# Using Constant Acceleration

**Introduction**

**Purpose**: To investigate various factors involved with constant acceleration.

**PART 1** Calculating displacement and acceleration, knowing velocity.

**Discussion**

Acceleration is the rate of speed over time, meaning that speed changes over time. Previously we worked with average velocity (*speed plus direction*), finding displacement over time (**v = d/t**). Therefore, we can find displacements, times and speed changes for experiments or real-life situations. For instance, if you are travelling 70 mph and travel for 2 minutes, how far have you traveled? If you are running at a constant speed and run a known distance, how long did it take you?

We can also find variables related to acceleration in much the same way. We can work with displacements, times and velocities because these are variables of acceleration as described by [ **a = (vf – vi) / t** ]. If we know certain variables, we can calculate other variables because they are all mathematically related. For instance, if we want to calculate the final velocity of an object, we can rearrange the equation as follows:

**vf = vi + a t**

The simplest way to investigate this is to use **constant acceleration**. We know that average velocity is displacement over time (**v = d/t**). We can also find average velocity by adding velocities and dividing by the total number of velocities [ **v = (vf + vi) / 2** ]. If we place the first average velocity equation into the second, we get the following: **d/t = (vf + vi) / 2** . Solving for displacement, we get:

**d = ½ (vf + vi) t**

**Materials**

2 m Track Stop Watch Motion Cart or Ball

200 cm

*d3*

*d2*

*d1*

*150 cm*

*100 cm*

*0 cm*

**Procedures** [**http://somup.com/crhI03FLpV**](http://somup.com/crhI03FLpV) **(0:30)**

1. Set up the 2-meter track by raising one end exactly 10 cm off the lab counter. [*You can place two 2-m long boards next to each other so the ball rolls down the gap between them*.]
2. Place the motion cart or ball on the 200 cm mark.
3. Take three time trials of how long it takes for the motion cart to travel to the 150 cm mark. Find the average time for that distance.
4. Record the actual distance the cart traveled.
5. Repeat the procedures for the motion cart traveling from the “200 cm” to the “100 cm” mark.
6. Repeat the procedures for the motion cart traveling from the “200 cm” to the “0 cm” mark.

## Calculations and Data [SHOW ALL EQUATIONS AND WORK]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Total Distance | Actual Distance | Total Time  (from 200 cm mark) | Time to Travel Actual Distance |
| *d1* |  |  |  |  |
| *d2* |  |  |  |  |
| *d3* |  |  |  |  |

1. Calculate the final velocity for each of the three distances using acceleration and time. (*Assume the constant acceleration on this track is* ***0.430 m/s/s***.)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Acceleration | Total Distance | Actual Distance | Time to Travel | Calculated Velocity |
| *d1* |  |  |  |  |  |
| *d2* |  |  |  |  |
| *d3* |  |  |  |  |

**d = ½ (vf + vi) t**

**vf = vi + a t**

1. Calculate the distances for each velocity using velocity and time.
2. Determine percent error for your distance calculations.
3. Complete the chart below, showing actual distances, average times, calculated velocities, calculated distances and percent errors for distance for Part I.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Actual Distance | Time to Travel | Calculated Velocity (**vf**)  vf = vi + at | Calculated Distance  d = ½ (vf + vi) t | Percent Error for Distance |
| *d1* |  |  |  |  |  |
| *d2* |  |  |  |  |  |
| *d3* |  |  |  |  |  |

**PART 2** Calculating displacement knowing acceleration and time.

**Discussion** As a continuation to Part 1, we can calculate displacements if we know time and acceleration. If the initial velocity, acceleration, and time interval are known, the displacement of an object can be found by combining equations already used.

Beginning with [ **a = (vf – vi) / t**] we can solve for **vf** as get: **vf = vi + at**. Then, we can substitute this equation in the displacement equation, **d = ½ (vf + vi) t** … d = ½ (vi + at + vi) t which is rewritten: d = ½ (2vi + at) t and get:

**d = vi t + ½ at2**

There are two terms in this equation. The first term, **vi t** , corresponds to the displacement of an object if it were moving with constant velocity, **vi** . The second term, **½ at2**, gives the displacement of an object starting from rest and moving with uniform acceleration.

The sum of these two terms, **vi t** and **½ at2**, gives the displacement of an object that starts with an initial velocity and accelerates uniformly. For an object that starts from rest, the equation reduces to: **d =** **½ at2**.

**Procedure**

1. You will use the information you obtained and calculated in Part 1 to do Part 2.

**Calculations and Data** [SHOW ALL EQUATIONS AND WORK]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Actual Distance | Time to Travel | Initial Velocity | Calculated Distance  d = vi t + ½ at2 | Percent Error for Distance |
| ***d1*** |  |  |  |  |  |
| ***d2*** |  |  |  |  |  |
| ***d3*** |  |  |  |  |  |

1. Based on the Part 2 discussion, calculate the displacement for each of the settings in Part 1 using acceleration and initial velocity as follows:
2. distanceusing the 200 cm to 150 cm velocities.
3. distanceusing the 150 cm to 100 cm velocities.
4. distanceusing the 100 cm to 0 cm velocities.
5. Determine percent error for your distance calculations.

**Part 3** Calculating acceleration using displacement and velocity

**Discussion** We can combine the equations for final velocity and displacement to form an equation relating initial and final velocities, acceleration, and displacement in which time does not appear.

Beginning with [**d = ½ (vf + vi) t**] and **vf = vi + at** we can rearrange the latter equation by solving for time. That equation becomes: **t = ( vf - vi ) / a .** Now, we can substitute this equation in the first equation, **d = ½ (vf + vi) ( vf - vi ) / a** … yielding:

**a = (vf2 - vi2) / 2d**

**d = (vf2 - vi2) / 2a**

or

depending on what variable you are solving for.

**Procedure**

1. Use previously gathered information to do Part 3.

## Calculations and Data [SHOW ALL EQUATIONS AND WORK]

1. Based on the Part 3 discussion, the calculated velocities, and the actual GIVEN acceleration, calculate the displacement for *d1*, *d2*, and *d3*.
2. Determine average percent error for your distance calculations.
3. Based on the Part 3 discussion, the ACTUAL distances, and calculated velocities, calculate the acceleration for *d1, d2,* and *d3*.
4. Complete the chart below, showing your actual distances, calculated distances, calculated accelerations and percent errors for distance and acceleration.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Actual Distance | Time to Travel | Calculated Distance  d = (vf2 - vi2)/2a | Percent Error for Distance | Calculated Acceleration  a = (vf2 - vi2)/2d | Percent Error for Acceleration |
| *d1* |  |  |  |  |  |  |
| *d2* |  |  |  |  |  |  |
| *d3* |  |  |  |  |  |  |

## Conclusions and Questions [Show equations and work]

1. You are given the following chart showing position versus time for uniformly accelerated motion. What aspect of the graph shows you the velocity of an object at any point? What would be the shape of the graphed points and why would they be that shape?

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Position versus Time | | | | | | |
| Time (s) | 0 | 1 | 2 | 3 | 4 | 5 |
| Position (m) | 0 | 10 | 40 | 90 | 160 | 250 |

1. If an object has zero acceleration, does that mean its velocity must be zero? Explain.
2. If an object has zero velocity at some instant, does that mean its acceleration must be zero? Explain.
3. Explain why you used different equations to calculate displacement in Part I and Part II. Name the variable(s) that are needed and that are missing in each case.
4. An airplane must reach a velocity of 71 m/s for takeoff. If the runway is 1.0 km long, what must the constant acceleration be? (*Show equation and all work*.)

1. The same plane in question 5 lands going 71 m/s. It slows to a halt with a n acceleration of –2.5 m/s2 . How much runway does it require? (*Show equation and all work*.)

#### EXPECTED RESULTS FOR LAB

**ACCELERATION**:

200 cm

*d2*

*d3*

*d1*

track

##### “Blow Up”

gsin@

@

g

sin@ = opp/hyp

@

* Using the track lifted 10 cm at one end, the calculated acceleration is

gsin@ or 9.8 m/s/s x 10 cm/228 cm = **0.430 m/s/s**

## Part 1 Summary Chart

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Total Distance | Actual Distance | Total Time  (from 200 cm mark) | Time to Travel Actual Distance |
| *d1* | 0.5 m | 0.5 m | 1.53 s | 1.53 s |
| *d2* | 1.0 m | 0.5 m | 2.16 s | .63 s |
| *d3* | 2.0 m | 1.0 m | 3.05 s | .89 s |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Acceleration | Total Distance | Actual Distance | Time to Travel | Calculated Velocity |
| *d1* | 0.430 m/s/s | 0.5 m | 0.5 m | 1.53 s | 0.66 m/s |
| *d2* | 1.0 m | 0.5 m | .63 s | 0.93 m/s |
| *d3* | 2.0 m | 1.0 m | .89 s | 1.31 m/s |

**d = ½ (vf + vi) t**

**vf = vi + a t**

**vf**  = 0 m/s + (0.430 m/s2) (1.53 s) **d =** ½(0.658 m/s + 0) (1.53 s)

**vf** = 0.66 m/s / 0.43 m/s2 **d =** 0.503 m

**vf** = 0.658 m/s

**200 cm → 150 cm**

**vf**  = 0 m/s + (0.430 m/s2) (1.53 s) **d1** = ½(0.658 m/s + 0) (1.53 s)

**vf** = 0.658 m/s = 0.66 m/s **d1** = 0.503 m

% Error = (A – O)/A = (0.50 m – 0.50 m)/0.50 m x 100% = 0 %

**150 cm → 100 cm**

**vf**  = 0.66 m/s + (0.430 m/s2) (0.63 s) **d2** = ½(0.93 m/s + 0.66 m/s) (0.63 s)

**vf** = 0.93 m/s **d2** = 0.501 m

% Error = (A – O)/A = (0.50 m – 0.50 m)/0.50 m x 100% = 0 %

**100 cm → 0 cm**

**vf**  = 0.93 m/s + (0.430 m/s2) (0.89 s) **d3** = ½(1.31 m/s + 0.93 m/s) (0.89 s)

**vf** = 1.31 m/s **d3** = 0.998 m = 1.0 m

% Error = (A – O)/A = (1.0 m – 1.0 m)/ 1.0 m x 100% = 0 %

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Actual Distance | Time to Travel | Calculated Velocity (**vf**)  vf = vi + at | Calculated Distance  d = ½ (vf + vi) t | Percent Error for Distance |
| ***d1*** | 0.5 m | 1.53 s | 0.66 m/s | 0.50 m | 0.00% |
| ***d2*** | 0.5 m | .63 s | 0.93 m/s | 0.50 m | 0.00% |
| ***d3*** | 1.0 m | .89 s | 1.31 m/s | 1.00 m | 0.00% |

Part 2 Calculating “d” given “t” and “a”

150 cm

100 cm

200 cm

*d2*

*d3*

*d1*

a = (vf – vi) / t therefore **t = (vf – vi) / a**

* The **vf** calculated for the 200 cm 🡪 150 cm mark becomes the **vi** for 150 cm 🡪 100 cm

**t** = (0.93 m/s – 0.6 m/s) / 0.43 m/s2 **t = 0.63 s**

**d = vi t + ½ at2**

**d** = (0.63 m/s)(0.63 s) + ½ (0.43 m/s2)(0.63 s)2 = 0.48 m

**200 cm → 150 cm**

**d = vi t + ½ at2** vi = 0

**d** = 0 + ½ (0.43 m/s2)(1.53 s)2

d = 0.503 m

% Error = (A – O)/A = (0.50 m – 0.50 m)/0.50 m x 100% = 0 %

* The **vf** calculated for the 200 cm  150 cm mark becomes the **vi** for 150 cm  100 cm

**150 cm → 100 cm**

**d = vi t + ½ at2**  vi = 0.66 m/s

**d** = (0.66 m/s)(0.63 s) + ½ (0.43 m/s2)(0.63 s)2

d = 0.501 m

% Error = (A – O)/A = (0.50 m – 0.50 m)/0.50 m x 100% = 0 %

* The **vf** calculated for the 100 cm mark becomes the **vi** for 100 cm  0 cm

**100 cm → 0 cm**

**d = vi t + ½ at2** vi = 0.93 m/s

**d** = (0.93 m/s)(0.89 s) + ½ (0.43 m/s2)(0.89 s)2

d = 0.998 m = 1.0 m

% Error = (A – O)/A = (1.0 m – 1.0 m)/ 1.0 m x 100% = 0 %

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Actual Distance | Time to Travel | Initial Velocity  (previous table) | Calculated Distance  d = vi t + ½ at2 | Percent Error for Distance |
| ***d1*** | 0.5 m | 1.53 s | 0 m/s | 0.50 m | 0.00% |
| ***d2*** | 0.5 m | .63 s | 0.66 m/s | 0.50 m | 0.00% |
| ***d3*** | 1.0 m | .89 s | 0.93 m/s | 1.0 m | 0.00% |

###### Part 3

Calculating “d” and “a’ without “t”

**200 cm → 150 cm**

d = (vf2 – vi2)/2a d = ((0.66 m/s)2 – 0) / 2(0.43 m/s) d = 0.51 m

% Error = (A – O)/A = (0.50 m – 0.51 m)/0.50 m x 100% = 2 %

**150 cm → 100 cm**

d = (vf2 – vi2)/2a d = ((0.93 m/s)2 – (0.66 m/s)2) / 2(0.43 m/s) = 0.499 m = 0.50 m

% Error = (A – O)/A = (0.50 m – 0.50 m)/0.50 m x 100% = 0%

**100 cm → 0 cm**

d = (vf2 – vi2)/2a d = ((1.31 m/s)2 – (0.93 m/s)2) / 2(0.43 m/s) = 0.99 m

% Error = (A – O)/A = (1.00 m – 0.99 m)/1.00 m x 100% = 1 %

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Actual Distance | Calculated Distance  d = (vf2 - vi2)/2a | Percent Error for Distance | Calculated Acceleration  a = (vf2 - vi2)/2d | Percent Error for Acceleration |
| ***d1*** | 0.5 m | 0.51 m | 2.00% | 0.44 m/s2 | 2.00% |
| ***d2*** | 0.5 m | 0.50 m | 0.00% | 0.43 m/s2 | 0.00% |
| ***d3*** | 1.0 m | 0.99 m | 1.00% | 0.43 m/s2 | 0.00% |

**200 cm → 150 cm**

a = (vf2 - vi2)/2d a = ((0.66 m/s)2 – 0) / 2(0.50 m) a = 0.44 m/s2

% Error = (A – O)/A = (0.43 m – 0.44 m)/0.43 m x 100% = 2 %

**150 cm → 100 cm**

a = (vf2 - vi2)/2d a = ((0.93 m/s)2 – (0.66 m/s)2) / 2(0.50 m) = 0.43 m/s2

% Error = (A – O)/A = (0.43 m – 0.43 m)/0.43 m x 100% = 0 %

**100 cm → 0 cm**

a = (vf2 - vi2)/2d a = ((1.31 m/s)2 – (0.93 m/s)2) / 2(1.0 m) = 0.425 m/s2 = 0.43 m/s2

% Error = (A – O)/A = (0.43 m – 0.43 m)/0.43 m x 100% = 0 %

## Conclusions and Questions [Show equations and work]

1. You are given the following chart showing position versus time for uniformly accelerated motion. What aspect of the graph shows you the velocity of an object at any point? What would be the shape of the graphed points and why would they be that shape?

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Position versus Time | | | | | | |
| Time (s) | 0 | 1 | 2 | 3 | 4 | 5 |
| Position (m) | 0 | 10 | 40 | 90 | 160 | 250 |

*The graph would have a hyperbolic curve (exponential) because acceleration indicates an increase in distance for each time interval as shown below.*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Position versus Time | | | | | | |
| Time (s) | 0 | 1 | 2 | 3 | 4 | 5 |
| Position (m) | 0 | 10 | 40 | 90 | 160 | 250 |
| *Increase in position* | *0* | *10* | *30* | *50* | *70* | *90* |

2. If an object has zero acceleration, does that mean its velocity must be zero? Explain.

*Velocity does NOT have to be zero for an object to have a zero acceleration. For instance, a constant velocity 0f 30 m/s has no acceleration.*

3. If an object has zero velocity at some instant, does that mean its acceleration must be zero? Explain.

*The key word phrase is “at some instant.” If an object is moving and suddenly stops (e.g. hits a wall), the instant it stops it is decelerating from the previous instant.*

4. Explain why you used different equations to calculate displacement in Part 1 and Part 2. Name the variable(s) that are needed and that are missing in each case.

*The displacement in Part 1 was calculated using average velocity. However, in Part 2, the displacement was calculated using instantaneous velocity.*

5. An airplane must reach a velocity of 71 m/s for takeoff. If the runway is 1.0 km long, what must the constant acceleration be? (*Show equation and all work*.)

*d = (vf2 – vi2)/2a d = ((71 m/s)2 – (0 m/s)2) / 2(1000 m) = 2.52 m/s2*

6. The same plane in question 5 lands initially going 71 m/s. It slows to a halt with an acceleration of –2.5 m/s2. How much runway does it require? (*Show equation and all work*.)

*d = (vf2 – vi2)/2a d = ((0 m/s)2 – (71 m/s)2) / 2(-2.5 m/s2) = 1008 m = 1 km*