Air Resistance

A Variable Force…

Dynamics

I. Newton's 3 Laws of Motion
- inertia, force, mass, weight
- interaction & nature of force

II. Normal Force

III. Compression, Tension, Sections

IV. Pulleys and Systems

V. Friction (between solids)

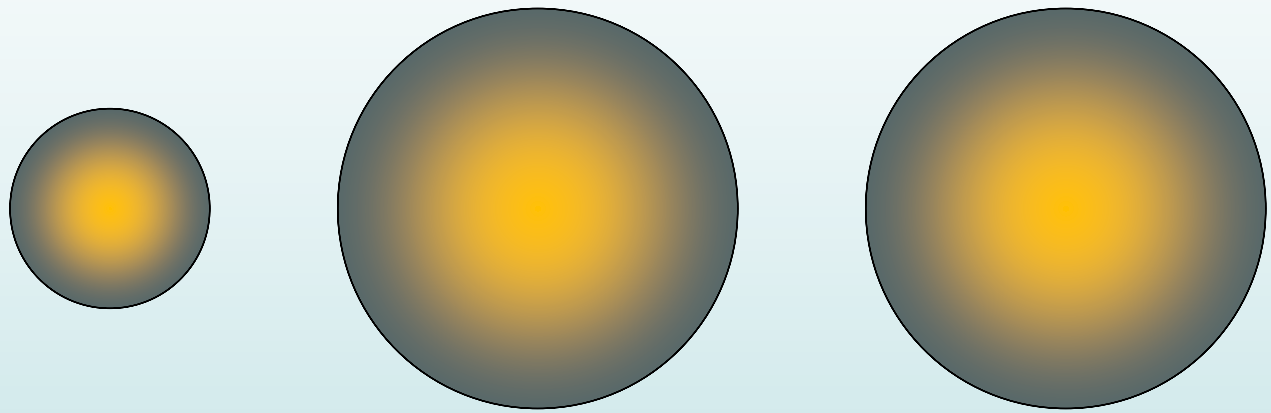
VI. Air Resistance

VII. Inclines, ramps, etc.

	The student will be able to:	HW:
1	State Newton's 1^{st} and 2^{nd} Laws of Motion and apply these laws to physical situations in order to determine what forces act on an object and to explain the object's resulting behavior. Define and apply the concept of inertia and inertial frame of reference.	1 – 7
2	Recognize and state the proper SI unit of force and give its equivalence in fundamental units and use the relation $\mathbf{F}_{net} = m\mathbf{a}$ to solve problems.	8 – 10
3	Recognize the difference between weight and mass and convert from one to the other.	11 – 14
4	State and utilize Newton's 3^{rd} Law to solve related problems.	15 – 18
5	Understand and utilize the concept of the normal force to solve related problems.	19, 20
6	Define and apply the concepts of compression and tension and use the method of sections to solve for these.	21 – 26
7	Solve force problems involving pulleys, including those involving multiple objects and systems of equations (such as Atwood's machine).	27 – 31
8	Understand and utilize the relation between friction force, normal force, and coefficient of friction for both cases: static and kinetic.	32 – 37
9	Solve problems involving air resistance in which friction is assumed directly proportional to velocity; define and apply the concept of terminal velocity.	38 – 39
10	Apply force components to objects on an incline and solve related problems.	40 – 44

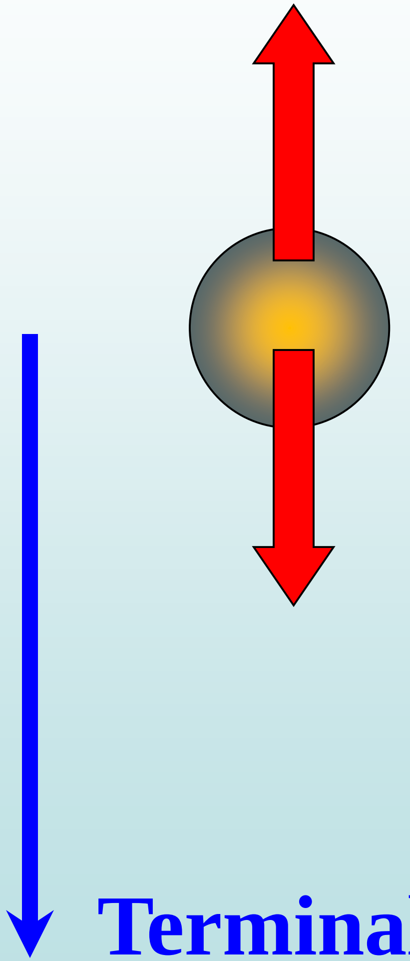
Which object would experience the greatest amount of air resistance when falling?

How would the speeds compare when falling?



Weight:	**1 N**	**1 N**	**4 N**
Diameter:	**10 cm**	**20 cm**	**20 cm**

A falling object accelerates and gains speed as long as the downward pull of gravity (weight) is greater than the air resistance (drag). However, because drag increases with speed, eventually there is enough air resistance to perfectly balance the pull of gravity and cause the acceleration to be zero – this is the terminal velocity state.



Air resistance = 1 N

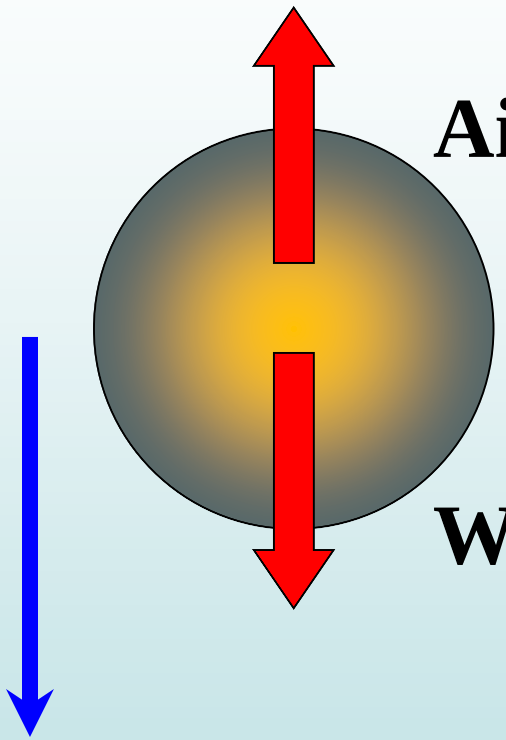
Weight = 1 N

Terminal velocity = 8 m/s

For a relatively lightweight object there will be a relatively low terminal velocity because not too much air resistance is required to prevent acceleration.

Twice the diameter as previous…

With twice the diameter there is four times the cross-sectional area as the previous, increasing the drag by factor four at a given speed. Terminal velocity occurs at half the speed as before because drag is most closely proportional to the square of the speed.



Air resistance = 1 N

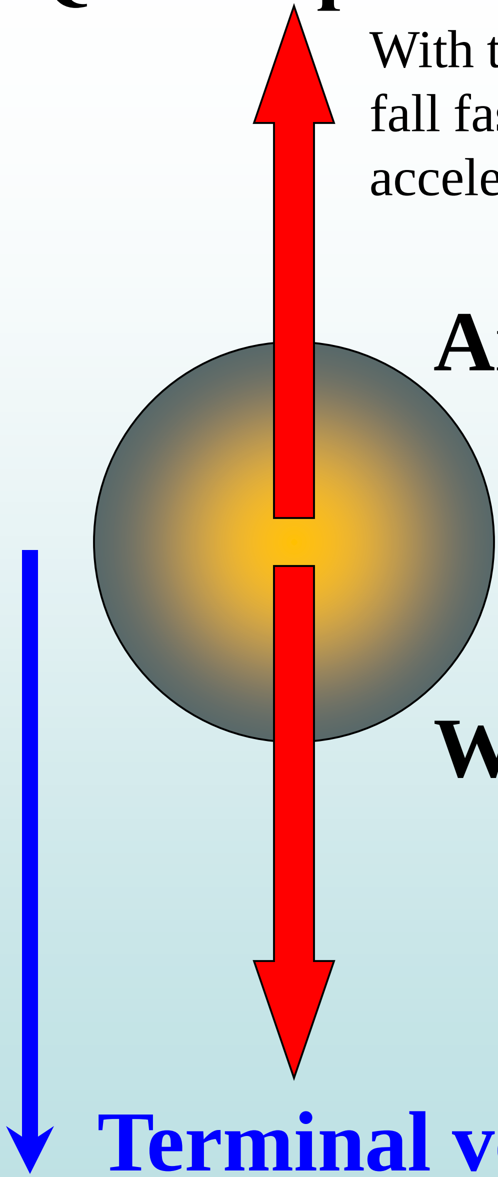
Weight = 1 N

With weight unchanged from the previous the amount of air resistance at terminal velocity would be the same as before. However, this amount of drag occurs at a lower speed.

Terminal velocity = 4 m/s

Quadruple the weight as the previous…

With twice the pull of gravity as the previous the object must fall faster through the air to produce enough drag to prevent acceleration.



Air resistance = 4 N

Weight = 4 N

Terminal velocity = 8 m/s

At twice the speed through the air as previous there would be approximately four times the drag. This object would have the same terminal velocity as the smallest object in this example set of three. But, it would experience four times the amount of air resistance.

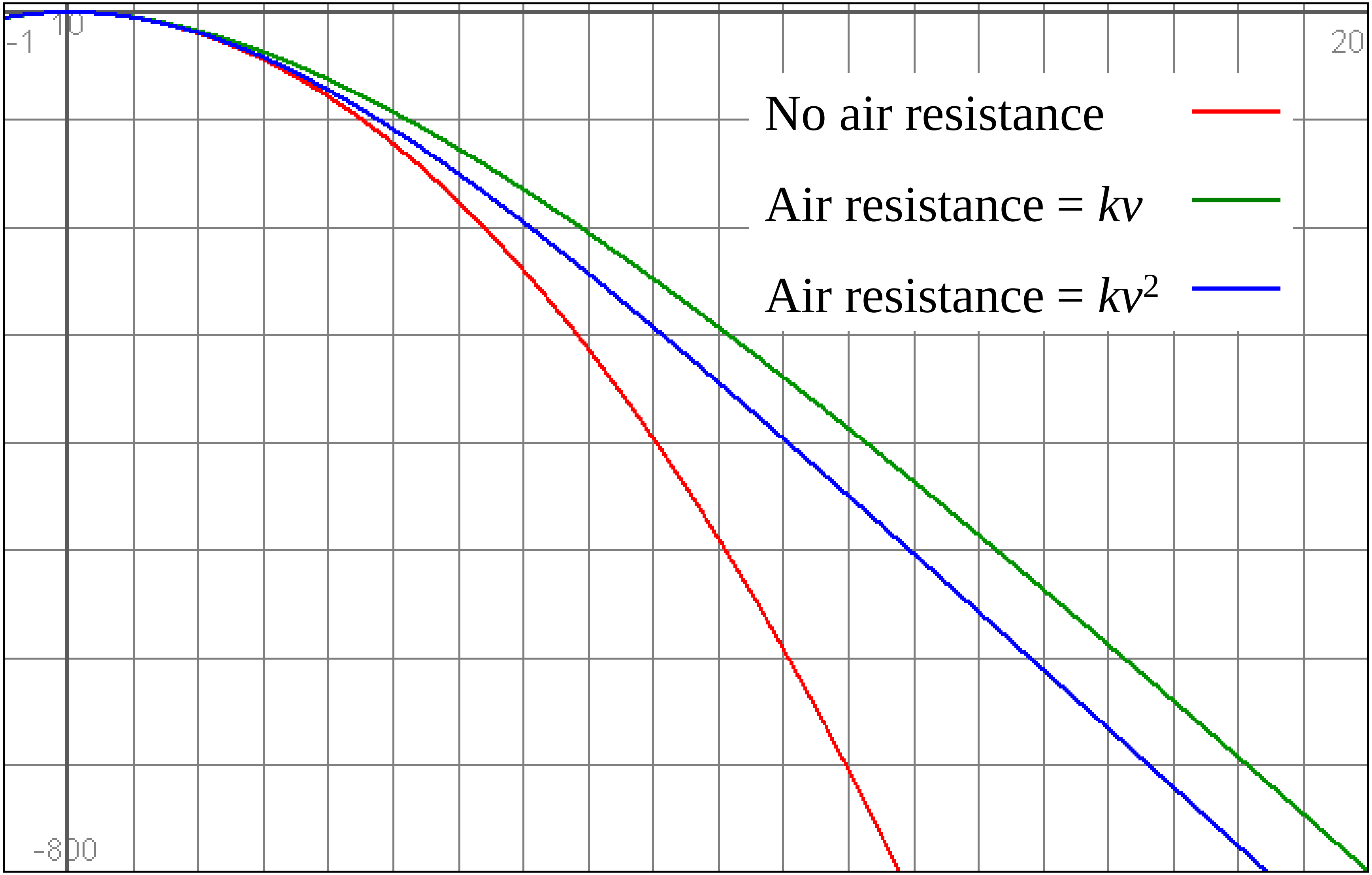
Modeling Motion through Air

- Air resistance is often ignored and acceleration is assumed constant 9.8 m/s^2 downward – the object is said to be in "freefall"
- In reality, air resistance depends on speed, cross-sectional area, density of the air, and the aerodynamic shape (*i.e.* how "streamlined").
- Usually it is assumed that air resistance is proportional to speed or that it is proportional to the square of the speed. Although neither assumption is exactly correct, the latter is usually more accurate especially at higher speeds.
- Air resistance is directly proportional to cross-sectional area and density of air.

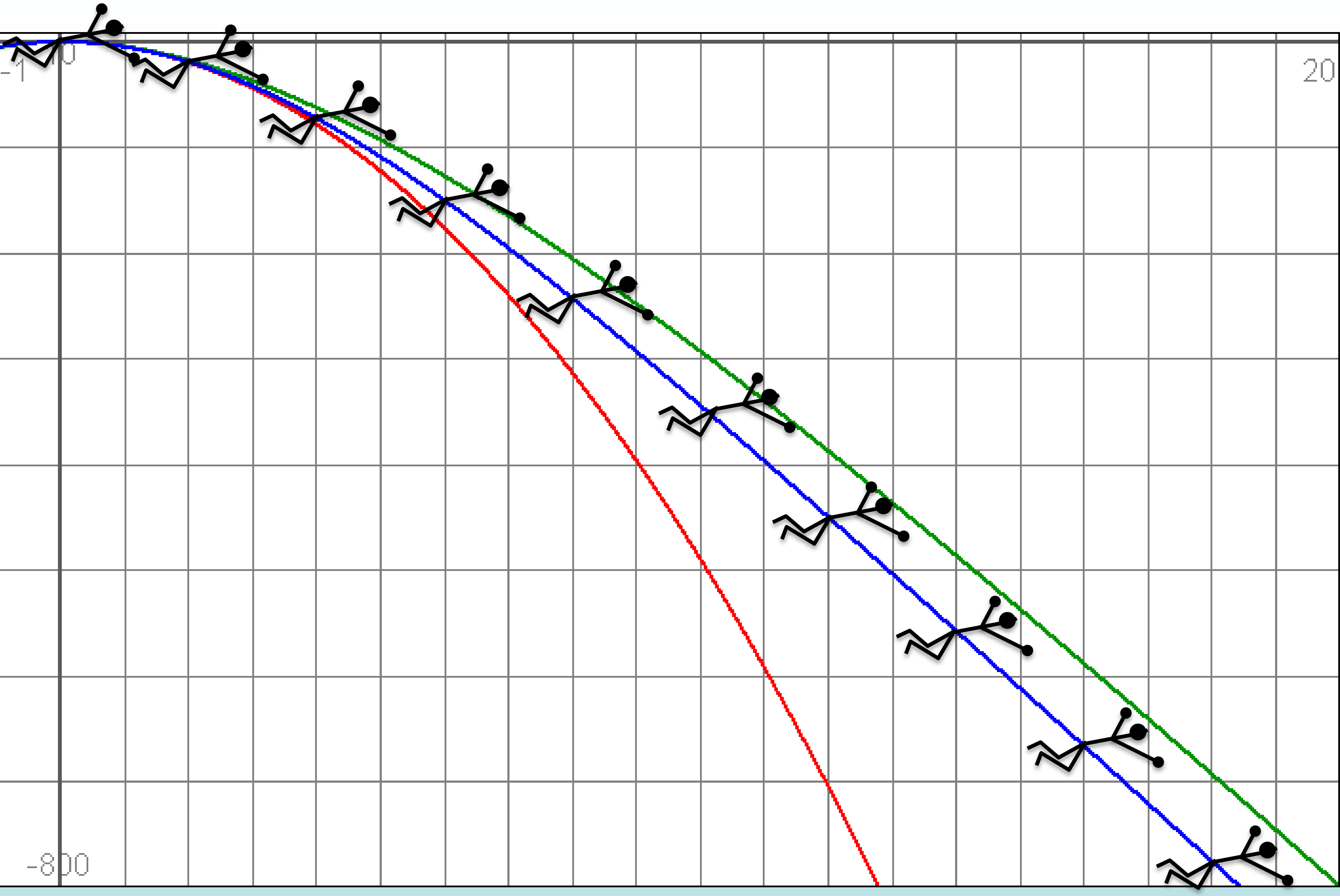
Modeling Motion through Air

- The graphs that follow illustrate the kinematics of objects moving through the air based on the three different modeling approaches.
- The red lines/curves represent freefall.
- The blue curves represent air resistance proportional to speed squared (and best represent reality in most situations).
- The green curves represent air resistance proportional to speed (a common approach used in physics to approximate reality).

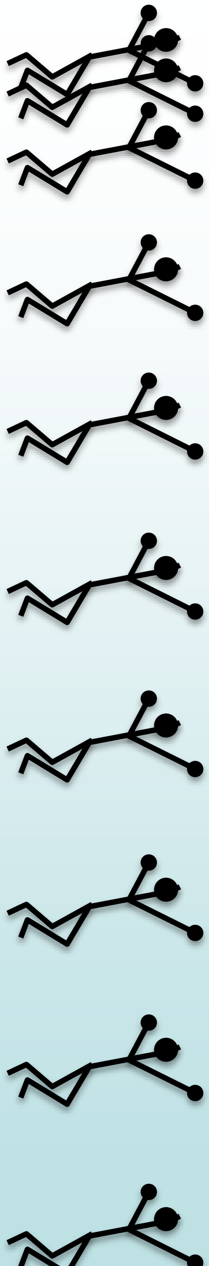
Position vs. Time for a Skydiver



initial velocity = zero; terminal speed = 55 m/s

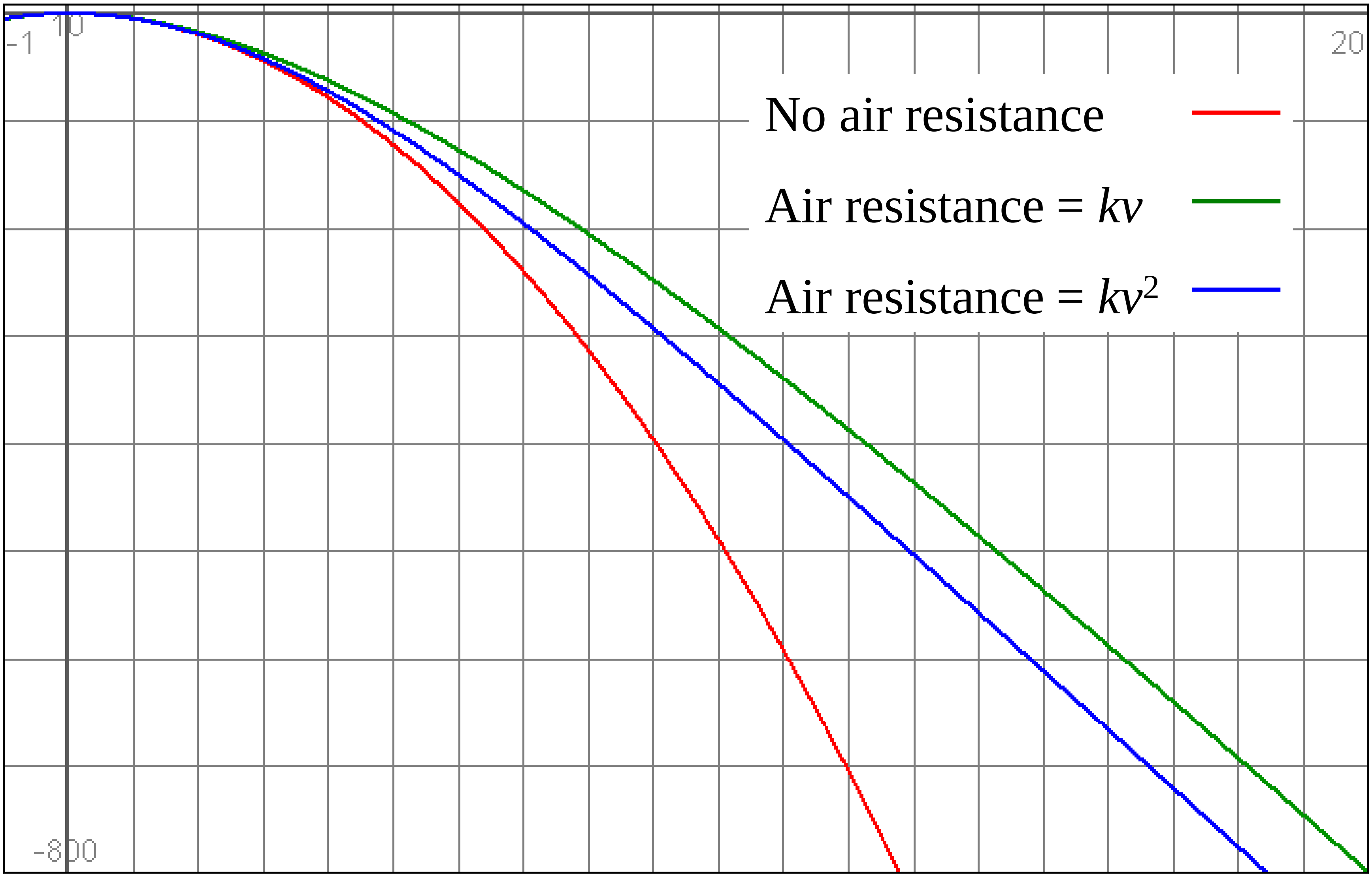


-1
0
20
-800



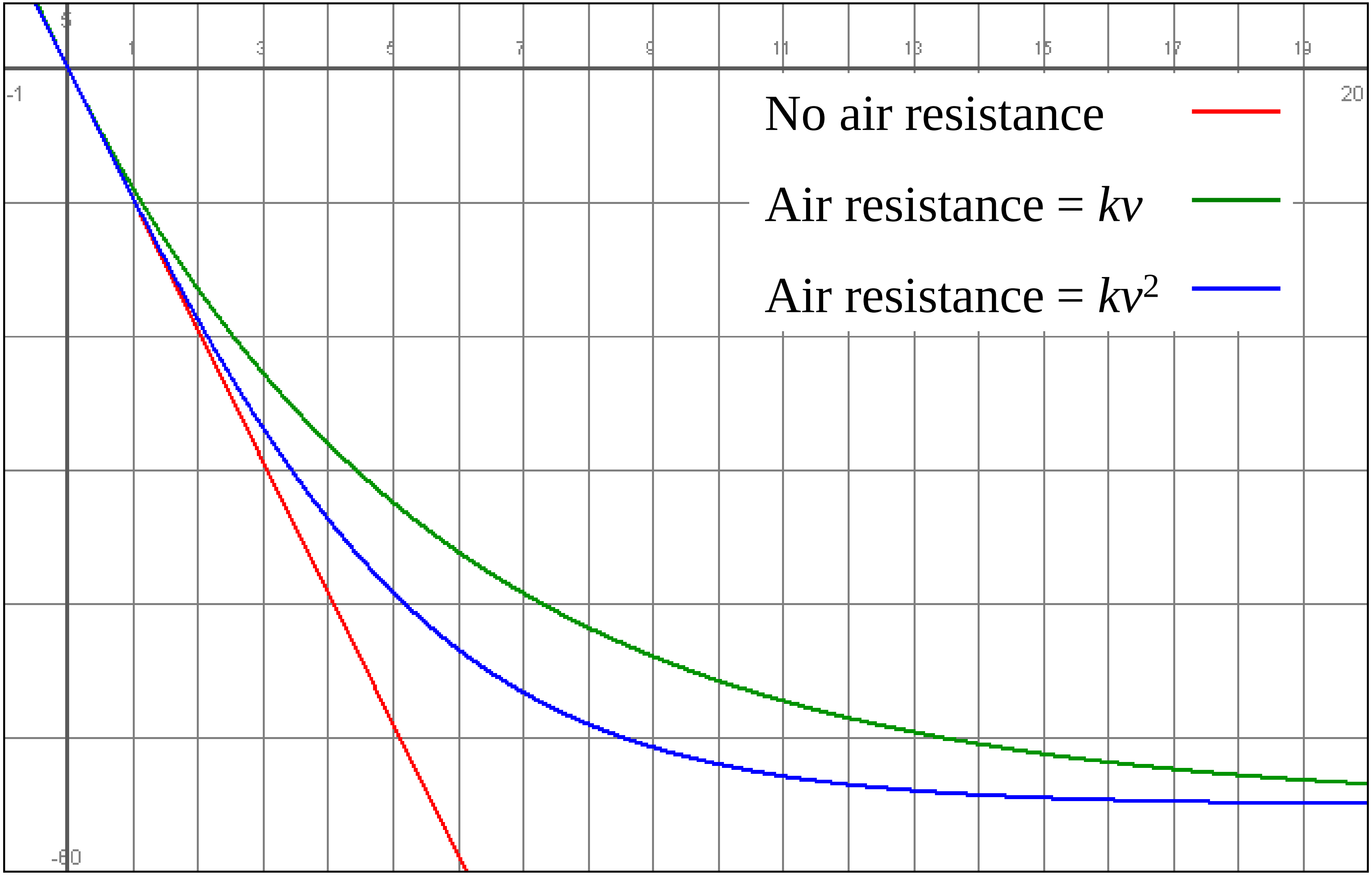
	drag	net force	acceleration	speed
t = 0 s	0	800 N	9.8 m/s^2	0
t = 2 s	80 N	720 N	8.7 m/s^2	19 m/s
t = 4 s	290 N	510 N	6.2 m/s^2	34 m/s
t = 6 s	500 N	300 N	3.7 m/s^2	44 m/s
t = 8 s	640 N	160 N	2.0 m/s^2	49 m/s
t = 10 s	718 N	82 N	1.0 m/s^2	52 m/s
t = 12 s	757 N	43 N	0.53 m/s^2	53 m/s
t = 14 s	779 N	21 N	0.26 m/s^2	54 m/s
t = 16 s	789 N	11 N	0.13 m/s^2	55 m/s
t = 18 s	795 N	5 N	0.06 m/s^2	55 m/s

Position vs. Time for a Skydiver



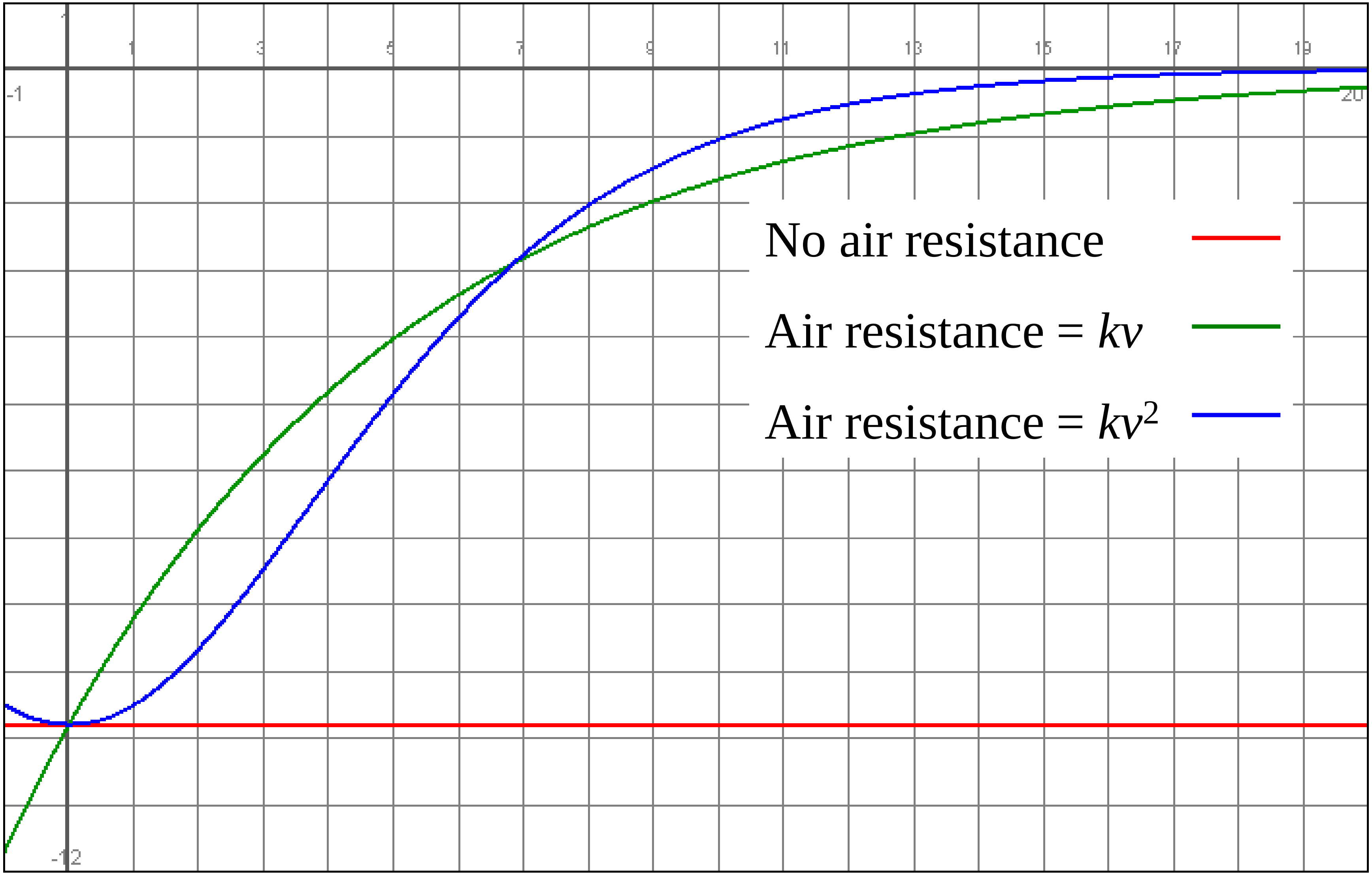
initial velocity = zero; terminal speed = 55 m/s

Velocity vs. Time for a Skydiver



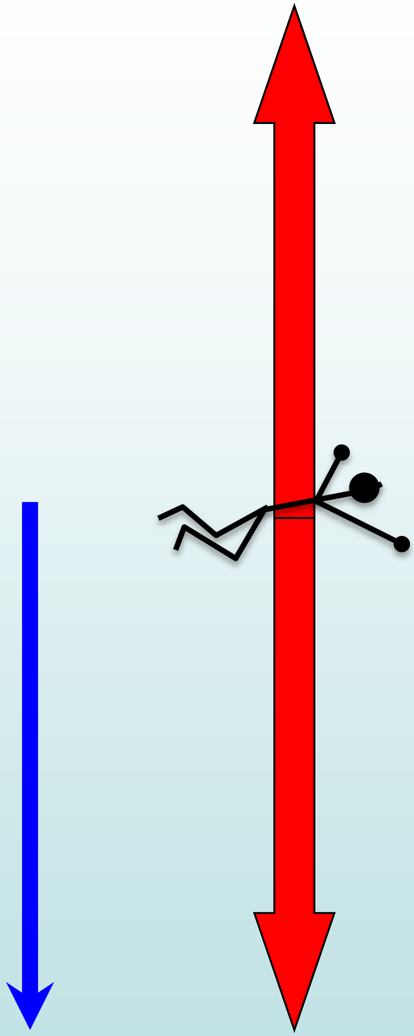
initial velocity = zero; terminal speed = 55 m/s

Acceleration vs. Time for a Skydiver



initial velocity = zero; terminal speed = 55 m/s

Note that the terminal velocity of a skydiver can be different depending on how he is falling: when “spread eagle” the cross-sectional area is maximized & terminal speed is about 120 mph.

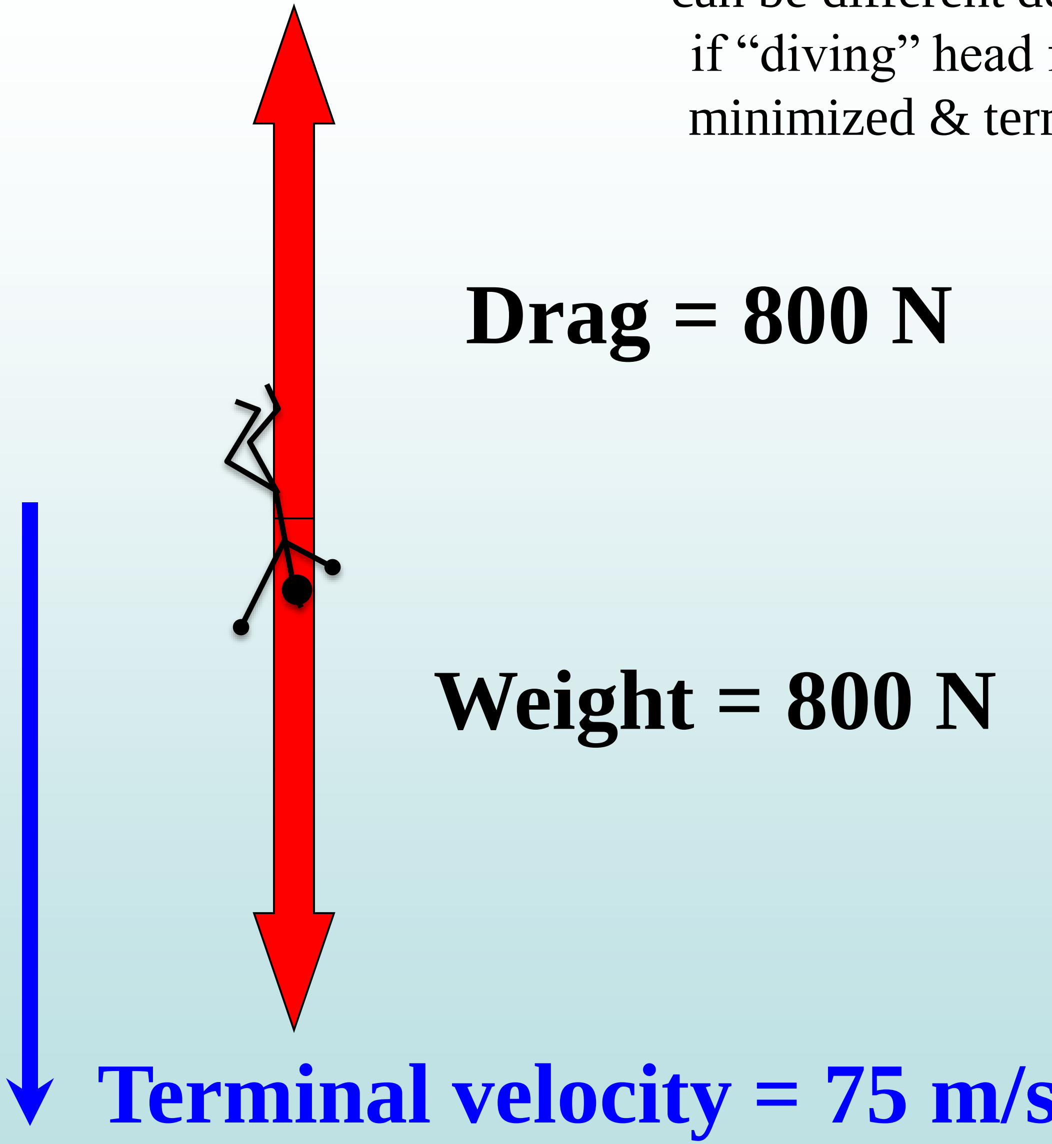


Drag = 800 N

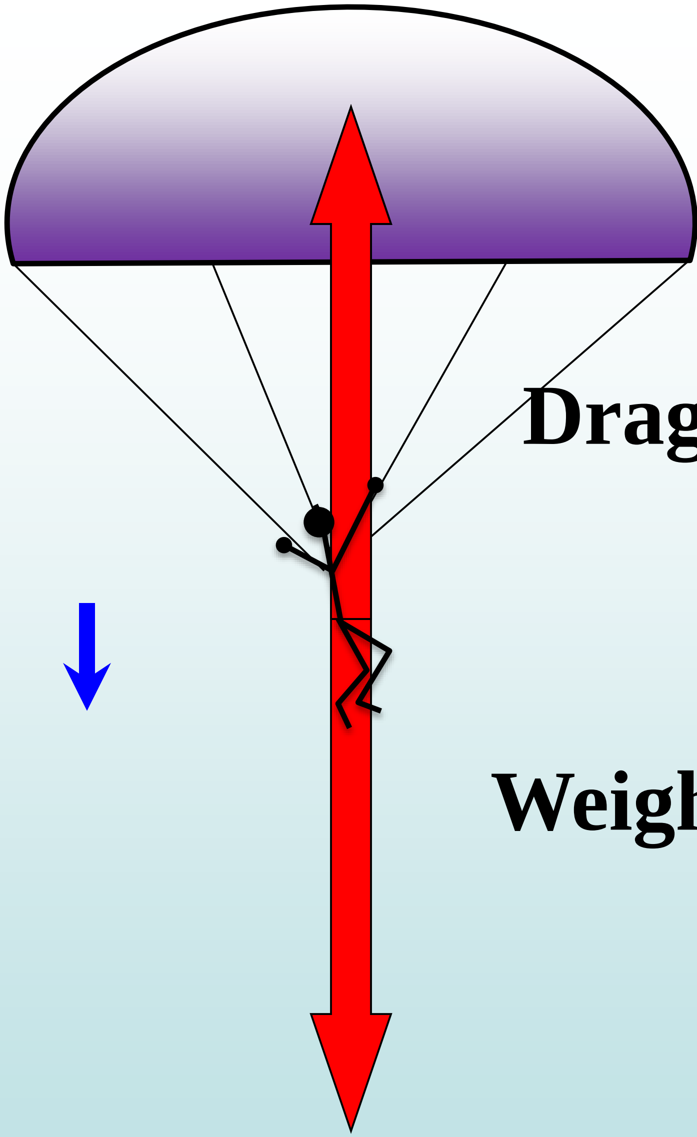
Weight = 800 N

Terminal velocity = 55 m/s

Note that the terminal velocity of a skydiver can be different depending on how he is falling: if “diving” head first the cross-sectional area is minimized & terminal speed is about 170 mph.



Note that the terminal velocity of a skydiver can be different depending on how he is falling: with chute open cross-sectional area is greatly increased as is the coefficient of drag, and therefore terminal velocity is about 10 mph.

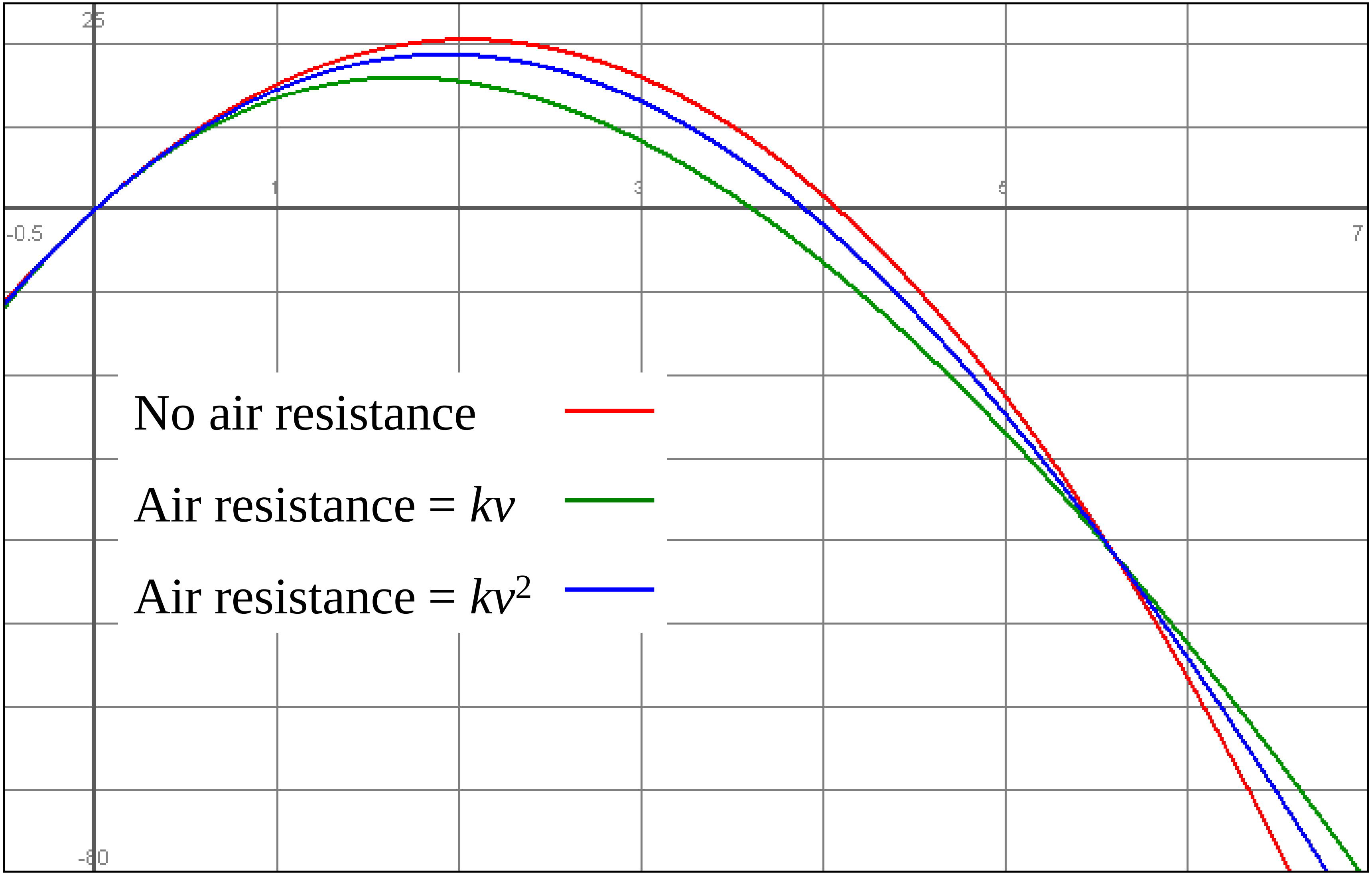


Drag = 800 N

Weight = 800 N

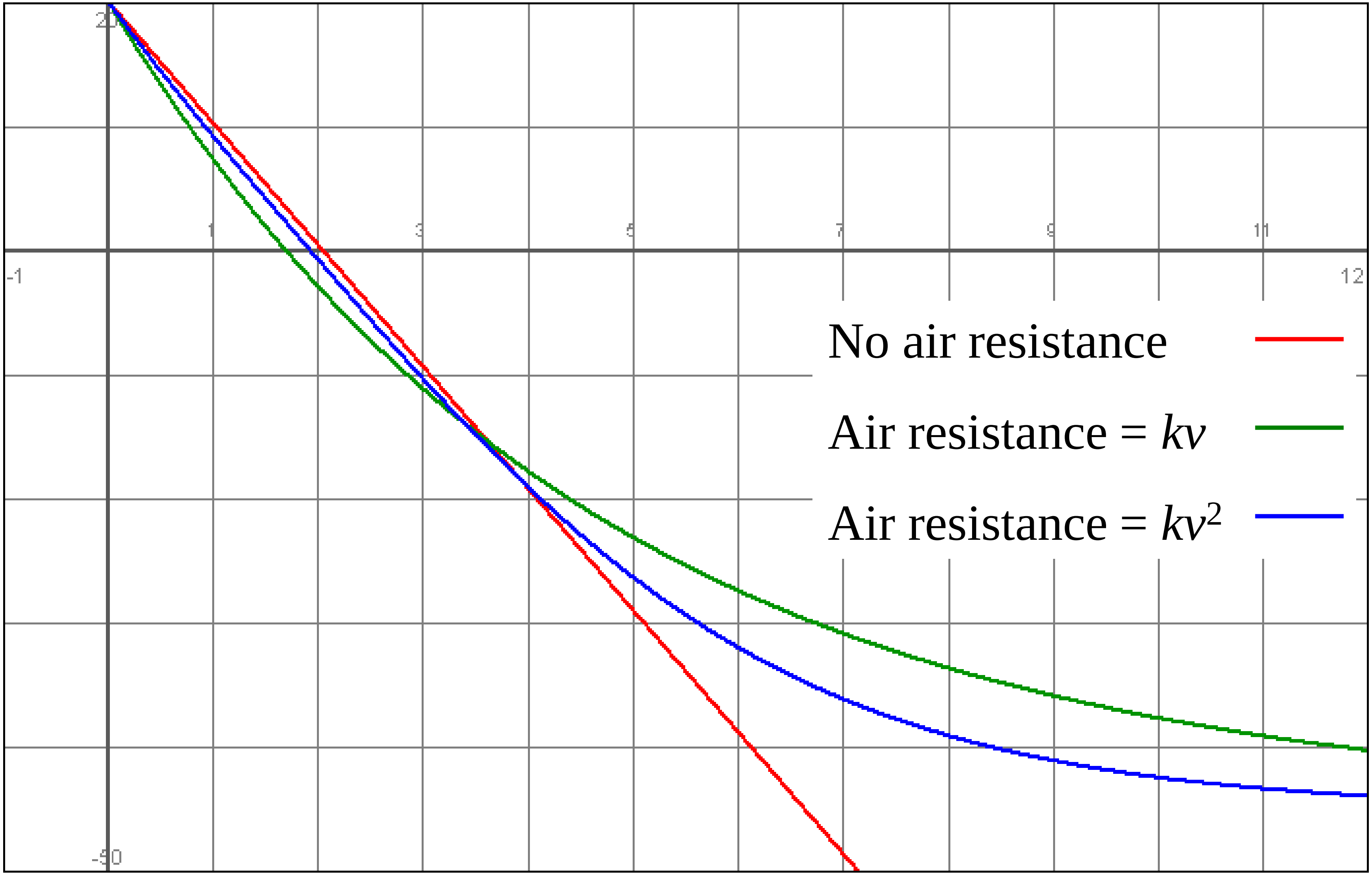
Terminal velocity = 5 m/s

Position vs. Time for a Baseball



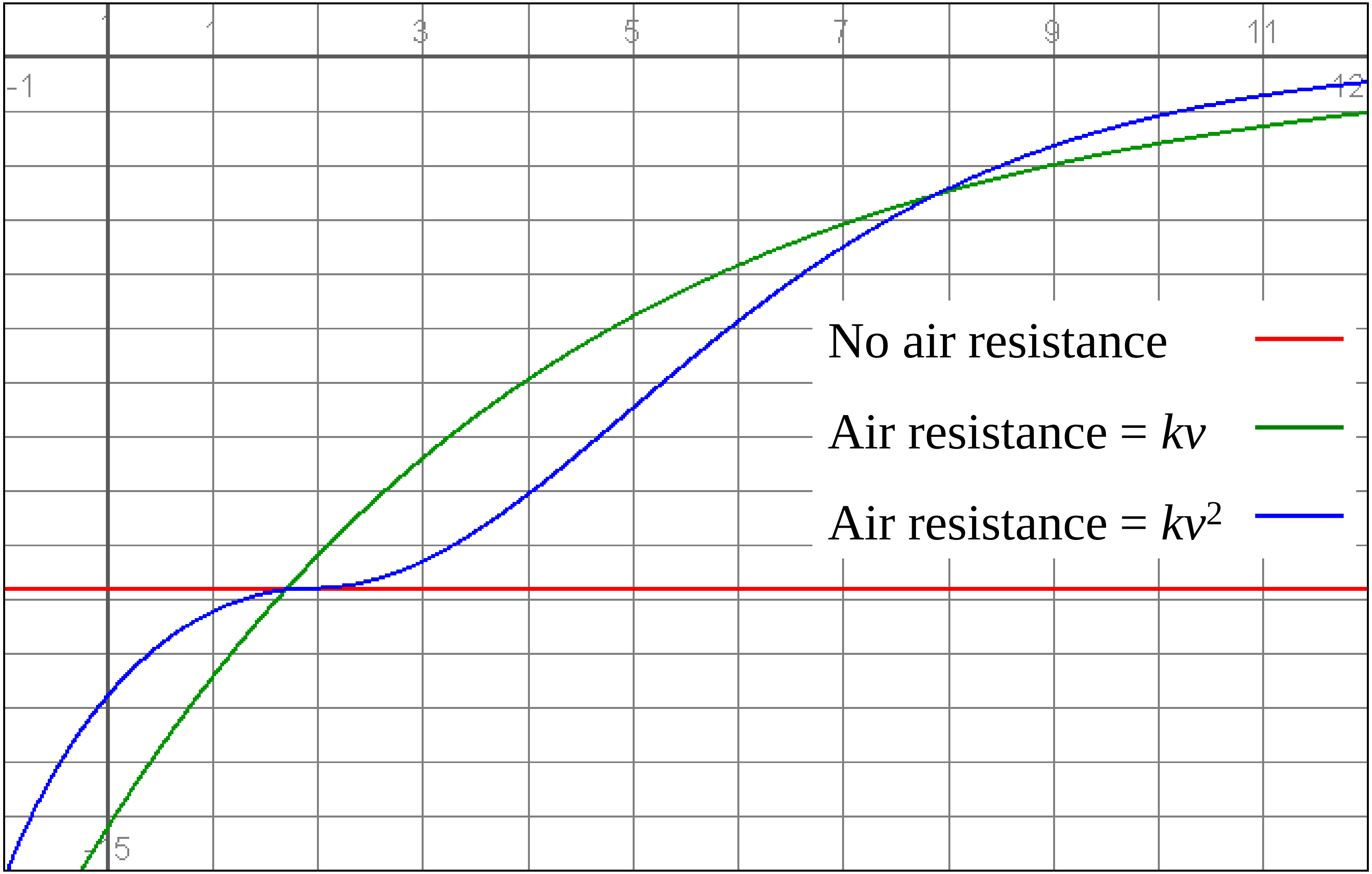
initial velocity = 20 m/s, upward; terminal speed = 45 m/s

Velocity vs. Time for a Baseball



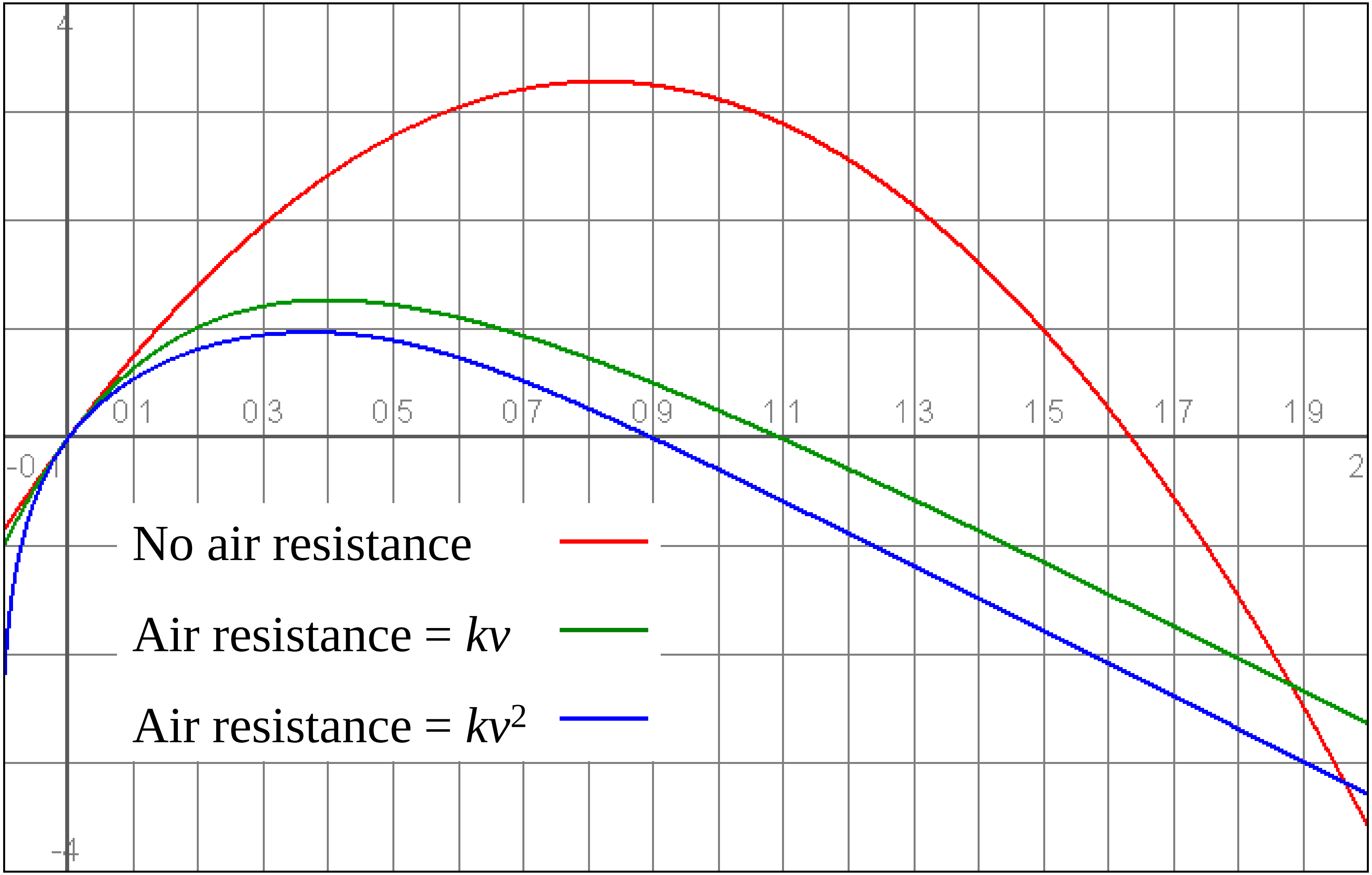
initial velocity = 20 m/s, upward; terminal speed = 45 m/s

Acceleration vs. Time for a Baseball



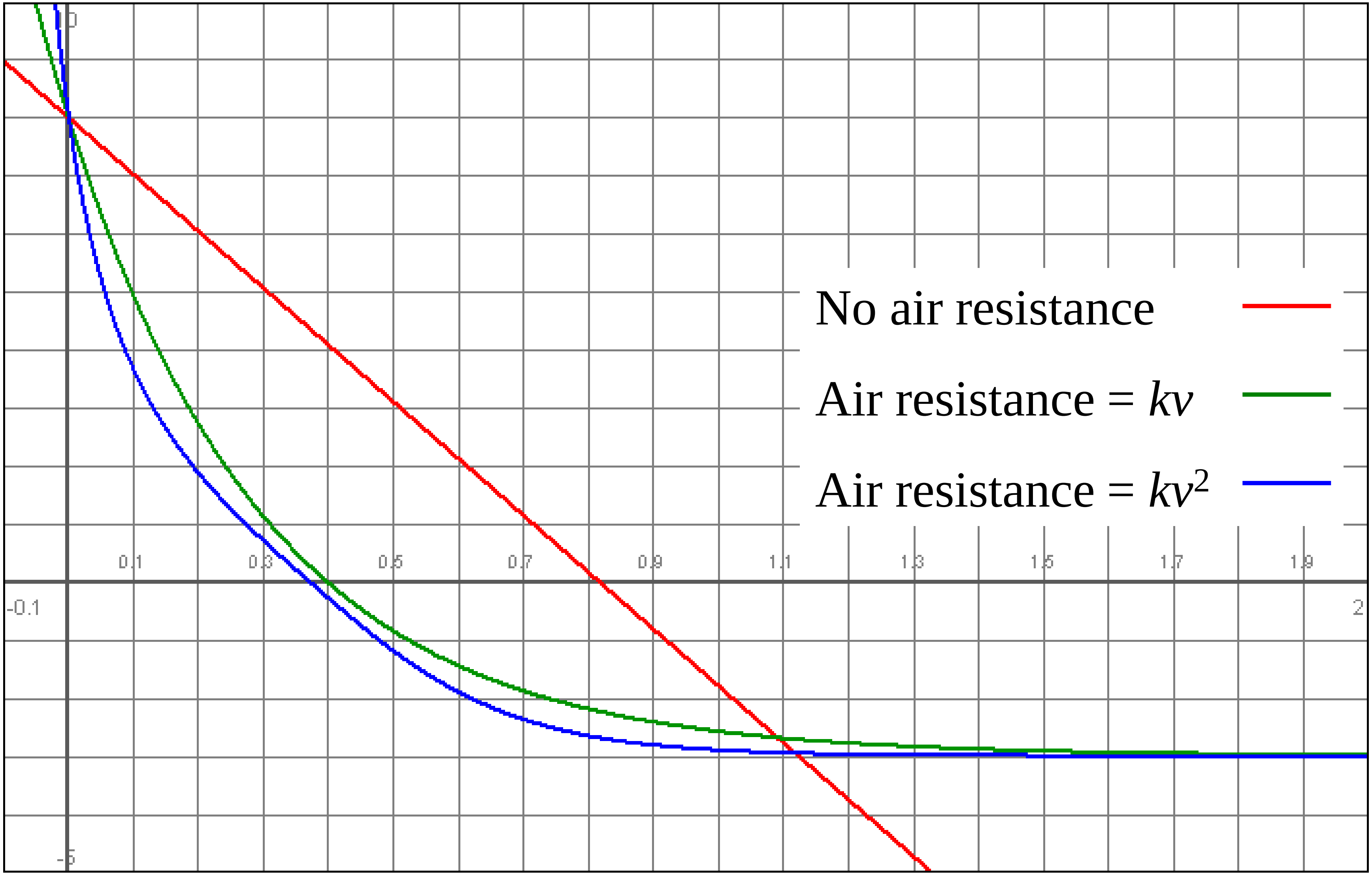
initial velocity = 20 m/s, upward; terminal speed = 45 m/s

Position vs. Time for a Balloon



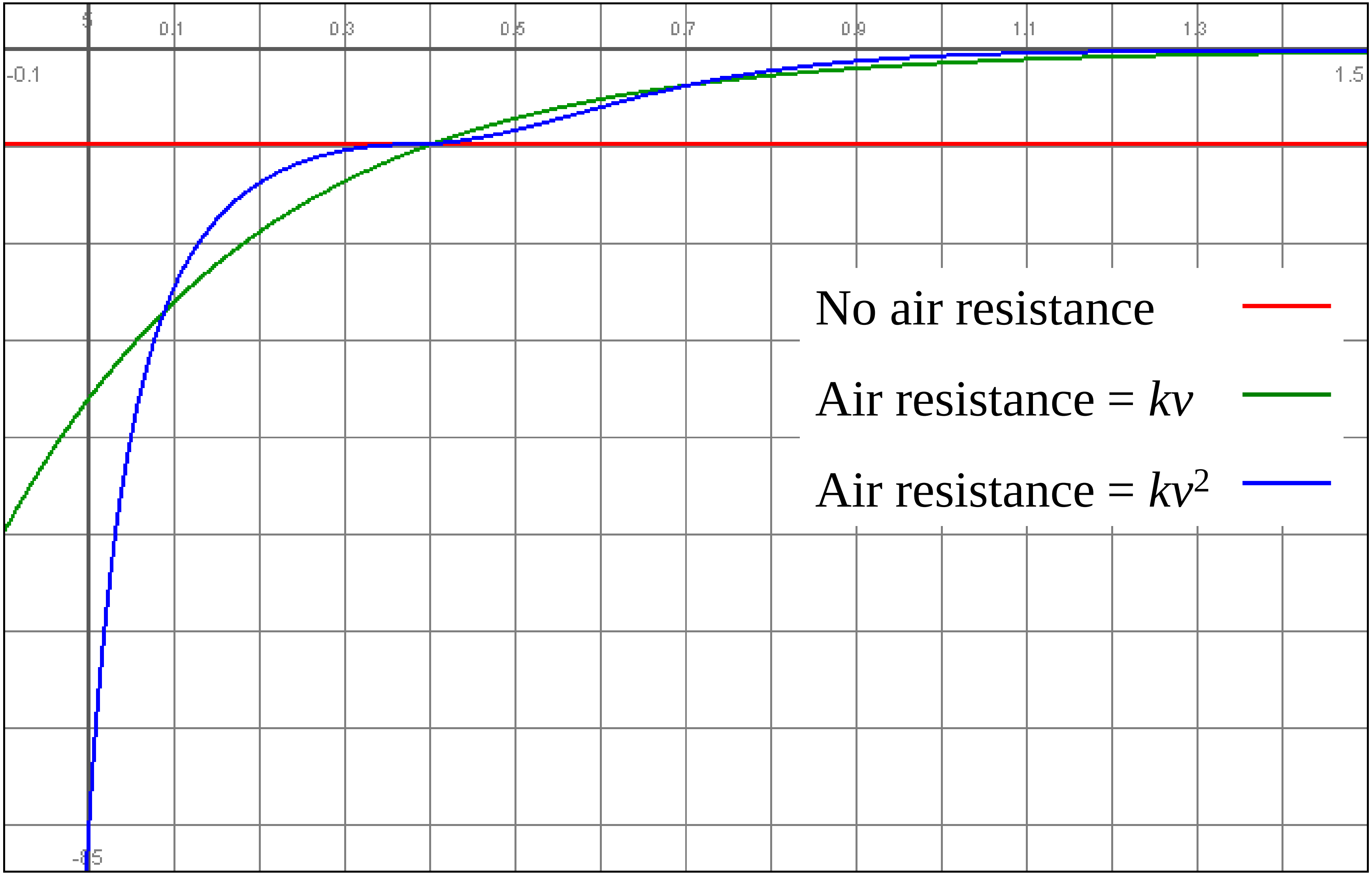
initial velocity = 8 m/s, upward; terminal speed = 3 m/s

Velocity vs. Time for a Balloon



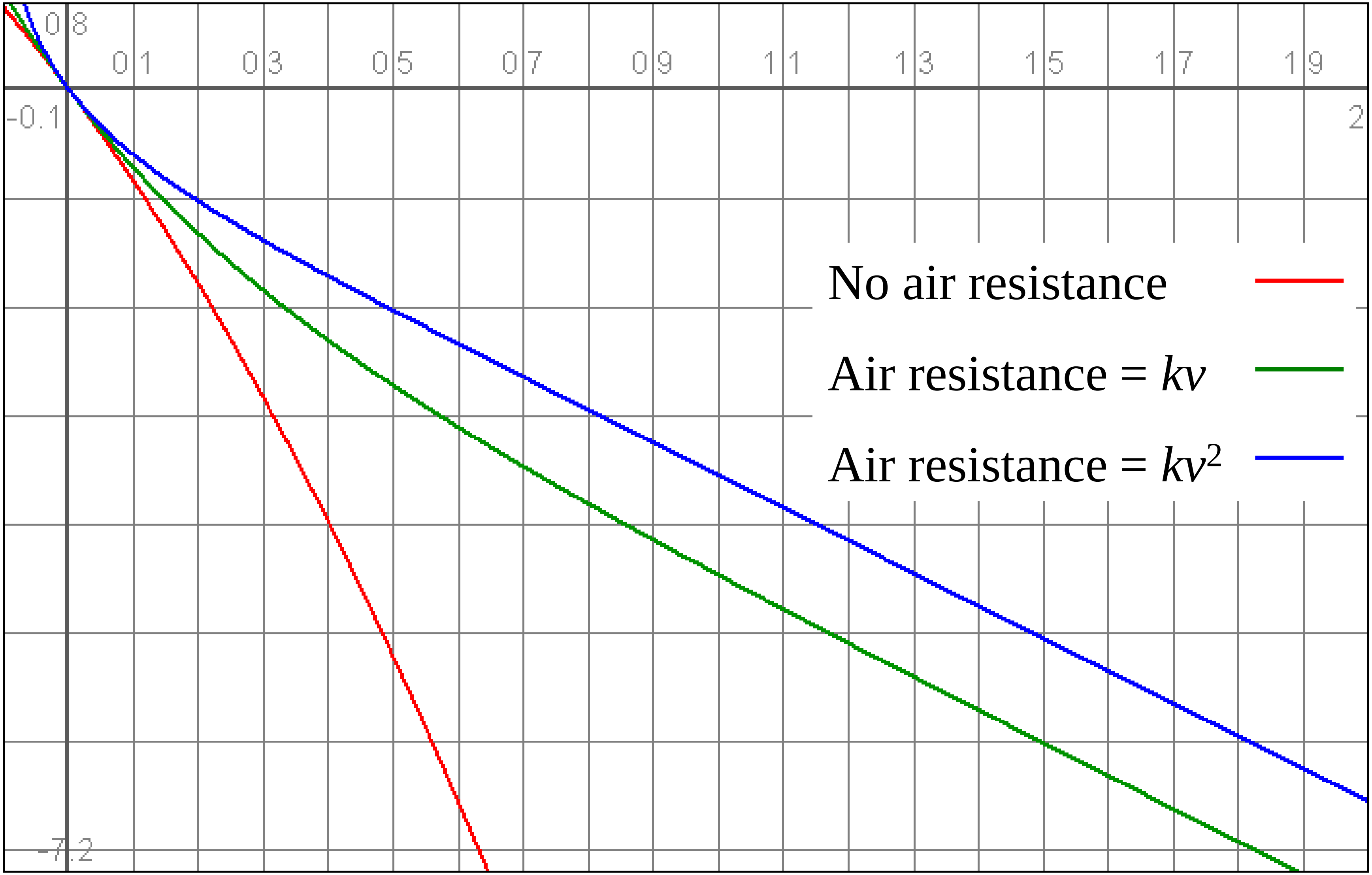
initial velocity = 8 m/s, upward; terminal speed = 3 m/s

Acceleration vs. Time for a Balloon



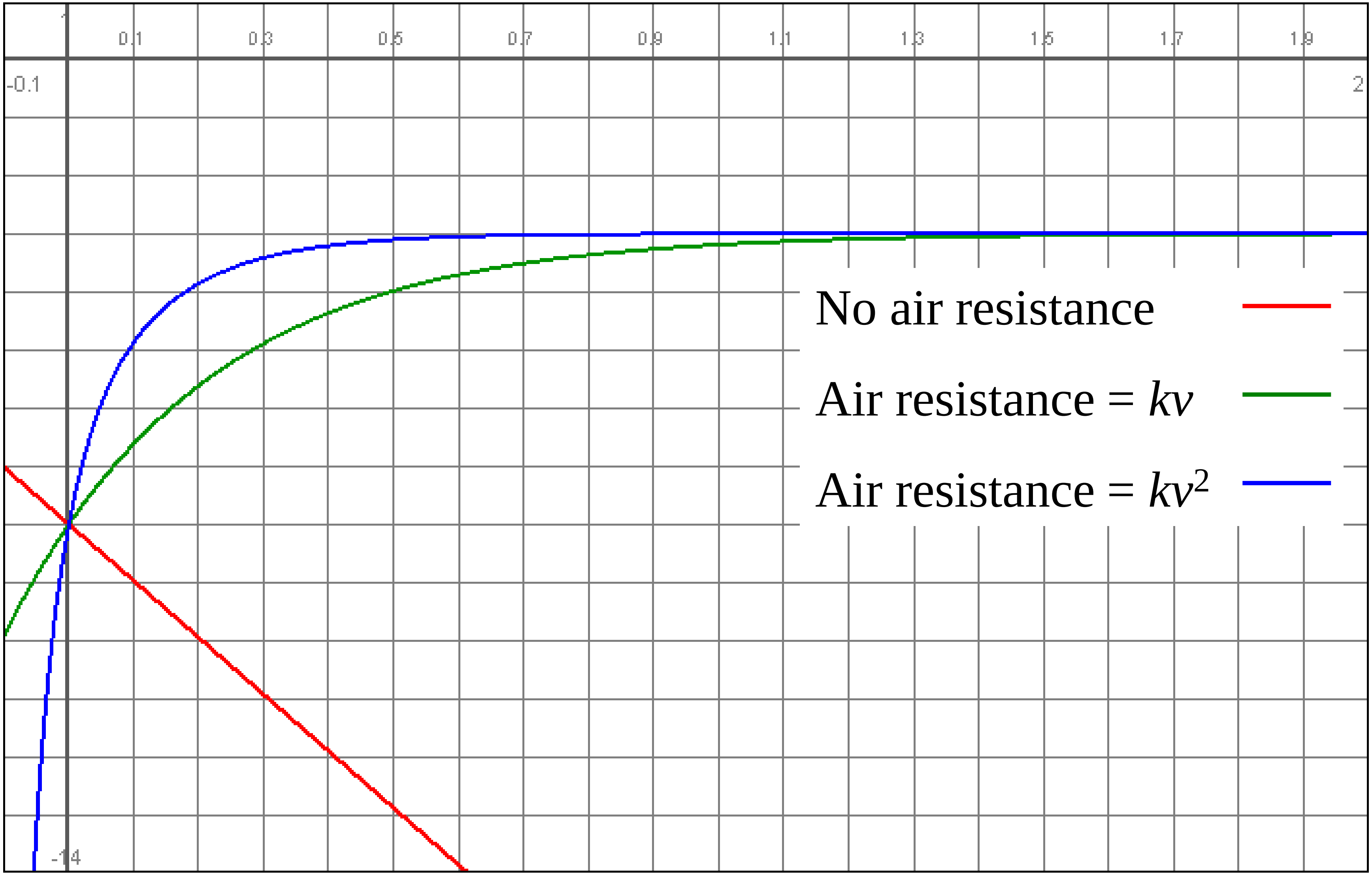
initial velocity = 8 m/s, upward; terminal speed = 3 m/s

Position vs. Time for a Balloon



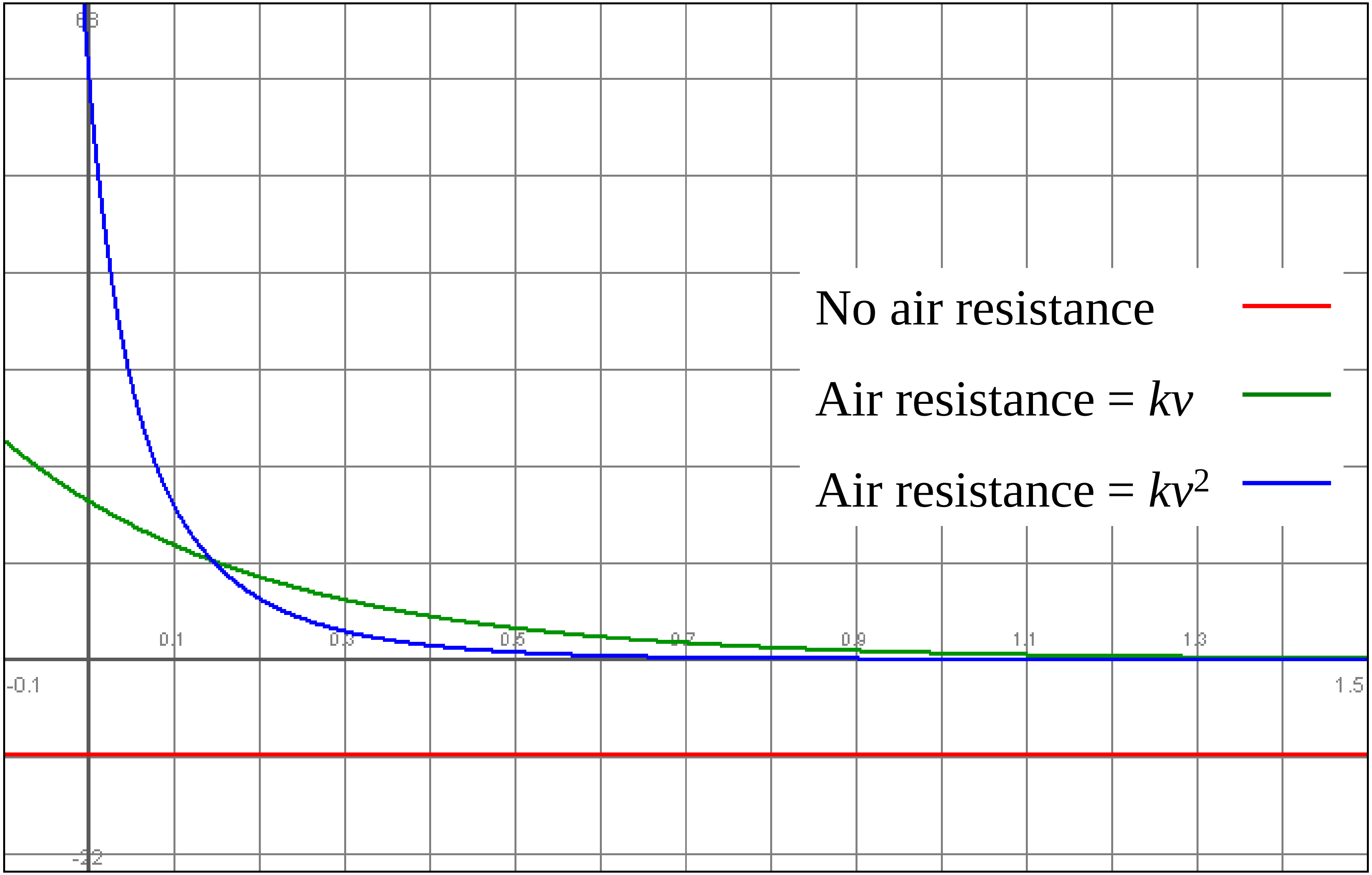
initial velocity = 8 m/s, downward; terminal speed = 3 m/s

Velocity vs. Time for a Balloon

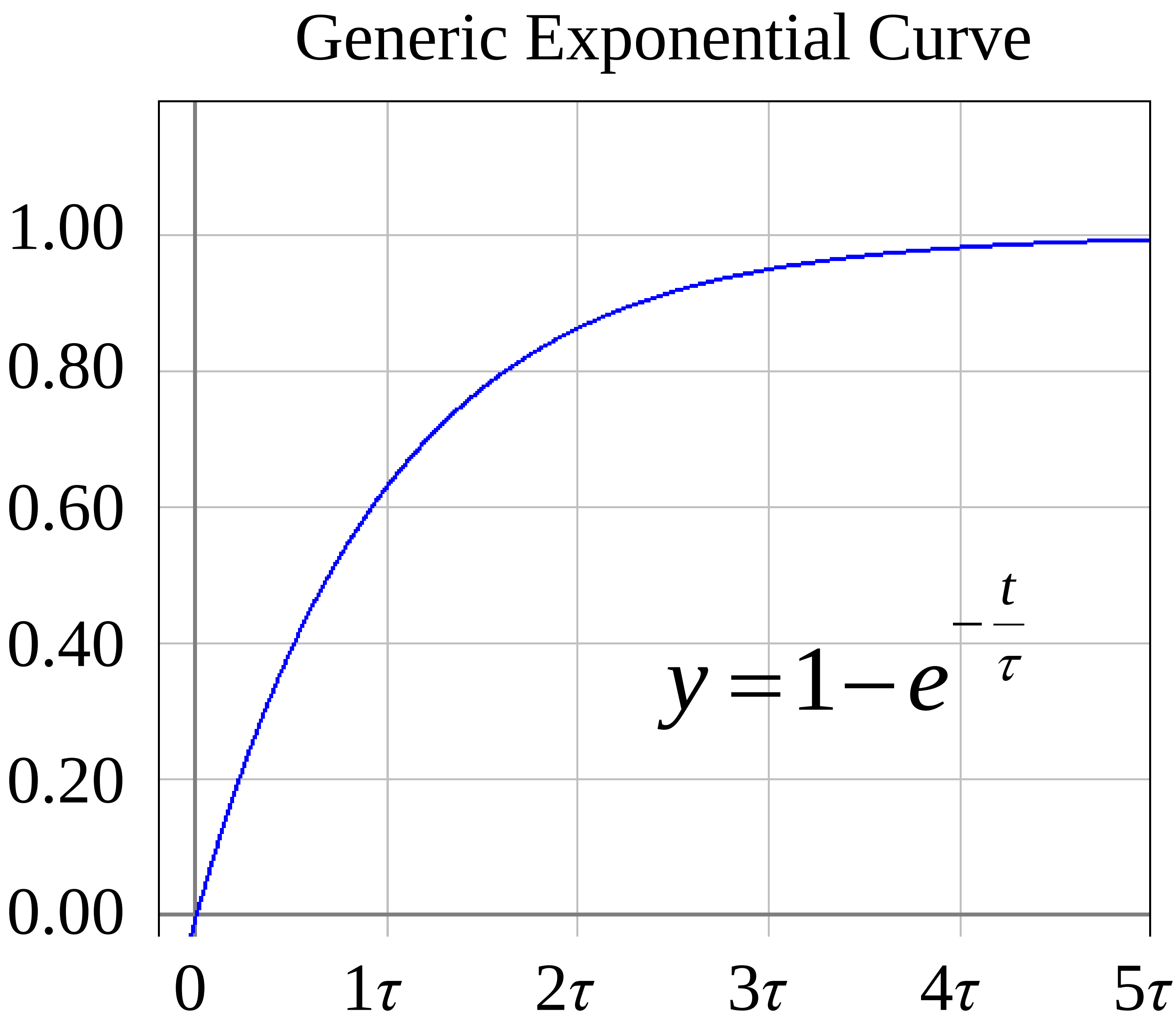


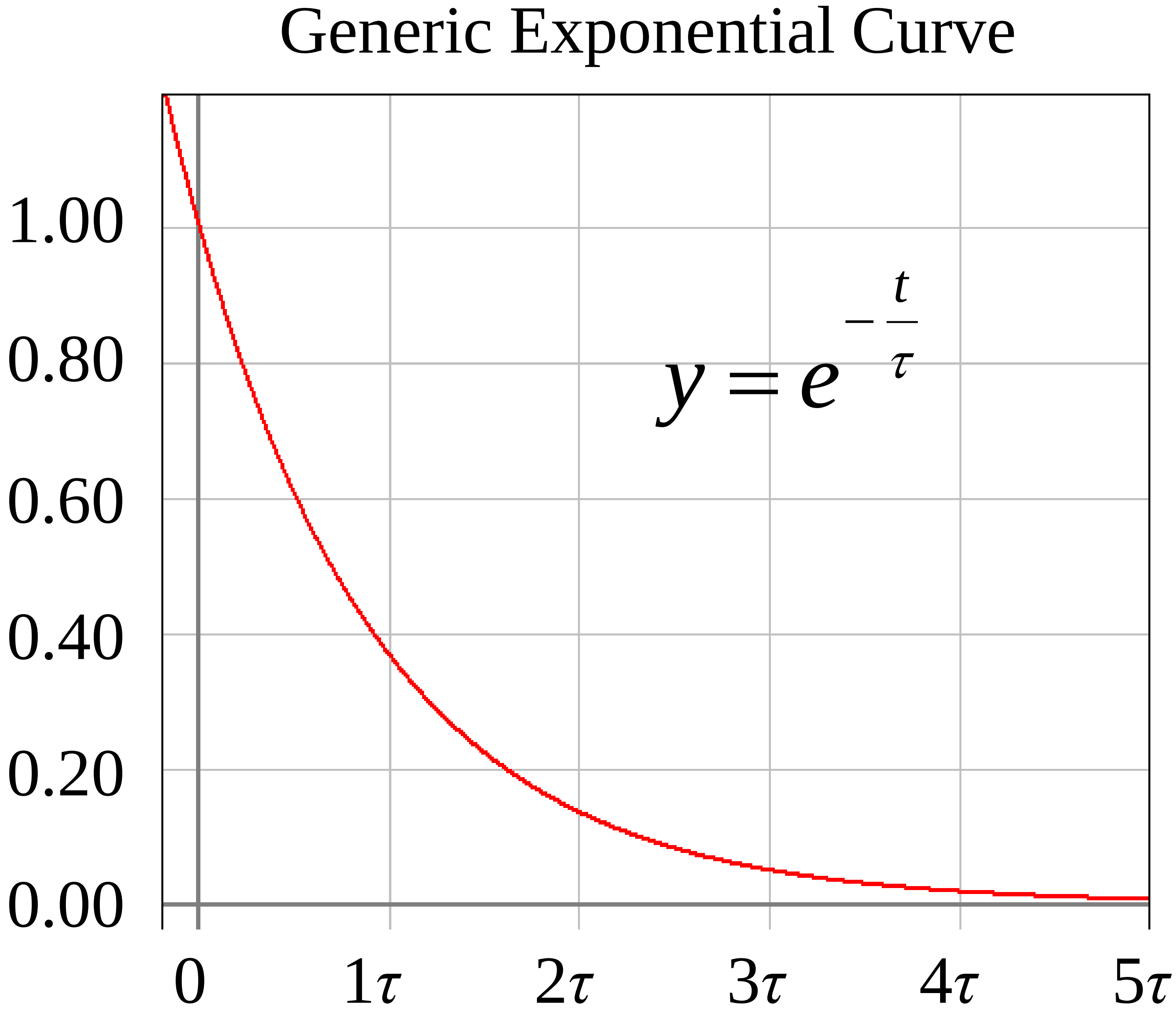
initial velocity = 8 m/s, downward; terminal speed = 3 m/s

Acceleration vs. Time for a Balloon



initial velocity = 8 m/s, downward; terminal speed = 3 m/s


Generic Exponential Curve
1.00
0.80
0.60
0.40
0.20
0.00
0
1τ
2τ
3τ
4τ
5τ
$y = 1 - e^{-\frac{t}{\tau}}$



Generic Exponential Curve
1.00
0.80
0.60
0.40
0.20
0.00
0
1τ
2τ
3τ
4τ
5τ
$y = e^{-\frac{t}{\tau}}$

The "time constant" τ is often used as a convenient way to analyze exponential functions. Using the model that drag = kv it can be shown that the time constant is given by $\tau = m/k$. For the particular case of a falling object the time constant can also be found by $\tau = v_t/g$.

Falling Object		
time	speed	acceleration
0	0 % v_t	100 % g
1τ	63 % v_t	37 % g
2τ	86 % v_t	14 % g
3τ	95 % v_t	5 % g
4τ	98 % v_t	2 % g
5τ	99 % v_t	1 % g