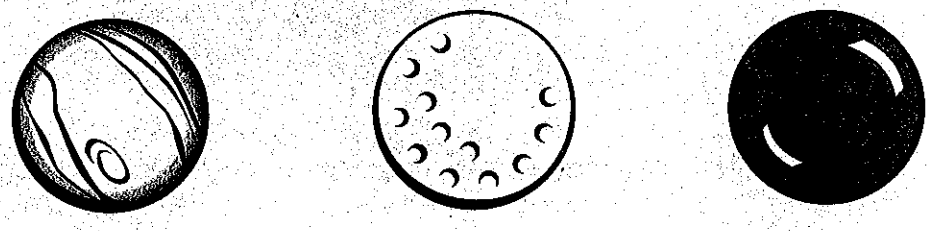
Dropping Balls



Reggie has three different types of balls. Each ball is about the same size.

Ball 1 is a wooden ball. Its mass is 28 g.

Ball 2 is a golf ball. Its mass is 46 g.

Ball 3 is a metal ball. Its mass is 110 g.

Reggie held his arm out and dropped the three balls at the same time from the same height. In what order will the balls hit the floor? Circle your prediction:

Prediction A: Ball 1, then ball 2, then ball 3.

Prediction B: Ball 3, then ball 2, then ball 1.

Prediction C: Ball 2, then ball 3, then ball 1.

Prediction D: All three balls will hit the floor at about the same time.

Prediction E: Ball 3 will hit first, followed by ball 1 and ball 2 hitting the floor at the same time.

Explain your thinking. What "rule" or reasoning did you use to make your prediction?

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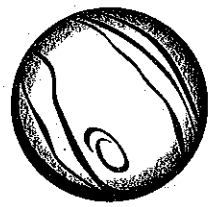
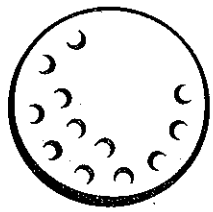
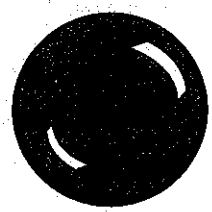
Teacher Notes

Purpose

The purpose of this assessment probe is to elicit students' ideas about falling objects. The probe is designed to find out if students think the weight or mass of an object affects how fast it falls.

Related Concepts

acceleration, force, gravity, mass

Explanation

Prediction D is the best answer: All three balls will hit the floor at about the same time. The word *about* is used because the balls are not dropped in a perfect vacuum. In general, freely falling objects increase their speed at the same rate, 9.8 m/s each second, regardless of their mass. Ball 3 has more mass than the other two balls. Because of this, some students reason that if all three balls are dropped at the same time, the heaviest ball (ball 3) should reach the ground first. This is a seemingly logical conclusion, but it actually hits the floor at the same time as the lighter balls due to the way forces affect the motion of objects.

Objects with more mass accelerate more slowly than objects with less mass, if pushed or pulled with equal force. This phenomenon is clear to anyone who has pushed a very heavy object in order to start it moving. If you could push an object with the same constant force every time, you would actually find that an object with *twice* the mass speeds up exactly *half* as quickly. On the other hand, if you pushed twice as hard on any given object, the object would speed up twice as quickly.

This same effect applies to falling objects like balls. At first thought, it would seem that

the stronger gravitational force on the metal ball should speed it up more quickly. In fact, the stronger pull on this ball is canceled out by the extra effort required to speed up this more massive ball. If Reggie decided to drop a ball that had five times more mass than ball 3, the force pulling the ball downward would be five times greater, but the ball would also be five times more difficult to speed up. As a result, this very heavy ball would speed up equally quickly and hit the ground at the same time as ball 1, 2, or 3. The rate at which free-falling objects fall is 9.8 m/s/s, regardless of their mass.

However, because the balls are falling through the air, the air exerts an upward force on them as they fall. This force can differ depending on an object's size, density, and speed. Because of this force, objects dropped together in an experiment will not hit the ground at the same time if air resistance is a factor. For example, if a Ping-Pong ball with a mass of 2.7 g were dropped with the three balls in the probe, it would not hit the ground at the same time as the other three because air resistance would be a significant factor. If a sheet of paper and a book were dropped at the same time from the same height, the book would land first because air resistance cannot be ignored with the sheet of paper. This probe assumes that the effect of air resistance on the balls is negligible. If the air could be removed and the balls dropped in a vacuum, they would always hit the ground at exactly the same time.

Curricular and Instructional Considerations

Elementary Students

In the elementary school grades, students observe that things fall when dropped and later relate this to Earth's gravitational pull. They observe how different objects fall and that they can change how fast an object falls by changing its shape. At this stage, their investigations of the motion of falling objects are primarily observational.

Middle School Students

In the middle school grades, students engage in concrete experiences involving force and motion from which a more comprehensive understanding of force and motion can be developed later in high school. Students observe the effects of different forces on falling, rolling, and sliding objects and begin to move from qualitative descriptions to quantitative ones.

High School Students

Students at the high school level move from understanding gravity as a general universal force to understanding more of the details and mathematical description of gravitational forces. At this level, students are better able to engage in the more abstract thinking involved with mathematical representations, such as the acceleration of a falling object, and also to learn of the many contexts in which gravity plays an important role. High school students are also able to move from qualitative descriptions of motion toward quantitative ones and should

be encouraged to do so (AAAS 1993). Before launching into applications of mathematical formulae, students should demonstrate the ability to describe the subtleties involved in changing motion. By learning mathematical descriptions and specific terminology associated with motion concepts (*velocity, acceleration,* etc.) and after acquiring a broad foundation of firsthand experiences observing and describing motion, students can use vocabulary and calculations with meaning. At this grade level the concept of force is better understood but students' intuitive ideas about the effects of forces on objects are still tenacious.

Administering the Probe

Show students a wooden ball, golf ball, and similarly sized metal ball and have them hold them to feel their "felt weight" (or show three other similarly shaped objects of different masses). Make sure that students know that the balls will be released at exactly the same time, from exactly the same height.

Related Ideas in *National Science Education Standards* (NRC 1996)

K–4 Position and Motion of Objects

- The position and motion of objects can be changed by pushing or pulling. The size of the change is related to the strength of the push or pull.

5–8 Motions and Forces

★ If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

9–12 Motions and Forces

- Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship Force = Mass × Acceleration, which is independent of the nature of the force.
- Gravitation is a universal force that each mass exerts on any other mass.

Related Ideas in *Benchmarks for Science Literacy* (AAAS 1993)

K–2 Motion

- Things near the Earth fall to the ground unless something holds them up.
- Things move in many different ways, such as straight, zigzag, round and round, back and forth, and fast and slow.

3–5 Motion

- Changes in speed or direction of motion are caused by forces. The greater the force is, the greater the change in motion will be.
- The Earth's gravity pulls any object toward it without touching it.

★ Indicates a strong match between the ideas elicited by the probe and a national standard's learning goal.

6–8 Motion

- An unbalanced force acting on an object changes its speed or direction of motion, or both.
- Every object exerts gravitational force on every other object.

9–12 Motion

- The change in motion of an object is proportional to the applied force and inversely proportional to the mass.

Related Research

- Students do not always identify a force to account for falling objects. They think objects "just fall naturally" or that the person letting go of the object has caused it to fall (Driver et al. 1994).
- Studies by Osborne (1984) found that students think heavier objects fall faster.
- Students, including university students, tend to think that heavier objects fall to Earth faster because they have a bigger acceleration due to gravity (Driver et al. 1994).

Suggestions for Instruction and Assessment

- This probe lends itself well to an inquiry investigation. Have students try this with the materials mentioned in the probe or with other objects such as different size rocks, different coins, or blocks made of different materials. Realize, however, that dropping two or more objects in exactly the same way and at the same time is difficult, and that this and some effects of air resistance can make it hard to reproduce the expected results. As a result, student investigations alone can run the risk of reinforcing incorrect student ideas. You may want to help guide students toward procedures, including dropping only two objects at a time, and materials that minimize these problems.
- Encourage students to investigate changing how some objects fall in order to observe the effects of air resistance. Have students drop a piece of paper both unfolded and as a crumpled ball. Also have students drop paper and a book side-by-side and then with the paper placed on top of the book. As with most experiences, students should make predictions about what they expect to see prior to these experiences and discuss the results afterward.
- Show students videos of this situation performed under highly controlled conditions—many examples can be found. A film of an astronaut dropping a hammer and feather together on the Moon is especially interesting. However, be aware this film may cause students to think that something special about being on the Moon, such as less gravity, causes the objects to drop together. A movie of the Apollo 14 "Hammer-Feather Drop" can be viewed online at *http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_15_feather_drop.html*.
- Connect this probe scenario to the historical example of Galileo's famous experiments with falling objects.

Related NSTA Science Store Publications and NSTA Journal Articles

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* New York: Oxford University Press.

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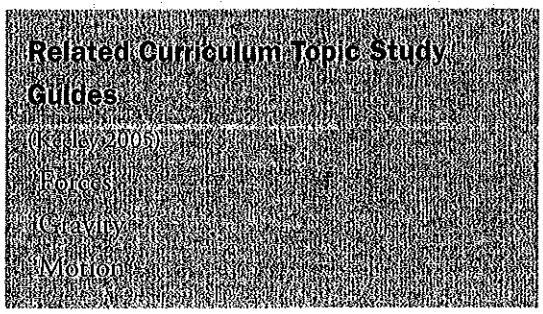

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Osborne, R. 1984. Children's dynamics. *The Physics Teacher* 22 (8): 504–508.