Exploring Position and Momentum in the Quantum World

Introduction

Have you been learning about position and momentum in school? You're not alone. Basic **classical physics** concepts such as position, velocity, and momentum are the starting point for most introductory physics courses. These ideas are absolutely fundamental to all fields of science; they are some of the first topics that all scientists learn about as building blocks to other concepts in physics, chemistry, biology, and beyond.

Given their basic position within science, you may think that scientists completely understand how concepts such as position and momentum work and that there are no new questions to explore about them. We know that position is simply the location of an object, and momentum is associated with objects that are in motion.

But if you zoom in...way in, things get a little complicated. So complicated that classical physics doesn't cut it anymore. At the smallest scales, the objects physicists are interested in are individual particles like the electrons, protons, and neutrons that make up atoms and these smallest units of matter are in the domain of **quantum physics**. Over the past one hundred years, since the trailblazing work in quantum physics in the early twentieth century, scientists have come to better understand how the classical and quantum domains are related. The difference really comes down to scale: the laws of classical physics, like Newton's laws, work to explain the behavior of everyday objects, but when you are working with interacting objects at incredibly small scales, Newton's laws don't work. Instead, you need quantum laws.

Much of the most closely watched work in physics today, such as advances in nanotechnology, occurs at the quantum scale and is governed by quantum laws--which can seem to conflict or disagree with basic laws of classical physics. In quantum physics, for example, particles can "tunnel" through barriers - appearing as if by magic (but, really, by quantum physics) on the other side of seemingly solid walls. In quantum physics, particles don't actually exist at specific, single locations, but instead have some probability to exist at many locations at the same time.Oh, and particles can have negative mass. It's all a bit bananas.

But the fact is, you interact with the quantum world every day. Quantum tunneling, for example, powers the flash memory drive in your cell phone. Other applications of quantum mechanics enable your camera to take digital pictures, and your bank to keep your records secure. In this lesson, you will explore not an application, but a principle of the quantum world that can be framed as a simple question: How do we know where a single particle is at any given time? The old answer was: we can't. The new answer: maybe we can...

What To Do

Answer the analysis questions below, reading the Bite when instructed.

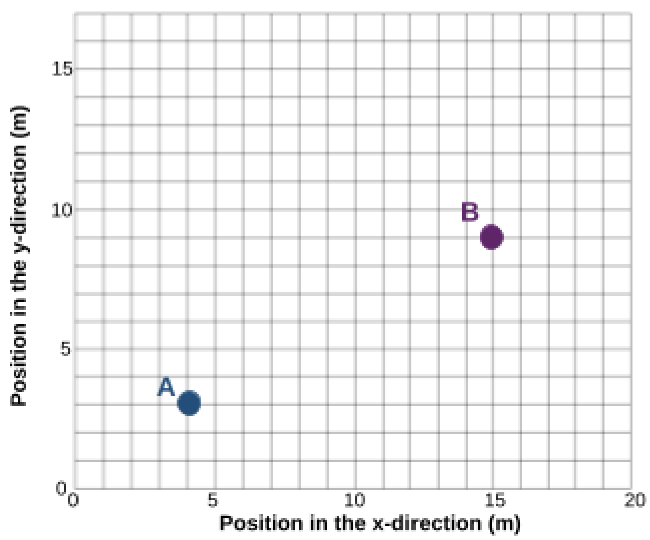
Analysis Questions

1. Compare and contrast classical physics with quantum physics.

2. Why do you think most first year physics courses focus on classical physics instead of quantum physics?

STOP & read Science Bite: Fighting the Quantum Conspiracy

3. Examine the diagram below.



   a. What is the position of point A with respect to the origin?

   b. What is the position of point B with respect to the origin?

c. What is the position of point B with respect to point A?

d. How is finding the position of B with respect to A similar to how the researchers propose using a negative mass particle to measure the position and momentum of a positive mass particle?

4. A person is standing on a city sidewalk. A blue car and an orange truck on the street, as shown in **Figure 1**. Both vehicles are traveling in the positive direction. The blue car travels 60 meters in 4 seconds. The orange truck travels 36 meters in 3 seconds.

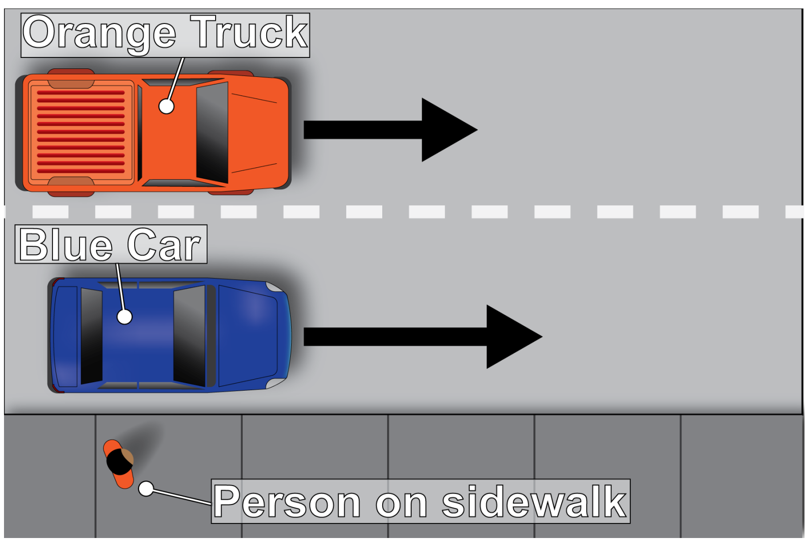


Figure 1. Orange Truck, Blue Car. Both vehicles are traveling in the positive direction.

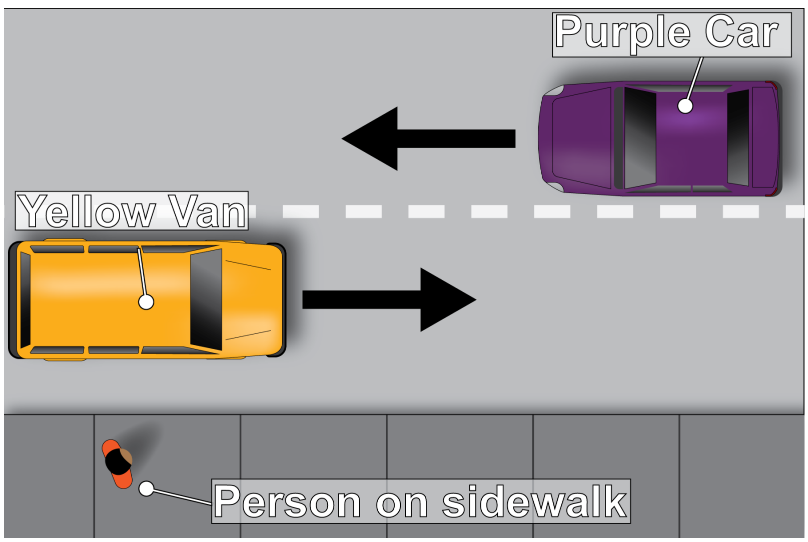
a. What is the velocity of the blue car with respect to the person on the sidewalk?

b. What is the velocity of the orange truck with respect to the person on the sidewalk?

c. What is the velocity of the blue car with respect to the orange truck?

d. How is finding relative position similar to finding relative velocity for two objects moving in the same direction? More generally, what makes position different than velocity?

5. Now the person on the sidewalk sees a purple car going in the negative direction and a yellow van traveling in the positive direction. The purple car travels 16 meters in 2 seconds, while the yellow van travels 11 meters in 2.5 seconds.



a. What is the velocity of the purple car with respect to the person on the sidewalk?

b. What is the velocity of the yellow van with respect to the person on the sidewalk?

c. What is the velocity of the purple car with respect to the yellow van?

6. Consider how we found the velocity of the blue car with respect to the orange truck and the velocity of the purple car with respect to the yellow van.

a. How is finding relative velocity similar to how the researchers propose using a negative mass particle to measure the position and momentum of a positive mass particle?

b. In what ways do both of our analogies (comparing the research to finding relative position and finding relative velocity) not accurately describe the research?

7. **Connect to the Big Question.** This research deals with particles that are far too small for human eyes to see, yet asking how we can make observations about their position and momentum gives us new insights into the fundamental properties of the universe. How do these scientists' proposed observations differ from the observations you make in your everyday life? Does it change your personal definition of what it means to observe? Explain.