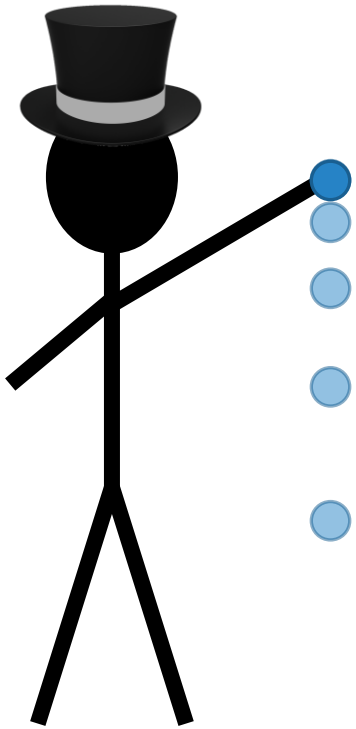
A.2

Drag

IB PHYSICS | MOTION

Review: What is Free Fall?

A.2



The only force acting on the object is gravity

No Air Resistance

Let's start to think about how air resistance will affect moving objects…

What Factors Affect Drag?

A.2

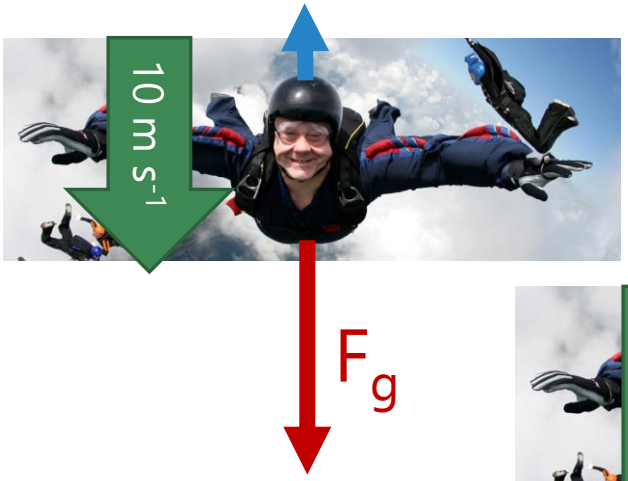
Shape

Speed

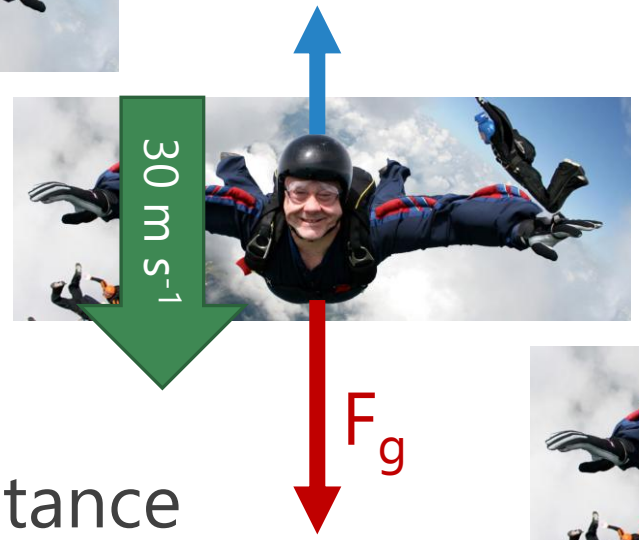
Surface Area

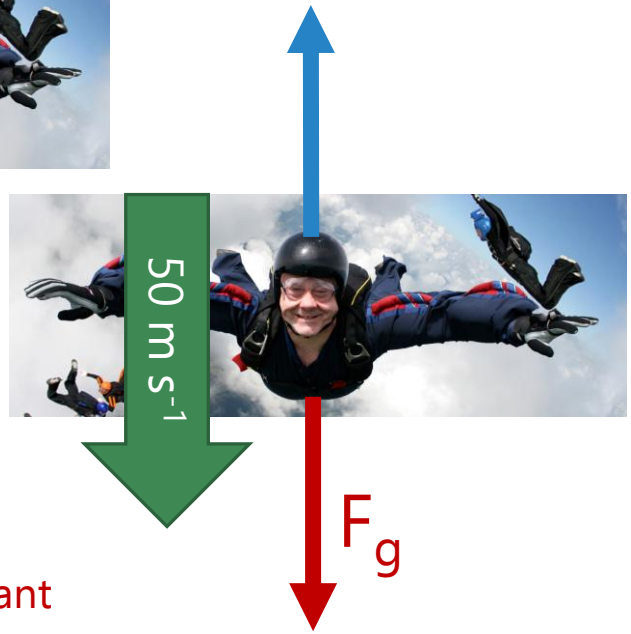
Air Resistance

A.2



Force of gravity is always constant



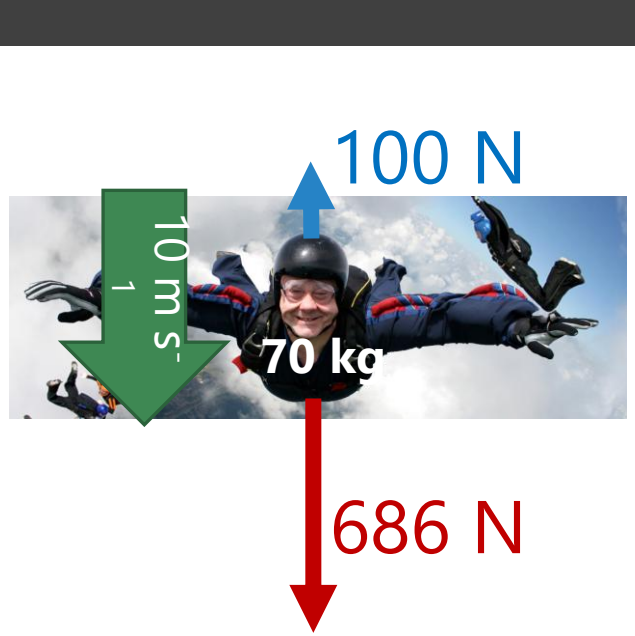


Force of air resistance increases when velocity increases

**Assume shape/surface area stay relatively constant

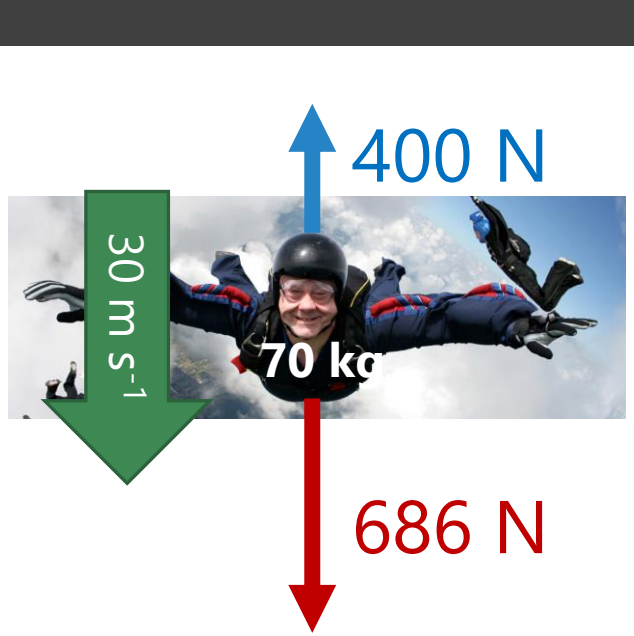
Calculate the Acceleration

A.2



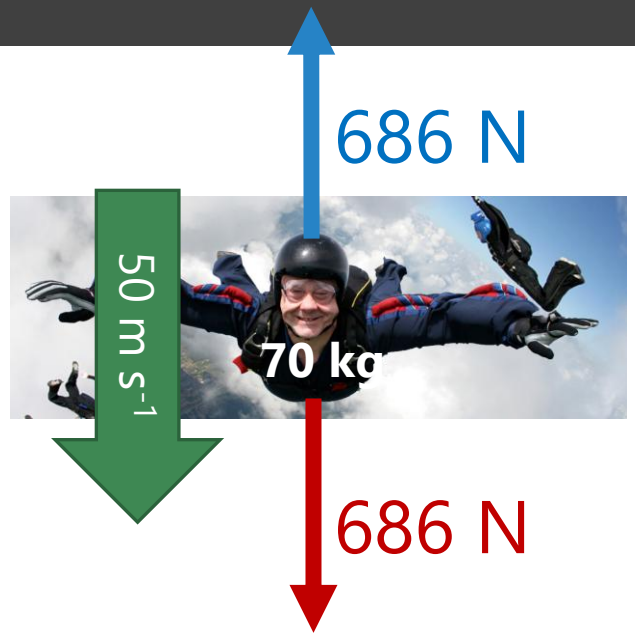
F_{net} = 586 N ↓

$$a = \frac{F}{m} = \frac{586}{70} = \mathbf{8.37\ m\ s^{-2}}$$



F_{net} = 286 N ↓

$$a = \frac{286}{70} = \mathbf{4.09\ m\ s^{-2}}$$

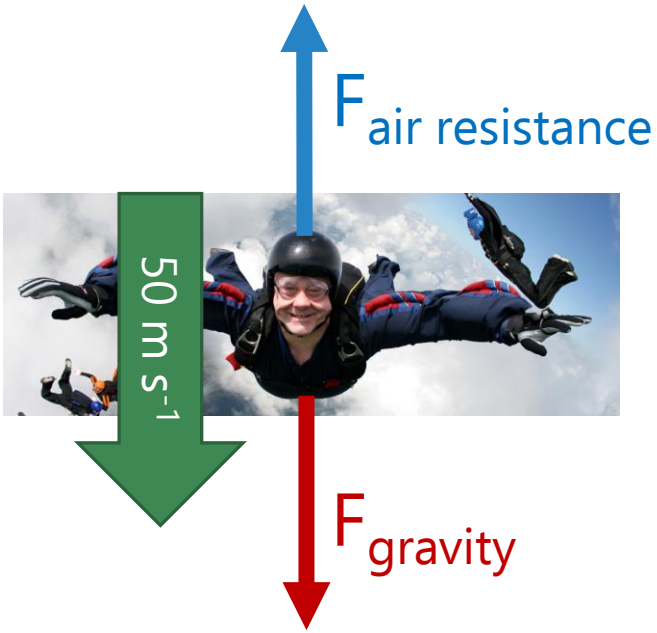


F_{net} = 0 N

$$a = \frac{0}{70} = \mathbf{0\ m\ s^{-2}}$$

Terminal Velocity

A.2



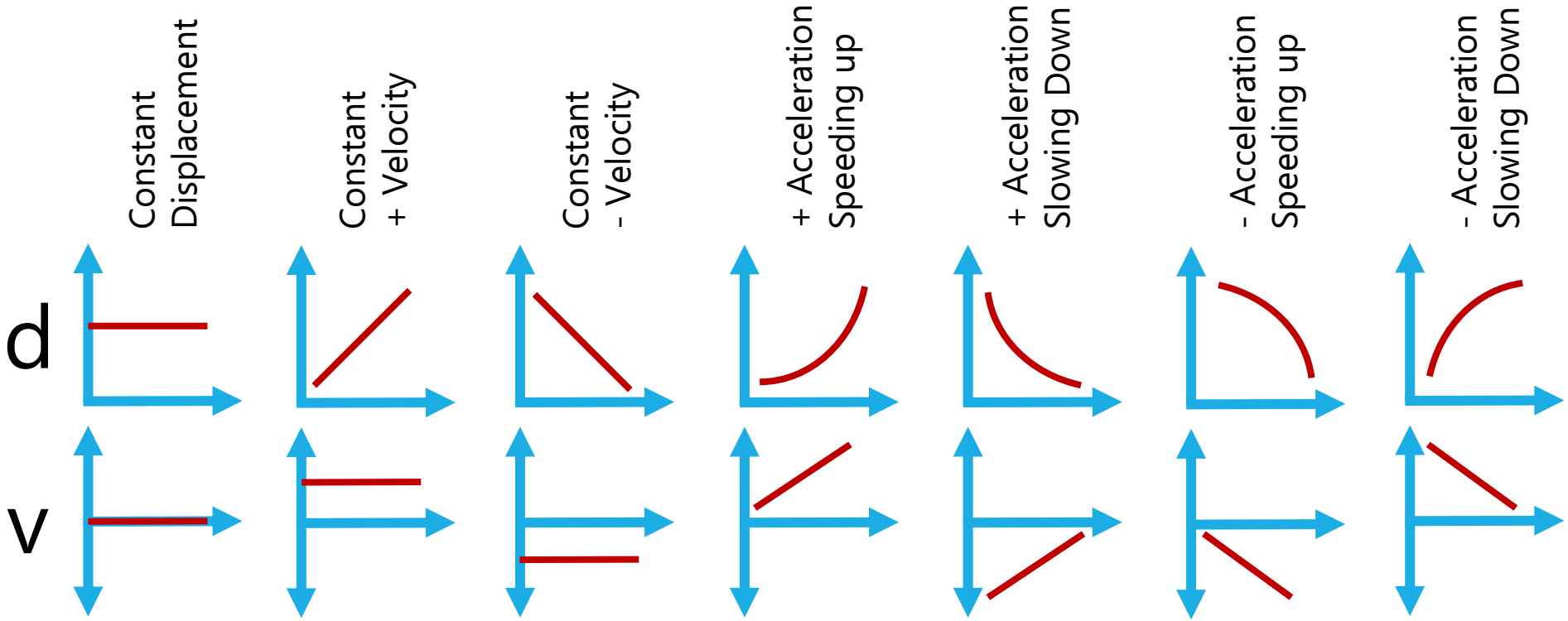
At a certain velocity, the air resistance acting on an object (or person) is equal to the force of gravity.

$F_{net} = \mathbf{0\ N}$

This is the top speed for a falling object

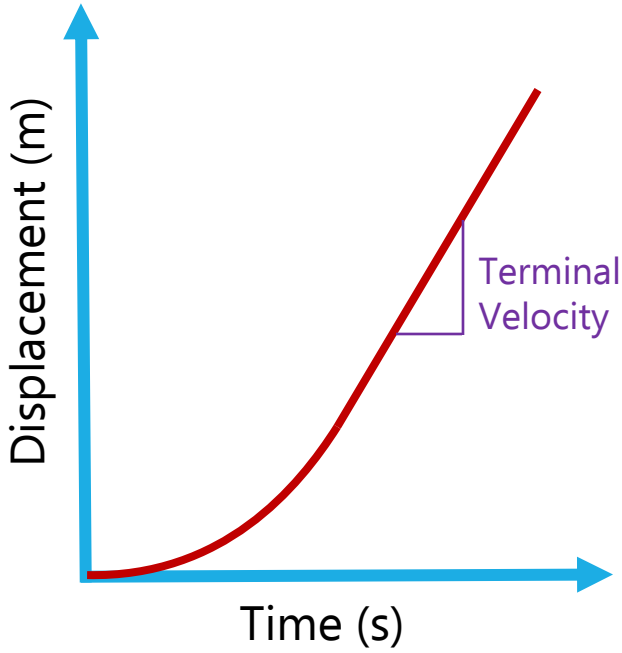
Motion Graphs Guide

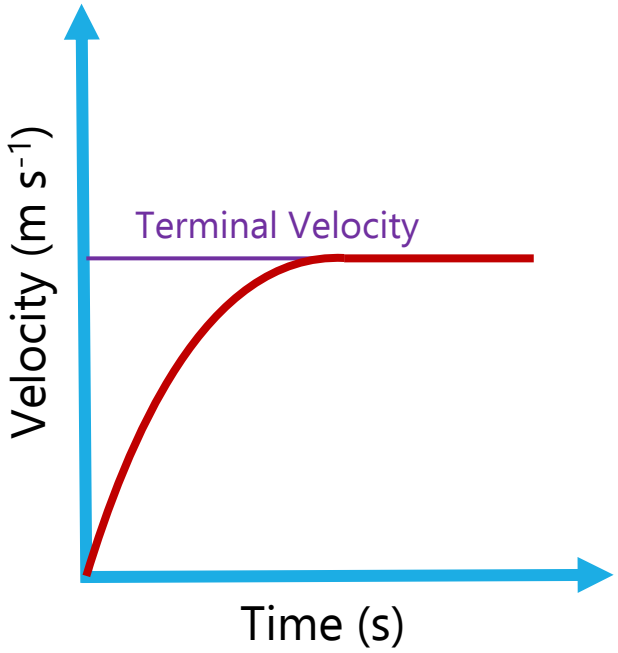
A.2



Terminal Velocity

A.2





Note: these graphs treat the downward direction as positive

When the Parachute opens...

A.2

$F_{net} = 514\ N\uparrow$

$$a = \frac{F}{m} = \frac{514}{70} = \mathbf{7.34\ m\ s^{-2}}$$

$F_{net} = 314\ N\uparrow$

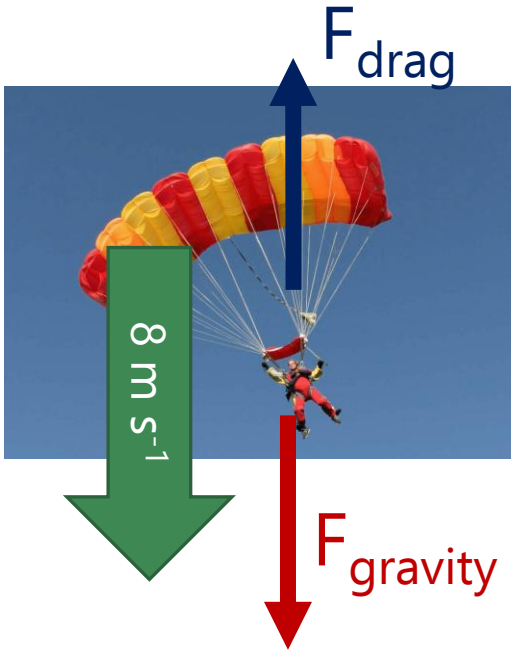
$$a = \frac{314}{70} = \mathbf{4.49\ m\ s^{-2}}$$

$F_{net} = 0\ N$

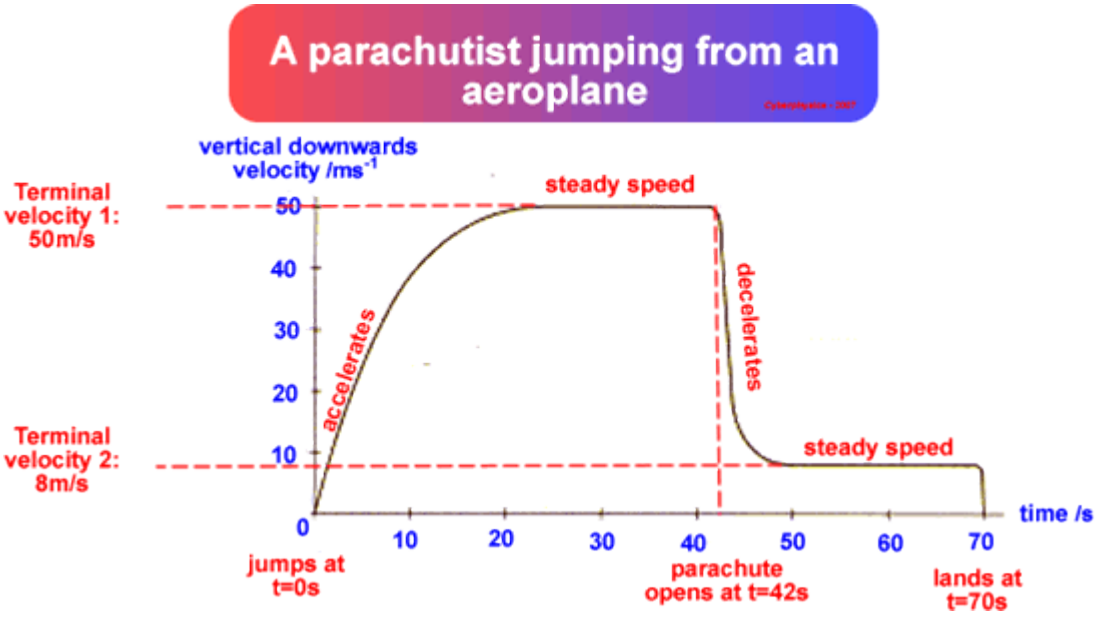
$$a = \frac{0}{70} = \mathbf{0\ m\ s^{-2}}$$

Terminal Velocity

A.2

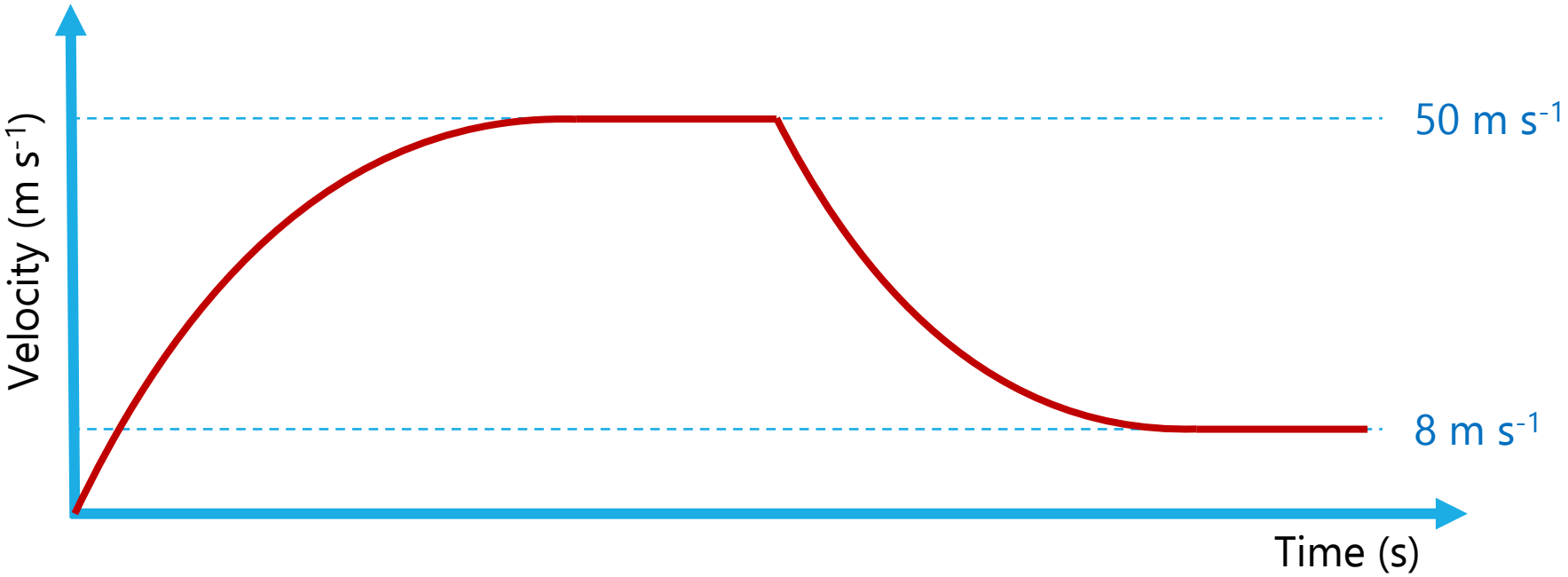


A parachute dramatically decreases the terminal velocity where air resistance balances out the weight



Terminal Velocity

A.2

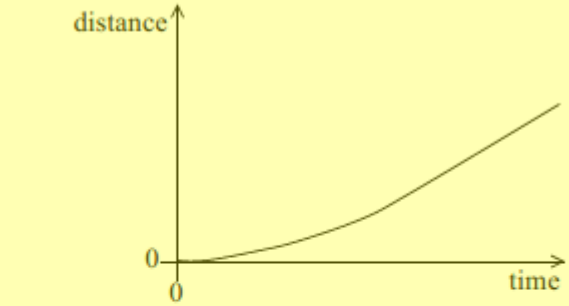


A.2

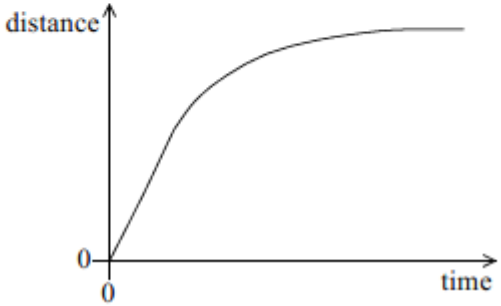
Sample IB Problem

An object falls vertically from rest. Air resistance acts on the object and it reaches a terminal speed. Which of the following is the distance-time graph for its motion?

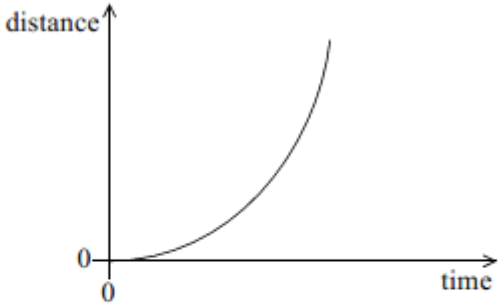
A.



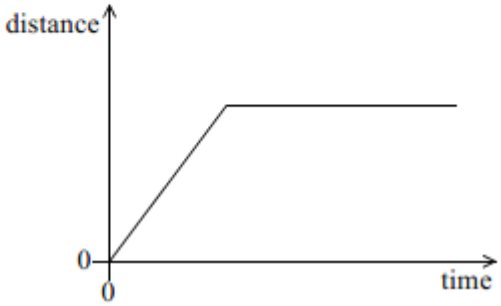
B.



C.



D.



Sample IB Problem

A.2

3. A skydiver jumped out of an airplane. On reaching a terminal speed of 60 $m s^{-1}$, she opened her parachute. Which of the following describes her motion after opening her parachute?

A. She went upwards for a short time, before falling to Earth at a speed of 60 $m s^{-1}$.

B. She continued downwards at 60 $m s^{-1}$, but hit the ground with less force.

C. She continued to fall but reached a new terminal speed of less than 60 $m s^{-1}$.

D. She went upwards for a short time, before falling to Earth at a speed of less than 60 $m s^{-1}$.

Sample IB Problem

A.2

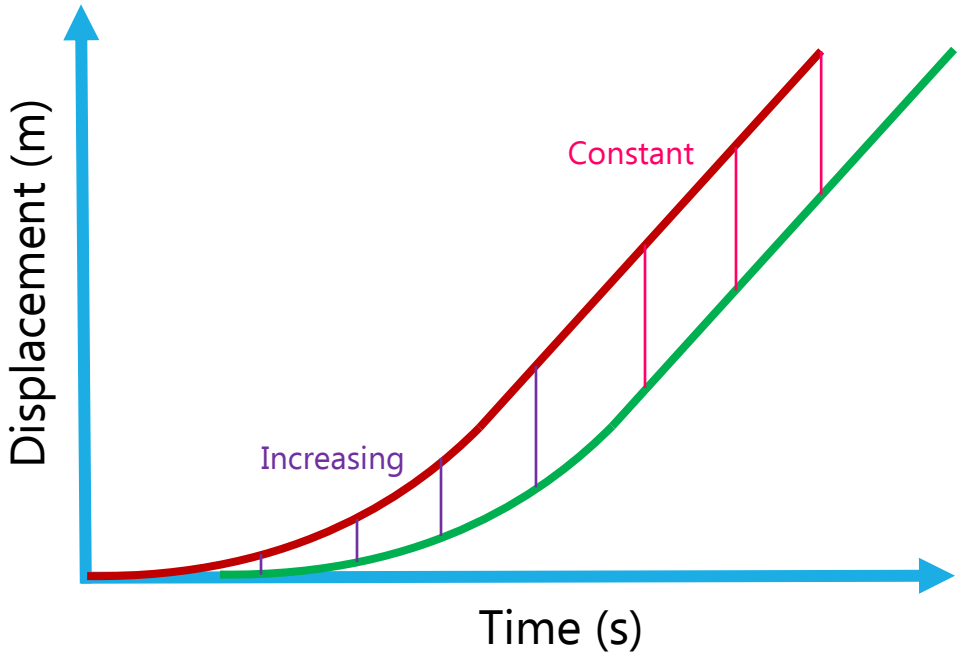
4. Two identical balls are dropped from a tall building, one a few seconds after the other. Air resistance is **not** negligible. As the balls fall, the distance between the balls will

A. decrease.

B. increase.

C. increase then remain constant.

D. remain constant.



A.2

Stokes' Law

For a **sphere** moving through a fluid with **laminar flow**, the drag force is equal to

$$F_d = 6\pi\eta r v$$

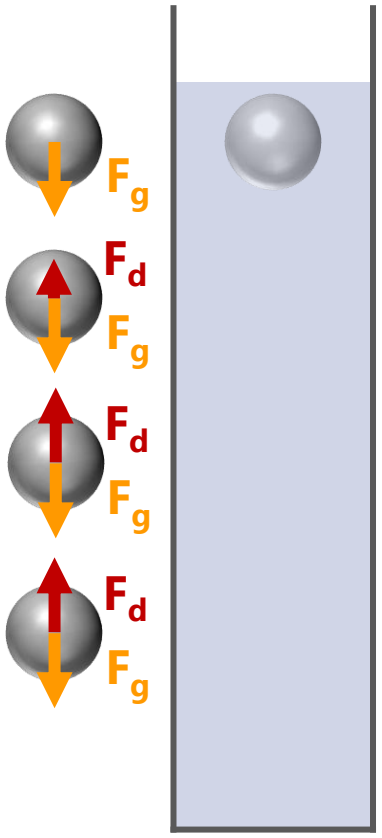
$F_d \rightarrow$ drag force [N]

$\eta \rightarrow$ dynamic viscosity [Pa s]

$$\text{Pa} = \frac{\text{N}}{\text{m}^2}$$

$r \rightarrow$ radius of sphere [m]

$v \rightarrow$ speed of sphere [m s^{-1}]



Physics Data Booklet

A.2

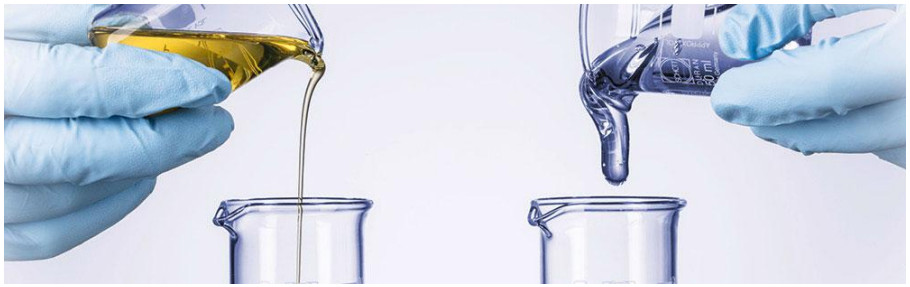
A.2 Forces and momentum	
	$F_f \leq \mu_s F_N$
	$F_f = \mu_d F_N$
	$F_H = -kx$
	$F_d = 6\pi\eta rv$
	$F_b = \rho Vg$
	$F_g = mg$
	$p = mv$
	$J = F\Delta t$
	$F = ma = \frac{\Delta p}{\Delta t}$
	$a = \frac{v^2}{r} = \omega^2 r = \frac{4\pi^2 r}{T^2}$
	$v = \frac{2\pi r}{T} = \omega r$

A.2

Dynamic Viscosity

Dynamic Viscosity at 25°C

Substance	Viscosity (Pa s)
Hydrogen Gas	8.8×10^{-6}
Neon Gas	3.2×10^{-5}
Water	8.9×10^{-4}
Mercury	1.5×10^{-3}
Olive Oil	8.4×10^{-2}
Pancake Syrup	2.5



High-Viscosity Fluid

- High resistance to deformation
- Pours slowly

Low-Viscosity Fluid

- Low resistance to deformation
- Pours quickly

Data from https://en.wikipedia.org/wiki/Viscosity

Try This... | #1

A raindrop of radius 0.3 mm falls through the air with a terminal velocity of 1 m s^{-1}. The viscosity of air is 1.8×10^{-5} Pa s. What is the drag force on the raindrop?

$$F_d = 6\pi\eta r v$$

$\eta = 1.8 \times 10^{-5}$ Pa s

$r = 0.3$ mm $= 0.0003$ m

$v = 1$ m s^{-1}

$$F_d = 6\pi(1.8 \times 10^{-5})(0.0003)(1)$$

$$F_d = \mathbf{1.02 \times 10^{-7}\ N}$$

Try This... | #2

A.2

What is the terminal velocity for a 5-gram marble with a radius of 6 mm as it falls through olive oil with a viscosity of 8.4×10^{-2} Pa s and a density of 911 kg m^{-3}

$$F_{net} = 0 = F_b + F_d - F_g$$

$$F_g = mg = (0.005)(9.8) = 0.049 \text{ N}$$

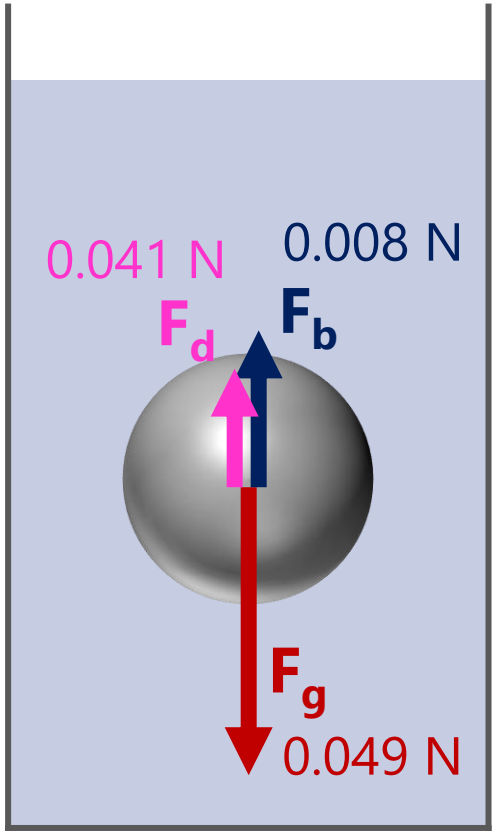
$$F_b = \rho V g = (911)(\frac{4}{3} \times \pi \times 0.006^3)(9.8) = 0.008 \text{ N}$$

$$F_d = F_g - F_b = 0.049 - 0.008 = 0.041 \text{ N}$$

$$F_d = 6\pi\eta r v$$

$$0.041 = 6\pi(8.4 \times 10^{-2})(0.006)v$$

$$\boldsymbol{v = 4.3 \text{ m s}^{-1}}$$



Lesson Takeaways

A.2

- ❑ I can identify the variables that affect drag and air resistance
- ❑ I can describe the motion and forces for an object that is experiencing terminal velocity
- ❑ I can recognize the d vs t and v vs t graphs for an object falling with air resistance
- ❑ I can calculate drag force using Stokes' Law