14300 Dynamics Carts w/o Hoops

Student Instructions: Name:____

- *Required Accessories*
  - (2) Table stops (wooden bars)
  - (4) C-Clamps
  - (2) Recording Timers (#15210 or #15215)
  - (5) Bricks or Books (or other identical objects for use as masses)
  - (1) Meter Stick
  - (1) Pan Balance
  - (1) Table Clamp Pulley (#33020)
  - Modeling Clay
  - Masking Tape
  - Screwdriver
  - Thread
  - Assorted Weights

- *Optional Accessories*
  - Accelerometer (#10-100)
  - Spirit Level
  - Ultrasonic Motion Detector
  - Spring Scale
  - (2) Two Pair of spring Hoops, (#10-4300ACC)

PURPOSE

- To investigate the vector nature of forces and conservation of momentum.

SAFETY

- The exploder mechanism will arrive in cocked position. Handle with care. Place the cart on a table before releasing the exploder mechanism, and keep hands and face away from the piston.
- While performing these experiments, be sure to stop moving carts before they reach the edge of the table. Stand clear of any area where carts or weights could fall. Carts may break if they fall from a table.
- While rubber bands are inherently harmless, do not use rubber bands as projectiles or as projectile launchers.
- Fasten metal bumpers securely to carts. While inherently harmless, do not use bumpers as weapons.
- Do not leave carts on the floor, where they may present a slipping hazard.
- Wear appropriate eye protection when performing this experiment.

ASSEMBLY

- *Carts.* Both carts are previously assembled; Optional steel bumpers must be attached to the screws at the front of the cart. Use a screwdriver to loosen and tighten screws.
- *Recording Timer.* Consult instruction manual for assembly advice.

TIME REQUIREMENT

- Each procedure should require no more than 10 minutes for initial setup time.
- Procedure A should be completed in about 30-40 minutes.
- Procedure B should be completed in about 45-60 minutes.
- Procedure C should be completed in about 30-40 minutes.
- Procedure D should be completed in about 45-60 minutes.
- Individual times may vary based on time necessary for questions, discussion, or addressing student concerns.

INTRODUCTION

Sir Isaac Newton (1643-1727), an English scientist and mathematician, laid the groundwork for nearly three centuries of work in physics. With his three laws of motion and a description of celestial and terrestrial movement, Newton provided a framework for the process of inquiry in physics. Newton's Laws of Motion provide an important insight into forces, mechanics and gravitation (just to name a few subjects!) and are still pertinent to physics nearly 300 years later.

CONCEPTS

<u>Newton's Laws of Motion.</u>

To move an object, one must exert a force on it. Mathematically, forces are described by the equation

$$\Sigma \mathbf{F} = \mathbf{ma}$$

where '**ΣF**' is the net force on a particular object, '**m**' is the mass of that object, and '**a**' is the acceleration caused by the force. Force and acceleration are both vectors, and both point in the same direction.

Newton's Laws of Motion briefly describe the nature of forces:

- Newton's 1st Law (Inertia): Unless acted upon by a net force, an object will remain at rest or at constant velocity.
- Newton's 2nd Law (**ΣF = ma**): The acceleration of an object is directly proportional to the net force on that object, and inversely proportional to the mass of the object.
- Newton's 3rd Law (Reciprocity): When one object exerts a force on a second object, the second object will exert an equal and opposite force on the first object.

<u>Conservation of Linear Momentum</u>

The linear momentum of an object in motion is given by the formula

$$\mathbf{p} = \mathbf{mv}$$

where '**p**' is the linear momentum of the object, '**m**' is the mass of the object, and '**v**' is the velocity of the object. Momentum and velocity are both vectors pointing in the same direction.

In all collisions, the sum of the momenta of two objects after they collide is equal to the sum of their momenta before they collide. In an *elastic* collision, the kinetic energy of the objects is the same before and after the collision; kinetic energy is conserved. In an *inelastic* collision, kinetic energy is not conserved; some kinetic energy is lost to friction and heating during the collision. In an explosive event, kinetic energy (from spring potential energy, chemical energy, etc.) increases, although total momentum remains unchanged. For example, when a gun is fired, both the gun and bullet have increased kinetic energy, but their equal and opposite momenta remain at total of zero.

PROCEDURE A (ACCELERATION - RUBBER BAND VARIATION)

<u>Preparation.</u>

A large, smooth, flat surface is necessary for all experiments using this apparatus. Before conducting these experiments, use a spirit level (or allow a cart to roll freely in various directions) to check the flatness of the surface. Also, clean the surface of any dust or grit, and check for any bumps. Any of these imperfections will influence your results.

Use a C-clamp to attach a recording timer to your table. Cut a length of ticker tape suitable to the length of the table. Attach the ticker tape to the underside of the cart with masking tape. Align your carts with the recording timer so that the tape runs smoothly. See Figure 1 for an example of this setup.

Use a pan balance to determine the mass of one cart.

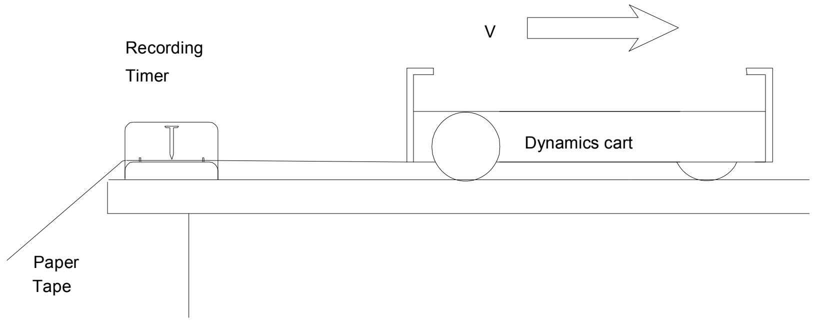

Figure 1: A typical layout of the cart/recording timer setup.

(1) Changes in Velocity with a Constant Force.

When ready to begin, turn the recording timer on and give the cart a quick push. After the cart has finished rolling, examine the tape and determine the average velocity and acceleration of the cart. In the absence of an applied force, the cart should move at a constant speed. This initial test will allow you to determine the effects of friction due to the surface.

Q1. Do sources of 'friction' exist in this experiment? Explain.

Rubber bands are provided with this apparatus as a simple means of exerting a constant and reproducible force on the dynamics carts. A rubber band that is stretched to a specific length will provide a constant (but unknown) force, so long as it remains at that length. If available, a spring scale of appropriate capacity may also be used to provide a constant force.

Place a rubber band (or spring scale) over the vertical post at one end of the cart. Place a brick or another uniform mass on the cart (if you use bricks, clean any grit from the table as you conduct the experiments). Stretch the rubber band to a certain length (25 centimeters or so), or pull the spring scale to a particular force reading. Maintaining this length or force reading will apply a constant and reproducible force to the cart. *Practice this technique before collecting data.* Measure the displacements recorded on the ticker tape, and determine the acceleration of the cart. (Use the data table and analysis steps on page 18.)

(2) Dependence of Acceleration on Force.

Using the same setup from the previous experiment, determine the acceleration of the cart when using two, three and four rubber bands to apply a force to the cart, using one particular length for all trials. If using a spring scale, increase the force exerted by the spring scale for each experimental run. Describe how the cart accelerates in terms of the amount of force applied by the rubber bands or spring scale.

(3) Dependence of Acceleration on Mass.

Using one rubber band, pull the cart when it is loaded with two, three, four, and five masses. Once again, be sure to stretch the rubber band to a standard length. Record the motion of the cart, and observe the acceleration for each trial. Describe the acceleration in terms of the mass of the cart.

Q2. Are your results for experiments (2) and (3) consistent with Newton's 2nd Law? Explain.

(4) Force Acting at an Angle.

Attach a rubber band to the post on the cart and pull the rubber band at an angle of 45 degrees to the long axis of the cart. *After practicing this technique*, record the displacement of the cart using the recording timer. From this data, describe the acceleration of the cart, and the net force acting on the cart.

Q3. How does the acceleration of the cart due to a force at an angle differ from a force exerted with no angle?

Predict the net force on the cart if the angle is increased from 45 to 60 degrees. Test your prediction by recording the displacement of the cart when a force is applied at 60 degrees to the long axis of the cart.

Q4. Is there an angle that will yield maximum acceleration? Minimum acceleration? Explain.

ASSESSMENT A

(1) Changes in Velocity with a Constant Force.

Does the cart have an acceleration in this experiment?

If so, in what direction would you have to exert a force on the cart in order to move it at a constant velocity?

(2) Dependence of Acceleration on Force.

Are the results you obtained in this experiment consistent with Newton's Laws of Motion? Explain.

Explain how you would find the average force exerted by each rubber band.

(3) Dependence of Acceleration on Mass.

How does the acceleration of the cart change as you add mass?

What if you doubled the force exerted by the rubber band(s) in this experiment? How would your data change?

PROCEDURE B (CHANGES IN MOMENTUM)

(1) Elastic Collisions. {Possible with optional hoops}

Attach the steel spring bumpers to both carts. On a clear table, leave one cart stationary while giving the other cart a quick push towards it, so that the carts collide on the spring bumpers. Observe the behavior of the carts during and after the collision.

Q1. How do the carts exert forces on one another? Explain.

Next, create a situation where both cars are in motion and collide 'head-on'.

Q2. Predict the motion of the two carts during and after the collision, and justify your prediction.

Q3. Observe and write descriptions the behavior of both carts during and after the collision. Was your prediction correct?

(2) Inelastic Collisions.

Stick a ball of modeling clay on the end of each cart. Leave one cart stationary, and give the other cart a quick push, so that it collides with the stationary cart. Repeat the situation where both cars are in motion and collide 'head-on'.

Q4. Predict the motion of the two carts during and after the collision, and justify your prediction.

Q5. Observe and write descriptions the behavior of both carts during and after the collision. Was your prediction correct?

Try adding different masses to both carts, and create different situations where a collision can take place. Observe and write descriptions of several different collisions.

Q6. Are your results in this section consistent with Newton's 3rd Law? How can you tell?

ASSESSMENT B

Estimate the total momentum of the two-cart system before and after the collision in (1). Is momentum conserved in this experiment? Explain.

Estimate the total momentum of the two-cart system before and after the collision in (2). Is momentum conserved in this experiment? Explain.

PROCEDURE C (ACCELERATION - HANGING MASS VARIATION)

(1) Determining the Effect of Friction.

Use the pan balance to measure the mass of one cart. Before attaching the cart to the recording timer, roll the cart down the table and notice its behavior. The cart should roll at a constant speed if no net force acts on it.

Q1. Draw a free-body diagram of the cart as it rolls down the table. Does a net force act on the cart? Explain your answer.

Attach a table clamp pulley to your table, in line with your recording timer. Tie a loop at each end of a piece of thread, and attach one loop to the vertical post on one cart. Use the other loop to hang weights from the cart in these experiments. (See the data table on page 18 for an example of how to record and analyze data for this series of experiments.)

Now, attach the ticker tape to the cart and turn the recording timer on. With the thread attached to the cart and fed through the pulley wheel, attach masses of 10 to 50 grams to the thread. Drop the masses. Repeat with different masses, until you produce a ticker tape that indicates constant speed. Based on the weight of the masses, calculate the force needed to produce this movement.

Q2. Are your observations consistent with Newton's 1st Law? Explain.

(2) Dependence of Acceleration on Force.

Starting from the 'equilibrium point' that you determined in the previous section, add mass to the cart-pulley-falling mass system in increments of 20 grams. After adding a mass to the system, produce a ticker tape that describes the motion of the system.

Calculate the acceleration of the cart, and repeat for five or six masses. Plot the acceleration of the cart as a function of the weights of the falling masses.

Q3. How does acceleration change as the force on the cart increases?

Q4. Do the hanging masses and the cart have the same acceleration?

(3) Dependence of Acceleration on Mass.

Hang a 100 gram mass from the thread, allow it to fall, and produce a ticker tape that describes the motion of the cart. Calculate an acceleration from the ticker tape. Repeat this procedure after adding a 250 gram weight to the cart. Produce ticker tapes for each run that describe the motion of the cart, and calculate an acceleration from these tapes. Plot the acceleration of the cart as a function of the mass of the cart.

Q5. How does acceleration change as the mass of the cart increases?

Q6. Are your results for these two experiments consistent with Newton's 2nd Law? Explain.

ASSESSMENT C

(1) Determining the Effect of Friction.

Does the cart have an acceleration in this experiment?

If so, what force would you have to exert on the cart in order to move it at a constant velocity? Specify magnitude and direction.

(2) Dependence of Acceleration on Force.

How would you calculate the amount of force provided by the hanging weights in this experiment? (Hint: look at Q4. in the procedure.)

(3) Dependence of Acceleration on Mass.

How does the acceleration of the cart change as you add mass, yet keep the net force on the cart constant?

What if you doubled the amount of mass hanging from the thread in this experiment? How would your data change?

PROCEDURE D (CHANGES IN MOMENTUM: QUANTITATIVE ANALYSIS)

Arm the exploder cart by pushing the exploder piston into the cart and latching the piston into place. Place the dummy cart in front of the exploder cart so that the piston and the cart collide when the piston is released. With this setup, the two carts should move in opposite directions.

Attach two recording timers to the table, with each timer in line with one of the carts. Use a plastic arm to attach the ticker tape to each cart, or attach the ticker tape to the side of the carts. After completing the setup, turn on the recording timers, and release the piston by tapping the red switch with a meter stick. See Figure 2 for this setup.

(Note: while the carts in this experiment move with low friction, limiting forces from friction in conjunction with drag from the recording timer will noticeably affect your results and yield significant errors. In order to take the best data possible, try to take ticker tape data that is as close to the time of the collision as possible.)

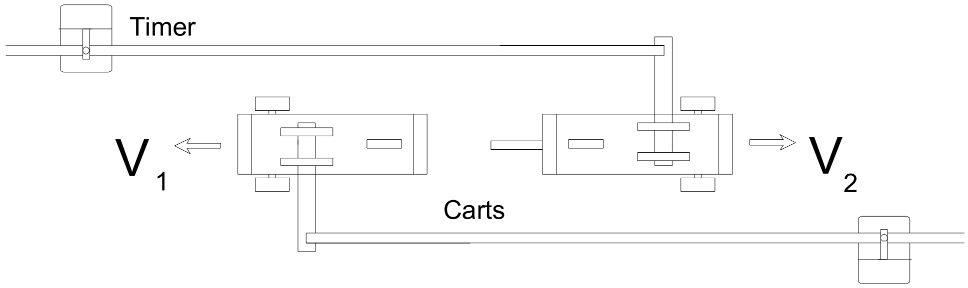

Figure 2: An example of the dual-cart layout.

Determine the velocities of the two carts after the collision (the best data will occur at the beginning of the run). Measure the mass of the two carts. From these two values, calculate the momentum of each cart.

Add more mass to the exploder cart and record the results. Also, move the masses from the exploder cart to the dummy cart and record the results.

Q1. What factors, aside from the friction between the cart and the table, could influence your results in this experiment?

Now, **using the optional bumpers**, set up the collision detailed in Figure 3 (see next page). Cart A is moving with velocity $\mathbf{v}_1$ (determined by measurement recorded on the ticker tape) before the collision. Cart B is at rest, and is hit by Cart A during the collision. From the ticker tapes generated during the experiment, determine the momentum of the system before and after the collision. (Remember that momentum is a vector quantity. To use this in calculations, a cart moving to the left should have negative momentum, while a cart moving to the right should have positive momentum.)

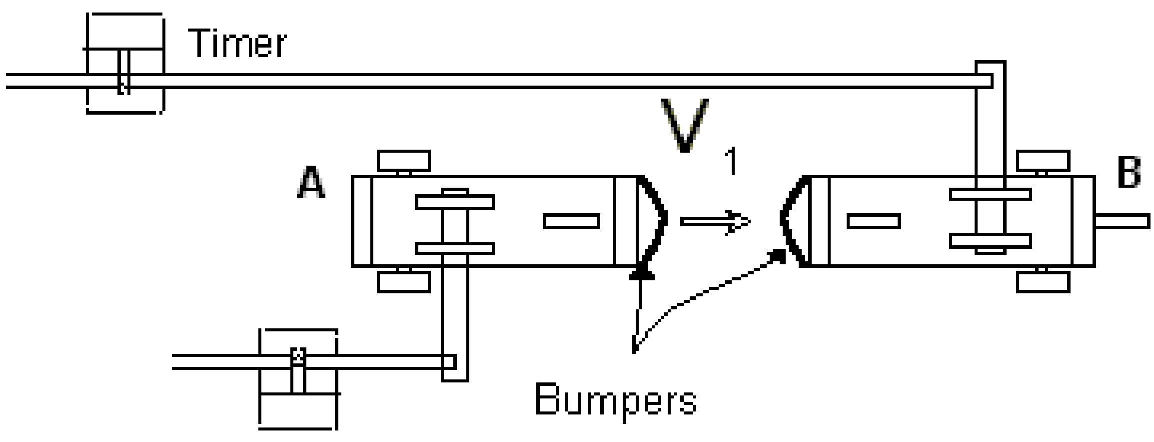

Figure 3. Another dual-cart setup.

Q2. How does the momentum of Cart A before the collision compare to its momentum after the collision?

Q3. How does the momentum of Cart B before the collision compare to its momentum after the collision?

Q4. What happened to the momentum of Cart A after its collision with Cart B in the collision described above? Explain in terms of the net force on each cart.

Next, again **using the optional bumpers**, set up the collision detailed in Figure 4. Place a 500 g (or higher) mass on Cart A, and then send Cart A toward Cart B as shown in the diagram. From the ticker tapes generated in this experiment, determine the momentum of the two-cart system before and after the collision.

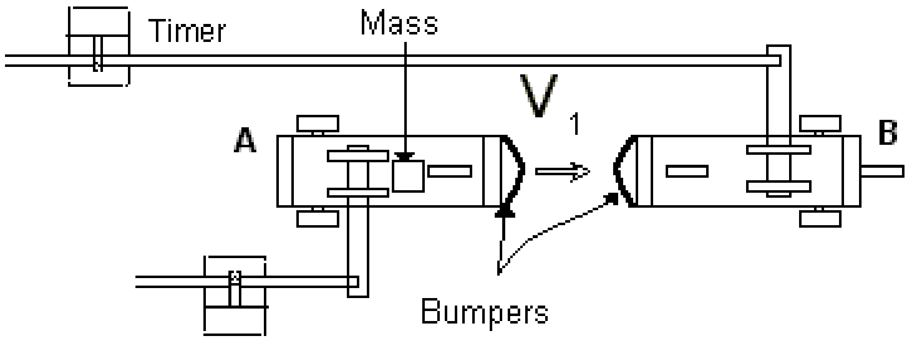

Figure 4. Dual-cart setup with bumpers and mass (elastic collision).

Q5. How does the momentum of Cart A before the collision compare to its momentum after the collision?

Q6. How does the momentum of Cart B before the collision compare to its momentum after the collision?

Q7. Why did Cart A continue moving, instead of coming to a stop as it did in the previous collision? Explain in terms of the forces on each cart.

Finally, set up the inelastic collision detailed in Figure 5. Attach one piece of modeling clay to each cart, and then send Cart A toward Cart B as shown in the diagram. From the ticker tapes generated in this experiment, determine the momentum of the two-cart system before and after the collision.

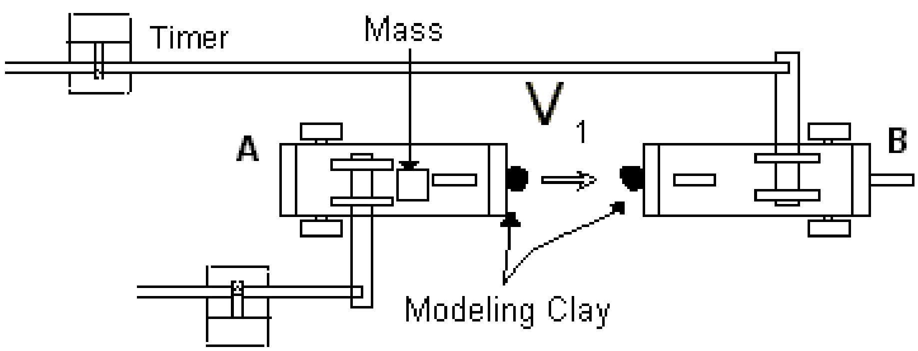

Figure 5. Dual-cart setup with modeling clay (inelastic collision).

Q8. How does the momentum of Cart A before the collision compare to its momentum after the collision?

Q9. How does the momentum of Cart B before the collision compare to its momentum after the collision?

Q10. What happens to Cart A after its collision with Cart B?

Q11. Explain why Carts A and B are moving more slowly after they collide than Cart A moved before the collision.

Q12. Cart A is heavier than Cart B in this experiment. What do you think would happen during the collision if they had the same mass? Test to see if your prediction is correct.

Q13. Consider the possibility of performing these experiments in a near-weightless environment (such as the International Space Station). How would this environment change the results of the experiment?

ASSESSMENT D

What were your results for the total momentum of each two-cart system before and after the collision? Is momentum conserved in all of these experiments? Explain.

How would the behavior of both carts in these experiments change if one cart were twice as heavy as the other for each collision? Would momentum still be conserved? (Hint: think about the forces involved in each collision.)

For each of the two-cart events, calculate the total kinetic energy of the carts before and after each event.(Remember that kinetic energy is not a vector quantity, so kinetic energy is a positive value regardless of the direction of motion of the carts.) What happens to the total kinetic energy during each event? Is kinetic energy conserved in any of the events?

TABLE FOR DATA COLLECTION

For recording and analyzing data from Recording Timer tapes. (See notes on next page.)

Time	Position	Velocity ($\Delta t = t_{t+1} - t_t$)	Acceleration
		NO VALUE	NO VALUE
$t_0=0$	$x_0=$ ___________	$v_1=(x_1-x_0)/\Delta t$	
$t_1=n/60$	$x_1=$ ___________	$v_2=(x_2-x_1)/\Delta t$	$a_1=(v_2-v_1)/\Delta t$
$t_2=2n/60$	$x_2=$ ___________	$v_3=(x_3-x_2)/\Delta t$	$a_2=(v_3-v_2)/\Delta t$
$t_3=3n/60$	$x_3=$ ___________	$v_4=(x_4-x_3)/\Delta t$	$a_3=(v_4-v_3)/\Delta t$
$t_4=4n/60$	$x_4=$ ___________	$v_5=(x_5-x_4)/\Delta t$	$a_4=(v_5-v_4)/\Delta t$
$t_5=5n/60$	$x_5=$ ___________	$v_6=(x_6-x_5)/\Delta t$	$a_5=(v_6-v_5)/\Delta t$
$t_6=6n/60$	$x_6=$ ___________	$v_7=(x_7-x_6)/\Delta t$	$a_6=(v_7-v_6)/\Delta t$
$t_7=7n/60$	$x_7=$ ___________	$v_8=(x_8-x_7)/\Delta t$	$a_7=(v_8-v_7)/\Delta t$
$t_8=8n/60$	$x_8=$ ___________	$v_9=(x_9-x_8)/\Delta t$	$a_8=(v_9-v_8)/\Delta t$
$t_9=9n/60$	$x_9=$ ___________	. . .	. . .
. . .	. . .		

SUGGESTIONS FOR USE OF THE DATA TABLE

- For the recording timer, the interval between strikes is 1/60 of a second, so time is the number of spaces divided by 60. (Using 1/50 of a second in countries which use 50 Hz AC electricity, change each "60" in the "Time" column to a "50.").
- In the "Time" column, "n" is a multiplier for the number of intervals between strikes that you choose to count. For example, if you count displacement on your ticker tape as a span of five intervals between strikes, then n = 5 for your particular data set.
- The starting point for measuring displacement ($x_0 = 0$) is at any dot which can be clearly distinguished from the smudge of dots made by starting the timer, or any arbitrary starting position on the tape that is useful for your experiment.
- In the "Position" column, record the distance of the dot on the ticker tape measured from the starting point (at $x_0 = 0$).
- Speed is a change in displacement divided by a change in time ($v = \Delta x/\Delta t$). You must have at least two position terms to calculate a velocity. If you find it useful, you can note the changes in displacement, Δx, in the extra space under each "Position" value recorded as x_0, x_1, x_2, x_3, etc.
- Note that speeds (velocities) that are recorded are the average speeds calculated for the time intervals between each listed time. We have no way to calculate speed before the first change in displacement, so "NO VALUE" is shown prior to v_1.
- Acceleration is a change in velocity divided by a change in time ($a = \Delta v/\Delta t$). You must have at least two velocity terms to calculate an acceleration. If you find it useful, you can note the changes in velocity, Δv, in the extra space under each "Velocity" value recorded as v_1, v_2, v_3, etc.
- Accelerations that are recorded are average accelerations calculated for approximately each of the listed times. We have no way to calculate acceleration before the first change in velocity, so "NO VALUE" is shown prior to a_1.