Velocity
What is Motion?

An object's change in position relative to a reference point.

Relative to the earth:
Moving 17,500 mph

Relative to the shuttle:
Not moving
## Distance vs. Displacement

<table>
<thead>
<tr>
<th>Distance</th>
<th>How far travelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>How far from origin</td>
</tr>
</tbody>
</table>
Try this | Distance and Displacement

You walked 3 miles East, turned left, then walked 4 miles North. What is your distance? displacement?

Distance: 7 miles
Displacement: 5 miles
Constant Displacement

Not moving

Distance (m)

Time (s)

Velocity (m s\(^{-1}\))

Time (s)
Average Speed and Velocity

Average Speed  \[= \frac{\text{Total Distance}}{\text{Total Time}}\]
* Always Positive

Average Velocity  \[= \frac{\text{Total Displacement}}{\text{Total Time}}\]
* Includes Direction
New world record for a marathon (26.2 miles) was set several years ago. David Kimetto finished in 2.04 hours. What was his average speed?

\[ v = \frac{d}{t} = \frac{26.2}{2.04} = 12.8 \text{ mi hr}^{-1} \]
Marathon Runners are FAST

Run With Ryan

Best Of the ASICS Treadmill Challenge
Consider this...

The gold medalist for the men’s 400 m (one complete lap of the track) in Rio was Wayde van Niekerk with a WR time of 43.03 s. What was his average speed? Average velocity?

\[
Avg \ Speed = \frac{400 \text{ m}}{43.03 \text{ s}} = 9.3 \text{ m s}^{-1}
\]

\[
Avg \ velocity = \frac{400 \text{ m}}{0 \text{ s}} = 0 \text{ m s}^{-1}
\]
What is a Vector?

A Vector is a quantity that includes both direction and magnitude.
## Vector vs Scalar

<table>
<thead>
<tr>
<th>Vector Quantities</th>
<th>Scalar Quantities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>Distance</td>
</tr>
<tr>
<td>Velocity</td>
<td>Speed</td>
</tr>
<tr>
<td>Force</td>
<td>Energy</td>
</tr>
</tbody>
</table>
Racing against Usain...

In 2012, Usain Bolt’s Gold Medal 100 meter dash took just 9.63 seconds.

In 1896, the gold medalist finished in 12.00 seconds.

Making the assumption that they are traveling at a constant velocity (they aren’t really), how far behind Usain would the 1896 medalist be?

Method 1:

\[
100 - \left(\frac{9.63}{12}\right)100 = 19.75 \text{ m}
\]

Method 2:

\[
\frac{100}{12} = 8.3 \text{ m s}^{-1}
\]

\[
(8.3 \text{ m s}^{-1})(9.63 \text{ s}) = 80.25 \text{ m}
\]

\[
100 - 80.25 = 19.75 \text{ m}
\]
Plot this problem on a D vs T graph

Displacement (m)

Time (s)

80.25 m
Racing against Usain...
Constant Positive Velocity

Changing position at a constant rate \textit{forward}
Changing position at a constant rate backward
Plotting Displacement vs Time

- Runner A
- Runner B
- Runner C

Which runner was moving the fastest?

Steeper Slope
The power of the slope!

Slope

Displacement vs Time

Velocity vs Time
What is the Average Velocity?

$slope = \frac{rise}{run} = \frac{\Delta x}{\Delta y}$

\[
\frac{100}{8} = 12.5
\]

$\frac{[m]}{[s]} = \text{m s}^{-1}$

$12.5 \text{ m s}^{-1}$
Acceleration

IB PHYSICS | UNIT 2 | MOTION
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Velocity</strong></td>
<td><strong>Acceleration</strong></td>
</tr>
<tr>
<td>change in <em>position</em> over time</td>
<td>change in <em>velocity</em> over time</td>
</tr>
<tr>
<td>“speed <em>with direction</em>”</td>
<td></td>
</tr>
</tbody>
</table>
Types of Acceleration

- Speeding Up
- Slowing Down
- Changing Direction
Acceleration

Velocity (m s\(^{-1}\))

Time (s)

slope = \frac{[\text{m s}^{-1}]}{[\text{s}]} = [\text{m s}^{-2}]

0-30 m s\(^{-1}\) in 10 seconds

0-30 m s\(^{-1}\) in 2.5 seconds
The power of the slope!

- Displacement vs Time
- Velocity
- Acceleration
- Velocity vs Time
Constant Positive Acceleration

Changing velocity by **speeding up** at a constant rate
Constant Negative Acceleration

Changing velocity by **slowing down** at a constant rate
Motion Variables

<table>
<thead>
<tr>
<th>Displacement</th>
<th>Initial Velocity</th>
<th>Final Velocity</th>
<th>Acceleration</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>u</td>
<td>v</td>
<td>a</td>
<td>t</td>
</tr>
</tbody>
</table>

Whenever we are describing the motion of an accelerating object, there are five variables that we need to take into account.

*Note: The variables used in IB Physics vary slightly from other nomenclature standards*
Calculating Acceleration

\[ \text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{change in time}} \]

**Symbols**
- \( a \) = \( v - u \) / \( t \)

**Units**
- \( \text{ms}^{-2} = \frac{\text{ms}^{-1} - \text{ms}^{-1}}{\text{s}} \)
Think about this unit...

\[ a = \frac{v - u}{t} \]

\[ \text{m/s/s} \]
\[ \text{m/s}^2 \]
\[ \text{m s}^{-2} \]
What is the acceleration of a car that accelerates from 15 m s\(^{-1}\) to 35 m s\(^{-1}\) in 10 seconds?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( u )</td>
<td>15 m s(^{-1})</td>
</tr>
<tr>
<td>( v )</td>
<td>35 m s(^{-1})</td>
</tr>
<tr>
<td>( a )</td>
<td>?</td>
</tr>
<tr>
<td>( t )</td>
<td>10 s</td>
</tr>
</tbody>
</table>

\[
a = \frac{v - u}{t} = \frac{35 - 15}{10} = 2 \, \text{ms}^{-2}
\]
Find the average acceleration of a northbound train that slows down from 12 m s\(^{-1}\) to a complete stop in 8 sec

*Tip: You can get a negative value!*

<table>
<thead>
<tr>
<th>(u)</th>
<th>12 ms(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(v)</td>
<td>0 ms(^{-1})</td>
</tr>
<tr>
<td>(a)</td>
<td>?</td>
</tr>
<tr>
<td>(t)</td>
<td>8 s</td>
</tr>
</tbody>
</table>

\[
a = \frac{v - u}{t} = \frac{0 - 12}{8}
\]

\[
a = -1.5 \text{ ms}^{-2}
\]
Solve for $v$

$$a = \frac{v - u}{t}$$

$$v = u + at$$
### Sub-topic 2.1 – Motion

<table>
<thead>
<tr>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v = u + at$</td>
</tr>
<tr>
<td>$s = ut + \frac{1}{2} at^2$</td>
</tr>
<tr>
<td>$v^2 = u^2 + 2as$</td>
</tr>
<tr>
<td>$s = \frac{(v + u)t}{2}$</td>
</tr>
</tbody>
</table>
How far have I gone?

\[ s = vt = (80 \text{ m s}^{-1})(10 \text{ s}) = 800 \text{ m} \]

\textit{area under graph} = (80 \text{ m s}^{-1})(10 \text{ s}) = 800 \text{ m}
Use the graphs to tell you MORE!

Displacement vs Time

Velocity vs Time

Velocity vs Time

Acceleration

Slope

Area Under Curve

Displacement
How far have I gone?

**area under graph** = \( \frac{1}{2} (100 \text{ m s}^{-1}) (8 \text{ s}) = 400 \text{ m} \)

\[ s = \left( \frac{v + u}{2} \right) \times t \]

**Average Velocity** = \( \frac{v + u}{2} \)
### Sub-topic 2.1 – Motion

<table>
<thead>
<tr>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v = u + at )</td>
</tr>
<tr>
<td>( s = ut + \frac{1}{2} at^2 )</td>
</tr>
<tr>
<td>( v^2 = u^2 + 2as )</td>
</tr>
<tr>
<td>( s = \frac{(v + u)t}{2} )</td>
</tr>
</tbody>
</table>
You speed up with a uniform acceleration from 0 m/s to 30 m/s in 5 seconds. How far have you gone?

\[
s = \frac{(v+u)t}{2}
\]

\[
s = \frac{(30+0)(5)}{2} = 75 \text{ m}
\]
What if I don’t know v?

\[ S = \frac{(v+u)t}{2} \]

\[ v = u + at \]

\[ S = \frac{(u+at+u)t}{2} = \frac{(2u+at)t}{2} \]

\[ S = \frac{2ut+at^2}{2} \]

\[ S = ut + \frac{1}{2}at^2 \]
<table>
<thead>
<tr>
<th>Sub-topic 2.1 – Motion</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v = u + at$</td>
</tr>
<tr>
<td>$s = ut + \frac{1}{2}at^2$</td>
</tr>
<tr>
<td>$v^2 = u^2 + 2as$</td>
</tr>
<tr>
<td>$s = \frac{(v + u)t}{2}$</td>
</tr>
</tbody>
</table>
If a plane on a runway is accelerating at 4.8 m s\(^{-2}\) for 15 seconds before taking off, how long should the runway be?

\[
s = ut + \frac{1}{2}at^2
\]

\[
= (0)(15) + \frac{1}{2}(4.8)(15)^2
\]

\[
s = 540 \text{ m}
\]

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>?</td>
</tr>
<tr>
<td>u</td>
<td>0 m s(^{-1})</td>
</tr>
<tr>
<td>v</td>
<td>------</td>
</tr>
<tr>
<td>a</td>
<td>4.8 m s(^{-2})</td>
</tr>
<tr>
<td>t</td>
<td>15 s</td>
</tr>
</tbody>
</table>
One more equation

\[ v^2 = u^2 + 2as \]
## Equations

<table>
<thead>
<tr>
<th>Units</th>
<th>( m )</th>
<th>( m \ s^{-1} )</th>
<th>( m \ s^{-1} )</th>
<th>( m \ s^{-2} )</th>
<th>( s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v = u + at )</td>
<td>( u )</td>
<td>( v )</td>
<td>( a )</td>
<td>( t )</td>
<td></td>
</tr>
<tr>
<td>( s = ut + \frac{1}{2}at^2 )</td>
<td>( s )</td>
<td>( u )</td>
<td>( a )</td>
<td>( t )</td>
<td></td>
</tr>
<tr>
<td>( v^2 = u^2 + 2as )</td>
<td>( s )</td>
<td>( u )</td>
<td>( v )</td>
<td>( a )</td>
<td></td>
</tr>
<tr>
<td>( s = \frac{(v+u)t}{2} )</td>
<td>( s )</td>
<td>( u )</td>
<td>( v )</td>
<td>( t )</td>
<td></td>
</tr>
</tbody>
</table>
A driver slams on the brakes and skids for 3 seconds before coming to a stop. You go and measure that the skid marks show a deceleration over 9 m. What was the initial speed of the car?

\[ s = \frac{(v+u)t}{2} \]

\[ u = \frac{2s}{t} - v = \frac{2(9)}{(3)} - 0 \]

\[ u = 6 \text{ m s}^{-1} \]
In a stroboscopic photograph, a new snapshot is captured every ___ seconds and combined to show the motion over a period of time.

Circle the part of the motion where this soccer ball is moving the FASTEST

Circle the part of the motion where this soccer ball is moving the SLOWEST
Stroboscopic Photographs

Constant Velocity or Accelerating? How do you know?

More spacing between pictures = moving faster
Constant Acceleration

\[ s = ut + \frac{1}{2}at^2 \]

15 = (0)(5) + \frac{1}{2}a(5)^2

\[ a = 1.2 \text{ m} \]
Freefall

IB PHYSICS | UNIT 2 | MOTION
A car traveling in a straight line has a velocity of +4.8 m s\(^{-1}\). After an acceleration of 0.65 m s\(^{-2}\), the car’s velocity is +9.9 m s\(^{-1}\). Over what time interval did the acceleration occur?

\[
v = u + at
\]

\[
9.9 = 4.8 + (0.65)t
\]

\[
t = 7.85 \text{ s}
\]
Warm Up

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Velocity (m s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Velocity at 5 s: 5 m s\(^{-1}\)

Position at 5 s: 12.5 m

Area: \(\frac{1}{2}(5)(5)\) = 12.5 m

Warm Up

Velocity (m s$^{-1}$)

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>13</td>
<td>11</td>
<td>9</td>
<td>7</td>
<td>5</td>
</tr>
</tbody>
</table>

Position at 2 s

12.5 m

Velocity at 2 s

5 m s$^{-1}$
Warm Up – Match these Graphs!

Displacement vs Time

Velocity vs Time
What is Free Fall?

The only force acting on the object is gravity

*No Air Resistance*
Acceleration due to Gravity

\[-9.81 \text{ m s}^{-2}\]

Remember Direction!

negative
What if you drop something?

![Diagram of a person dropping an object]

What do you know?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td></td>
</tr>
<tr>
<td>$u$</td>
<td>0 m s$^{-1}$</td>
</tr>
<tr>
<td>$v$</td>
<td></td>
</tr>
<tr>
<td>$a$</td>
<td>-9.81 m s$^{-2}$</td>
</tr>
<tr>
<td>$t$</td>
<td></td>
</tr>
</tbody>
</table>
What if you throw something up?

What do you know?

<table>
<thead>
<tr>
<th>First Half</th>
<th>Second Half</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td>$s$</td>
</tr>
<tr>
<td>$u$</td>
<td>$u$</td>
</tr>
<tr>
<td>$v$</td>
<td>$v$</td>
</tr>
<tr>
<td>$a$</td>
<td>$a$</td>
</tr>
<tr>
<td>$t$</td>
<td>$t$</td>
</tr>
</tbody>
</table>

$0 \text{ m s}^{-1}$

-9.81 m s$^{-2}$

-9.81 m s$^{-2}$
What if you throw something down?

What do you know?

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td></td>
</tr>
<tr>
<td>$u$</td>
<td></td>
</tr>
<tr>
<td>$v$</td>
<td></td>
</tr>
<tr>
<td>$a$</td>
<td>$-9.81 \text{ m s}^{-2}$</td>
</tr>
<tr>
<td>$t$</td>
<td></td>
</tr>
</tbody>
</table>
### Reminder of our Equations

<table>
<thead>
<tr>
<th>Units</th>
<th>$m$</th>
<th>$m , s^{-1}$</th>
<th>$m , s^{-1}$</th>
<th>$m , s^{-2}$</th>
<th>$s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v = u + at$</td>
<td>$u$</td>
<td>$v$</td>
<td>$a$</td>
<td>$t$</td>
<td></td>
</tr>
<tr>
<td>$s = ut + \frac{1}{2}at^2$</td>
<td>$s$</td>
<td>$u$</td>
<td>$a$</td>
<td>$t$</td>
<td></td>
</tr>
<tr>
<td>$v^2 = u^2 + 2as$</td>
<td>$s$</td>
<td>$u$</td>
<td>$v$</td>
<td>$a$</td>
<td></td>
</tr>
<tr>
<td>$s = \frac{(v+u)t}{2}$</td>
<td>$s$</td>
<td>$u$</td>
<td>$v$</td>
<td>$t$</td>
<td></td>
</tr>
</tbody>
</table>
If you drop a marble off of the Empire State Building (~380 m), how fast will it be going once it reaches the ground?

\[ v^2 = u^2 + 2as \]

\[ v = \sqrt{0^2 + 2(-9.81)(-380)} \]

\[ v = -86.3 \text{ m s}^{-1} \]

*The negative indicates a downward direction*
What is the vertical velocity of a basketball required to reach the rim of the basketball hoop? (~3.0 m high)

\[ v^2 = u^2 + 2as \]

\[ 0^2 = u^2 + 2(-9.81)(3) \]

\[ u = 7.67 \text{ m s}^{-1} \]
You flip a coin and catch it. It is in the air for a total of 0.6 seconds. How high did it go?

\[ s = ut + \frac{1}{2}at^2 \]

\[ s = \frac{1}{2}(-9.81)(0.3)^2 \]

\[ s = 0.441 \text{ m} \]
Warm Up

<table>
<thead>
<tr>
<th></th>
<th>Velocity</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>+5 m s⁻¹</td>
<td>-9.81 m s⁻²</td>
</tr>
<tr>
<td>B</td>
<td>0 m s⁻¹</td>
<td>-9.81 m s⁻²</td>
</tr>
<tr>
<td>C</td>
<td>-5 m s⁻¹</td>
<td>-9.81 m s⁻²</td>
</tr>
</tbody>
</table>
Warm Up

Velocity (m s\(^{-1}\))

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Slope = -9.81 m s\(^{-2}\)
Motion Graphs Guide

- **d**: Constant Displacement
- **v**: Constant Velocity
- **a**: Constant Acceleration

- **Speeding up**
  - **d**: Constant Displacement
  - **v**: Constant Velocity
  - **a**: Constant Acceleration

- **Slowing down**
  - **d**: Constant Displacement
  - **v**: Constant Velocity
  - **a**: Constant Acceleration
Acceleration | Slowing or Speeding?

When the acceleration is in the \textbf{same} direction as the velocity, the object is \underline{speeding up}.

When the acceleration is in the \textbf{opposite} direction as the velocity, the object is \underline{slowing down}.

“Foot on the Gas”

“Foot on the Brake”
Information from a V vs T graph

What is the velocity at 4 seconds?

4 m s\(^{-1}\)

What is the acceleration from 1 s – 4 s?

Slope = 1 m s\(^{-2}\)

What is the displacement after 4 s?

Area = 8 m
What is the velocity at 4 seconds?

\[ \frac{1}{2}(4)(-4) = -8 \]

\[-4 \text{ m s}^{-1}\]

What is the acceleration from 0 s – 4 s?

Slope = -1 m s^{-2}

What is the displacement after 4 s?

Area = -8 m
Information from a V vs T graph

What is the velocity at 4 seconds?

4 m s\(^{-1}\)

What is the acceleration from 0 s – 4 s?

Slope = 0.5 m s\(^{-2}\)

What is the displacement after 4 s?

Area = 12 m
What is the velocity at 3 seconds?

\[-2 \text{ m s}^{-1}\]

What is the acceleration from 1 s – 3 s?

Slope = \(-2 \text{ m s}^{-2}\)

What is the displacement after 3 s?

Area = \(2 \text{ m}\)
Use the graphs to tell you MORE!

- Slope
  - Displacement vs Time
  - Velocity
  - Velocity vs Time
  - Acceleration

- Area Under Curve
  - Velocity vs Time
  - Displacement
Time to Practice...

- Lots of examples posted
- Complete the missing graphs
- Check answers with the KEY
- Make sure you try at least one per page because they get increasingly more difficult
Horizontal Projectiles

IB PHYSICS | UNIT 2 | MOTION
## Reminder of our Equations

<table>
<thead>
<tr>
<th>Units</th>
<th>m</th>
<th>m s(^{-1})</th>
<th>m s(^{-1})</th>
<th>m s(^{-2})</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td>(v = u + at)</td>
<td>u</td>
<td>v</td>
<td>a</td>
<td>t</td>
<td></td>
</tr>
<tr>
<td>(s = ut + \frac{1}{2}at^2)</td>
<td>s</td>
<td>u</td>
<td>a</td>
<td>t</td>
<td></td>
</tr>
<tr>
<td>(v^2 = u^2 + 2as)</td>
<td>s</td>
<td>u</td>
<td>v</td>
<td>a</td>
<td></td>
</tr>
<tr>
<td>(s = \frac{(v+u)t}{2})</td>
<td>s</td>
<td>u</td>
<td>v</td>
<td>t</td>
<td></td>
</tr>
</tbody>
</table>
Dropping the Ball

How much time will it take this ball to hit the ground when dropped? The impact velocity?

\[ s = ut + \frac{1}{2}at^2 \]
\[ -25 = \frac{1}{2}(-9.81)t^2 \]
\[ t = 2.26 \text{ s} \]

\[ v^2 = u^2 + 2as \]
\[ v = \sqrt{2as} = \sqrt{2(-9.81)(-25)} \]
\[ v = -22.2 \text{ m s}^{-1} \]

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( s )</td>
<td>-25 m</td>
</tr>
<tr>
<td>( u )</td>
<td>0 m s(^{-1})</td>
</tr>
<tr>
<td>( a )</td>
<td>-9.81 m s(^{-2})</td>
</tr>
<tr>
<td>( t )</td>
<td></td>
</tr>
</tbody>
</table>
Air Time - Comparison

Which ball will have more air time?

The ball’s hit the ground at exactly the same time.
Bullet Fired vs Bullet Dropped - Mythbusters for the Impatient
Air Time - Comparison
X and Y Components

Constant Velocity

Free Fall
How far does the ball travel?

\[ s = vt = (10 \text{ m s}^{-1})(2.26 \text{ s}) \]

\[ s = 22.6 \text{ m} \]
2-D Problem Solving Steps

1. Start with “suvat” in the vertical direction and pretend it’s just a freefall problem

2. The air time is the same for horizontal motion

3. Solve for horizontal using $v = \frac{s}{t}$

<table>
<thead>
<tr>
<th>Vertical Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
</tr>
<tr>
<td>$u$</td>
</tr>
<tr>
<td>$v$</td>
</tr>
<tr>
<td>$a$</td>
</tr>
<tr>
<td>$t$</td>
</tr>
</tbody>
</table>
Try This

$s = ut + \frac{1}{2}at^2$

\[-0.15 = \frac{1}{2}(-9.81)t^2\]

$t = 0.175 \text{ s}$

$v = \frac{s}{t} = \frac{1 \text{ m}}{0.175 \text{ s}}$

$v = 5.71 \text{ m s}^{-1}$

<table>
<thead>
<tr>
<th>Vertical Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
</tr>
<tr>
<td>$u$</td>
</tr>
<tr>
<td>$v$</td>
</tr>
<tr>
<td>$a$</td>
</tr>
<tr>
<td>$t$</td>
</tr>
</tbody>
</table>
Vector Components

All vectors can be broken down into x and y components

\[
\begin{align*}
\sin \theta &= \frac{y}{13} \\
\cos \theta &= \frac{x}{13}
\end{align*}
\]

\[
x = 13 \cos(22.62) = 12 \\
y = 13 \sin(22.62) = 5
\]
Sub-topic 1.3 – Vectors and scalars

\[ A_H = A \cos \theta \]
\[ A_V = A \sin \theta \]
What are the x and y components of a 20 N force applied 34° from horizontal?

\[ x = 20 \cos(34) = 16.6 \]
\[ y = 20 \sin(34) = 11.2 \]

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Component</td>
<td>16.6 N</td>
</tr>
<tr>
<td>Y-Component</td>
<td>11.2 N</td>
</tr>
</tbody>
</table>
Impact Velocity and Angle?
Impact Velocity and Angle

Horizontal Velocity:

From previous problem →

\[ v_x = 5.71 \text{ m s}^{-1} \]

Vertical Velocity:

\[ v^2 = v_x^2 + 2as \]
\[ v = \sqrt{2as} = \sqrt{2(-9.81)(-0.15)} \]

\[ v_y = -1.72 \text{ m s}^{-1} \]

Impact Velocity:

\[ v = \sqrt{5.71^2 + 1.72^2} \]
\[ v = 5.96 \text{ m s}^{-1} \]

Impact Angle:

\[ \theta = \tan^{-1}(1.72/5.72) \]
\[ \theta = 16.8^\circ \]
Projectiles at an Angle
## Reminder of our Equations

<table>
<thead>
<tr>
<th>Units</th>
<th>$m$</th>
<th>$m \text{ s}^{-1}$</th>
<th>$m \text{ s}^{-1}$</th>
<th>$m \text{ s}^{-2}$</th>
<th>$s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v = u + at$</td>
<td>$u$</td>
<td>$v$</td>
<td>$a$</td>
<td>$t$</td>
<td></td>
</tr>
<tr>
<td>$s = ut + \frac{1}{2}at^2$</td>
<td>$s$</td>
<td>$u$</td>
<td>$a$</td>
<td>$t$</td>
<td></td>
</tr>
<tr>
<td>$v^2 = u^2 + 2as$</td>
<td>$s$</td>
<td>$u$</td>
<td>$v$</td>
<td>$a$</td>
<td></td>
</tr>
<tr>
<td>$s = \frac{(v+u)t}{2}$</td>
<td>$s$</td>
<td>$u$</td>
<td>$v$</td>
<td>$t$</td>
<td></td>
</tr>
</tbody>
</table>
2-D Problem Solving Steps

1. Start with “suvat” in the vertical direction and pretend it’s just a freefall problem

2. The air time is the same for horizontal motion

3. Solve for horizontal using \( v = s/t \)

<table>
<thead>
<tr>
<th>Vertical Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>( s )</td>
</tr>
<tr>
<td>( u )</td>
</tr>
<tr>
<td>( v )</td>
</tr>
<tr>
<td>( a )</td>
</tr>
<tr>
<td>( t )</td>
</tr>
</tbody>
</table>
Remember Vectors?

\[ v = 24 \text{ m s}^{-1} \]

\[ u_x = 24 \cos(55) = 13.8 \]

\[ u_y = 24 \sin(55) = 19.7 \]
One Dimensional Motion

Vertical
Accelerating

Horizontal
Constant Velocity
Horizontal Projectile

Constant Horizontal Velocity

\[ v = \frac{s}{t} \]
Two Dimensional Projectile

Same as the horizontal projectile
Projectile – First Half

\[ v_x = 13.8 \text{ m s}^{-1} \]
\[ v_y = 0 \text{ m s}^{-1} \]

1\text{st} Half Vertical

| \( s \) | 19.8 m |
| \( u \) | 19.7 m s\(^{-1}\) |
| \( v \) | 0 m s\(^{-1}\) |
| \( a \) | -9.81 m s\(^{-2}\) |
| \( t \) | 2.01 s |

\[ v = u + at \]
\[ 0 = 19.7 + (-9.81)t \]
\[ t = 2.01 \text{ s} \]

\[ v^2 = u^2 + 2as \]
\[ 0^2 = 19.7^2 + 2(-9.81)s \]
\[ s = 19.8 \text{ m} \]
**Projectile – Full Thing**

<table>
<thead>
<tr>
<th>Total Time</th>
<th>4.02 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>55.5 m</td>
</tr>
</tbody>
</table>

First Half = 2.01 s
Total Time = 2.01 × 2 = **4.02 s**

\[ s = vt = (13.8)(4.02) = 55.5 \text{ m} \]
## Projectile – In General

### 1st Half Vertical

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td>Total Height</td>
</tr>
<tr>
<td>$u$</td>
<td>$u_y$</td>
</tr>
<tr>
<td>$v$</td>
<td>0 m s$^{-1}$</td>
</tr>
<tr>
<td>$a$</td>
<td>-9.81 m s$^{-1}$</td>
</tr>
<tr>
<td>$t$</td>
<td></td>
</tr>
</tbody>
</table>

### Total Time

2t

### Displacement

$u_x(2t)$
You hit a baseball at 24° above the horizontal as a speed of 30 m s\(^{-1}\). How far does the ball travel before it hits the ground?

\[
\begin{align*}
    u_x &= 30 \cos(24) = 27.4 \text{ m s}^{-1} \\
    u_y &= 30 \sin(24) = 12.2 \text{ m s}^{-1} \\
    v &= u + at \\
    0 &= 12.2 + (-9.81)t \\
    t &= 1.24 \text{ s} \\
    v^2 &= u^2 + 2as \\
    0^2 &= 12.2^2 + 2(-9.81)s \\
    s &= 7.56 \text{ m} \\
    v_t &= 27.4 \text{ m s}^{-1} \\
    v_y &= 0 \text{ m s}^{-1} \\
    a &= -9.81 \text{ m s}^{-2} \\
    s &= (27.4)(2.48) \\
    s &= 68 \text{ m} \\
    t &= 1.24 \text{ s}
\end{align*}
\]