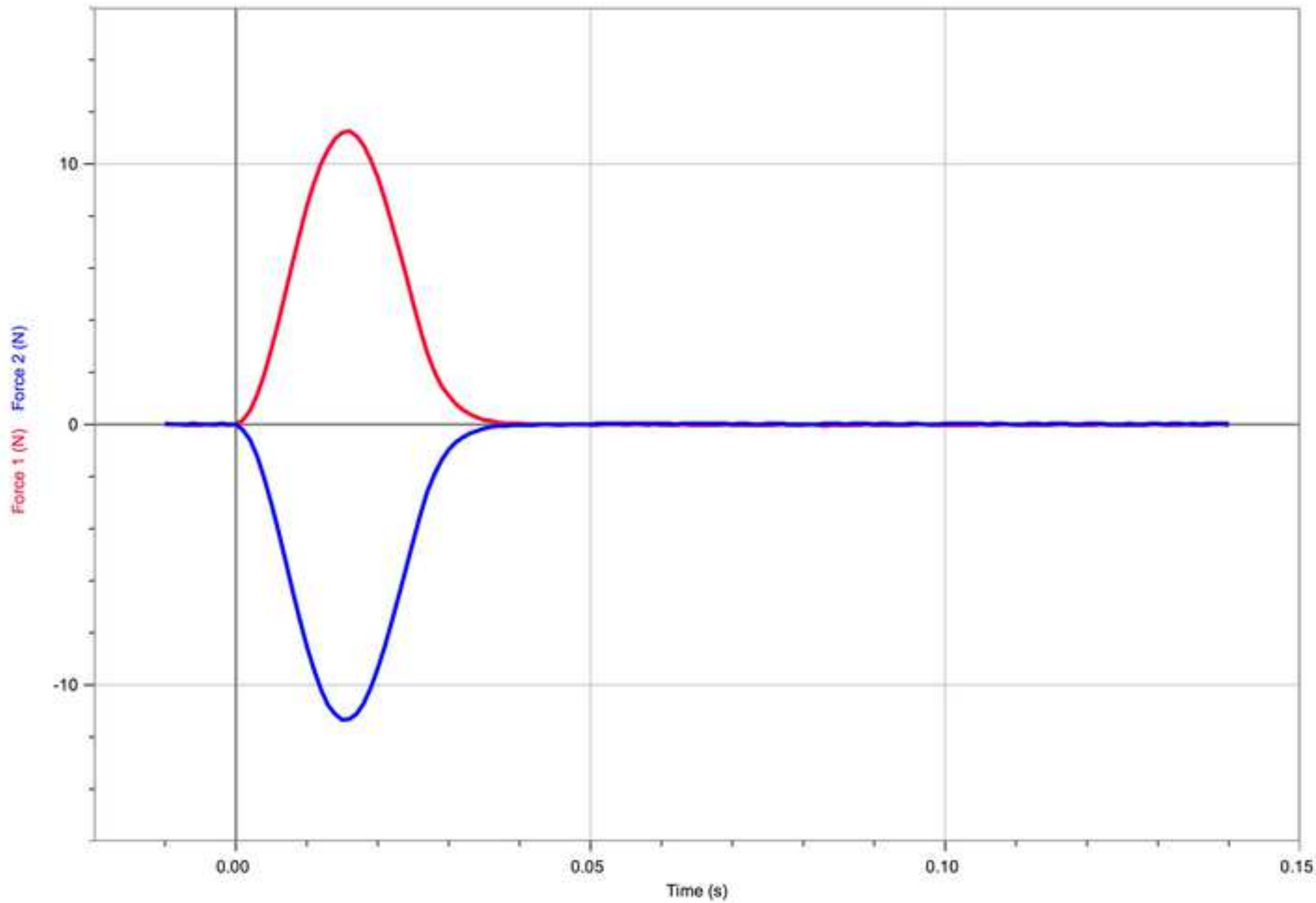

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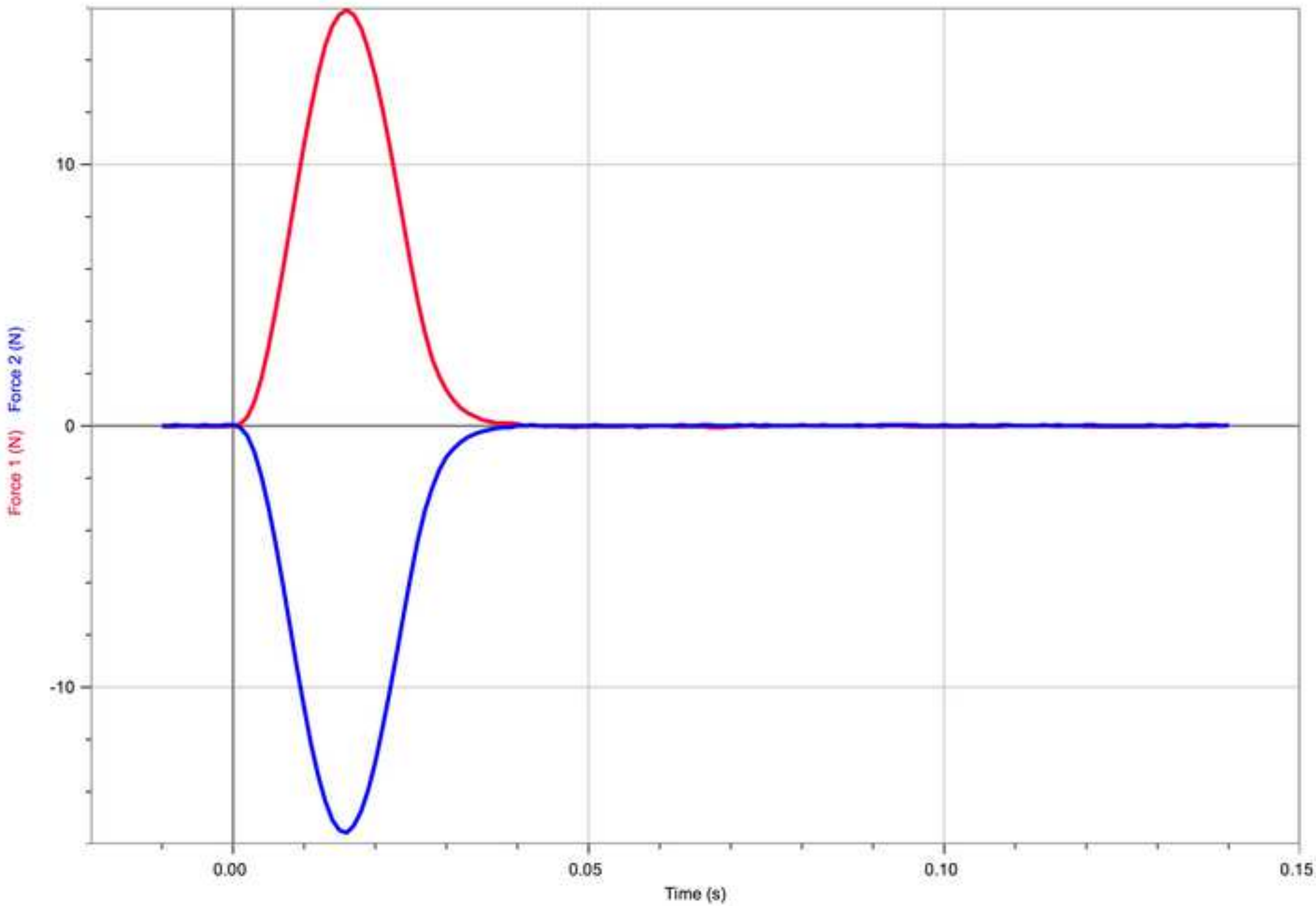

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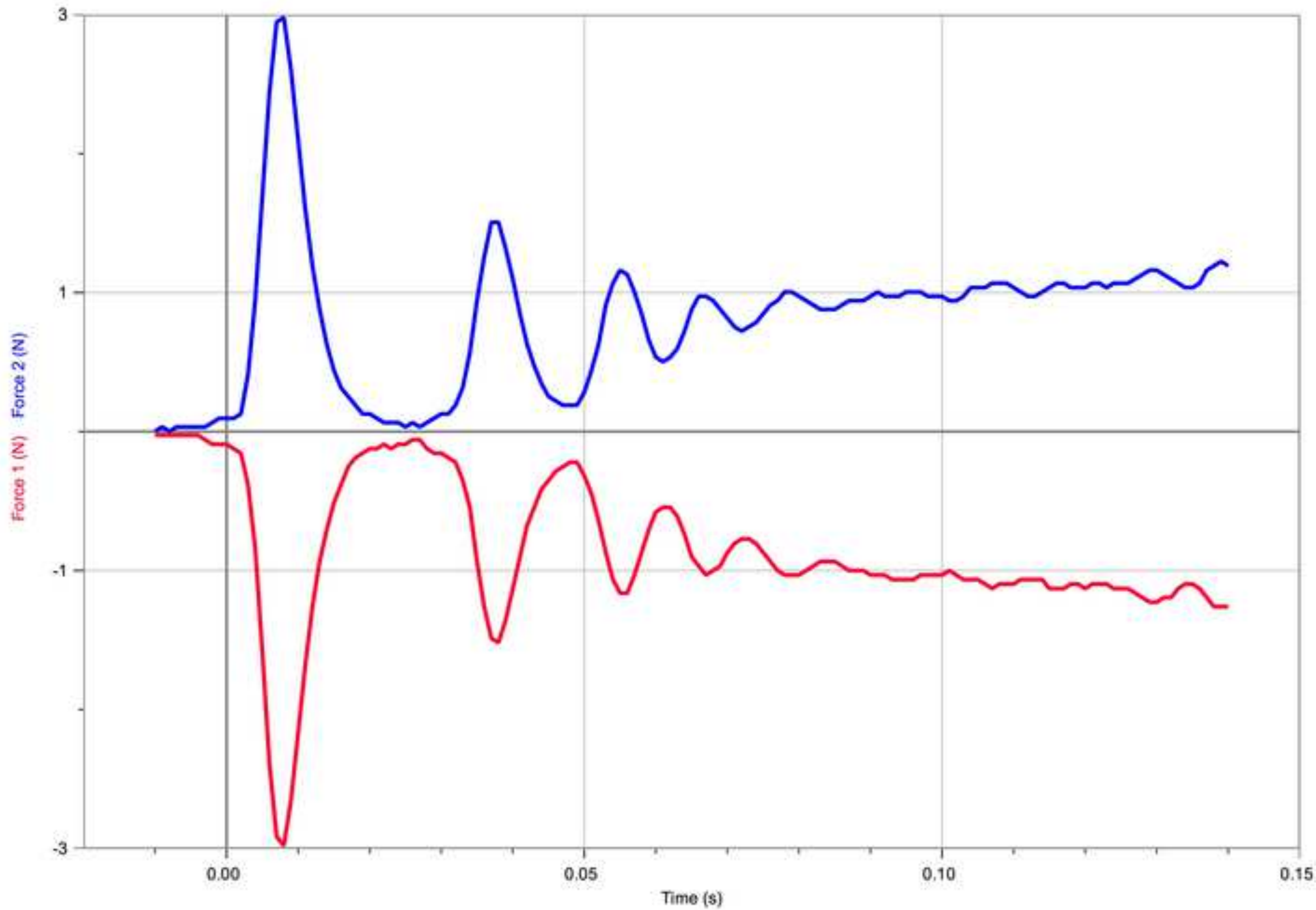

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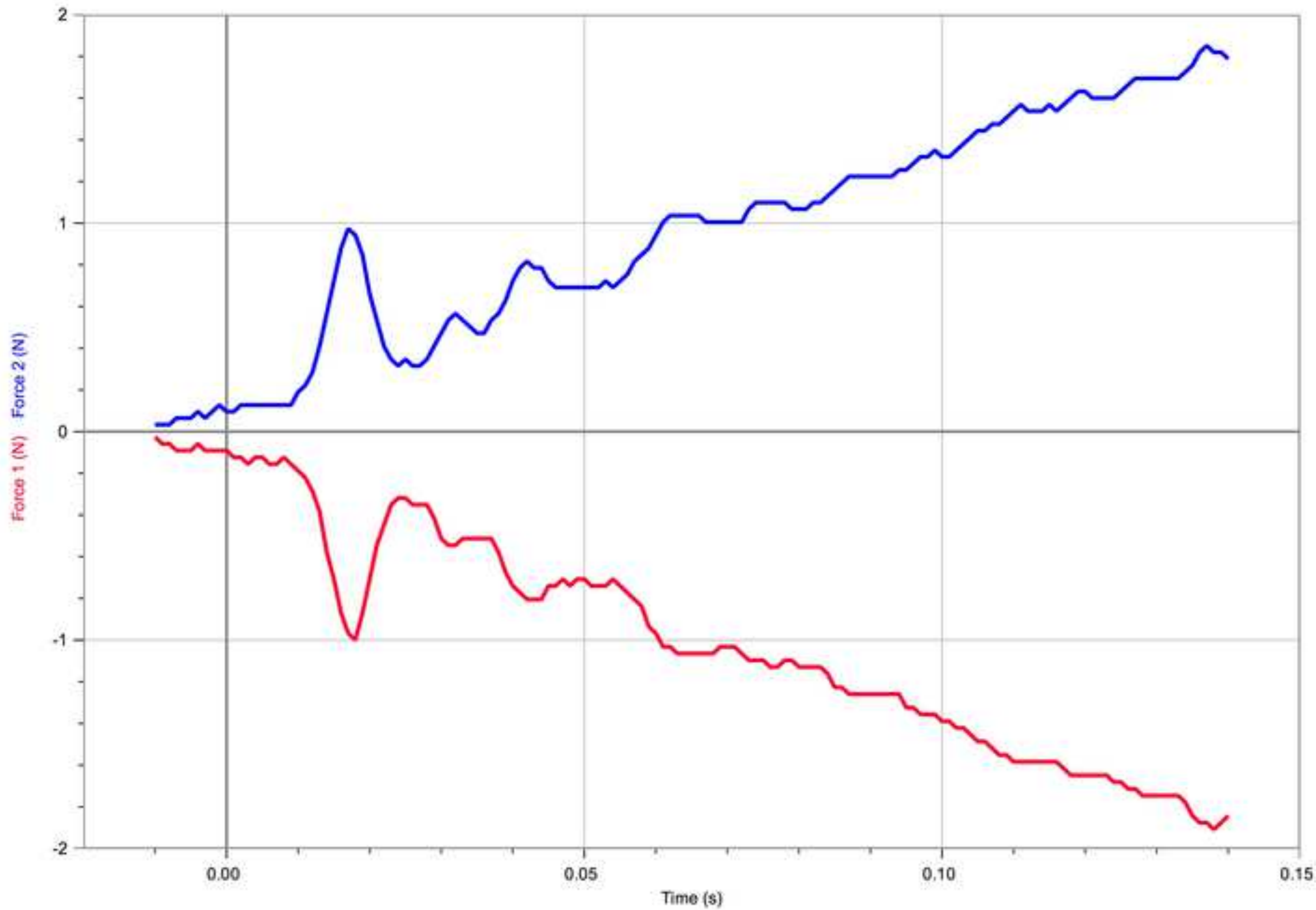

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Second, it examines the forces that two objects exert on one another while one cart is pushing or pulling the second one. Again, the focus is on exploring in what situations the two forces have the same magnitude, and in what situations they have different magnitudes.

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Comment [DM1]: Moved to Results.

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1.3. Zero the force sensors before each trial (next to the green arrow that starts data collection, there is a zero button).

1.4. Check to see that the positive direction (to the right) is defined appropriately for each force sensor.

1.4.1. Pushing in on the force sensor mounted on the right of the car should result in a positive force reading. Pushing in on the force sensor mounted on the left of the cart should result in a negative force reading.

1.4.2. If both are wrong, simply reverse the position of the carts.

1.4.3. If only one is wrong, go to the Experiment menu, select “Setup Sensors”. Choose the appropriate force sensor and select “Reverse Direction.”

1.5. The first collision involves carts of equal mass. Designate one cart to be stationary prior to the collision. The other cart is given an initial velocity toward the stationary cart, so the carts collide.

~~**1.6.** Give an initial velocity to the second cart toward the stationary cart.~~

~~**1.7.** Predict which cart will experience a larger force in this collision.~~

~~1.8.~~1.6. Hit the Collect button (the green arrow), and push one cart toward the other. Give one cart a small shove, release the cart, and observe the collision. Peak force values between about 8 and 20 newtons are what should be observed in a typical trial. Adjust the push if the peak force values are much smaller than or much larger than this range.

~~1.9.~~1.7. Once completed, the computer will display a graph of “force vs. time” as recorded by each force sensor.

~~1.10.~~1.8. If the graphs don’t show up, reverse the triggering.

~~1.10.1.~~1.8.1. After hitting the Collect button, no data is actually recorded until one of the force sensors records a value above (or below) a certain trigger level. However, if the trigger level is set to a positive value and the force sensor is only giving negative force values, or vice versa, the computer will never get the signal telling it to record data.

~~1.10.2.~~1.8.2. To check, or reverse, the trigger setting, press the Data Collection icon (immediately to the left of the Zero icon), and select the “Triggering” tab.

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Comment [A2]: Is there a range of acceptable velocities? Do you just push it with your hand?

Comment [A3]: This step (and the other “predict” steps) are more appropriate in a lab exercise, less in a demonstration video.

Comment [DM4]: Understood, we can skip it.

~~1.11.~~1.9. In the second collision, the stationary cart has 2-3 times the mass of the cart that is moving before the collision. To achieve that, add one or more weights to the stationary cart. Repeat the process (see steps below).

~~1.11.1.~~1.9.1. Designate ~~one~~ the higher-mass cart to be stationary prior to the collision.

~~1.11.2. Predict which of the carts will experience a larger force in this collision.~~

~~1.11.3.~~1.9.2. Hit the Collect button, and push the lower-mass cart toward the higher-mass cart.

~~1.11.4.~~1.9.3. The computer will display the two "force vs. time" graphs.

~~1.12.~~1.10. In the third collision, the cart that is moving before the collision has 2-3 times the mass of the stationary cart. Achieve that by transferring the extra weight(s) from one cart to the other. Repeat the process of carrying out the collision and collecting data.

Comment [A5]: When/how do you increase the mass?

Comment [A6]: As above, include a step where you increase the mass.

2. Pushing and Pulling Situations

2.1. Replace the rubber bumpers with hooks on each force sensor.

2.2. Hook the carts together to allow one cart to push or pull the other cart.

2.3. Reverse the triggering condition, as described in step 1.10.

2.4. Start with carts of equal mass.

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2.6. Either pull or push one of the carts so it pulls or pushes the other cart, or rock it back and forth so there is both pulling and pushing happening.

2.7. Designate that the cart being pulled and/or pushed has 2-3 times the mass of the other cart. Repeat the process.

2.7.1. Record "force vs. time" data in a pushing/pulling scenario.

2.8. Designate the cart doing the pulling and/or pushing has 2-3 times the mass of the other cart. Repeat the process.

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- The gravitational force the Sun applies to the Earth is equal and opposite to the gravitational force the Earth applies to the Sun.
- The gravitational force the Earth applies to the Moon is equal and opposite to the gravitational force the Moon applies to the Earth. (Figure 8)
- The gravitational force the Earth exerts on an apple is equal and opposite to the gravitational force the apple applies to the Earth.
- In a collision, such as that between a car and a truck on the street, or between two football players (Figure 9), the forces are always equal-and-opposite, no matter how the masses compare.
- When a person stands on a floor, or sits on a chair, the force exerted on them by the floor or the chair is equal-and-opposite to the force they exert on the floor or chair.

Results:

Newton's third law states that whenever two objects interact, the second object exerts a force on the first object that is equal in magnitude, and opposite in direction, to the force the first object exerts on the second object. This is simple to state, but can be hard to accept, with it often assumed that a larger object will exert a larger force on a smaller object than the smaller object exerts back on the larger object.

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Figure 5. Result of the first pushing and pulling situation. The forces experienced by the carts are equal and opposite.

Figure 6. Result of the second pushing and pulling situation. The forces experienced by the carts are equal and opposite.

Comment [A7]: As this is a video, we need visuals to go with any applications we cover. Which of these applications can you provide visuals and/or data for?

Comment [DM8]: I've added a couple.

Comment [A9]: Add a Results section that covers this idea, and expands on it.

Comment [DM10]: His comment above about having the Principles be at the end is in response to this comment. I've modified the manuscript to reflect that, though it leaves the Principles section a bit thin.

Comment [AD11]: I'm pretty sure the manuscript I originally submitted had the Principles section toward the end – it is quite important not to have that at the beginning, otherwise there's not a lot of point to going through the rest, because that gives away the result. Can we move that text back to here? Feel free to re-title it Results. This lab is a bit different from others - we don't want to give the main result away at the beginning.

Figure 7. Result of the third pushing and pulling situation. The forces experienced by the carts are equal and opposite.

Figure 8. If an object with comparable mass to that of the Earth were to fall towards it, then the corresponding acceleration of the Earth would be observable.

Figure 9. Two American football players.

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