Unit 1: 1D Kinematics

1 – The Big 3 Kinematics Equations

Kinematics is a ***fun***damental branch of Physics focusing on the motion of objects. It will be something we touch back on over the course of the next two years. At this point you should be familiar with the following:

- *Finding and propagating error (uncertainty).*
- *Finding and calculating Significant Figure's (Sig Fig's).*
- *Basic Mathematical Skills (Using a calculator, geometry, trigonometry, and algebra).*
- *Creating and in interpreting basic motion graphs. (d vs. t, v vs. t, and a vs. t)*
- *The difference between **Scalar** and **Vector**, as well as understanding which terms are **Scalars** and which are **Vectors**.*
- *The similarities and differences between the terms **Distance/Displacement**, **Speed/Velocity** and **Acceleration**.*
- *Completing basic calculations involving **Distance/Displacement**, **Speed/Velocity** and **Acceleration**.*

So let's pick up the story from there…

At this point you should have been introduced to the following equations and variables:

$$\Delta\vec{v} = \frac{\Delta\vec{d}}{\Delta t}$$

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$$

In order to solve problems with **uniform acceleration** we need to use the variables:

v_f = final velocity
v_o = initial velocity
a = acceleration
d = displacement
t = time

A couple of new things to be aware of….

The ➔ above a term indicates the term is a vector, the **Δ** indicates a change in something.

$$\Delta\vec{v} = \vec{v}_f - \vec{v}_o$$

The subscripts **f** and **o** indicate the final and initial velocity of an object respectively. The equation reads as follows….

The change in velocity of an object is equal to the final velocity minus the initial velocity.

Deriving the Big Three – **Equation #1**

From the equation $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$ derive (***step-by-step!***) $\vec{v}_f = \vec{v}_o + \vec{a}t$.

$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$

1) $a = \frac{V_f - V_o}{t}$

2) $at = V_f - V_o$

3) $\boxed{V_f = V_o + at}$

Now let's practice…

Please make sure to include a **Conceptual Equations** for each problem and ***Show ALL Work***!

Example:
A fully loaded Boeing 747 with all engines at full thrust accelerates at +2.6 m/s^2. Its minimum takeoff speed is +70 m/s. How much time will the plane need to reach its takeoff speed?

$V_f = \cancel{V_o}^{0} + at$

$V_f = at$

$t = \frac{V_f}{a}$

$t = \frac{+70\cancel{m}/\cancel{s}}{+2.6\cancel{m}/s^{\cancel{2}}}$

$\boxed{t = 26.9\,s}$

Example:
A supersonic jet traveling at 200. m/s [E] is accelerated uniformly from at a rate of 23.1 m/s^2 [E] for 20.0 s. What is the jets final speed?

$V_f = V_o + at$

$V_f = 200\,m/s + (23.1\,m/s^2)(20.0\,s)$

$\boxed{V_f = 662\,m/s\ [E]}$

Remember Displacement, Velocity, and Acceleration are vectors and therefore must include….

Magnitude, Units, and direction

3.0 m/s [W]

Deriving the Big Three – **Equation #2**

From the equations $\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$ and $\vec{d} = (\frac{\vec{v}_f + \vec{v}_o}{2})t$ derive (***step-by-step!***) $\vec{v}_f^2 = \vec{v}_o^2 + 2\vec{a}\vec{d}$.

$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$ and $\vec{d} = (\frac{\vec{v}_f + \vec{v}_o}{2})t$

1) $t = \frac{\Delta v}{a}$

Sub 1) into 2)

2) $2d = (v_f + v_o)t$

3) $2d = \frac{(v_f + v_o)\Delta v}{a}$

4) $2ad = (v_f + v_o)(v_f - v_o)$

5) $2ad = v_f^2 + \cancel{v_o v_f} - \cancel{v_o v_f} - v_o^2$

6) $\boxed{v_f^2 = v_o^2 + 2ad}$

Now let's practice…

Example: Mr. Branco gets on the highway in his 1967 Shelby 427 Cobra traveling at 11 m/s. To his right he see's his nemesis, Mr. Trask in his red 1998 Honda Civic guns it! After 145 m he is traveling at 32 m/s. What is the Cobra's acceleration? $v_f^2 = v_o^2 + 2ad$ $a = \frac{v_f^2 - v_o^2}{2d}$ $a = \frac{(32\,m/s)^2 - (11\,m/s)^2}{2(145\,m)}$ $\boxed{a = 3.1\,m/s^2}$	Example: An engineer is to design a runway to accommodate airplanes that must gain a ground speed of 360. km/hr (100. m/s) before they can take off. These planes are capable of being accelerated uniformly at the rate of 2.78 m/s^2. How many kilometers long must the runway be? $v_f^2 = \cancel{v_o^2}^{\,0} + 2ad$ $d = \frac{v_f^2}{2a}$ $d = \frac{(100\,m/s)^2}{2(2.78\,m/s^2)} = 1,799\,m$ $\boxed{d = 1.799\,km}$

Remember all calculations must be completed using System International Units! ***In Canada that means…***

meter's, seconds, kilograms, kelvin's ect.

Deriving the Big Three – **Equation #3**

Finally from the equations $\vec{v}_f = \vec{v}_o + \vec{a}t$ and $\vec{d} = (\frac{\vec{v}_f + \vec{v}_o}{2})t$ derive (***step-by-step!***) $\vec{d} = \vec{v}_o t + \frac{1}{2}\vec{a}t^2$.

$\vec{v}_f = \vec{v}_o + \vec{a}t$ and $\vec{d} = (\frac{\vec{v}_f + \vec{v}_o}{2})t$

1) $v_f = v_o + at$

2) $d = \left(\frac{v_f + v_o}{2}\right)t$

plug 1) into 2)

3) $d = \left(\frac{v_o + at + v_o}{2}\right)t$

4) $d = \frac{2v_o t + at^2}{2}$

5) $\boxed{d = v_o t + \frac{1}{2}at^2}$

Now let's practice…

Example: You are a bungee jumping fanatic and want to be the first bungee jumper on Jupiter. The length of your bungee cord is 45.0 m (*this is the length before your cord starts to pull up!*). Free fall acceleration on Jupiter is 23.1 m/s^2 [Down]. How long does it take you to fall 45.0 m? $d = \cancel{v_o t}^{\,0} + \frac{1}{2}at^2$ $t = \pm\sqrt{\frac{2d}{a}}$ why $\pm$??? $t = \pm\sqrt{\frac{2(45m)}{(23.1 m/s^2)}}$ $t = +1.97 s$ only + makes sense!!	Example: A fully loaded Boeing 747 with all engines at full thrust accelerates at +2.6 m/s^2. Its minimum takeoff speed is +70 m/s. What minimum length of runway does the plane require for takeoff? → hmm this looks familar! $v_f = \cancel{v_o}^{\,0} + at$ $t = \frac{v_f}{a} = \frac{+70 m/s}{+2.6 m/s^2} = 26.9 s$ $d = \cancel{v_o t}^{\,0} + \frac{1}{2}at^2$ $d = \frac{1}{2}(2.6 m/s^2)(26.9 s)^2$ $\boxed{d = 942 m}$

Example:
A car is traveling +20.0 m/s when the driver sees a moose standing on the road. She takes 0.80 s to react the steps on the brakes and slows at 7.1 m/s^2. If the moose is initially 45 m away from the car will the car hit the moose?

Constant Velocity

$d_1 = v_o t$

$d_1 = (+20.0 m/s)(0.80 s) = 16.0 m$

slowing down

$\cancel{v_f}^{2\,0} = v_o^2 + 2ad_2$

$d_2 = \frac{-v_o^2}{2a}$

$d_2 = \frac{-(+20.0 m/s)^2}{2(-7.1 m/s^2)}$

$d_2 = 28.2 m$

Total $d = d_1 + d_2$

$\boxed{d_T = 44.2 m \quad \text{No!!!}}$

Worksheet – The Big 3

A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die and a new generation grows up that is familiar with it. – Max Planck

1. A racecar accelerates from rest to a speed of 287 km/h in 6.8 seconds. What is its average acceleration?

2. The space shuttle undergoes an acceleration of 53.9 m/s^2. How fast is it traveling at the end of 55.2 s?

3. You are in an elevator that is accelerating you upward at 4.55 m/s^2. How much time does it take you to reach a speed of 11.0 m/s?

4. A car is traveling at 108 km/h, stuck behind a slower car. Finally the road is clear and the car pulls over to make a pass. The driver stomps on the gas pedal and accelerates up to a speed of 135 km/h. If it took 3.5 s to reach this speed, what is the average acceleration of the car?

5. A driver has a reaction time of 0.50 s, and the maximum deceleration of her car is 6.0 m/s^2. She is driving at 20 m/s when suddenly she sees an obstacle in the road 50 m in front of her. Can she stop the car to avoid the collision?

6. Chameleons catch insects with their tongues, which they can rapidly extend to great lengths. In a typical strike, the chameleon's tongue accelerates at a remarkable 250 m/s^2 for 20 ms, then travels at a constant speed for another 30 ms. During this total time of 50 ms, how far does the tongue reach?

7. You're driving down the highway late one night at 20 m/s when a deer steps onto the road 35 m in front of you. Your reaction time before stepping on the brakes is 0.50 s, and the maximum deceleration of your car is 10 m/s^2. How much distance is between you and the deer when you come to a stop? What is the maximum speed you could have and still not hit the deer?

8. When a jet lands on an aircraft carrier, a hook on the tail of the plane grabs a wire that quickly brings the plane to a halt before it overshoots the deck. In a typical landing, a jet touching down at 240 km/h is stopped in a distance of 95 m. What is the magnitude of the jet's acceleration as it is brought to rest? How much time does the landing take?

9. A simple model for a person running the 100 m dash is to assume the sprinter runs with constant acceleration until reaching top speed, then maintains that speed through the finish line. If the sprinter reaches his top speed of 11.2 m/s in 2.14 s, what will be his total time?

Answers:

1. 12 m/s
2. 2980 m/s
3. 2.2 s
4. 2.14 m/s^2
5. Yes! She will come to a stop in 43.3m
6. 0.20 m or 20 cm
7. 5.0 m and 22 m/s
8. 23.4 m/s^2 and 2.85 s
9. 10.0s

Unit 1: 1D Kinematics

2 – Free Fall

Free Fall is a special case of 1D Kinematics where objects fall due to the Force of Gravity alone.

- NEWS FLASH!!! We live on Earth
- IMPORTANT… not all objects on the surface of the Earth feel the same Gravitational Force (more on this in future chapters!)

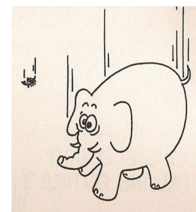
However….

- On the surface of the Earth all **Free Falling** objects accelerate downwards (towards the center of the Earth) at the same rate.

A couple of things…

- Unless stated otherwise… ignore air resistance/friction
- The acceleration due to gravity is given a unique symbol "g".
- Even though the distance from the surface of the Earth to the core of the Earth varies assume a constant acceleration of…

$$\boxed{g = -9.8\,m/s^2}$$



- And we can STILL use our **BIG 3 Equations!**

Example:

A heavy rock is dropped from rest at the top of a cliff and falls 150 m before hitting the ground. How long does the rock take to hit the ground? What is the rocks velocity right before it hits the ground?

$$d = \cancel{v_o}^{0} t + \tfrac{1}{2}at^2$$

$$t = \pm\sqrt{\frac{2d}{a}}$$

$$t = \pm\sqrt{\frac{2(-150m)}{(-9.80m/s^2)}} = \boxed{+5.5s}$$

$$V_f^2 = \cancel{V_o^2}^{0} + 2ad$$

$$V_f = \pm\sqrt{2ad}$$

$$V_f = \pm\sqrt{2(-9.8m/s^2)(150m)}$$

$$V_f = \boxed{-54.2\,m/s}$$

Example:

A springbok is an antelope found in southern Africa that gets its name from its remarkable jumping ability. When a springbok is startled, it will leap straight up into the air (called a "pronk"). A springbok goes into a crouch to perform a print. It then extends its legs forcefully, accelerating at 35 m/s^2 for 0.70 m as its legs straighten. Legs fully extended, it leaves the ground and rises into the air. At what speed does the springbok leave the ground. How high does it go?

$$V_f^2 = \cancel{V_o^2}^{0} + 2ad$$

$$V_f = \pm\sqrt{}$$

$$V_f = \pm\sqrt{2(35m/s^2)(0.70m)}$$

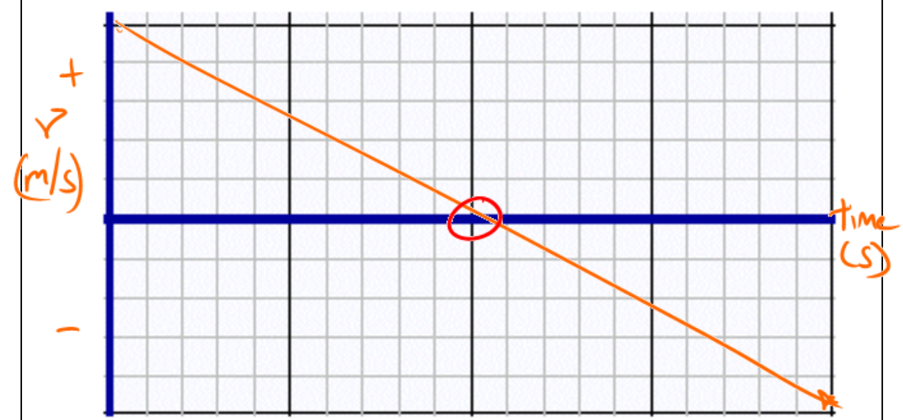
$$V_f = \boxed{+7.0\,m/s}$$

0m/s at top of jump

$$\cancel{V_f^2}^{0} = V_o^2 + 2ad$$

$$d = \frac{-V_o^2}{2g} = \frac{-(7.0m/s)^2}{2(-9.8m/s^2)} = \boxed{+2.5m}$$

Example:
Draw a motion diagram and a velocity-time graph for a ball tossed straight up in the air from the point that it leaves the hand until just before it is caught.

Motion Diagram of the ball	**Velocity-Time Graph**
	

Based on the Velocity vs. Time Graph… ***Explain each answer***

a. What should the slope of the line represent? acceration

b. What should the area under the line represent? displacement

c. At what point in the motion of the ball is its acceleration zero?

Never!!!

d. At what point in the motion of the ball is its velocity zero?

When it crosses the x-axis

e. How is the ball's initial velocity (the point it leaves the hand) related to the balls final velocity (just before it returns to the hand)?

Equal in magnitude; opposite in direction.

f. What is the relationship between the time the ball was going up and the time the ball was going down? How does the time it was going up relate to the TOTAL time the ball was in the air?

$T_{up} = T_{down}$

$T_{Total} = 2 \times T_{up} = 2 \times T_{down}$

Example:

A volcano ejects a chunk of rock straight up at a velocity of +30 m/s. Ignoring air resistance, what will the velocity just before it returns to the surface of the volcano?

a. greater than +30 m/s
b. +30 m/s
c. 0 m/s
d. -30 m/s
e. less than -30 m/s

Example:

An English teacher uses a potato launcher to shoot a potato straight up in the air. The potato goes up and inevitably comes straight down onto the English teachers head. If the total airtime was 9.6 s, how long did it take the potato to reach its maximum height?

a. 0s b. 2.4 s c. 4.8 s d. 7.2 s e. 9.6 s

$T_{1/2}$

Example:

A baseball is thrown straight up into the air; it hits the ground 5.2 s later. What is the maximum height the ball reaches and at what speed did it leave the throwers hand.

$+t$

$t_{1/2} = 2.6s$

$\cancel{V_f} = V_o + at_{1/2}$ ($V_f = 0$)

$V_o = -gt_{1/2} = +(+9.8 m/s^2)(2.6s) = \boxed{+25.5 m/s}$

$d = V_o t + \frac{1}{2}gt^2$

$d = (25.5 m/s)(2.6 m/s) + \frac{1}{2}(-9.8 m/s^2)(2.6s)^2$

$\boxed{d = +33.1 m}$

Example: (AP Level Question ALERT)

A cliff jumper stands on top of a 50. m high cliff pool of water. He throws two stones vertically downward 1.0 s apart and sees that they hit at the EXACT same time. If the initial speed of the first stone was 2.0 m/s.

a. How long after the release of the first stone does the second stone hit the water?
b. What was the initial speed of the second stone?
c. What is the speed of each stone as it hits the water?

a) $V_f^2 = V_o^2 + 2ad$ ← 1st stone

$V_f = \pm\sqrt{V_o^2 + 2gd}$

$V_f = \pm\sqrt{(2.0 m/s)^2 + 2(-9.8 m/s^2)(-50. m)}$

$\boxed{V_f = -31.4 m/s}$ → speed of 1st stone

$V_f = V_o + at$

$t = \frac{V_f - V_o}{g}$

$t = \frac{-31.4 m/s - (-2.0 m/s)}{-9.8 m/s^2}$

$\boxed{t = 3.00 s}$

b) 2nd stone

$t = 3.00s - 1.00s$

$t = 2.00s$

$d = V_o t + \frac{1}{2}at^2$

$V_o = \frac{d - \frac{1}{2}gt^2}{t}$

$V_o = \frac{(-50m) - \frac{1}{2}(-9.8 m/s^2)(2s)^2}{2s}$

$\boxed{V_o = -15.2 m/s}$

c) $V_f = V_o + at$ ← for 2nd stone

$V_f = (-15.2 m/s) + (-9.8 m/s^2)(2.0s)$

$\boxed{V_f = -34.8 m/s}$

AP Physics – 1D Kinematics with Free Fall

What you are called____Per ___

Computers in the future may weigh no more than 1.5 tons. -- Popular Mechanics, 1949

1. A race car accelerates at a rate of 15.6 m/s^2. If it starts from rest, how much time till it is traveling at 325 km/h?
2. A truck falls off a cliff. If the cliff is 33.5 m high, how much time for the truck to reach the bottom?
3. You toss a ball straight up in the air, it goes up, comes down, and you catch it. If it took 5.6 s from when you threw it to when you caught it, how high did it go?
4. The speed of sound is 344 m/s. You have built a really fantastic car that can really go fast. If the car can accelerate at 22.4 m/s, how much time till you reach the speed of sound? How many kilometers will you travel before you reach that speed?
5. In 1947 Bob Feller, a pitcher for the Cleveland Indians, threw a baseball across the plate at 98.6 mph or 44.1 m/s. For many years this was the fastest pitch ever measured. If Bob had thrown the pitch straight up, how high would it have gone?
6. You are on top of a building that is 75.0 m tall. You toss a ball straight up with an initial velocity of 33.8 m/s. How high does the ball travel? It goes up and then falls down to the ground below. How much time is it in the air?
7. Excellent human jumpers can leap straight up to a height of 110 cm off the ground. To reach this height, with what speed would a person need to leave the ground?
8. In an action movie, the villain is rescued from the ocean by grabbing onto the ladder handing from a helicopter. He is so intent on gripping the ladder that he lets go of his briefcase of counterfeit money when he is 130 m above the water. If the briefcase hits the water 6.0 s later, what was the speed at which the helicopter was ascending?

Answers:

1. 5.79 s
2. 2.61 s
3. 38 m
4. 15.4 s and 2.66 km
5. 99.2 m
6. Height: 58.3 Time up: 3.45 s Time Down: 5.22 Total Time: 8.67 s
7. 4.6 m/s
8. 7.7 m/s

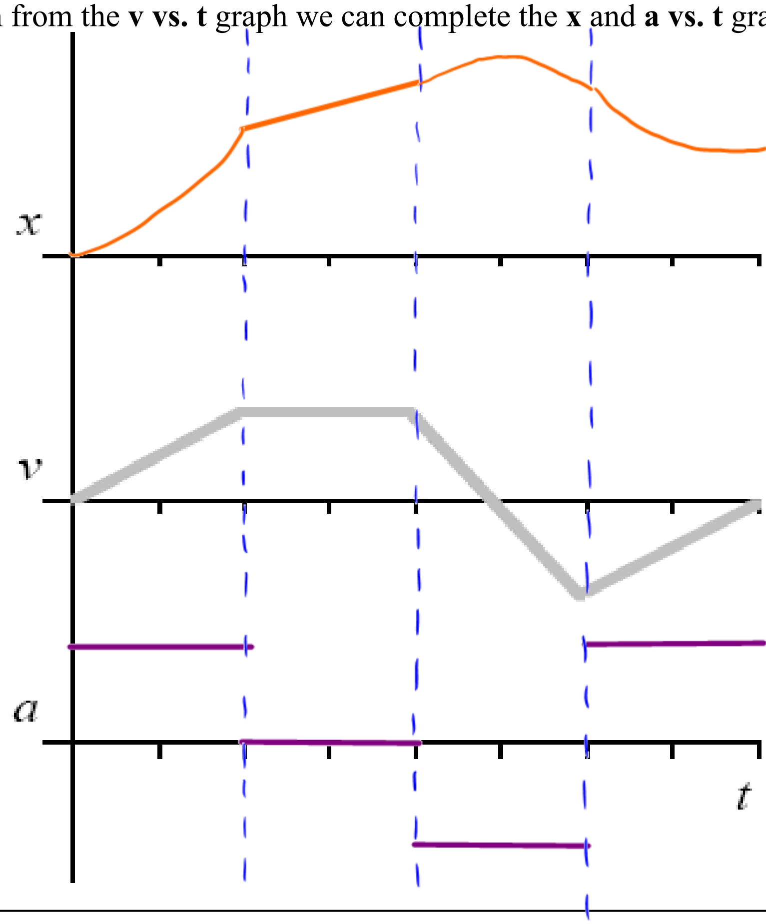
Unit 1: Kinematics in 1D
3 – Curve Straightening Graphs

There is certain information that can be taken from position vs. time (d vs. t) and velocity vs. time (v vs. t) graphs.

For Example:

Displacement vs. Time graphs:	Velocity vs. Time graphs:
Slope: Velocity	Slope: Acceleration Area Under the Graph: Displacemt

Given the information from the **v vs. t** graph we can complete the **x** and **a vs. t** graphs



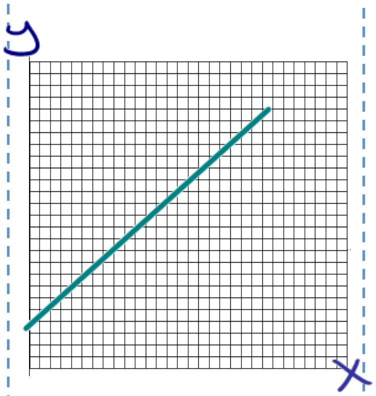
In AP Physics 1 you will be expected to perform more advanced graphical analysis on tests and in labs. EVERY time you make a graph you should follow the following rules.

- Label the axis
  - Independent variable on the x-axis → in most case time.
  - Dependent variable on the y-axis
- Give the graph an appropriate title. → velocity vs. time for a ball rolling down a ramp.
- Scale each axis
  - Use… as much grid as possible
  - Choose a scale that is… easy to read
  - Make sure to name and include units for each axis.
- Plot the points and draw a best fit curve.
- Determine if the curve is Linear or not. Linear is GOOD!

→ a direct relationship between variables!

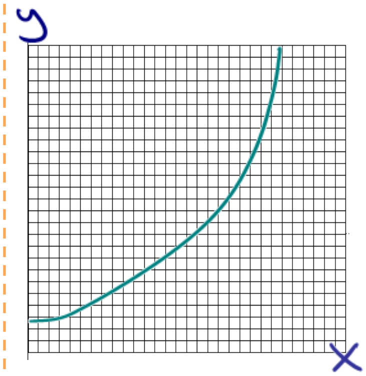
Direct: →proportional

$y \propto x$



Quadratic :

$y \propto x^2$

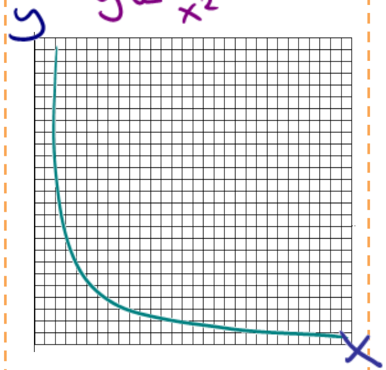


Inverse

$y \propto \frac{1}{x}$

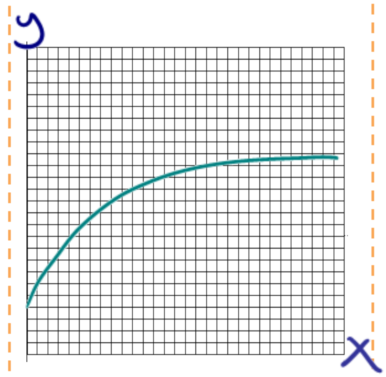
Inverse Square

$y \propto \frac{1}{x^2}$



Square Root:

$y \propto \sqrt{x}$



Finding Slope

To find the slope of a straight line:

- Choose… 2 points
- Choose them as…as far apart as possible
- Use only… points on the line. NO DATA POINTS!!!

Remember the equation of a line is:

$$y = mx + b$$

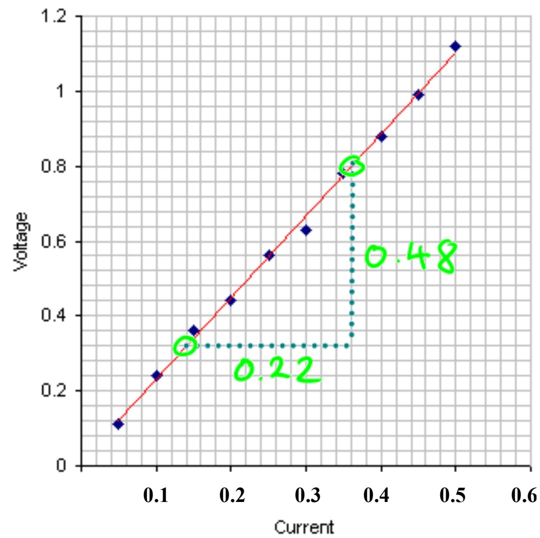
Determine the slope and y-intercept of the graph shown and write the equation describing this line.

$$\text{slope} = \frac{\text{rise}}{\text{run}} = m$$

$$m = \frac{0.48\,V}{0.22\,A}$$

$$m = 2.2\ V/A$$

y-int = 0



Curve Straightening

Linearization

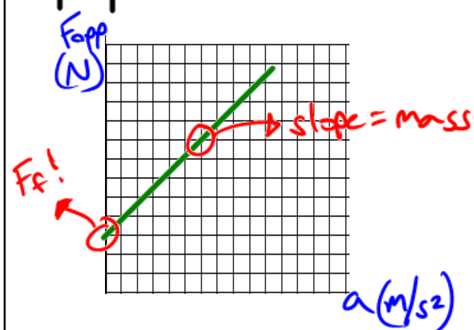
Ex 1: A student pushes a wooden block over a rough surface with different amounts of force and measures the acceleration each time.

F_{app}	a

$F_{app} - F_f = ma$

$F_{app} = ma + F_f$

$y = mx + b$



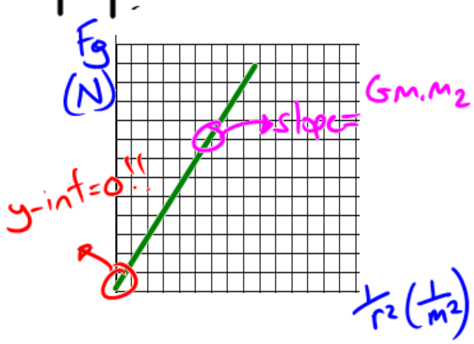
Ex 2: An astronaut standing on an asteroid measures the force of gravity acting on a 10 kg mass at different distances from the center of the asteroid.

F_g	r	$\frac{1}{r^2}$

$F_g = \frac{Gm_1m_2}{r^2}$

$F_g = Gm_1m_2\left(\frac{1}{r^2}\right)$

$y = m\ x + b$



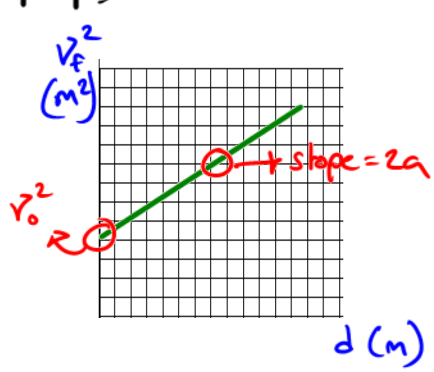
Ex 3: A car starts at a certain speed and accelerates uniformly. A student collects data of velocity at different displacements.

V_f	V_f^2	d

$V_f^2 = V_0^2 + 2ad$

$V_f^2 = 2ad + V_0^2$

$y = mx + b$



AP Physics 1 - Curve Straightening Worksheet Name: ________________ Date: ____________

1. Plot each of the following sets of data on a graph. Using a suitable curve-straightening technique, determine an equation (include the value of the slope and the units for the slope) that represents the data. In addition, for questions b and c, find the meaning of the slope and the y-int.

a. $y = x^2$

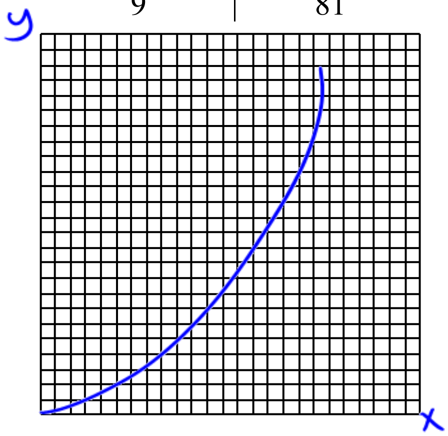
x	y
1	1
2	4
3	9
4	16
5	25
6	36
7	49
8	64
9	81

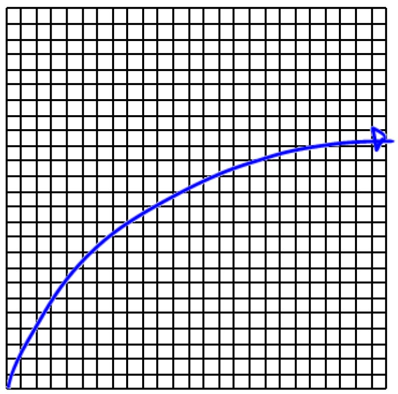
b. $a = \frac{F}{M}$

mass (kg)	acceleration (m/s^2)
2.0	48.0
4.0	26.2
6.0	20.0
8.0	11.3
10.0	10.0
12.0	7.5
14.0	7.2
16.0	6.1
18.0	5.6

c.

time (s)	position (m)
0.0	10
1.0	22
2.0	32
3.0	40
4.0	45
5.0	62
6.0	73
7.0	81
8.0	90





y	x^2
1	1
4	4
9	9
16	16
25	25
36	36
49	49
64	64
81	81

a (m/s^2)	$\frac{1}{M}$ ($\frac{1}{kg}$)
48.0	0.5
26.2	0.25
20.0	0.167
11.3	0.125
10.0	0.10
7.5	0.083
7.2	0.0714
6.1	0.0625
5.1	0.0556