SI Physics - Full Discipline Demo

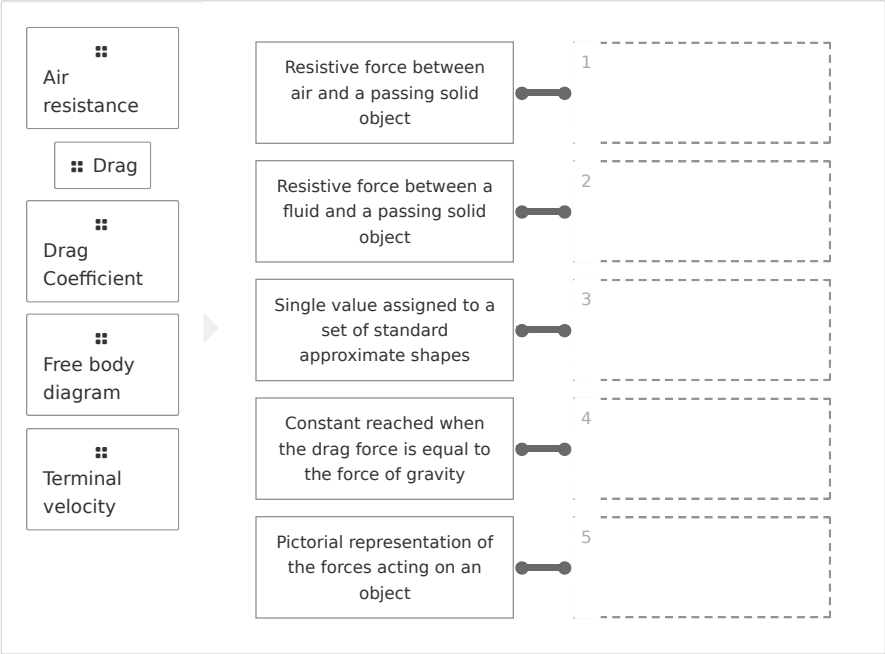
Air Resistance

Final Report - Answer Guide

Institution	Science Interactive University
Session	SI Physics - Full Discipline Demo
Course	SI Physics - Full Discipline Demo
Instructor	Sales SI Demo

Test Your Knowledge

Match each term with the best description.

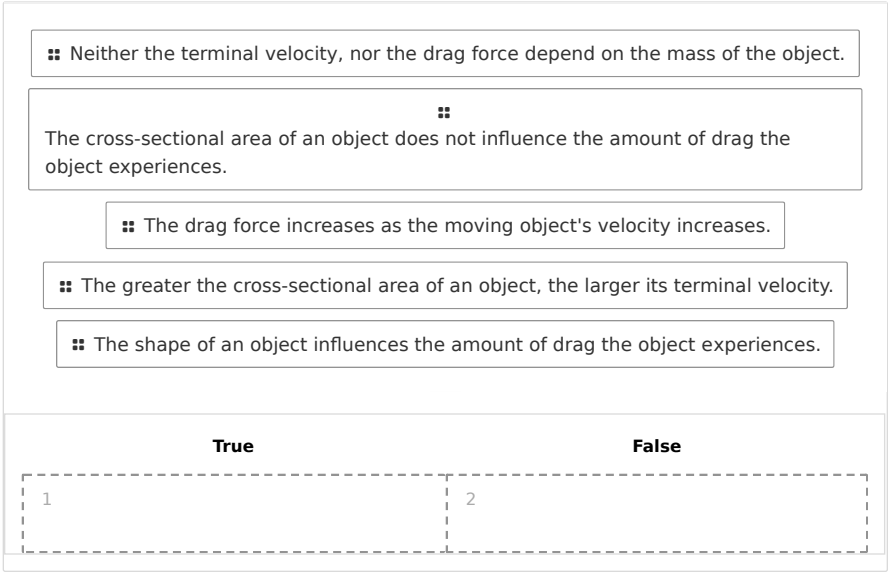


Correct answers:

1 Air resistance 2 Drag 3 Drag Coefficient 4 Terminal velocity

5 Free body diagram

Categorize each statement as true or false.



Correct answers:

1 The drag force increases as the moving object's velocity increases.

The shape of an object influences the amount of drag the object experiences.

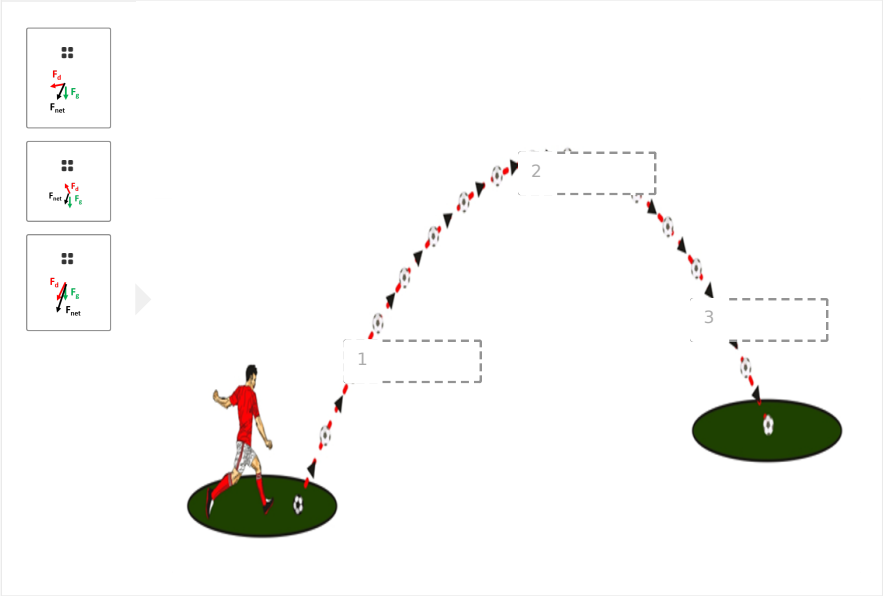
2

Neither the terminal velocity, nor the drag force depend on the mass of the object.

The cross-sectional area of an object does not influence the amount of drag the object experiences.

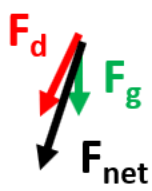
The greater the cross-sectional area of an object, the larger its terminal velocity.

Label the locations on the soccer ball trajectory with the correct force arrows.



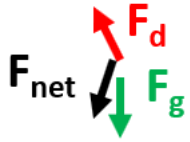
Correct answers:

1



2

3



Exploration

The resistive force of drag occurs between a passing object and ____.

- air
- water
- molasses
- All of the Above ✔

Drag points in the _____ the motion of a solid moving object.

- same direction as
- opposite direction of ✔
- perpendicular direction to
- None of the Above

For moving objects with speeds less than a few hundred meters per second, drag increases _____ the velocity.

- like the square root of
- like the
- like the square of ✔
- None of the Above

The _____ of the object influences the drag force.

- shape
- cross-sectional area
- velocity
- All of the Above ✔

When the drag force reaches the magnitude of the accelerating force the object _____.

- no longer accelerates ✔
- speeds up
- slows down
- None of the Above

The _____ depends on the mass of the object.

- drag force
- acceleration due to gravity
- terminal velocity ✔
- All of the Above

An object moving as a projectile experiences a _____ drag.

- constant
- constantly changing ✔
- constantly increasing
- None of the Above

The drag force increases the maximum height and maximum range traveled by a projectile.

- True
- False ✔

Exercise 1

How does air resistance affect the trajectory of a projectile? Consider maximum height reached, range, and trajectory symmetry.

Air resistance shortens the range and maximum height reached by a projectile. The shape of the trajectory becomes scrunched in the presence of air resistance and does not make a symmetric, parabolic path, as it seen in the absence of air resistance.

Draw the trajectory of a projectile in the presence of air resistance. On the trajectory, draw a free body diagram of the projectile at three points: its initial position, its maximum height, and its final position. Include the force due to gravity, the total drag force, and the net force. Upload an image of the diagram into Panel 1.

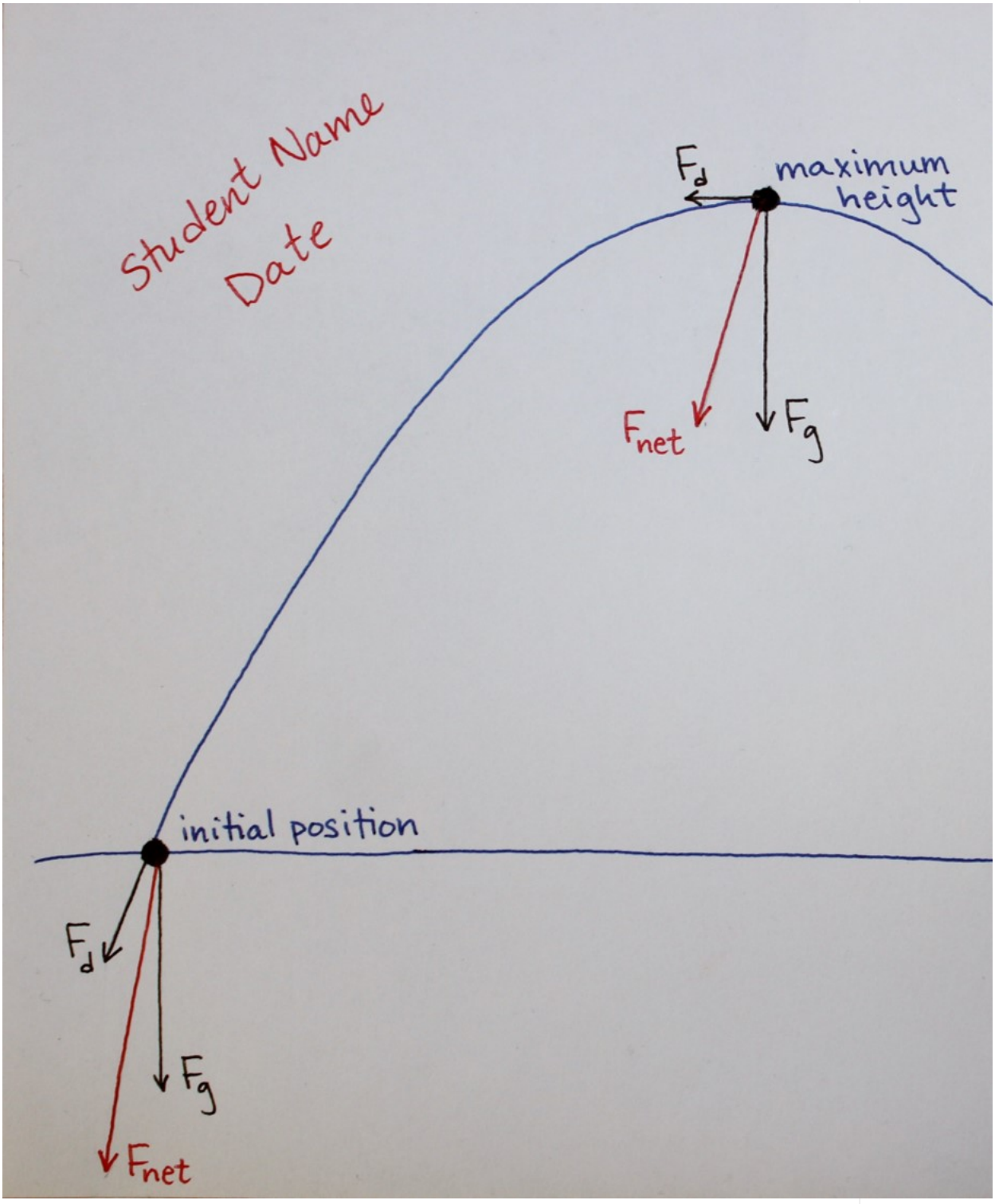
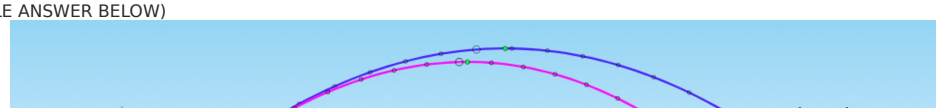
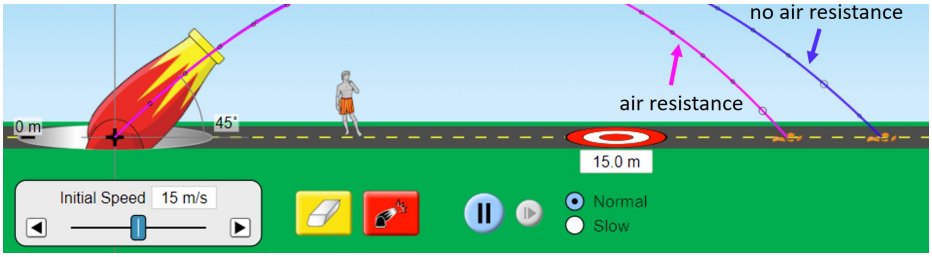


Photo 1: Trajectories of a Projectile With and Without Air Resistance

(SAMPLE ANSWER BELOW)





Data Table 1: Comparing Properties of Projectiles in the Presence and Absence of Air Resistance

(SAMPLE ANSWER BELOW)

Property	Description of Trajectory
Change in Trajectory	With no air resistance the range is longer and the maximum height is higher. The trajectory of the pumpkin without air resistance is symmetric whereas the trajectory with air resistance is not.
Change in Velocity Vector Components	The x-component of velocity remains constant throughout the projectile's flight. The y-component of velocity begins pointing upward, decreases to a magnitude of zero, then increases in magnitude, pointing in a direction opposite to its initial direction.
Change in Force Vector Components	The downward force due to gravity remains constant throughout the projectile's flight. The x-component of the drag force stays constant throughout the flight and always points in the opposite direction of the x-velocity component. The y-component of the drag force decreases in magnitude, reaches a value of zero at the trajectory

	peak, then increases in magnitude. The y-component of the drag force always points in the opposite direction of the y-velocity component.

Photo 2: Projectile and Initial Velocity and Force Vectors
(SAMPLE ANSWER BELOW)

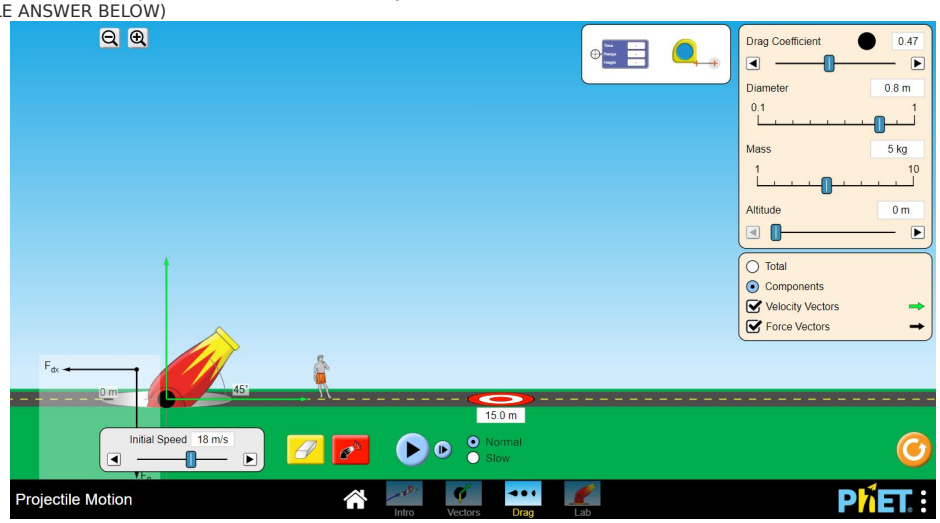


Photo 3: Projectile and Velocity and Force Vectors at Maximum Height
(SAMPLE ANSWER BELOW)

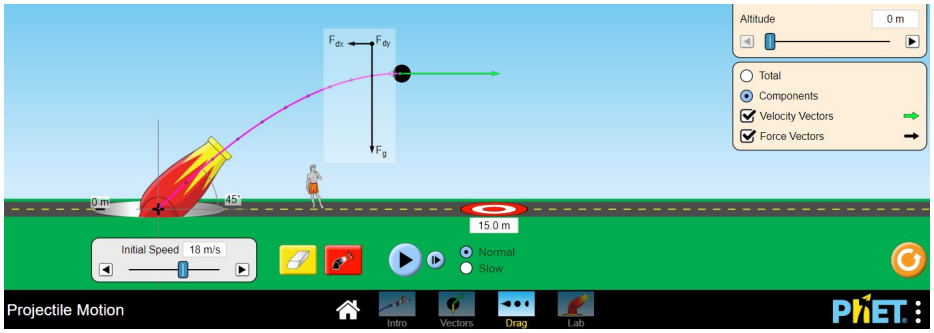
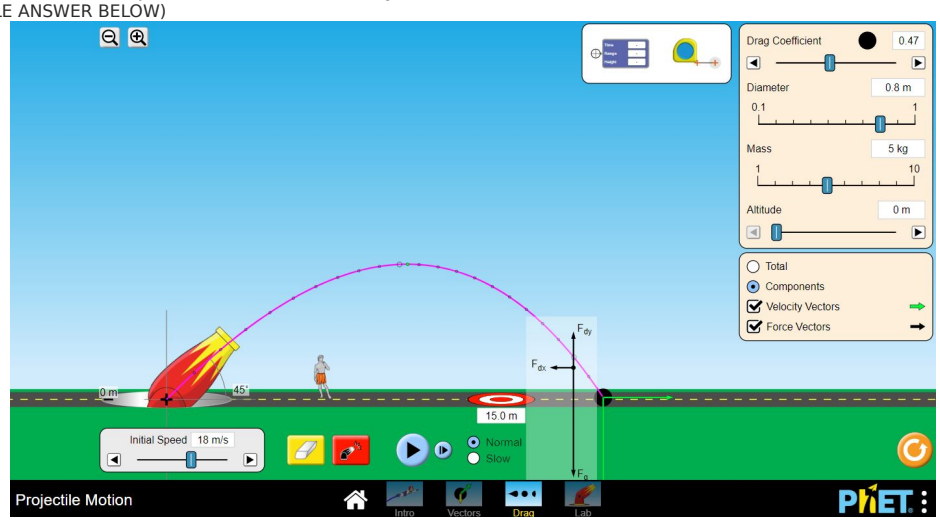
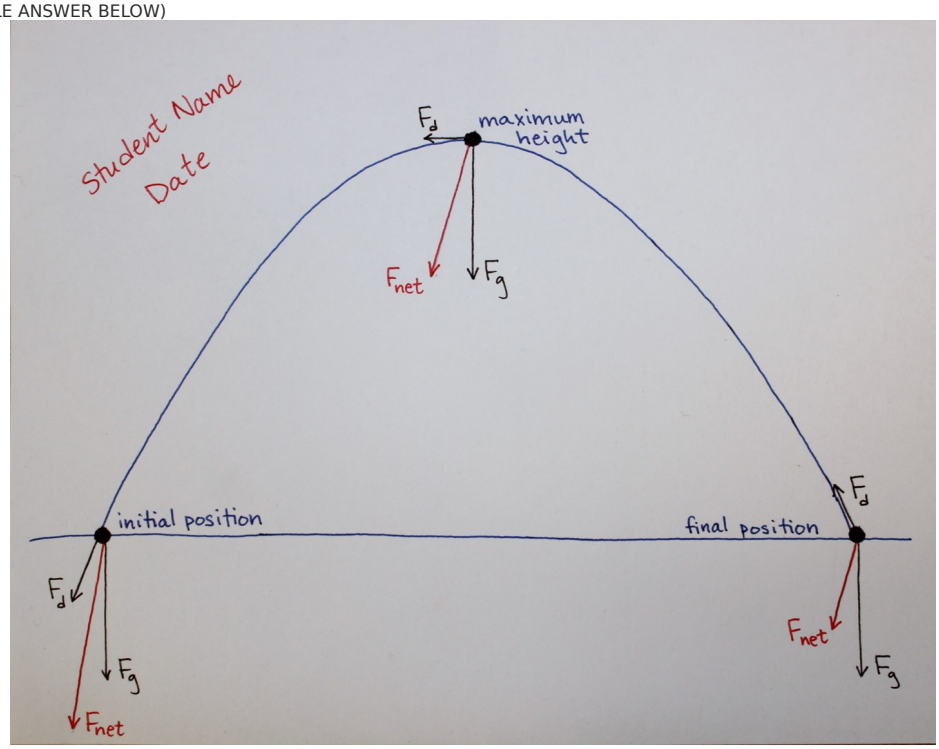


Photo 4: Projectile and Final Velocity and Force Vectors

(SAMPLE ANSWER BELOW)



Panel 1: Diagram for Question 2
(SAMPLE ANSWER BELOW)



Exercise 2

A sphere with a mass of 10 kg and radius of 0.5 m moves in free fall at sea level (where the air density is 1.22 kg/m^3). If the object has a drag coefficient of 0.8, what is the object's terminal velocity? What is the terminal velocity at an altitude of 5,000 m, where the air density is 0.736 kg/m^3? Show all calculations in your answer.

The equation for terminal velocity is SQRT(2mg/$C_d\rho A$). Here, A = πr^2 = π(0.5 m)^2 = 0.785 m^2. Plugging in our known values at sea level, $v_{terminal}$=SQRT((2 x 10 kg x 9.81 m/s^2)/(0.8 x 1.22 kg/m^3 x 0.785 m^2) = **16.0 m/s**. At an altitude of 5,000 m, we have $v_{terminal}$=SQRT((2 x 10 kg x 9.81 m/s^2)/(0.8 x 0.736 kg/m^3 x 0.785 m^2)) = **20.6 m/s**.

A sphere with a mass of 5 kg and radius of 0.8 m travels at a speed of 15 m/s at sea level. If the drag coefficient is 0.5, what is the drag force the object experiences? What is the drag force if the sphere moves with a speed of 20 m/s?

The equation for drag force is F_d = ½ $C_d\rho Av^2$. The area A = πr^2 = π(0.8 m)^2 = 2.01 m^2. With a speed of 15 m/s, the drag force is F_d = ½ x 0.5 x 1.22 kg/m^3 x 2.01 m^2 x (15 m/s)^2 = **138 N**. With a speed of 20 m/s, the drag force is F_d = ½ x 0.5 x 1.22 kg/m^3 x 2.01 m^2 x (20 m/s)^2 = **245 N**.

Two spherical objects at the same altitude move with identical velocities and experience the same drag force at a time t. If Object 1 has twice (2x) the diameter of Object 2, which object has the larger drag coefficient? Explain your answer using the drag equation.

The two objects experience the same drag force. Thus, the equations used to find the drag force for each object can be set equal to each other: $F_{d1} = F_{d2}$, or $\frac{1}{2} C_{d1}\rho_1 A_1 v_1^2 = \frac{1}{2} C_{d2}\rho_2 A_2 v_2^2$. Since the velocities are the same and the objects are at the same elevation, the air density and velocities cancel. Further, the constant factor of ½ cancels. The equation then becomes: $C_{d1}A_1 = C_{d2}A_2$. The area A is a function of the diameter, $A = \pi r^2 = \pi(d/2)^2$. The equation then becomes: $C_{d1}\,\pi(d_1/2)^2 = C_{d2}\,\pi(d_2/2)^2$, or $C_{d1}d_1^2 = C_{d2}d_2^2$. If Object 1 has twice the diameter of Object 2, $d_1 = 2d_2$. The equation then becomes: $C_{d1}(2d_2)^2 = C_{d2}d_2^2$, or $4C_{d1}d_2^2 = C_{d2}d_2^2$. Canceling d_2, this becomes $4C_{d1} = C_{d2}$. Thus, we see **the drag coefficient of Object 2 is larger** than the drag coefficient of Object 1.

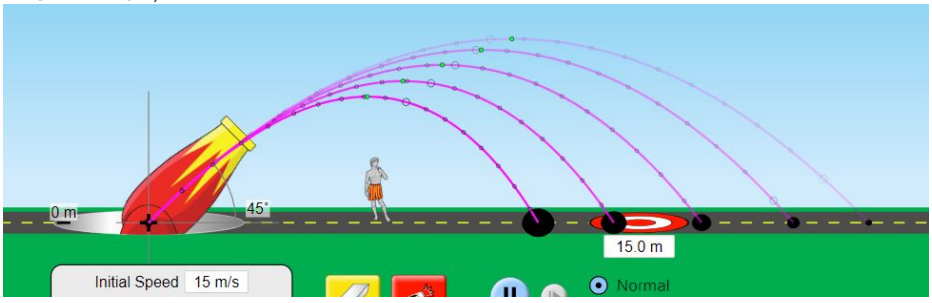
The drag force is not affected by mass. Does your data in Data Table 4 support or refute this statement? Explain your answer using Newton's second law, F=ma.

The data does supports this statement, though it is not obvious at first glance. The change in trajectory is due to Newton's second law which, rearranged, states a = F/m. Thus, the acceleration of a projectile changes inversely with mass, even when the drag force is unchanged. This change in acceleration alters the trajectory of the projectile. So, with a larger mass, there is a smaller net acceleration, allowing the projectile to move further and higher.

Data Table 2: Changing the Diameter of a Projectile
(SAMPLE ANSWER BELOW)

Diameter (m)	Flight Time (s)	Flight Range (m)	Maximum Height (m)	Cross-Sectional Area (m^2)	Initial Drag Force (N)
0.2	2.14	22.02	5.61	0.03	2.59
0.4	2.07	19.71	5.27	0.13	10.35
0.6	1.98	16.91	4.81	0.28	23.28
0.8	1.87	14.22	4.32	0.50	41.39
1.0	1.76	11.91	3.84	0.79	64.68

Photo 5: Projectiles and Trajectories with Varied Diameters
(SAMPLE ANSWER BELOW)



Data Table 3: Changing the Drag Coefficient of a Projectile

(SAMPLE ANSWER BELOW)

Drag Coefficient (m)	Flight Time (s)	Flight Range (m)	Maximum Height (m)	Initial Drag Force (N)
0.15	2.12	21.54	5.54	4.04
0.30	2.09	20.33	5.36	8.08
0.45	2.06	19.26	5.20	12.13
0.60	2.03	18.33	5.05	16.17
0.75	2.00	17.49	4.91	20.21

Photo 6: Projectiles and Trajectories with Varied Drag Coefficients

(SAMPLE ANSWER BELOW)

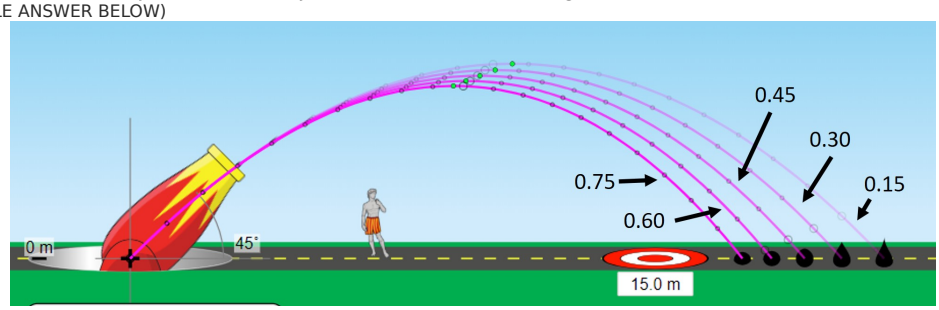
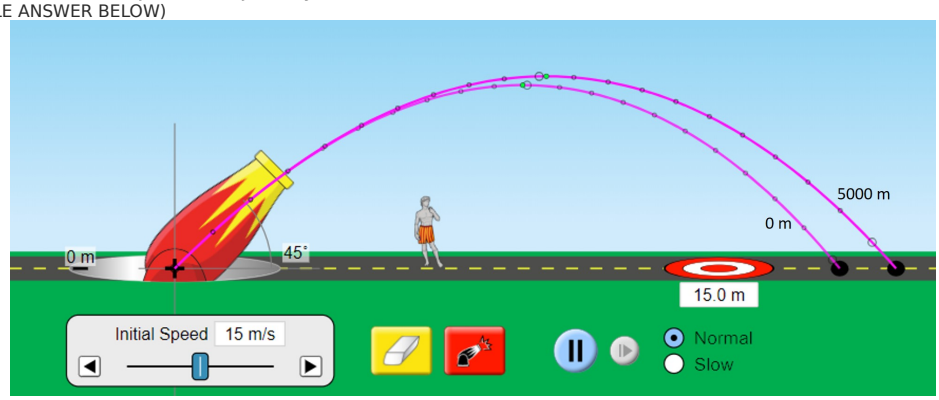


Photo 7: Projectile Trajectory at Two Different Altitudes
(SAMPLE ANSWER BELOW)



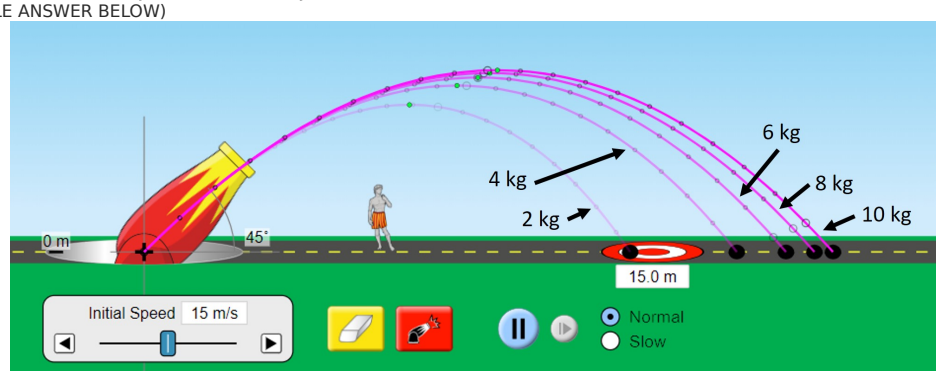
Data Table 4: Changing Mass of a Projectile

(SAMPLE ANSWER BELOW)

Mass (m)	Flight Time (s)	Flight Range (m)	Maximum Height (m)
2	1.87	14.34	4.34
4	2.00	17.49	4.91
6	2.05	18.94	5.15
8	2.07	19.78	5.28
10	2.09	20.33	5.36

Photo 8: Projectiles and Trajectories with Varied Masses

(SAMPLE ANSWER BELOW)



Competency Review

The _____ is a single value encompassing the influence of the shape of an object on its motion through a medium.

- drag force
- air resistance
- drag coefficient ✔
- None of the Above

Air resistance is another name for drag when an object is moving through the air.

- True ✔
- False

The drag force is _____ to the cross-sectional area of the object.

- proportional ✔
- inversely proportional
- not related
- None of the Above

The drag force is _____ to the density of the object.

- proportional
- inversely proportional
- not related ✔
- None of the Above

For an object in free-fall, when the drag force equals the _____, the object reaches terminal velocity.

- air resistance
- weight of the object ✔
- drag coefficient
- None of the Above

The more massive an object, the larger its terminal velocity.

- True ✔
- False

An object in free-fall will experience its maximum drag force at the maximum height of its trajectory.

- True
- False ✔

Air resistance makes the shape of a projectile's trajectory a less than perfect parabola.

- True ✔
- False

The larger the drag coefficient, the _____ the maximum height of a projectile.

- higher
- lower ✔
- more unpredictable
- None of the Above

Projectiles launched at higher altitudes (lower air densities) have _____ ranges.

- longer ✔
- shorter
- unchanged
- None of the Above

Mass does not influence the drag force experienced by an object.

- True ✔
- False

The terminal velocity is inversely proportional to the square root of the _____.

- drag coefficient
- density of the medium
- cross-sectional area
- All of the Above ✔

Extension Questions

Describe all the factors you should consider when designing a rocket that you want to experience minimal air resistance. (SAMPLE ANSWER BELOW)

The drag coefficient needs to be a small as possible, which means considering the shape of the rocket, something similar to an airfoil or bullet is preferable. The cross-sectional area of the rocket should also be minimized to reduce the air resistance experienced by the rocket. The rocket should not travel extremely fast either, because the air resistance is proportional to the square of the velocity of the rocket. The rocket should travel through high-altitude air if possible, because the air at high altitudes has lower density, which decreases the air resistance.