Lab #4 – Discussion

In this lab we introduced several new terms: air resistance, terminal velocity, and dynamic equilibrium. In our previous study of freely falling bodies, the only force acting on our projectiles was the pull of gravity, represented in a freebody diagram (FBD) by the projectile's weight. Since this single force is an unbalanced force, the projectiles experienced a downward acceleration towards the Earth's center. By referencing Newton's 2nd Law we have the relationship that

$$\begin{aligned} net\ F &= ma \\ -mg &= ma \\ -g &= a \end{aligned}$$

showing us that all objects in freefall experience the same acceleration regardless of their mass.

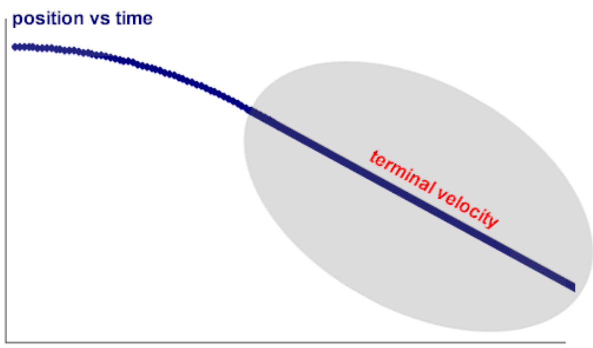
This lab introduced the concept of air resistance. The force of air resistance is often called a drag force and proportional to the object's surface area and the square of the object's velocity. The negative sign denotes the fact that it always acts in the opposite direction to the object's motion.

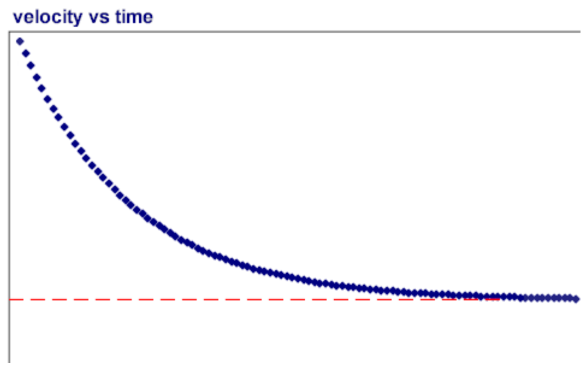
$$F_{\text{air resistance}} = -kv^2$$

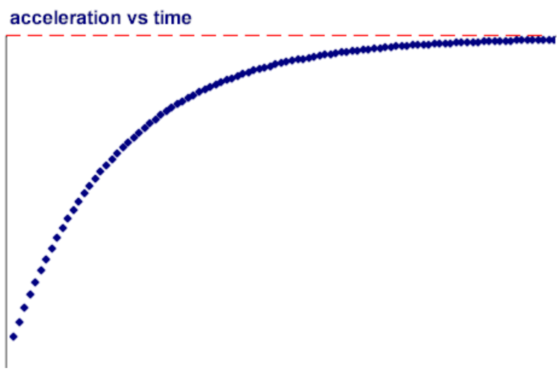
The constant, *k*, in this equation incorporates information regarding the object's surface area, the density of fluid (gas) through which the projectile is moving, and its drag coefficient. The drag coefficient for a smooth sphere is 0.1, a subsonic bullet is 0.295, a coffee filter 0.8-0.9, a falling surface perpendicular to the air flow is between 1.98-2.05. All drag coefficients are dimensionless numbers.

When the air resistance encountered by a falling object equals its weight, the object enters a state of dynamic equilibrium. This means that the falling object ceases to accelerate, continuing to move instead at a constant velocity.

If we compare the graphs of **position vs time**, **velocity vs time**, and **acceleration vs time** for freely falling bodies and bodies encountering air resistance our graphs would have total different shapes.



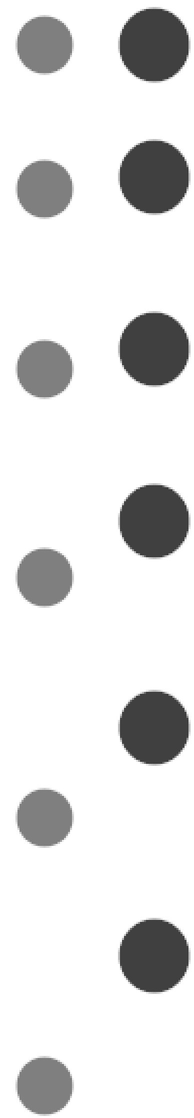




Notice that the graphs of **velocity vs time** and **acceleration vs time** now have horizontal asymptotes – that is, they approach limiting values. For **velocity vs time**, the asymptote equals the terminal velocity. For **acceleration vs time**, the asymptote approaches zero when the object enters dynamic equilibrium.

Position vs time ceases to be parabolic and becomes linear showing that the object has a constant velocity.

Practice Questions for Terminal Velocity



1. What is meant by the term “free fall”?

2. What is the ratio of force/mass for freely-falling bodies?

3. Why doesn't a heavy object accelerate more than a light object when both are freely falling?

4. What is the net force that acts on a 10-N freely falling object?

5. What is the net force that acts on a 10-N falling object when it encounters 4 N of air resistance?

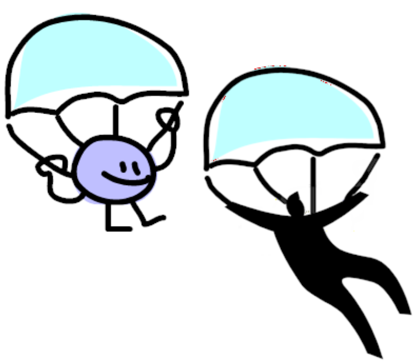
What is the net force with 10 N of air resistance?

6. What two principal factors affect the force of air resistance on a falling object?

7. In the picture to the right, there are two columns of images. Which column would represent the behavior of a golf ball? Which column would represent the behavior of a Styrofoam ball? Explain how you came to your decision..

8. What is the acceleration of a falling object that has reached its terminal velocity?

9. Why would a heavy parachutist fall faster than a lighter parachutist who wears the same size parachute?



10. If two objects, having the same size, fall through air at different speeds, which encounters the greater air resistance?

11. A parachutist, after opening the chute, finds herself gently floating downward, no longer gaining speed. She feels the upward pull of the harness, while gravity pulls her down.

Which of these two forces is greater?

Or are they equal in magnitude?

12. Why will a sheet of paper fall slower than one that is wadded into a ball?

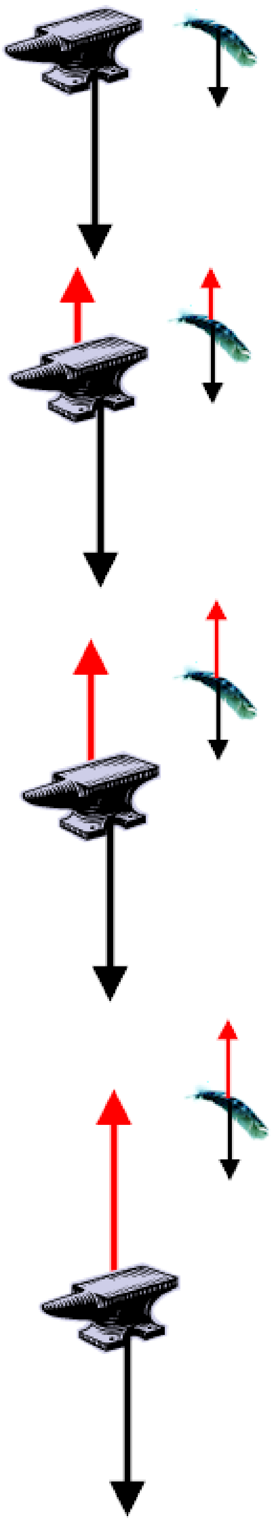
13. How does the terminal speed of a parachutist who is in a pike position before opening a parachute compare to terminal speed after the parachute opens? Why is there a difference?

14. How does the gravitational force on a falling body compare with the air resistance it encounters before it reaches terminal velocity?

After?

15. If a ball is thrown vertically into the air in the presence of air resistance, would you expect the time during which it rises to be longer or shorter than the time during which it falls? Why?

16. In the absence of air resistance, if a ball is thrown vertically upward with a certain initial speed, on returning to its original level it will have the same speed. When air resistance is a factor, will the ball be moving faster, the same, or slower than its throwing speed when it gets back to the same level? Why?



17. An anvil and a feather are both released from the roof of a very tall building. Which of the following statements are true?

1. The anvil encounters a smaller force of air resistance than the feather and therefore falls faster.
2. The anvil has a greater acceleration of gravity than the feather and therefore falls faster.
3. Both anvil and feather have the same force of gravity, yet the acceleration of gravity is greatest for the anvil.
4. Both anvil and feather have the same force of gravity, yet the feather experiences a greater air resistance.
5. Each object experiences the same amount of air resistance, yet the anvil experiences the greatest force of gravity.
6. Each object experiences the same amount of air resistance, yet the feather experiences the greatest force of gravity.
7. The feather weighs more than the anvil, and therefore will not accelerate as rapidly as the anvil.
8. Both anvil and feather weigh the same amount, yet the greater mass of the feather leads to a smaller acceleration.
9. The anvil experiences less air resistance and than the feather and thus reaches a larger terminal velocity.
10. The feather experiences more air resistance than the anvil and thus reaches a smaller terminal velocity.
11. The anvil and the feather encounter the same amount of air resistance, yet the anvil has a greater terminal velocity.

18. Use the 1st and 3rd trials from the following data chart to illustrate the relationship between mass and terminal speed for two objects having the same drag coefficients. Calculate a percent difference between your mass ratio and your velocity ratio.

Mass of the stack of filters, m (kg)	1.12×10^{-3}	2.04×10^{-3}	2.96×10^{-3}	4.18×10^{-3}	5.10×10^{-3}
Terminal speed, v_T (m/s)	0.51	0.62	0.82	0.92	1.06

$$m_1 g = k v_1^2$$
$$m_2 g = k v_2^2$$

Since both groups of filters are falling through the same strength gravitational field and have the same drag coefficient, we can cancel the common g and k in our equations. Giving us the ratio

$$\frac{m_1}{m_2} = \frac{v_1^2}{v_2^2}$$