Chapter 2

Kinematics in One Dimension
Displacement

• Suppose you are walking along the beach on a beautiful sunny day.
• To track your progress on the beach we will draw a coordinate system.
• In one dimension we have a vector that represents your starting point and a second vector that represents your end position.
• The displacement vector that represents the distance and direction that you walked is just the difference between the two vectors.
• Therefore, we can write the following to describe the displacement vector of our walk.
Average Speed

- Another useful physical principle is average speed.
- Average speed is defined as:

\[
\text{average speed} = \frac{\text{distance}}{\text{elapsed time}}
\]
Average Velocity

- A somewhat more useful term in physics is the average velocity.
- In many cases the average velocity can be thought of as the average speed along with the direction of motion.
• We denote the average velocity by the following:

• The units for average velocity are \( m/s \).
**Example**

Suppose a person drives 60 miles in two hours, but we check their times at various checkpoints: (1) calculate the average speed over each interval; (2) calculate the average speed between the first and fifth intervals.

<table>
<thead>
<tr>
<th>Checkpoint</th>
<th>Time (hrs)</th>
<th>miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>1.25</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>1.50</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td>2.00</td>
<td>60</td>
</tr>
</tbody>
</table>

40 miles/hr
20 miles/hr
80 miles/hr
10 miles/hr
<table>
<thead>
<tr>
<th>Checkpoint</th>
<th>Time (hrs)</th>
<th>miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
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<td>5</td>
<td>2.00</td>
<td>60</td>
</tr>
</tbody>
</table>

Note: even though this person’s AVERAGE SPEED was only 30 mph, they were speeding during one interval!
Instantaneous Velocity

• The instantaneous velocity often gives greater meaning to the motion of an object than does the average velocity.
• We can define the instantaneous velocity in the following way.
Acceleration

• Any object whose velocity is changing is said to be undergoing an acceleration.

• Since velocity is speed and direction then an acceleration occurs when either one or both of these quantities are changed.
Acceleration

- The average acceleration can be expressed as:

\[
\text{acceleration} = \frac{\text{change in velocity}}{\text{elapsed time}}
\]
• The instantaneous acceleration can be defined by the same limiting process as the instantaneous velocity.
• Note: For most of the problems in this course the acceleration will be constant.
Example: Suppose that a car is moving at a speed of 5 m/s. 10 seconds later it is moving at a speed of 20 m/s. What is the magnitude of its average acceleration?

Its velocity changed by \((20 \text{ m/s} - 5 \text{ m/s}) = 15 \text{ m/s}\) in 10 seconds.

The acceleration must be: \(a = \frac{15 \text{ m/s}}{10 \text{ s}} = 1.5 \text{ m/s}^2\)

Notice the units: \(\text{m/s}^2\) (read meters per second, per second or meters per second squared)
Calculate the acceleration in each time interval:

Answer: \( \frac{10 \text{ m/s}}{1 \text{ s}} = 10 \text{ m/s}^2 \)
Example

- 30 seconds after a skydiver jumps from a plane she deploys her parachute.
- Her speed just before the chute opens is 55.0 m/s.
- 34 seconds after she left the plane her speed is 4.50 m/s.
- Determine the average acceleration of the skydiver during this time.
Solution

• We are given an initial and final time as well as an initial and final velocity.
• Therefore,
Equations of Motion for Constant Acceleration

• For simplicity we will assume that our object is located at the origin at an initial time of $t_0 = 0$.

• Therefore,
• Additionally, since we are discussing one dimension only at this time, we can ignore the arrows on top of the vectors and just use + or – to indicate direction.
• Consider an object that has an initial velocity of $v_0$.

• Its average acceleration is:

• Rearranging we get the velocity as a function of time.
• The average velocity, assuming constant acceleration, is

• If we start from the origin at $t_0 = 0$ we get:
• Because the acceleration is constant the average velocity is just the one half of the initial velocity plus the final velocity.

• Therefore,
• If we plug this result back into our previous result for the displacement we get:
• We can derive another equation of motion by doing a substitution in for the final velocity.
• We can derive on final equation of motion by first solving for $t$ in the following equation.
• Now substitute our expression for $t$ into the following equation.
• Simplifying we get:

• Or
Equations of Motion

- We know four equations of motion that correspond to situations where the acceleration is constant.

\[
\begin{align*}
v &= v_0 + at \\
x &= x_0 + v_0 t + \frac{1}{2} at^2 \\
x &= x_0 + \frac{1}{2} (v_0 + v) t \\
v^2 &= v_0^2 + 2a (x - x_0)
\end{align*}
\]
Example

• A truck is traveling along a flat section of highway with a constant velocity of 40 m/s in the positive $x$-direction.

• The clutch on the truck is depressed and the truck is allowed to coast.

• If the acceleration on the truck due to wind resistance is $7.50 \text{ m/s}^2$, how far will the truck travel before it comes to rest?
Solution

- Note, if we take $x_0$ to be the origin, there are five possible variables in our equations of motion.

\[ x \quad a \quad v \quad v_0 \quad t \]
• We can organize the data that are given and the variable of which we are trying to determine into a table.

<table>
<thead>
<tr>
<th>$x$</th>
<th>$a$</th>
<th>$v$</th>
<th>$v_0$</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>7.50 m/s$^2$</td>
<td>0</td>
<td>40 m/s</td>
<td></td>
</tr>
</tbody>
</table>
• Now we look for an equation with the four variables present.
• Our equation of choice is:

\[ v^2 = v_0^2 + 2ax \]
• Now we rearrange and solve for the proper variable.

\[ x = \frac{1}{2a} \left( v^2 - v_0^2 \right) \]

• Now we substitute our values into this expression.

\[ x = \frac{1}{2 \left( 7.50 \text{ m} / \text{s}^2 \right)} \left( (40 \text{ m} / \text{s})^2 - 0 \right) = 106.7 \text{ m} \]
Galileo’s Law of Falling

Galileo performed many experiments with objects being dropped or rolling down incline planes. From these experiments he was able to formulate the following law.

• Galileo’s Law of Falling: If air resistance is negligible, then any two objects dropped together will fall together regardless of their weights or compositions.
Falling cont.

• When an object is dropped near the surface of the earth it experiences an acceleration of 9.8 meters per second per second.

• This means that for every second that an object falls, it increases its speed by 9.8 meters per second.
Falling cont.

• This acceleration due to gravity is often expressed with the letter “g”.

• Hence:

\[ g = 9.8 \, \text{m} / \text{s}^2 \]
Falling and Falling and Falling

• An object dropped from rest will fall 9.8 m/s, after the 1\textsuperscript{st} second, about 19.6 m/s after the 2\textsuperscript{nd} second, about 29.4 m/s after the 3\textsuperscript{rd} and so on.
An accelerated object is exactly like a falling object!!

**Galileo’s Law of Falling**: Neglecting Air resistance, all objects fall with the same acceleration.

**Acceleration due to gravity**: The acceleration of any freely falling object. On earth this is about 10 m/s² (actual value ≈ 9.8 m/s².)
Free Fall

• Suppose an object is thrown straight up or down and then allowed to fall.

• If we take the $y$-direction as being up, then our equation that describes this motion is:
• Since the acceleration of gravity near the surface of the earth is fairly constant we can replace our symbol for acceleration with $g$ when we are discussing free fall.
Example

• A peregrine falcon dives for its prey.
• During free fall it plummets 30.0 meters towards the ground.
• What is its speed at this point?
Solution

• Our equation of motion for this problem involving free fall is:
• Plugging in the numbers: