Inquiry-Based Physics in Middle School

David E. Meltzer

Mary Lou Fulton Teachers College
Arizona State University
Mesa, Arizona
U.S.A.

Supported in part by a grant from Mary Lou Fulton Teachers College

Classroom Context: 5th-8th grade

- All middle-school students from ASU Preparatory Academy (on-campus charter school) attended weekly science classes taught by DEM, August 2010-June 2011

- Grades 7/8 clustered, ~55 students divided into two classes, one hour each per week

- Grades 5/6 clustered, ~90 students divided into three classes, one hour each per week

Additional Context

- Generally one instructor, sometimes helped by graduate student aide
- Homework assigned and corrected most weeks; occasional quizzes (graded only for 7/8th grade)
- In 2009-2010, DEM had taught many of the same students ~1 hour/week, focused on properties of matter, motion, and batteries and bulbs
- Many of the same activities being taught during same semester to preservice elementary teachers

Topics Covered

- **Grades 7/8:** Major focus on motion and force (to prepare for Arizona 8th-grade science test); also did solar system astronomy, electromagnetism, some review of properties of matter, energy concepts, some chemistry
- **Grades 5/6:** solar system astronomy, optics, motion and force, energy concepts, electromagnetism, some biology

General Observations

- A lot of hands-on instructor assistance is needed to keep kids on task and on track;
- Logistics of handling supplies and maintaining equipment is a major concern;
- Written worksheets can be used if they are carefully edited and accompanied by frequent check-ins by the instructor.

General Impressions of Student Reactions to Activities

- *College students:* burdensome tasks that had to be gotten through
- *7th/8th graders:* Time to socialize with each other; moderate engagement
- *5th/6th graders:* Playtime: fun and high engagement

Motion and Force with 7/8th Graders

- Approximately 10-15 hours of activities, beginning with graph paper and stopwatches, moving on to dynamics carts and tracks, fan carts, motion sensors and GLX's (hand-held graphing computers).
- Many of the students had previous experience using GLX for position/time and velocity/time graphs.
- *Typical sequence:* explore with equipment; predict graphs for various motions; carry out series of experiments; describe and report results; explain and generalize.

Goals Tuned to Arizona 8th-Grade Science Standard

- Describe the various effects forces can have on an object (e.g., cause motion, halt motion, change direction of motion, cause deformation).
- Describe how the acceleration of a body is dependent on its mass and the net applied force (Newton’s 2nd Law of Motion).
- Create a graph devised from measurements of moving objects and their interactions, including:
  - position-time graphs
  - velocity-time graphs

Quiz Taken from Arizona 8th Grade Sample Test

1 A ball was attached to the end of a string and spun in a circle as shown in Figure 1 below. The ball moved in a counter-clockwise direction when seen from above as shown in Figure 2.

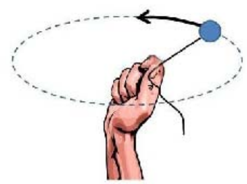


Figure 1 (view from side)

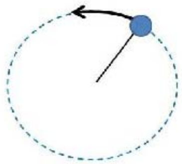
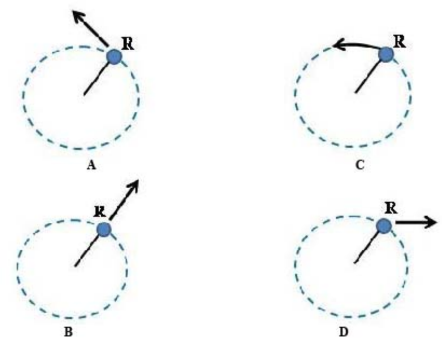


Figure 2 (view from above)

After several spins, the string was released when the ball was at point R. Which diagram shows the direction that the ball would fly the instant the string was released?



Grade 7/8 Results for Mechanics Instruction

- Good and consistent performance on position/time graphs
- On velocity/time graphs, 40-50% qualitatively correct, 15-30% quantitatively correct
- On acceleration graphs and force questions, 15-30% correct, 10-20% correct with correct explanations.

➢ **Overall impressions: State science standards are unrealistic, at least regarding mechanics**

Electromagnetism Unit

- Modeled on *Physics by Inquiry*
- Extended over two months (~ 8 class hours)

Homework Assignments for Grades 5/6

February 24:

On a blank sheet of paper, draw an outline of a bar magnet in the center of the paper.

Now imagine that you put a real bar magnet on the paper and then imagine that you put about 20-30 small compasses all around the bar magnet.

Use your class notes to draw arrows representing the direction of all of those compass needles. You should have 20-30 small arrows drawn on your paper, along with the outline of the bar magnet. Hand this in together with your class notes; make sure your name is on both sheets of paper.

Homework Assignments for Grades 5/6

March 4:

1. Describe what you saw when you put the compasses around the wire and connected the wire to the battery. Which way did the compasses point? Draw a diagram with many small arrows to show where all of the compass needles were pointing.

2. Describe what you saw when you switched the wire connections to the battery (when you took the wires connected to the "+" terminal and "-" terminal and switched them).

Homework, March 31

Name: ________________________

Grade 5/6 Science
Homework
March 31, 2011

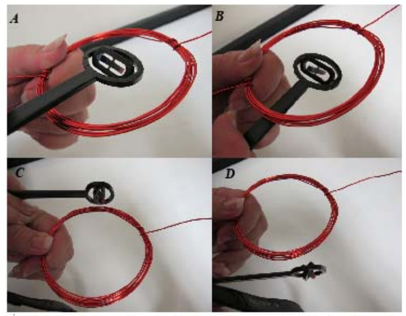
1. In class we learned that to figure out which end of a magnet is the "north" pole, you can put some compasses at each end of the magnet and see which way they point. When you do this, how can you tell which end is the north pole, and which end is the south pole?

2. Draw a diagram of a magnet and write "N" on one end to represent the north pole; leave some blank space above the north pole. Now draw a Magnaprobe needle just above the north pole. Color one end of the needle red and the other end blue to show how it would look.

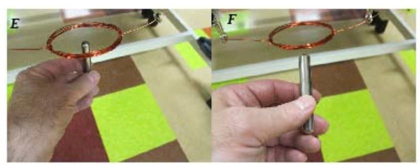
3. When we connected the wire coil to the battery, we saw the compass needles move around. If you put a compass at the top of the coil, it might point *towards* the coil or *away from* the coil.

   Suppose a compass located at the top of the coil points *away from* that coil. If you put a compass at the bottom end of the same coil, would it point *towards* or *away from* the coil?

Magnetic Field of the Flat Coil



Hold the Magnaprobe at different locations to check the direction of the magnetic field when the coil is connected to the battery (see photos above). Which way does the needle point when you hold it: (A) above the center of the coil; (B) below the center; (C) near one side; (D) near the other side? Where is the north pole of the coil? The south pole? How do your answers change when you reverse the connections to the battery terminals?



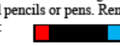
Try holding the magnet at different locations near the coil when the coil is connected to the battery: What happens to the coil when you hold the north pole of the magnet below the center of the coil as in photo *E* above? What happens when you hold it at the side of the coil (photo *F*)? How does this change when you flip the magnet around? How does it change when you reverse the connections to the battery terminals? See if you can make the coil spin around by holding the magnet in different positions while you repeatedly connect and disconnect the coil to the battery.

Quiz (April 7)

Name: ______________________

Grade 5/6 Science
April 6, 2011

In the middle of this page, draw a sketch of the wire coil and battery we used in last week's experiment; your diagram should show that the coil is connected to the battery. Write an "N" (for north pole) at one end of the coil (it doesn't matter which end), and write an "S" (for south pole) at the other end of the coil.

1. At the *top* of the coil, draw an arrow to represent the direction of a compass needle located at that point. At the *bottom* of the coil, draw another arrow to represent the direction of a compass needle located there.
2. At the *top* of the coil, draw a small diagram to represent the Magnaprobe needle when you hold it at that point. At the *bottom* of the coil, draw another small diagram to represent a Magnaprobe needle held there. Use the colored pencils or pens. Remember that one end of the Magnaprobe needle is red and the other is blue: 

Homework, April 7

1. When you put the steel bolt through the center of the coil and connected the coil to the battery, what did you observe?

2.
a) When you connected the flat, hanging coil to the battery and brought the bar magnet near to it, what did you observe?

b) What happened when you turned the bar magnet around when it was near the hanging coil? Why do you think this happened?

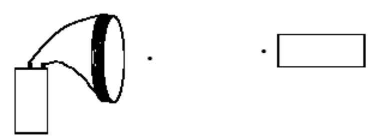
Homework, April 14

Name: ________________________

Grade 5/6 Science
Homework
April 14, 2011

1. Two magnets held near to each other are shown below. The arrows show the directions of compass needles held near the magnets. Would these magnets push each other apart, or would they pull each other together? Explain how you can tell.

2. The diagram shows a magnet, and a large flat coil connected to a battery. When you bring the magnet near to the coil, the coil and the magnet are pulled together, towards each other. Draw arrows at the positions of the two dots to indicate the direction of a compass needle held at those two points. Explain your answer. **IMPORTANT NOTE:** There is more than one correct answer for this question.



Homework, May 13

Name: ________________________

Grade 5/6 Science
Homework
May 13, 2011

We have used the compasses, Magnaprobes, and iron filings to explore the magnetic field surrounding a magnet. We can't actually *see* the magnetic field, but we can detect its presence and investigate its strength and shape. We say that the magnetic field is "strong" at a location where there is a strong pull or push on another magnet, or a strong pull on a paper clip or similar object.

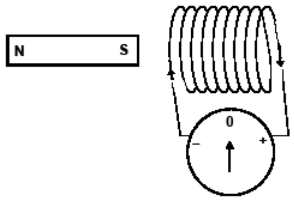
In your experiments with the wire coil and galvanometer, you had to find a way to make the galvanometer needle move. When the galvanometer needle moved, do you think that the strength of the magnetic field in the wire coil was *changing*, or was it *not changing*? Explain your answer.

Homework, May 19

Grade 5/6 Science
Homework
May 19, 2011

Name: ______________________

This diagram shows a coil connected to a galvanometer, with a bar magnet held next to the coil right near the center of the coil. The galvanometer needle is shown at one particular moment.



a. At this moment, is the magnet *moving toward* the coil, *moving away* from the coil, or *not moving*?

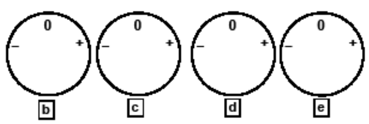
In b-e, draw the appropriate position of the galvanometer needle in the circles at the bottom of the page. Make sure that all of your drawings are consistent with ***each other****. Explain your answers to c and e.*

b. Suppose now the magnet is moving *toward* the coil. Draw the position of the galvanometer needle. *Note:* there is more than one possible response for this, but your answers to c-e must be consistent with it.

c. The magnet is held motionless inside the coil. *Explain your answer.*

d. The magnet is pulled out of the coil.

e. The magnet is pushed into the coil faster than it was in (b). *Explain your answer.*



Homework, May 27

Grade 5/6 Science
Homework
May 27, 2011

Name: ______________________

In the diagram, five points are shown in the neighborhood of the magnet: points A, B, C, D, and E.

1. At which point is the magnetic field the *strongest* (strongest pull)? ___________

2. At which point is the magnetic field the *weakest*? (weakest pull)? ___________

3. Where is the magnetic field stronger: at point B or at point C? ___________

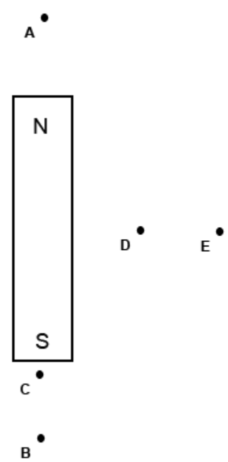
4. When you use a magnet and a coil to make the galvanometer needle move, there will be a magnetic field inside the coil. Which of these magnetic fields will make the galvanometer needle move? (Circle a, b, or c.)

   a. A magnetic field that is strong and always stays the same strength

   b. A magnetic field that is weak and always stays the same strength

   c. A magnetic field that changes from strong to weak, or from weak to strong

   Explain your answer:



Class Activity, May 11;18

Magnetism and Electric Current Activity

1. Connect the galvanometer to the flat coil. ***Without*** using the battery, but using the magnet, try to make the galvanometer needle deflect (move) either to the right or to the left. Do this ***without*** shaking or touching the galvanometer itself. Describe your method:

2. Once you have figured out how to make the galvanometer meter needle deflect, explain:

   a) how to make a *large* deflection, and how to make a *small* deflection.

   b) how to make a deflection to the left, and how to make a deflection to the right. Describe ***two methods*** for each.

      i) Deflection to the left:

      ii) Deflection to the right:

3. Construct an electromagnet using a steel bolt, wire, and battery. Connect the galvanometer to the flat coil or to the solenoid coil. Find a way to cause the galvanometer needle to deflect but ***without*** connecting the battery itself in the circuit containing the galvanometer.

   Never connect the battery in a circuit containing the galvanometer! It could severely damage the galvanometer.

   Describe your method:

Magnetism and Electric Current Activity #19A

1. Connect the galvanometer to the flat coil. ***Without*** using the battery, but using the magnet, try to make the galvanometer needle deflect (move) either to the right or to the left. Do this ***without*** shaking or touching the galvanometer itself. Describe your method:

Our method was to move the magnet over the coil and through the coil.

2. Once you have figured out how to make the galvanometer meter needle deflect explain:

   a) how to make a *large* deflection, and how to make a *small* deflection.

Large = move magnet through coil quickly.

Small = move magnet through coil slowly.

   b) how to make a deflection to the left, and how to make a deflection to the right. Describe ***two methods*** for each.

      i) Deflection to the left: move magnet in = one side of magnet
      move magnet out = one side of magnet

      ii) Deflection to the right: move magnet out = one side of magnet
      move magnet in = one side of magnet

3. Construct an electromagnet using a steel bolt, wire, and battery. Connect the galvanometer to the flat coil or to the solenoid coil. Find a way to cause the galvanometer needle to deflect but ***without*** connecting the battery itself in the circuit containing the galvanometer.

__Never__ connect the battery in a circuit containing the galvanometer! It could severely damage the galvanometer.

Describe your method:

First we connectd alligator clips to the battery and also to the long coil. Then we put the Steel bolt through the long coil.

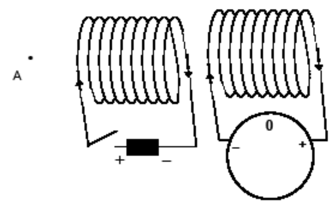
For the flat coil we connected the alligator clips to the galvanometer.

We pushed the Steel bolt through the flat coil. The Galvanometer moved!

Class Activity, June 3

Grade 5/6 Science
Coil and Galvanometer Activity
June 3, 2011

This diagram shows two identical coils next to each other. Point A is to the left, and a straight line could be drawn starting from point A through the exact middle of both coils. The left coil is connected to a battery through an open switch as shown. The arrow on the left coil shows the direction in which electric current flows through that coil.



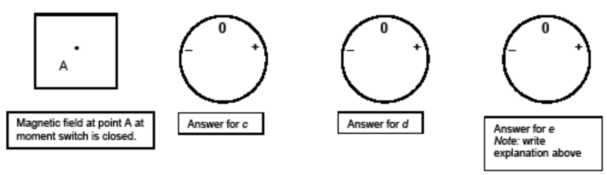
a. At the moment shown, draw the galvanometer needle with its correct position in the diagram above.

b. At a certain moment $t = 0$ seconds, the switch is closed. At the moment the switch is closed, draw an arrow in the box below to represent the direction of the magnetic field at point *A* that is due to the *left* coil. If there is no magnetic field, write "zero magnetic field."

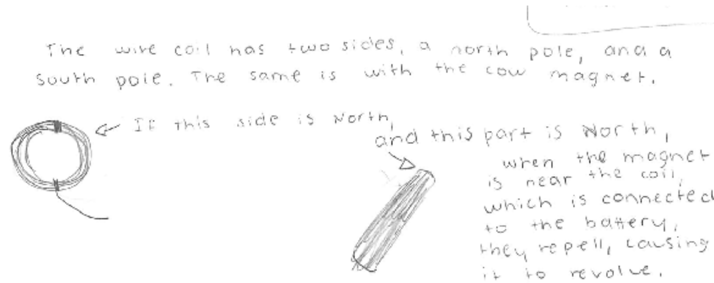
c. At the moment the switch is closed, draw (below) the *first* position to which the galvanometer needle moves. *Note:* There is more than one possible answer; however, it must be consistent with your other answers.

d. The switch is left closed for five seconds so the battery stays connected to the left coil during that period. Draw the approximate position of the galvanometer needle at $t = 3$ seconds.

e. At $t = 5$ seconds the switch is opened. Draw the *first* position to which the galvanometer needle moves at that moment. *Explain your answer.*



Motor Assignment (After Building Motor)



Why does the wire coil [motor] spin around?

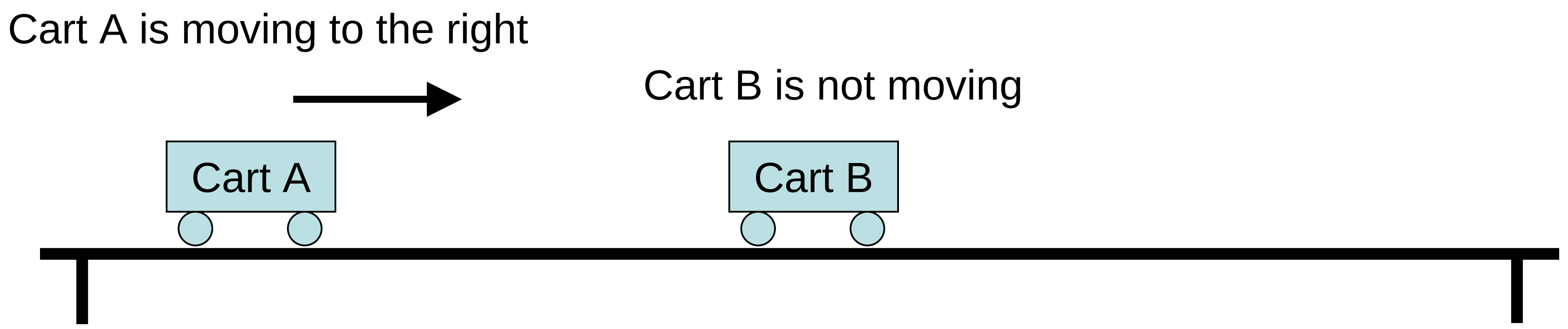
Impressions of Electromagnetism Outcomes

- Modest success in becoming familiar with magnetic fields of bar magnets and electric currents, induced currents, mechanisms of motors and generators;
- Much repetition and revisiting of activities with slight variations required;
- 7/8th graders significantly quicker to learn than 5/6th graders, but not more enthusiastic.

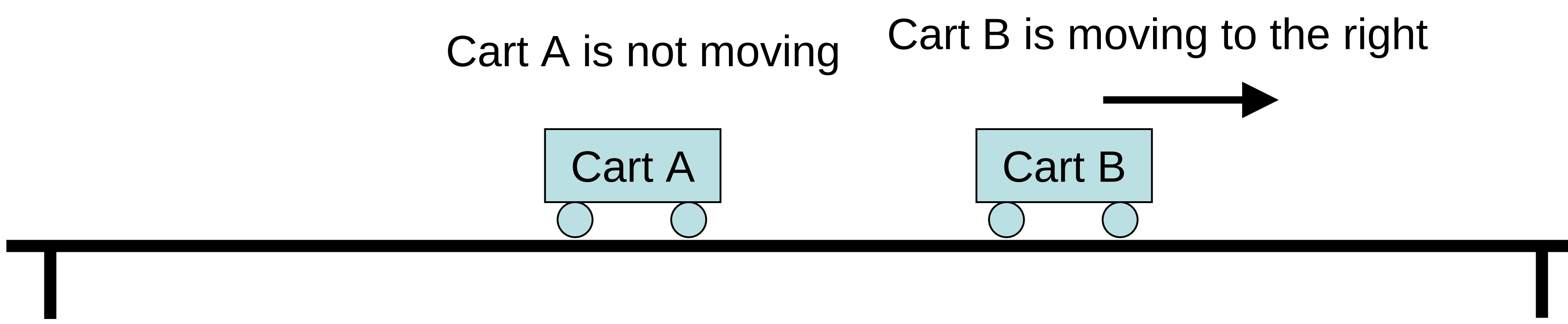
Brief Treatment of Energy (for Ages 10-14)

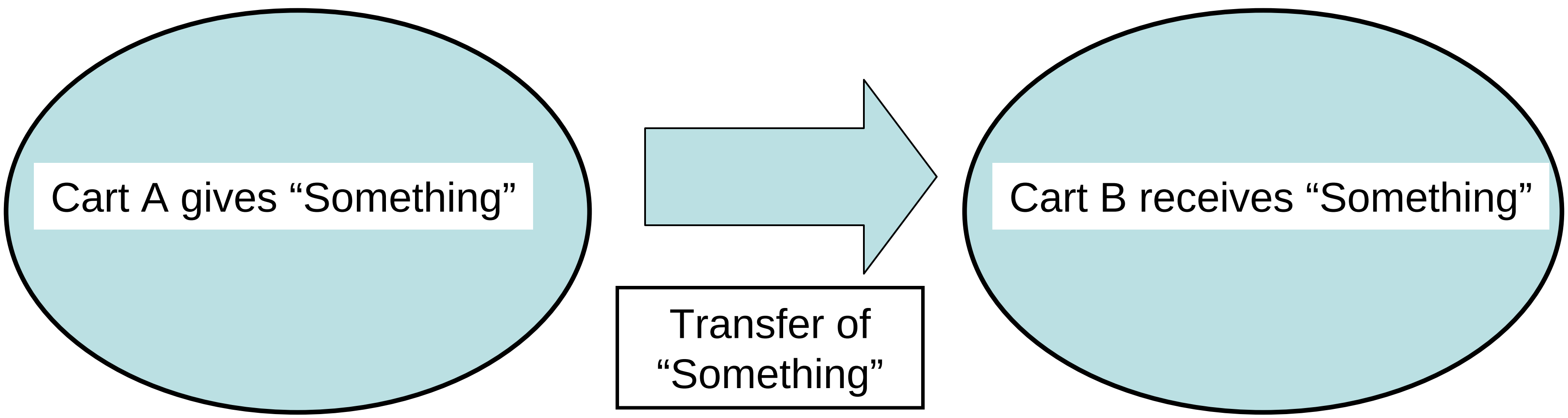
- Avoids explicit “definition” of energy, and instead focuses on energy sources, receivers, and transfers;
- Follows closely the treatment by Karplus *et al.* in *Energy Sources* (1978) [Science Curriculum Improvement Study, Teacher’s Guide, Level 6].
- Also uses bar chart approach of Van Heuvelen (e.g., Van Heuvelen and Zou, AJP, 2001).
- 2-3 hours of class activities and discussion

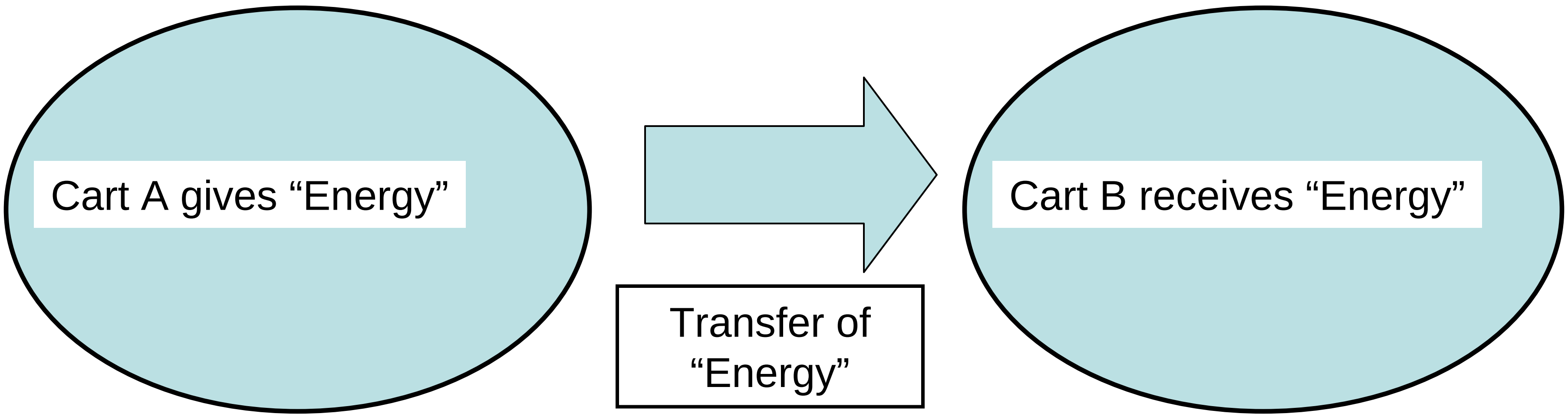
Before Collision
(identical carts)

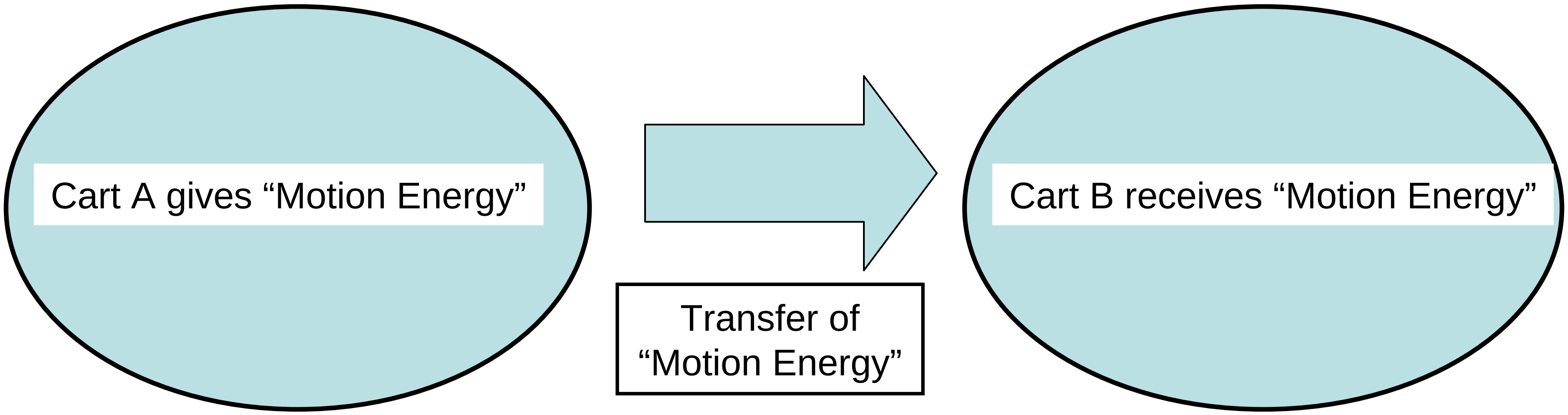


After Collision
(identical carts)



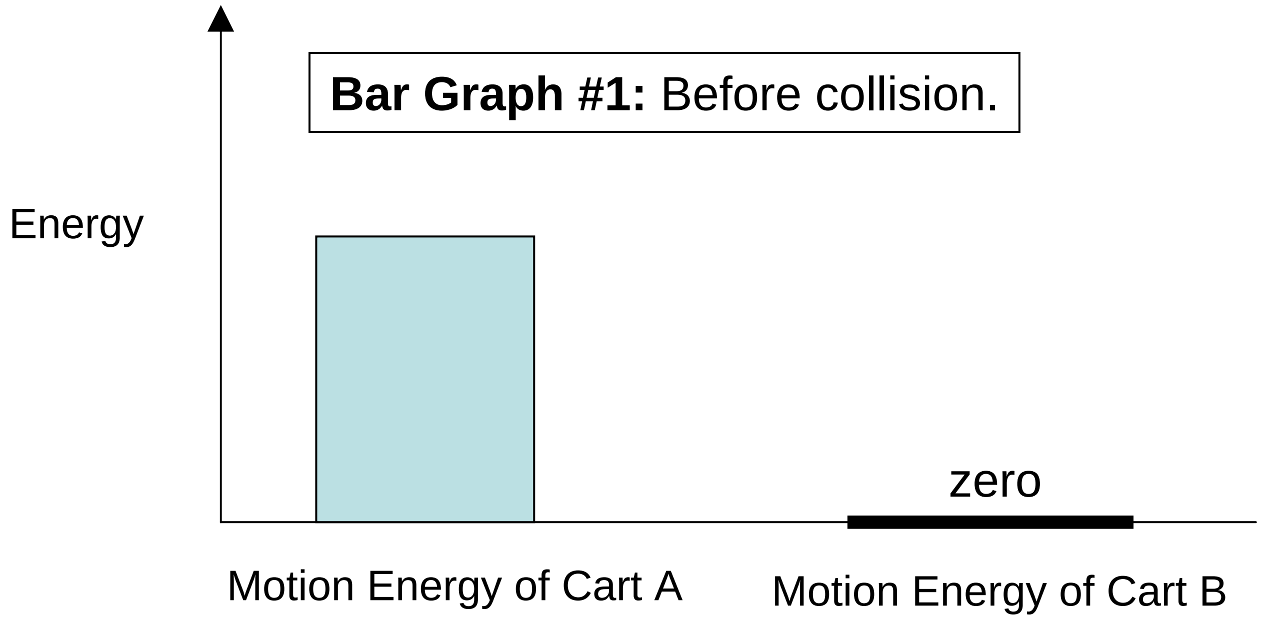

Cart A gives “Something”
Transfer of “Something”
Cart B receives “Something”


Cart A gives “Energy”
Transfer of “Energy”
Cart B receives “Energy”

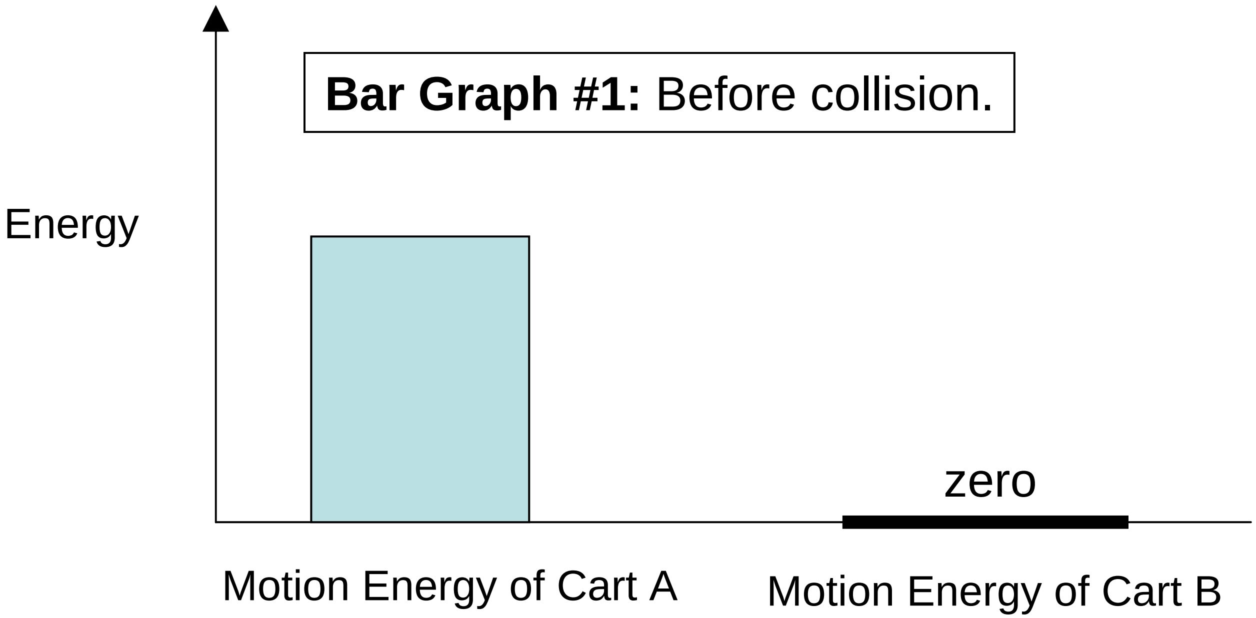


We say that the carts can have “motion energy”

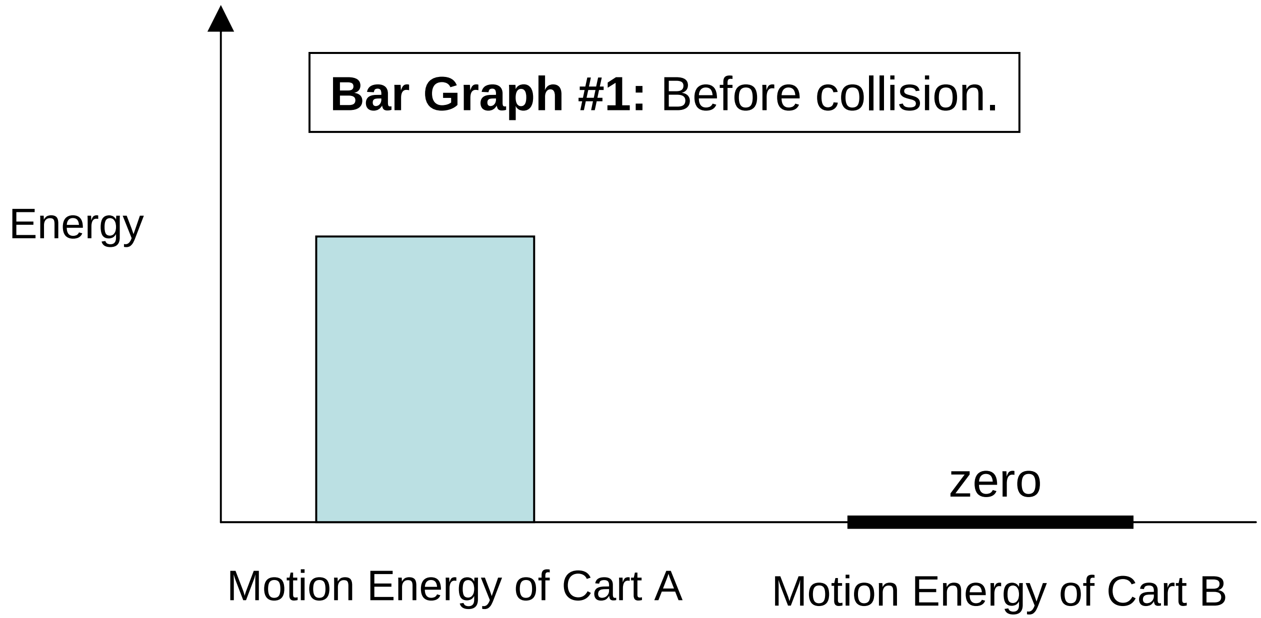
Bar Graph #1: Before Collision

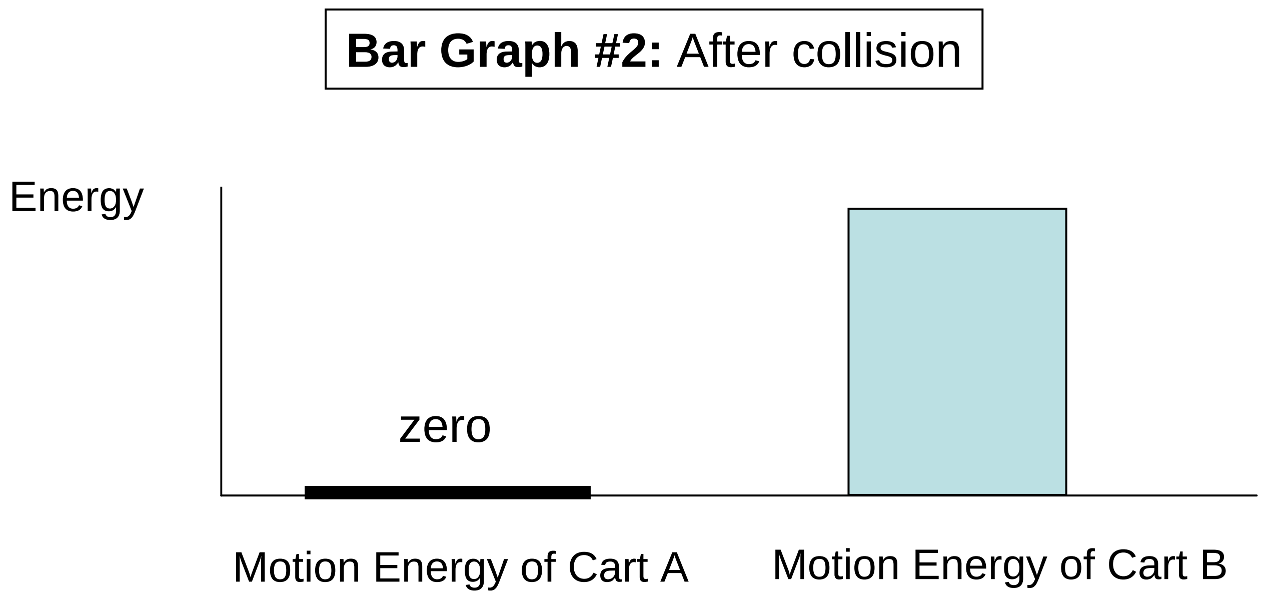

Bar Graph #1: Before collision.
Energy
zero
Motion Energy of Cart A
Motion Energy of Cart B

Bar Graph #1: Before collision.



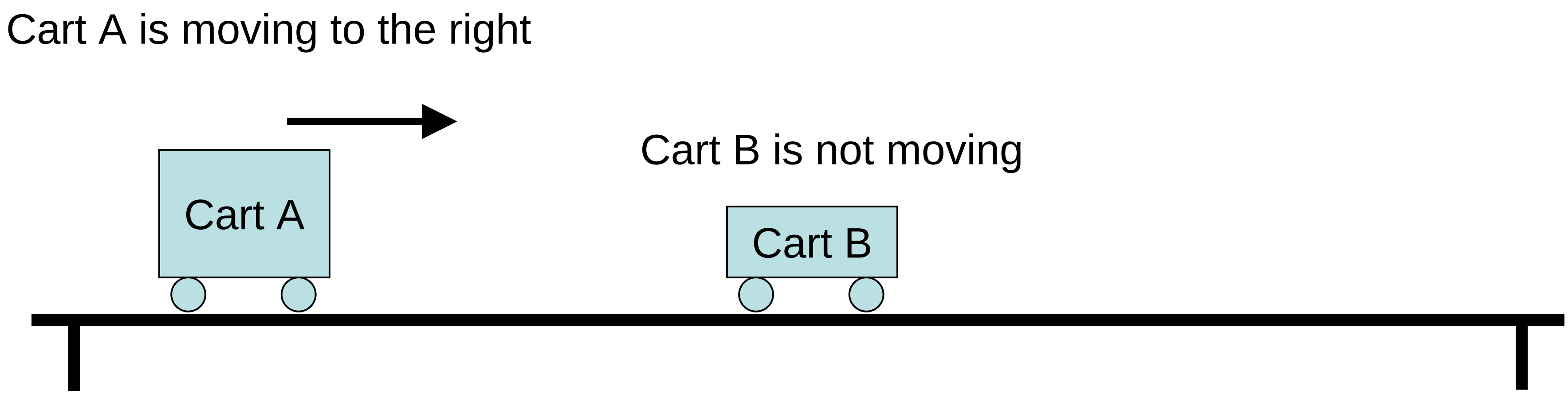
Bar Graph #2: After collision


Bar Graph #1: Before collision.
Energy
zero
Motion Energy of Cart A
Motion Energy of Cart B


Bar Graph #2: After collision
Energy
zero
Motion Energy of Cart A
Motion Energy of Cart B

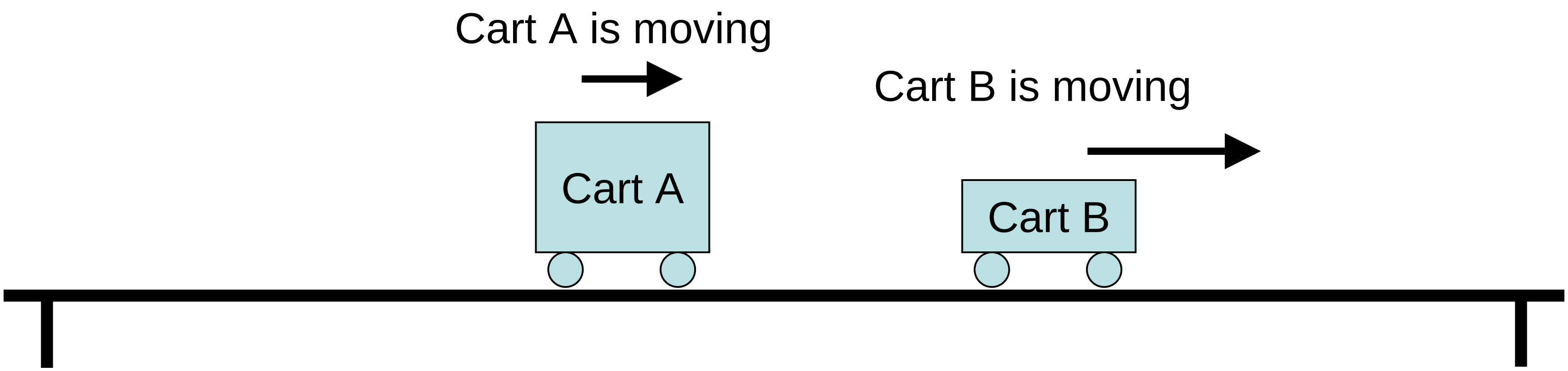
Before Collision

(Cart A larger than Cart B)

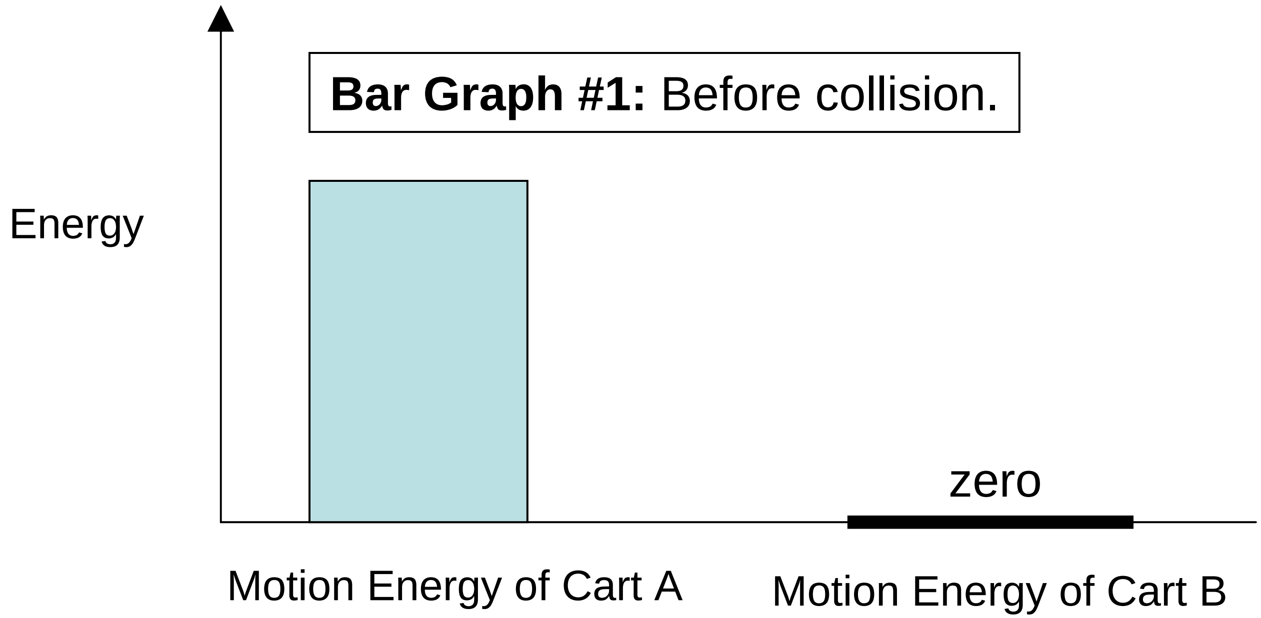


After Collision

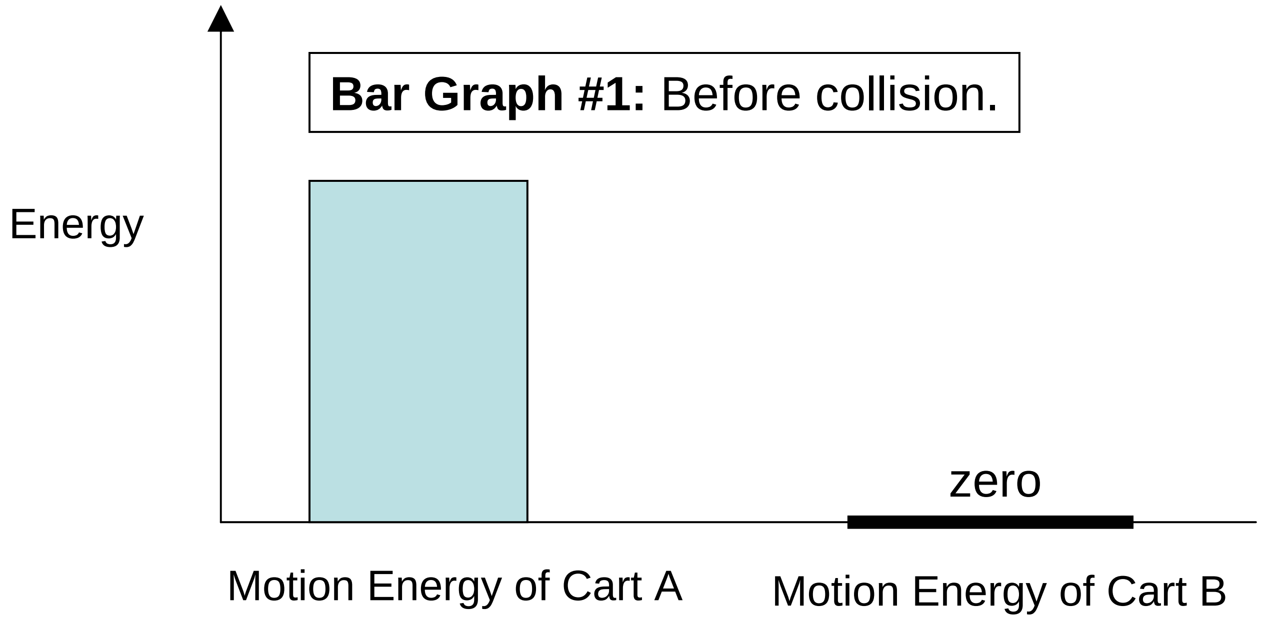
(Cart A larger than Cart B)



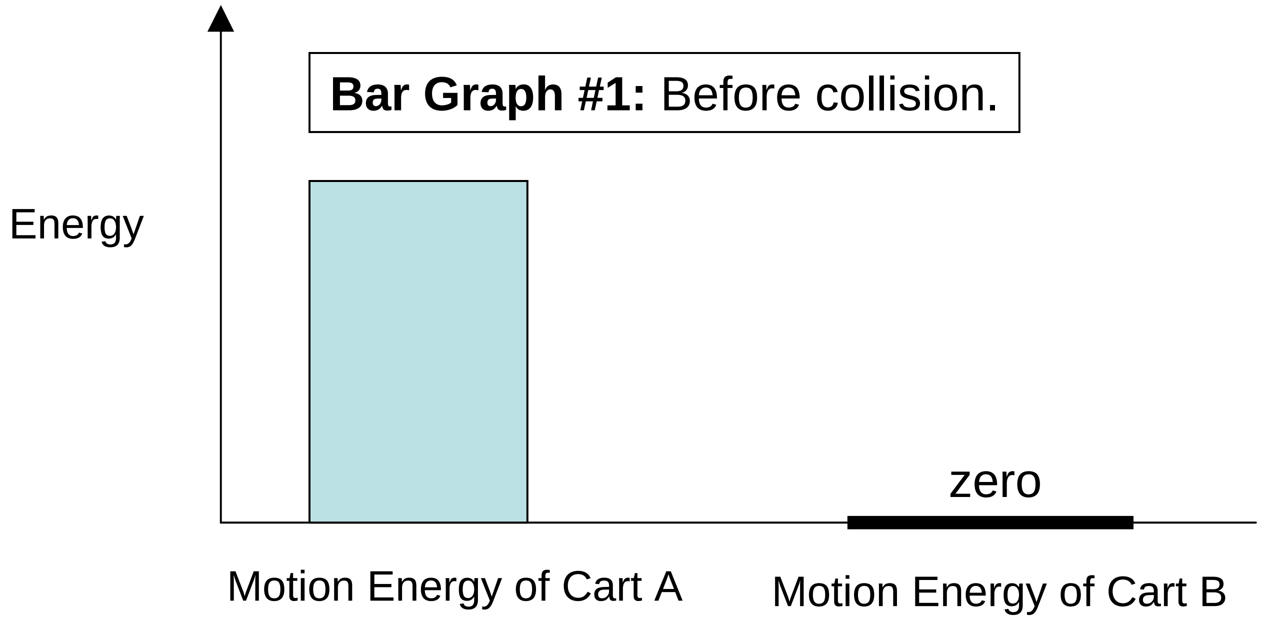
Bar Graph #1: Before Collision

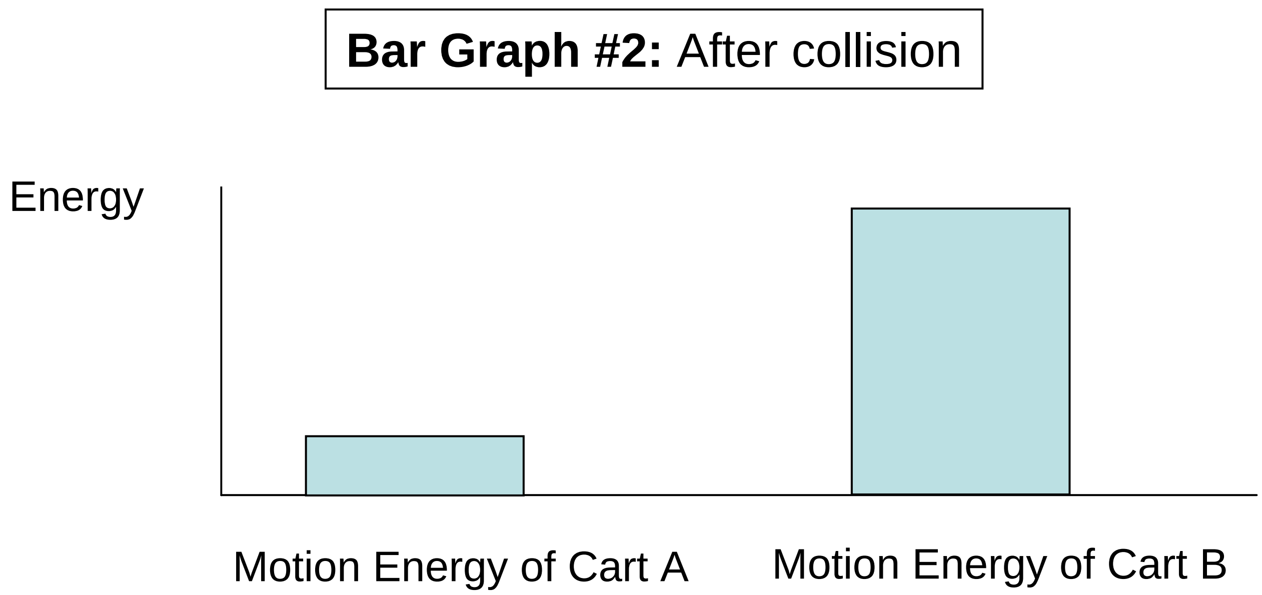

Bar Graph #1: Before collision.
Energy
zero
Motion Energy of Cart A
Motion Energy of Cart B

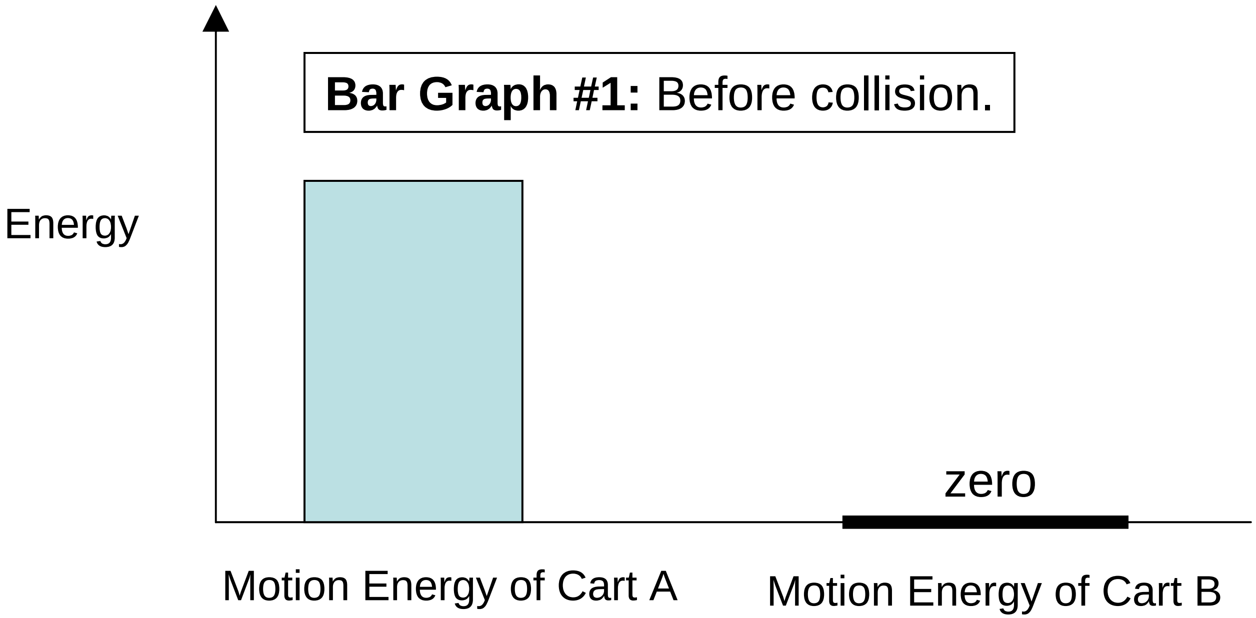
Bar Graph #1: Before collision.

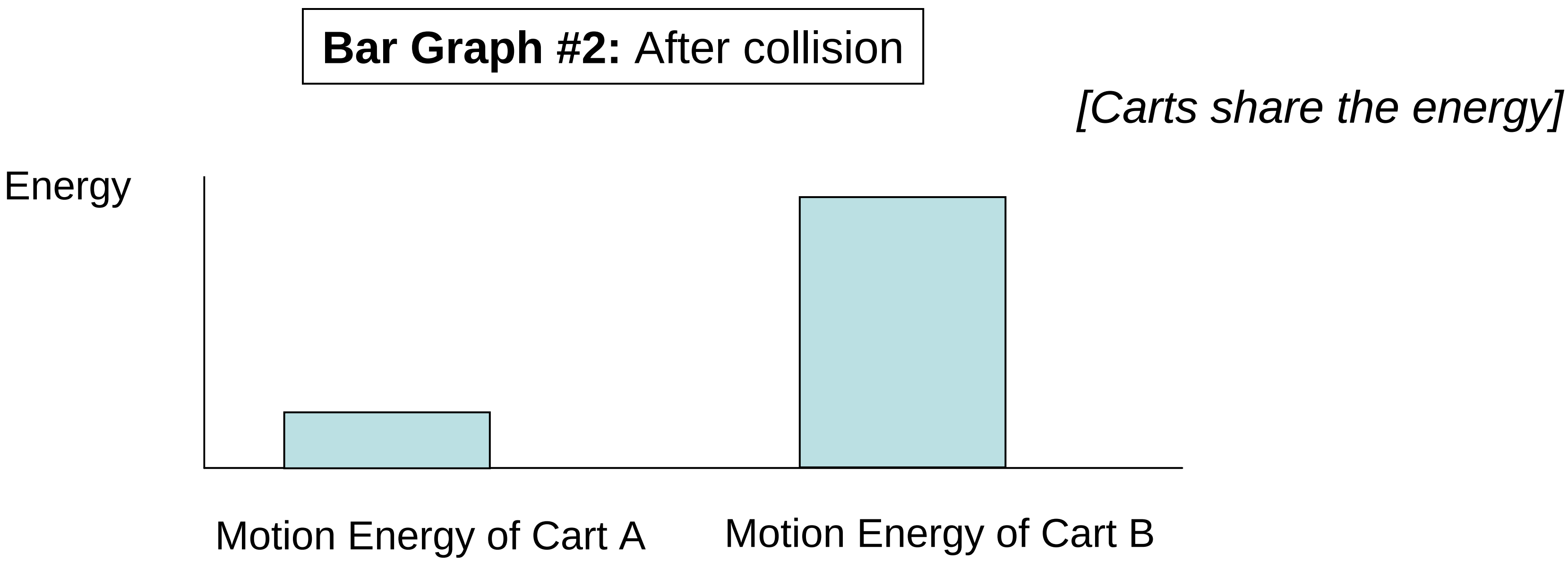


Bar Graph #2: After collision


Bar Graph #1: Before collision.
Energy
zero
Motion Energy of Cart A
Motion Energy of Cart B


Bar Graph #2: After collision
Energy
Motion Energy of Cart A
Motion Energy of Cart B

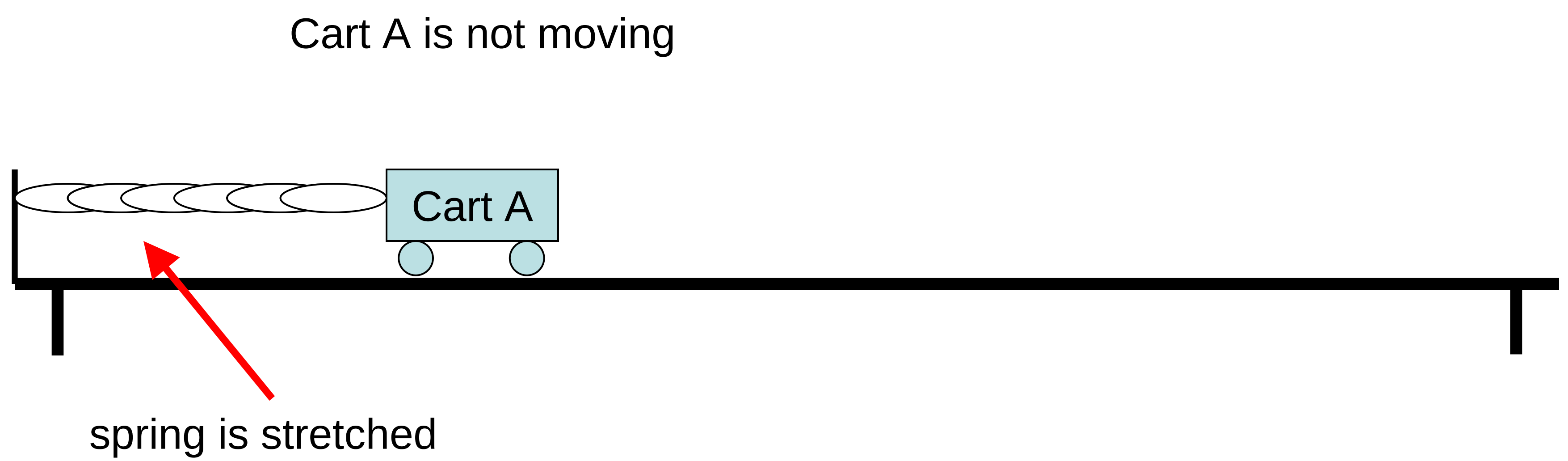

Bar Graph #1: Before collision.
Energy
zero
Motion Energy of Cart A
Motion Energy of Cart B


Bar Graph #2: After collision
[Carts share the energy]
Energy
Motion Energy of Cart A
Motion Energy of Cart B

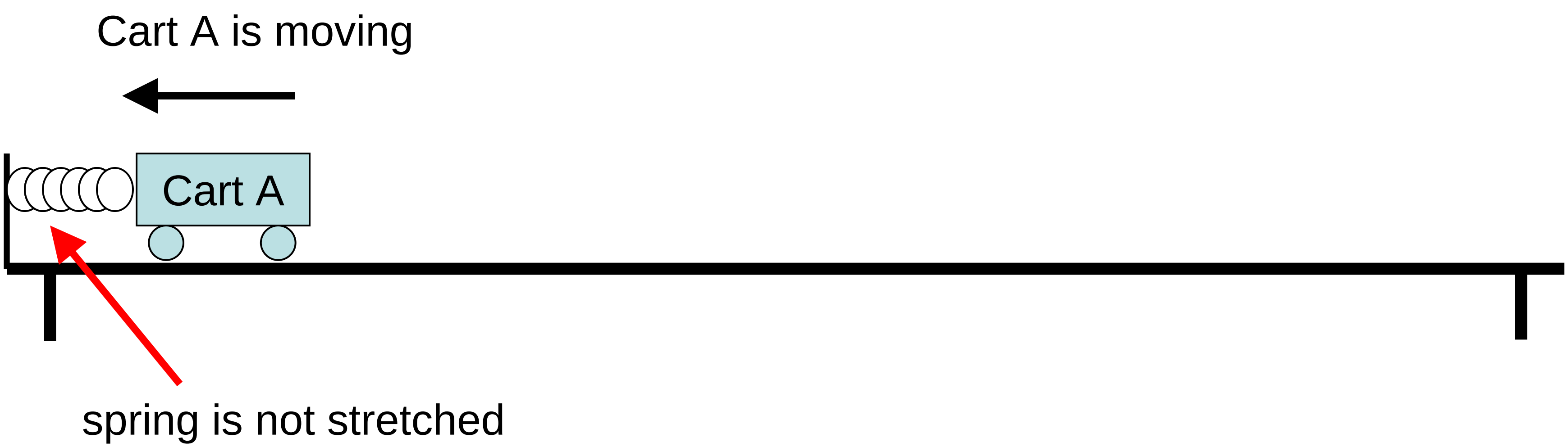
Class Discussion on Motion Energy

- What does Motion Energy depend on? *(Ask for student suggestions.)*
  - Speed. ("If speed increases, does motion energy increase, decrease, or remain the same?")
  - Mass (or "weight"). ("If mass increases, does motion energy increase, decrease, or remain the same?")

Spring Is Stretched



Spring Is Not Stretched

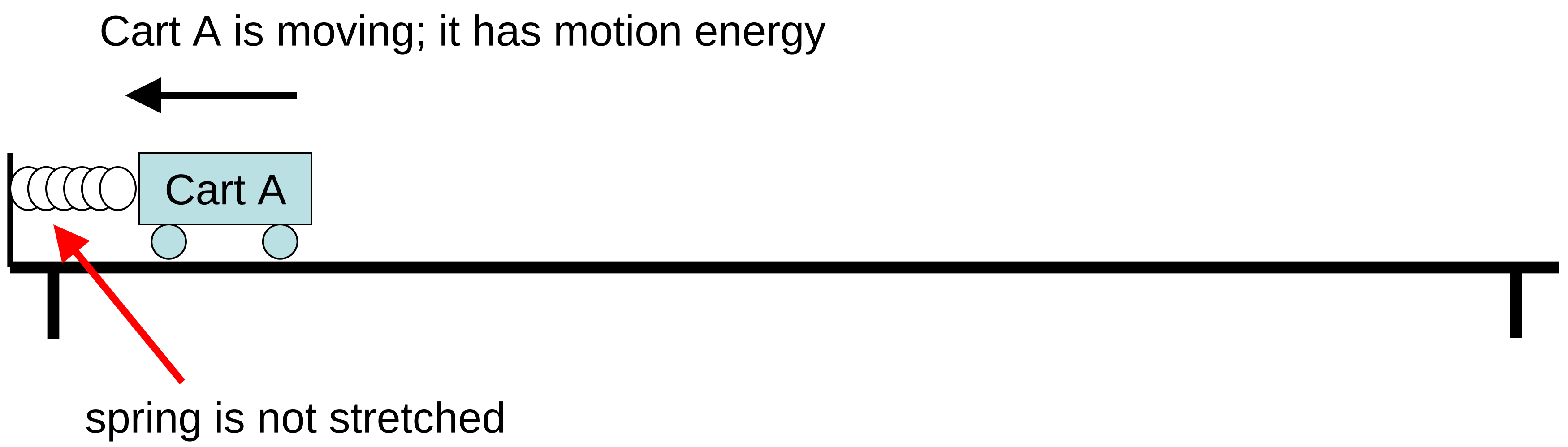


Spring Is Stretched

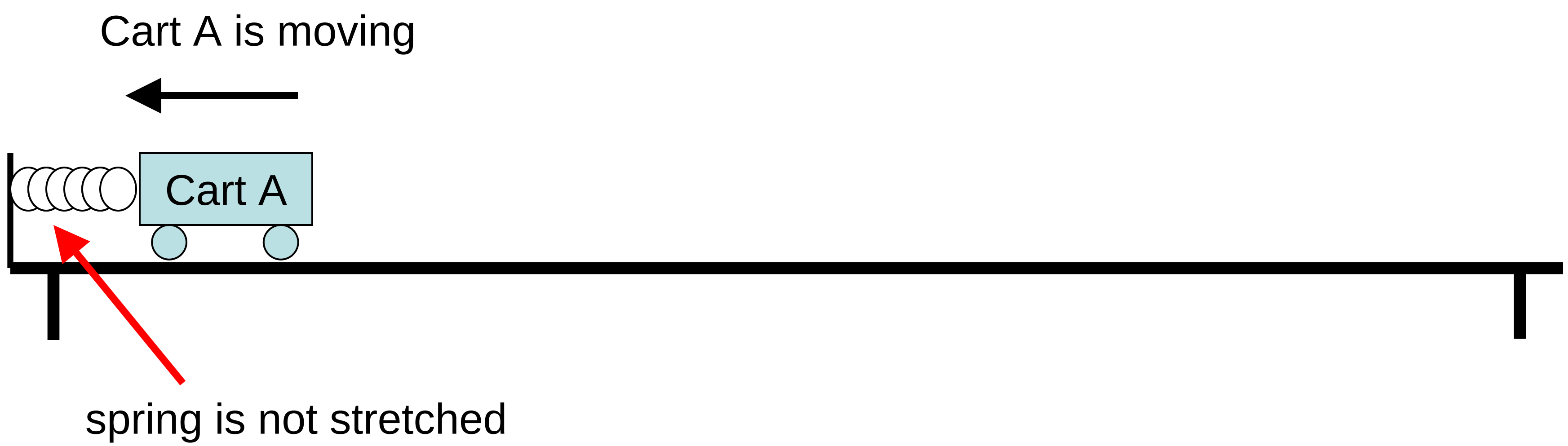
Cart A is not moving

spring is stretched; it has “stored energy”

Spring Is Not Stretched

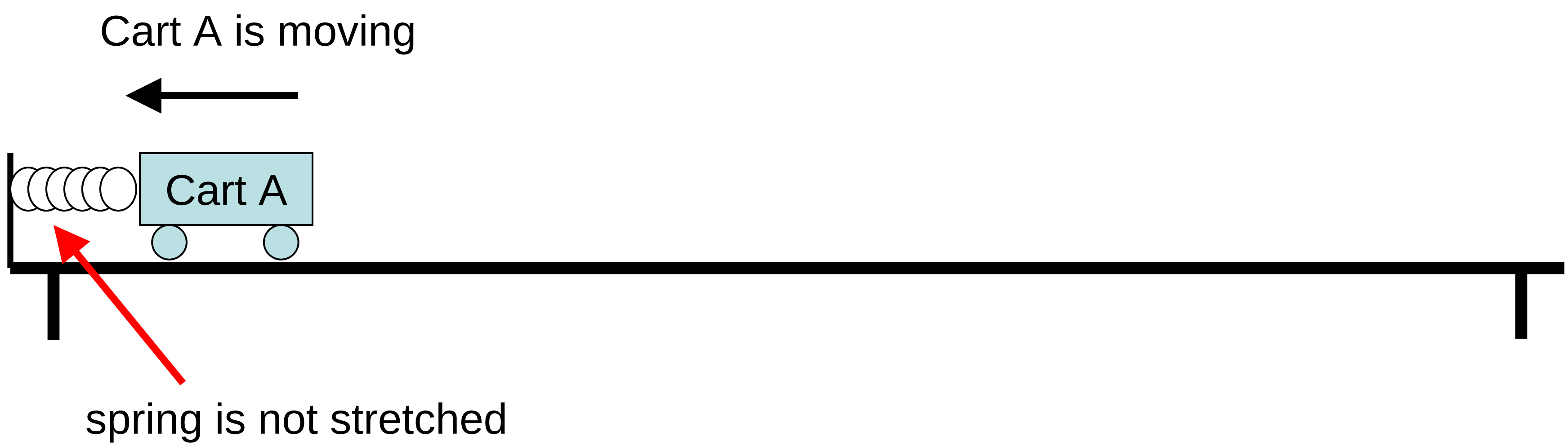


Spring Is Not Stretched

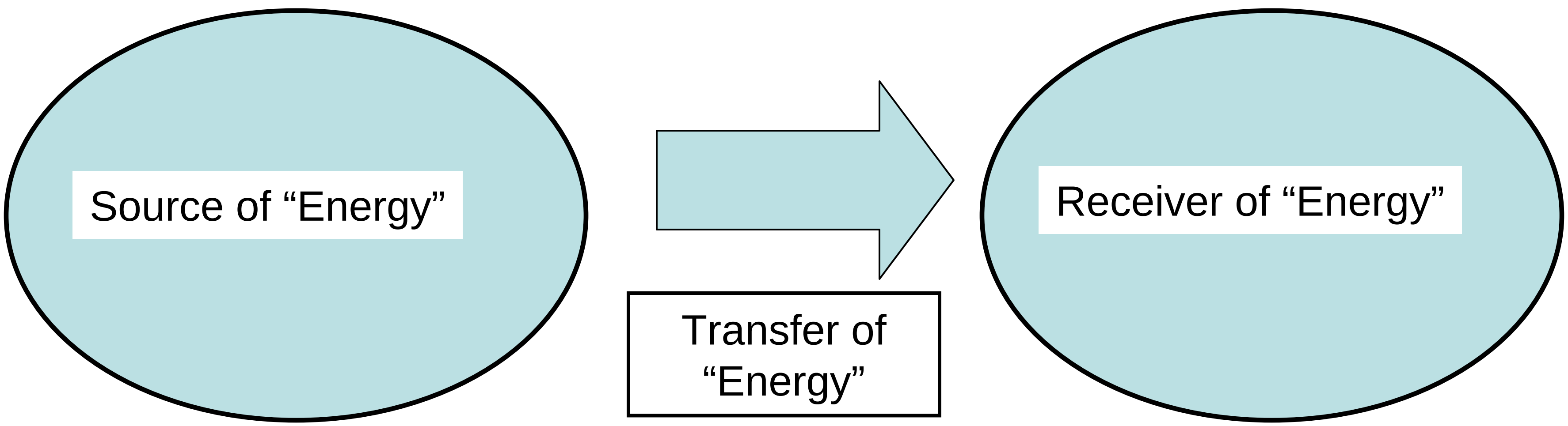


[Oversimplification, since this overlooks spring compression]

Spring Is Not Stretched



[In more advanced classes this system is replaced by a hanging mass system, with an explicit discussion of energy stored in stretching or in compression]


Source of “Energy”
Transfer of “Energy”
Receiver of “Energy”

Homework for Grade 5/6

For this homework you should use *two* bars:

(a) One of the bars should be labeled "motion energy of cart"

(b) The other bar should be labeled "stored energy in spring“

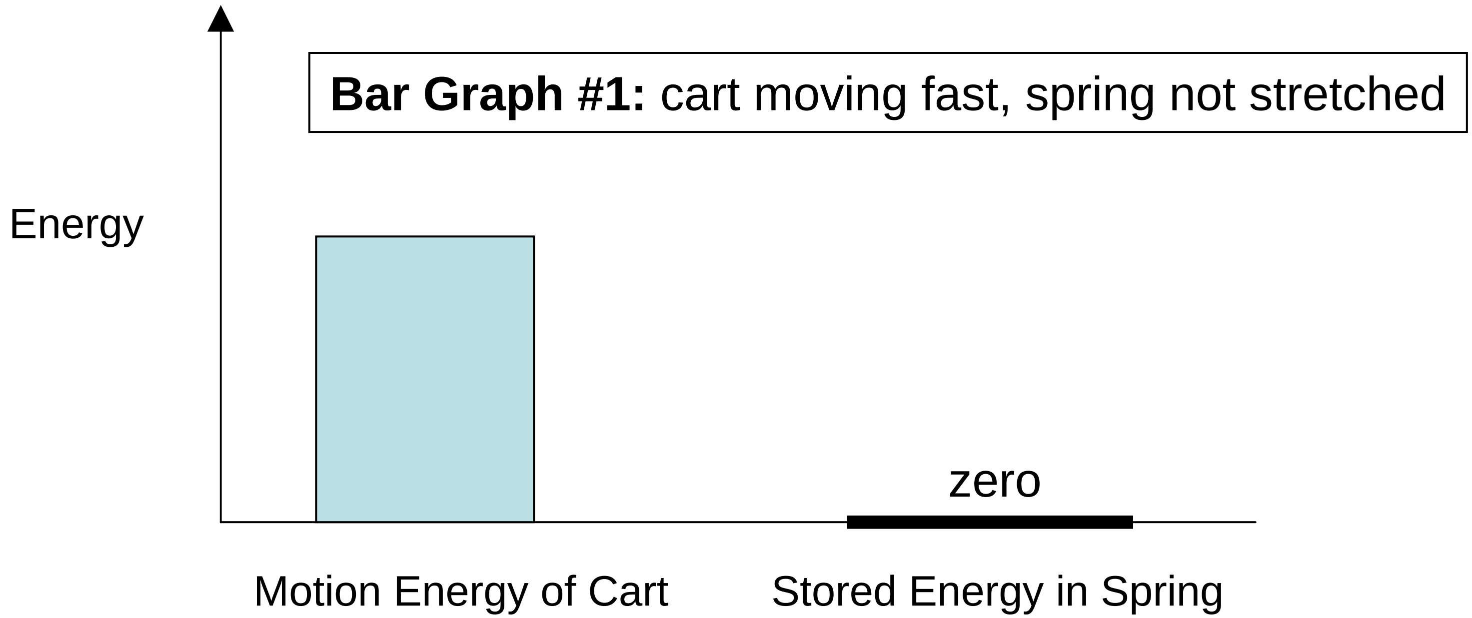
If a bar is zero in any situation, just write the name of the bar and write "zero“ above the horizontal axis just as we did in class.

Draw two different bar graphs representing the motion of the cart attached to the spring:

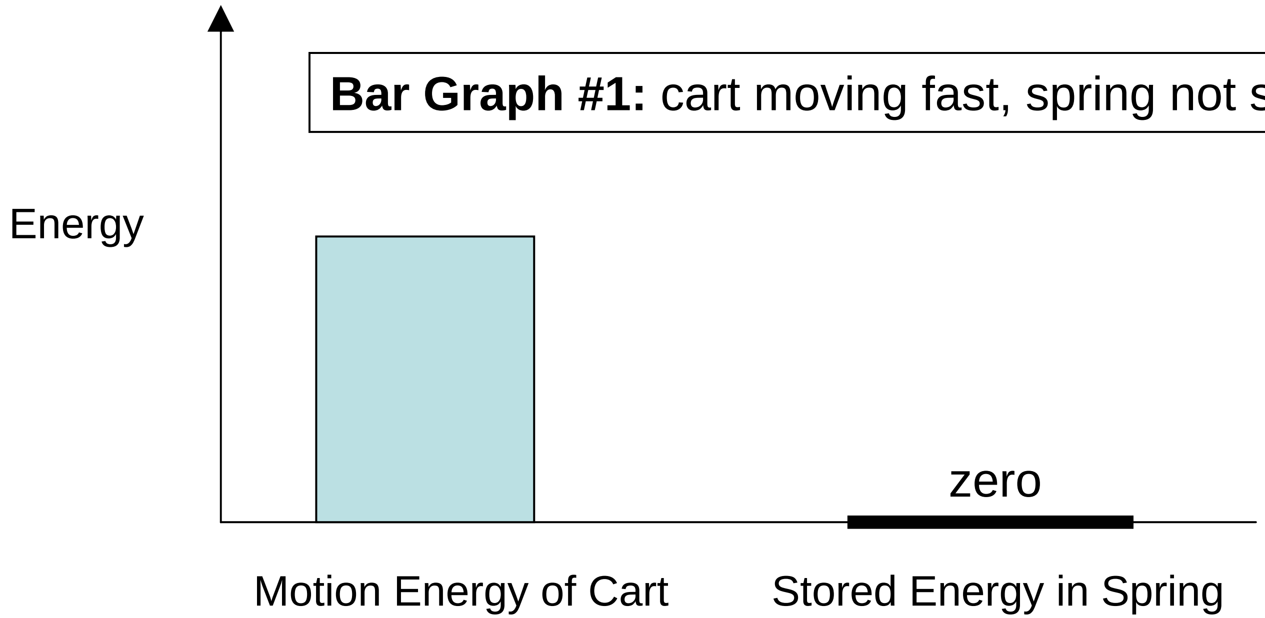
(1) For bar graph #1, the cart is moving fast but the spring is not stretched at all.

(2) For bar graph #2, the cart is not moving at all but the spring is stretched all the way out.

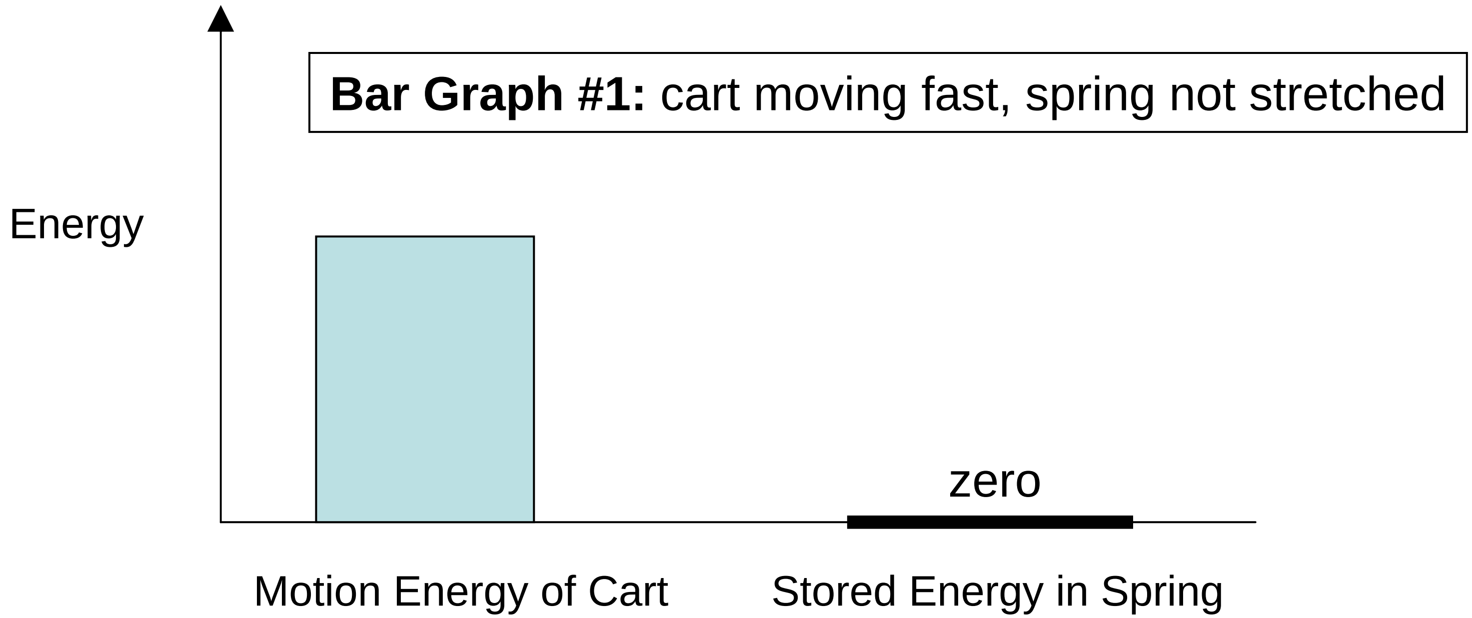
Bar Graph #1: cart moving fast, spring not stretched

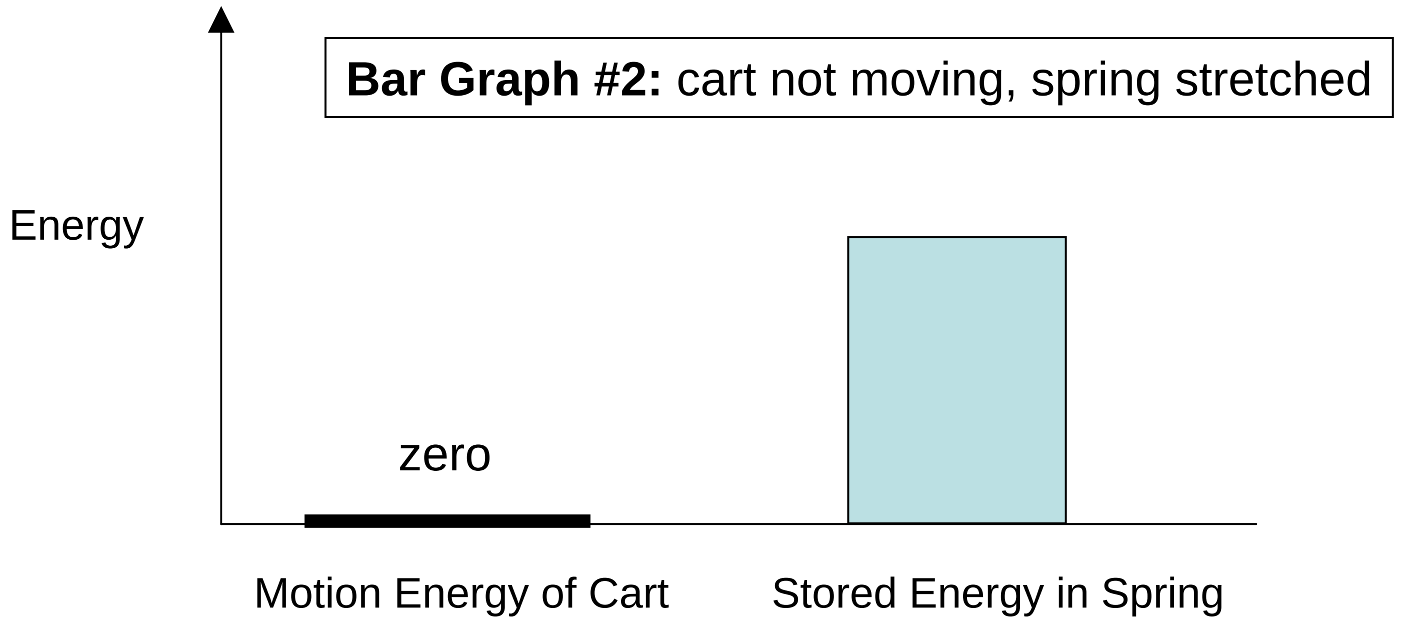

Bar Graph #1: cart moving fast, spring not stretched
Energy
zero
Motion Energy of Cart
Stored Energy in Spring

Bar Graph #1: cart moving fast, spring not stretched



Bar Graph #2: cart not moving, spring stretched


Bar Graph #1: cart moving fast, spring not stretched
Energy
zero
Motion Energy of Cart
Stored Energy in Spring


Bar Graph #2: cart not moving, spring stretched
Energy
zero
Motion Energy of Cart
Stored Energy in Spring

Student Performance on Homework (Ages 10-11)

- Large proportion (~ 50%) gave correct or mostly correct responses
- Large proportion of students seemed comfortable with semi-intuitive concepts of motion energy, stored energy, and total energy

⇒ *Very early stages of research;*
no definitive conclusions.

Summary

- For a college physics instructor, teaching young middle-schoolers is an enormously rewarding contrast to typically unenthusiastic college science classes.
- Gains in middle-school student understanding come slowly and unevenly, with much time and repetition required. But, progress is measurable.