Ballistics

1 Object

To measure the muzzle speed of a spring-loaded gun.

2 Apparatus

Computer, photo-gate, projectile launcher with steel ball, meter stick, paper, target.

3 Theory

When a ball is launched into the air with an initial speed $\mathbf{v}_o$ at an angle θ with respect to the horizontal, the motion can be broken into horizontal and vertical motions. If air resistance is negligible, the acceleration is g downward, where $g = 9.81\,m/s^2$. Then the vertical position y as a function of time t is given by

$$y = y_o + (v_o \sin\theta)t - \frac{1}{2}gt^2 \tag{1}$$

where y_o is the initial vertical position and g is the acceleration due to gravity. Since there is *no horizontal acceleration*, the horizontal position as a function of time is

$$x = x_o + (v_o \cos\theta)t \tag{2}$$

where x_o is the initial horizontal position. **Note**: the above equations assume up to be positive.

If you fire the ball horizontally and choose $x_o = 0$, then the equations simplify to

$$y = y_o - \frac{1}{2}gt^2 \tag{3}$$

$$x = v_o t \tag{4}$$

The speed v_o can be determined from where the ball hits the ground and the original height of the ball.

An alternative method of measuring v_o is to measure the distance d the ball travels horizontally (before it has fallen very far) and the time t to travel that distance. Then the speed is

$$v_o = d/t \tag{5}$$

4 Procedure

Use the same ball and launcher for the entire experiment.

4.1 Part 1. Direct measurement of muzzle speed by photo-gate

1. Clamp the projectile launcher onto the table so it will shoot down the length of the table
2. Loosen the screws which hold the launcher in place. Adjust the launcher so the plumb bob hangs at the 0° mark on the scale on the side of the launcher. Tighten the screws.

3. Measure the height of the *center* of the ball in the projectile launcher from the table – the location is drawn on the outside of the launcher. Set the height of the photo-gate beam to this height.

4. Cock the launcher all the way. Position the photo-gate close to the exit of the launcher so that the ball will pass through the center of the photo-gate. **Make sure the ball won't hit the photo-gate!**

5. Place the cardboard box 30 or 40 cm away and use it to catch the ball when fired.

6. Fire the ball. Record the time the ball blocked the beam.

7. Fire the ball 4 more times, recording the time for each one.

8. Find the mean and associated error of the 5 times – $\bar{t}$ and δt, respectively.

9. Using a caliper, measure and record the diameter D of the ball.

10. The photogate uses a beam of light to sense when something is between its sensors. The number that will appear on the computer screen is how long the photogate beam is blocked by the ball when the ball has been shot through it. If the photogate beam were very narrow, then it would read a time which was correct for the diameter blocking the beam. However, since the beam is not narrow, the photogate reads a time that corresponds to a distance less than the actual diameter. To correct for this, you will use drill bits to estimate the size of the beam. Start with the smallest bit and move it through (vertically) the photo-gate. If it does not register a time on the screen, then repeat with successively larger bits until one does register a time. The spot size is then found by subtracting the distance (bit size) of the last bit to NOT register a time from the measured diameter of the ball: $d = D -$ bit size.

11. The velocity of the ball is then $v_o = d/\bar{t}$, and the associated error is $\delta v_o = v_o \delta t/\bar{t}$.

4.2 Part 2. Determination of the muzzle speed using projectile motion

1. Clamp the projectile launcher on the bench next to the wall so the ball will pass parallel to and within $0.5\,m$ of one of the free-standing benches.

2. Adjust the angle of the launcher so it is horizontal again.

3. After making sure no one is in the way, cock the launcher all the way and test fire to see where the ball will land on the floor.

4. Tape a piece of paper to the floor centered on the point of impact.

5. Fire the launcher 5 times. Draw a circle around each point of impact.

6. Leaving the paper taped to the floor, measure the horizontal distance from where the ball leaves the launcher to each of the 5 impact points. Record these values.

7. Measure the height of the ball from the floor to the point where it leaves the launcher. Is this to the center, top, or bottom of the ball? Record this as y_o.

8. Calculate the mean distance $\bar{x}$ and its associated error δx.

9. Using equation 3, calculate the time t for the ball to drop from the launcher to the floor.

10. Using equation 4, calculate the muzzle speed v_o. Then $\delta v_o = v_o \delta x / \bar{x}$.
11. Enter the velocity and its associated error in the table. Also indicate agreement in the spaces provided.

5 Questions

1. Why is it necessary to cock the launcher the same every time?
2. How would your photo-gate measurements have been affected if you had set the photo-gate beam above or below the center of the ball?
3. How would your measurements have been affected if you had done this on the moon outdoors?
4. How would your measurements have been affected if you didn't have the photo-gate close to the mouth of the launcher?
5. Which of the two methods used to find the muzzle speed do you think is the most accurate? Explain why you think so.

6 Ballistics Data Sheet

6.1 Part 1 – Photo-gate data

Trial #	Time (s)	Diameter of ball (cm)	
1		d (cm)	
2		Mean time $\bar{t}$ (s)	
3		Associated error δt (s)	
4		Initial velocity v_o (m/s)	
5		Associated error δv_o (m/s)	

6.2 Part 2 – Muzzle speed data

Trial #	Distance to ball (cm)	Other data	
1		y_o (cm)	
2		$\bar{x}$ (m)	
3		δx (m)	
4		v_o (m/s)	
5		δv_o (m/s)	

Velocity and error part 1	Velocity and error part 2	Agreement?