611-1405 (40-112) Ballistics Car

Warranty:

We replace all defective or missing parts free of charge. All products warranted to be free from defect for 90 days. Does not apply to accident, misuse, or normal wear and tear.

Introduction

The Ballistic Car is a device that demonstrates that **horizontal** motion of an object (in this case, a ball) is unaffected by **vertical** motion. It consists of a gun mounted vertically on a car which propels a steel ball upward by means of a compressed spring. The car's low-friction wheel bearings allow it to free wheel at a speed that is essentially constant. If the gun is triggered while the car is free-wheeling, the ball rises and falls back into the barrel.

Compare this to actions within a *moving train.* Picture a passenger (the gun) inside a train (the car) throwing a ball straight up. The ball falls straight back into the passenger's hand provided the train moves at a constant speed. The Ballistics Car allows these proceedings to be watched by a stationary observer.

The purpose of the Ballistics Car is to show that the **horizontal component** of the ball's velocity must equal that of the car itself despite the considerable change in the **vertical component** of the velocity. This is the only way that the ball will fall back into the barrel of the gun, given any initial speed of the car and any initial power settings of the gun. This proves that the velocity as a vector can be resolved into two mutually perpendicular components, components which can then be treated separately.

At any point in a projectile's trajectory, its instantaneous velocity can be resolved in two perpendicular directions. The directions commonly used are the horizontal and the vertical. Since the horizontal components stays constant while the vertical component changes due to the Earth's gravitational pull, the projectile's trajectory can be calculated and predicted. At higher speeds - speeds that cannot be attained by the Ballistics Car - the effect of air friction needs to be included since friction reduces both components of high velocity.

The Ballistics Car serves as an introduction to frames of reference which are moving at constant velocity relative to each other.

The passenger in the train and the barrel of the gun are unaware of their respective movements. They *see* the ball move only in a vertical direction relative to their frame of reference. An observer on the ground, however, *sees* the ball curve in a parabola relative to his frame of reference.

The motion of the ball obeys Newton's Laws of Motion due to the effect of gravity in both frames of reference. An observer cannot tell from the motion of the ball whether he is moving at any constant horizontal velocity relative to the earth.

Operation

1. You need a level surface.

For best results, run the car on a smooth, hard surface that is dust-free and horizontal. Use a carpenter's spirit-level to make sure your surface is level. Even floors that look horizontal can be too inaccurate. Check in both perpendicular and parallel directions to that of the car's motion.

Do not drop or allow the car to run off the edge of any table because the bearings can be damaged.

2. Position and shoot ball from barrel.

• Make sure a fresh 9V battery is installed in the unit, and that the power switch on the bottom is activated.

• Place the ball on the piston inside the barrel. Push down to lock the piston in place.

• You are now ready to use the remote. Pressing any of the buttons on the remote will eject the ball.

• Give the car a gentle push. When desired, press the remote to eject the ball.

• The ball will rise about one foot after ejection.

• Try different speeds.

• If conditions are right, the ball falls back into the barrel.

This confirms that the horizontal motion of the ball keeps pace with that of the car. For each locking position, the ball always rises to the *same height* regardless of horizontal velocity, again demonstrating the independence of the two perpendicular components.

As the ejection is done internally without any external physical stress, there is no change in the velocity of the car. This shows that any activity must be solely a result of the motion of the car and of the ejected ball. This proves that horizontal and vertical motion exist independently of each other.

Measurements needed to quantify how far ahead of the barrel the ball should fall:

1. Height **H** to which ball rises from the mouth of the gun.

H can be measured with the car stationary.

2. Distance **D** the car travels from point where gun is fired to point where car, of its own accord, comes to rest.

3. Time **T** taken for the car to travel until it comes to rest. **T** and **D** must be measured together in the same trial.

Calculations:

Part A.

Measurement of **H** allows you to calculate the time the projectile is in the air. To determine the relationship between distance **H** fallen to elapsed time **T** for an object starting from rest and undergoing a constant gravitational acceleration **g** (which equals 9.8 m^2), use this equation:

$$H = 1/2 \, g \, T^2$$

The time from the top of the ball's flight to the barrel is:

$$T = \left(\frac{2H}{g}\right)^{1/2}$$

The time taken to reach this height in the first place would have been the same. Thus the time of flight must be:

$$T = 2\left(\frac{2H}{g}\right)^{1/2}$$

Part B.

The horizontal distance traveled by an ideal frictionless car would be given by the product of initial velocity, V_0, and time. For a real car, you need to know how the velocity decreases with time due to friction. Since the friction is likely to be a constant force, you can assure the velocity decreases at a uniform rate. The acceleration is a *negative* constant, **a**. Thus the velocity will have dropped to zero. This is written as:

$$0 = V_0 + aT \qquad \text{(Eqn 1)}$$

Therefore:

$$D = V_0 T + 1/2 \, aT^2 \qquad \text{(Eqn 2)}$$

where **a** has a negative value.

From Eqn 1, derive:

$$V_0 = -aT$$

Substituting Eqn 1 into Eqn 2 gives:

$$D = -aT^2 + 1/2 \, a \, T^2$$
$$= -1/2 \, a \, T^2$$

Therefore:

$$a = \frac{-2D}{T^2}$$

The measurements of **D** and **T** are combined to give the (negative) acceleration of the car. This can now be used to calculate what happens during the flight of the ball.

While the ball is in the air for T seconds, the ball travels a horizontal distance V_0T. The car, however, travels a distance calculated as follows:

$$D = V_0T + 1/2 \, a \, T^2$$

The ball travels further than the car. The further amount it travels is:

$$\Delta = V_0T - (V_0T + 1/2 \, a \, T^2)$$
$$\Delta = -1/2 \, a \, T^2$$

Substituting for **a** and **T** gives:

$$\Delta = -1/2 \left(\frac{2D}{T^2}\right) 4\left(\frac{2H}{g}\right)$$

$$\Delta = \frac{8DH}{T^2 \, g}$$

Typical values of D = 2.0 m, **H** = 0.27 m. **T** = 12 seconds yields:

$$\Delta = \frac{8 \times 2.0 \times 0.27}{12^2 \times 9.8}$$

$$\Delta = 0.003 \text{ m}$$
$$= 3 \text{ mm}$$

Therefore as long as friction is low enough to give similar values of delta (which are small compared with the barrel mouth) the demonstration is valid. The Ballistics Car is a real world case which shows how the horizontal motion of an object is unaffected by vertical motion.

How to Teach with Ballistics Car

Concepts Taught: Scalar vs vector quantities; velocity as a vector; horizontal and vertical components; their mutual independence. Projectile motion; Newton's Laws of Motion; Equations of Motion and calculation of variables using them; acceleration due to gravity.

Curriculum Fit: Physics Sequence; Motion & Force. *Unit: Causes of Motion*

Related Products:

Science First *manufactures over 50 science labs carried by most science education dealers.*

611-1310 Dynamics Car Pair - Two -all aluminum cars with small and large bumpers of 2 thicknesses, instructions.

611-1300 Mini-Dynamics Pair - Good for grades 6-8 up. Two plastic cars with low-friction wheels, spring-steel bumpers, instructions at a basic level.

611-0110 Second Law of Motion - Which of two balls strikes the ground first - the one dropped or the one shot outward? Plastic housing, spring plunger, two balls, instructions.

611-1220 Variable Inertia - Load two plastic discs with up to 8 steel balls, roll down incline. Which is fastest? Instructions, 8 balls, all hardware.