Historical Beliefs About Motion

There are many scientists who have made important advances in our knowledge of motion. In this course, we will explore the contributions of three scientists in detail.

Aristotle on Motion

Aristotle, the foremost Greek scientist, divided motion into two types: natural motion and violent motion.

Natural motion on Earth was thought to be either straight up or straight down, such as a falling boulder or a puff of smoke rising in the air. All objects would seek their "natural" resting places: boulders on the ground and smoke high in the air like the clouds. Aristotle believed that the planets moved in circular paths because, like a circle, the heavens had neither a beginning nor an ending. Natural motion was not thought to be caused by forces.

Violent motion referred to any kind of motion that was imposed on an object. It was the result of forces that either pushed or pulled. For example, a cart moves because it is pulled by a horse; a sailboat is pushed by the force of the wind. The important thing about defining violent motion was that it had an external cause.

Aristotle's views on motion, which held for nearly 2000 years, suggested that if an object was moving "against its nature," then a force of some kind was responsible. If there were no force, there would be no motion. Thus, the proper state of objects was to remain at rest, unless they were being pushed, pulled, or moving toward their natural resting place.

Galileo on Motion

Galileo, the foremost scientist of late-Renaissance Italy, did not agree with Aristotle's beliefs about motion. He worked to disprove Aristotle's theories.

According to Galileo, a **force** is any push or pull. **Friction** is the name given to the force that acts between materials that touch as they move past each other. Friction is caused by the irregularities in the surfaces of objects that are touching.

Galileo argued that only when friction is present, as it usually is, is a force needed to keep an object moving. He tested his idea by rolling balls along plane surfaces tilted at different angles. He noted that:

- a ball rolling down an inclined plane speeds up
- a ball rolling up an inclined plane slows down
- a ball rolling along a level surface has an almost constant velocity

Galileo proposed that, in the absence of friction, a ball moving along a level surface would move forever, at a constant velocity. No force would be required to keep it moving once it had been set in motion.

Galileo performed a second experiment to support his claims. He described two inclined planes facing each other, as shown below. A ball released to roll down one plane would roll up the other to reach nearly the same height. He noted that the ball tended to reach the same height even when the second plane was longer and inclined at a smaller angle then the first. Additional reductions of the angle of the second plane gave the same results. Always, the ball went farther and tended to reach the same height.

What if the angle on the second plane were reduced to zero so the plane was perfectly horizontal? Galileo realized that only friction would keep the ball from rolling forever. It was not the nature of the ball to come to rest, as Aristotle had claimed. Rather, the moving ball would naturally keep moving.

Galileo stated that the natural tendency of a moving body is to keep moving and that every material object resists change to its state of motion. We call this property of a body to resist change **inertia**.

Newton's Law of Inertia

Isaac Newton was born on Christmas day in the year that Galileo died. By the age of 24 he had developed his famous laws of motion. These laws replaced the Aristotelian ideas on motion that had dominated for 2000 years.

Newton's first law, usually called the **law of inertia**, is a restatement of Galileo's idea:

> Every object continues in its state of rest, or of motion in a straight line at constant speed, unless it is compelled to change that state by forces exerted upon it.

Simply put, things tend to keep on doing what they're already doing. A textbook on a tabletop, for example, is in a state of rest. It will tend to remain at rest, unless a force is exerted on it.

Consider an object in motion. If you slide a hockey puck along the street, it will come to rest fairly quickly. If you slide it along ice, it slides for a longer distance. This is because the frictional force is very small. If you slide it along an air table where friction is almost absent, it slides with no apparent loss of speed. This demonstrates that, in the absence of external forces, a moving object tends to continue moving in a straight line at a constant speed.

Mass – A Measure of Inertia

Kick an empty can and it moves. Kick a can filled with sand and it doesn't move as much. Kick a can filled with concrete and you'll hurt your foot. The concrete-filled can has more inertia than the sand-filled can, which in turn has more inertia than the empty can. The amount of inertia an object has depends on its mass. The mass of an object is a measure of the amount of material present in the object. The more mass an object has, the more inertia it has and the more force it takes to change its state of motion.

Mass Is Not Volume

Volume is a measure of space, and is measured in units such as cubic centimeters or cubic meters. Mass is measured in **kilograms**. An object with a large mass may or may not have a large volume. For example, equal sized bags of feathers and nails have the same volume, but clearly have different masses.

Mass Is Not Weight

Mass is a measure of the amount of material in an object and depends only on the number and kind of atoms that compose it. Weight on the other hand is a measure of the gravitational force acting on an object. Weight depends on an object's location.

The amount of material in an object is the same whether the object is on Earth, on the moon, or in outer space. Thus, the object's mass is the same in all of these locations. The weight of the object, however, would be very different on Earth and on the moon, and still different in outer space.

More specifically, we define mass and weight as follows:

Mass is the quantity of matter in an object. More specifically, mass is a measure of the inertia of an object.

Weight is the force of gravity on an object. It is measured in units called **Newtons**. The weight of an object is equal to its mass multiplied by a **gravitational constant**. The gravitational constant is different for every planet. On Earth, it has a value of $9.81\ N/kg$.

Thus, on Earth:

$$\text{Weight} = 9.81\ N/kg \times \text{Mass}$$

Motion Worksheet #6

1. Explain, in your own words, the difference between natural and violent motion.
2. What is the effect of friction on a moving object?
3. The speed of a ball increases as it rolls down an incline and decreases as it rolls up an incline. What happens to its speed on a smooth, horizontal surface?
4. Galileo found that a ball rolling down one incline will pick up enough speed to roll up another. How high will it roll compared with its initial height?
5. Does the law of inertia apply to moving objects, objects at rest, or both? Support your answer with examples.
6. The law of inertia states that no force is required to maintain motion. Why, then, do you have to keep pedaling your bicycle to maintain motion?
7. If you were in a spaceship and launched a cannonball into frictionless space, how much force would have to be exerted on the ball to keep it going?
8. Does a 2 kg rock have twice the mass of a 1 kg rock? Twice the inertia? Twice the weight (when weighed in the same location)?
9. Does a liter of molten lead have the same volume as a liter of apple juice? Does it have the same mass?
10. Why do physicists say that mass is more fundamental than weight?
11. What is the weight of 2 kg of yogurt?
12. If a woman has a mass of 50 kg, calculate her weight in Newtons.
13. Calculate, in Newtons, the weight of a 2000 kg elephant.
14. Many automobile passengers suffer neck injuries when struck by cars from behind. How does Newton's law of inertia apply here? How do headrests help to guard against this type of injury?
15. Suppose you place a ball in the middle of a wagon that is at rest and then abruptly pull the wagon forward. Describe the motion of the ball relative to (a) the ground and (b) the wagon.
16. When a junked car is crushed into a compact cube, does its mass change? Its volume? Its weight?

17. If an elephant were chasing you, its enormous mass would be very threatening. But if you zigzagged, the elephant's mass would be to your advantage. Why?

Motion Worksheet #6 Key

1. Natural motion is straight up or down. Violent motion is imposed.

2. It slows motion.

3. No change (ignoring friction and air resistance).

4. To the same height if there is no friction.

5. Both. (Examples will vary.)

6. To overcome friction.

7. None.

8. Yes; yes; yes.

9. Yes; no.

10. Mass is the same in all locations, while weight depends on the local gravity.

11. 19.6 N

12. 490 N

13. 19 600 N

14. When struck from behind, the car accelerates forward rapidly. The tendency of the passenger (body and head) is to remain moving with a constant velocity. The seat of the car causes the body to accelerate forward along with the car. The head, however, stays where it is (seeming to whip back). This causes an injury known as whiplash. Headrests work to keep the body and head moving together when the car is accelerated forward.

15. (a) Except for some change in motion due to friction, there will be no relative motion of the ball relative to the ground. (b) Relative to the wagon, the ball will move toward the back. (In reality, the wagon is moving forward while the ball remains stationary. This creates the appearance of the ball moving backward.)

16. No; yes; no. It has the same amount of matter before and after being crushed.

17. Because of its large mass, the elephant would have difficulty zigzagging. (Its large inertia means it would have trouble changing its state of motion.)