Chapter 2: Motion

Homework: All questions on the “Multiple-Choice” and the odd-numbered questions on “Exercises” sections at the end of the chapter.
Physics: The Most Fundamental Physical Science

• Physics is concerned with the basic principles that describe how the universe works.
• Physics deals with matter, motion, force, and energy.
Physics – Areas of Study

- Classical mechanics
- Waves and sounds
- Thermodynamics
- Electromagnetism
- Quantum mechanics
- Atomic and nuclear physics
- Relativity
Motion

• Motion is everywhere – walking, driving, flying, etc.
• This chapter focuses on definition/discussion of: speed, velocity, and acceleration.
• There are two basic kinds of motion:
  – Straight line
  – Circular
Defining Motion

• **Position** – the location of an object
  – *A reference point must be given in order to define the position of an object*

• **Motion** – an object is undergoing a continuous change in position

• **Description of Motion** – the time rate of change of position
  – *A combination of length and time describes motion*
Speed and Velocity

• In Physical Science ‘speed’ and ‘velocity’ have different (distinct) meanings.

• Speed – a scalar quantity, only magnitude
  – A car going 80 km/h

• Velocity – vector, both magnitude & direction
  – A car going 80 km/h north
Vectors

• Vector quantities may be represented by arrows. The length of the arrow is proportional to magnitude.

40 km/h

-40 km/h

80 km/h

-80 km/h
Vectors

Note that vectors may be both positive and negative.
Speed

- **Average Speed** = \( \frac{\text{distance traveled}}{\text{time to travel distance}} \)
- \( \bar{v} = \frac{d}{t} \) or \( v = \frac{\Delta d}{\Delta t} \)
  - (where \( \Delta \) means ‘change in’)
  - *Over the entire time interval, speed is an average*
- **Distance** – the actual path length traveled
- **Instantaneous Speed** – the speed of an object at an instant of time (*\( \Delta t \) is very small*)
  - *Glance at a speedometer*
Instantaneous speed
Velocity

- Velocity is similar to speed except a direction is involved.
- Average velocity = \[
\frac{\text{displacement}}{\text{total travel time}}\]
- Displacement = straight line distance between the initial and final position w/ direction toward the final position
- Instantaneous velocity – similar to instantaneous speed except it has direction
Displacement is a vector quantity between two points. Distance is the actual path traveled.
• **Describe the speed of the car above.**
• **GIVEN:** $d = 80 \text{ m}$ & $t = 4.0 \text{ s}$
• **EQUATION:** $\bar{v} = \frac{d}{t}$
• **SOLVE:** \( \frac{d}{t} = \frac{80 \text{ m}}{4.0 \text{ s}} = 20 \text{ m/s} = \text{average speed} \)
• **Velocity would be described as 20 m/s in the direction of motion (east?)**
Constant Velocity - Confidence Exercise

- **How far would the car above travel in 10s?**
- **EQUATION:** \( v = \frac{d}{t} \)
- **REARRANGE EQUATION:** \( vt = d \)
- **SOLVE:** \( (20 \text{ m/s}) (10 \text{ s}) = 200 \text{ m} \)
Example: How long does it take sunlight to reach earth?

• GIVEN:
  – **Speed of light** = 3.00 x 10^8 m/s = \(v\)
  – **Distance to earth** = 1.50 x 10^8 km = \(d\)

• EQUATION:
  – \(v = \frac{d}{t}\) → rearrange to solve for \(t\) → \(t = \frac{d}{v}\)

• SOLVE: \(t = \frac{d}{v} = \frac{1.50 \times 10^{11} \text{ m}}{3.00 \times 10^8 \text{ m/s}}\)

• \(t = 0.500 \times 10^3 \text{ s} = 5.00 \times 10^2 \text{ s} = 500 \text{ seconds}\)
Sunlight

1.50 \times 10^8 \text{ km} (93 \text{ million mi})

Time = 500 \text{ s (or 8.33 min)}
What is the average speed in mi/h of the earth revolving around the sun?

• GIVEN:
  – \(t = 365\) days (must convert to hours)
  – Earth’s radius \((r) = 9.30 \times 10^7\) miles (p. 19)

• CONVERSION:
  – \(t = 365\) days \(\times (24\text{h/day}) = 8760\) h

• MUST FIGURE DISTANCE \((d)\):

• \(d = ?\) Recall that a circle’s circumference = \(2\pi r\)
• \(d=2\pi r\) (and we know \(\pi\) and \(r!!\))
• Therefore \(\Rightarrow d = 2\pi r = 2 \times (3.14) \times (9.30 \times 10^7\) mi)
What is the average speed in mi/h of the earth revolving around the sun?

• SOLVE EQUATION:
• \( \bar{v} = \frac{d}{t} \)
• \( \frac{d}{t} = 2 \times (3.14) \times (9.30 \times 10^7 \text{ mi}) = 0.00667 \times 10^7 \text{ mi/h} \)
• \( \frac{d}{t} = \frac{8760 \text{ h}}{8760 \text{ h}} \)
• ADJUST DECIMAL POINT:
• \( \bar{v} = \text{avg. velocity} = 6.67 \times 10^4 \text{ mi/h} = 66,700 \text{ mi/h} \)
Confidence Exercise: What is the average speed in mi/h of a person at the equator as a result of the Earth’s rotation?

- Radius of the Earth = $R_E = 4000$ mi
- Time = 24 h
- Diameter of Earth = $2\pi r = 2 \times 3.14 \times 4000$ mi
  - Diameter of Earth = 25,120 mi
- $v = \frac{d}{t} = \frac{25,120 \text{ mi}}{24 \text{ h}} = 1047 \text{ mi/h}$
Acceleration

• Changes in velocity occur in three ways:
  – *Increase in magnitude* (speed up)
  – *Decrease in magnitude* (slow down)
  – *Change direction of velocity vector* (turn)

• When any of these changes occur, the object is accelerating.

• Faster the change $\rightarrow$ Greater the acceleration

• **Acceleration** – the time rate of change of velocity
Acceleration

- A measure of the change in velocity during a given time period

- Avg. acceleration = \( \frac{\text{change in velocity}}{\text{time for change to occur}} \)

- \( \bar{a} = \frac{\Delta v}{t} = \frac{v_f - v_o}{t} \) \( (v_f = \text{final} \quad \& \quad v_o = \text{original}) \)

- Units of acceleration = \( (m/s)/s = m/s^2 \)

- In this course we will limit ourselves to situations with constant acceleration.
Constant Acceleration of 9.8 m/s²

- As the velocity increases, the distance traveled by the falling object increases each second.
Finding Acceleration -- Example

• A race car starting from rest accelerates uniformly along a straight track, reaching a speed of 90 km/h in 7.0 s. Find acceleration.
• GIVEN: \( v_0 = 0 \), \( v_f = 90 \text{ km/h} \), \( t = 7.0 \text{s} \)
• WANTED: \( a \) in \( \text{m/s}^2 \)

\[ v_f = 90 \text{ km/h} \left( \frac{0.278 \text{ m/s}}{\text{ km/h}} \right) = 25 \text{ m/s} \]

\[ a = \frac{v_f - v_0}{t} = \frac{25 \text{ m/s} - 0}{7.0 \text{ s}} = 3.57 \text{ m/s}^2 \]
Using the equation for acceleration

- Remember that \( a = \frac{v_f - v_o}{t} \)
- Rearrange this equation:
- \( at = v_f - v_o \)
- \( v_f = v_o + at \) (solved for final velocity)
- This equation is very useful in computing final velocity.
Finding Acceleration – *Confidence Exercise*

- If the car in the preceding example continues to accelerate at the same rate for three more seconds, what will be the magnitude of its velocity in m/s at the end of this time ($v_f$)?
- $a = 3.57 \text{ m/s}^2$ (found in preceding example)
- $t = 10 \text{ s}$
- $v_0 = 0$ (started from rest)
- Use equation: $v_f = v_0 + at$
- $v_f = 0 + (3.57 \text{ m/s}^2)(10 \text{ s}) = 35.7 \text{ m/s}$
Acceleration is a vector quantity, since velocity is a vector quantity.

**Acceleration (Speed increases)**
- $a$
- $v = 10 \text{ km/h}$
- $a$
- $v = 20 \text{ km/h}$

**Deceleration (Speed decreases)**
- $a$
- $v = 30 \text{ km/h}$
- $v = 0$

**Acceleration (+)**  **Deceleration (-)**
Constant Acceleration = Gravity = 9.8 m/s²

- Special case associated with falling objects
- Vector towards the center of the earth
- Denoted by “g”
- g = 9.80 m/s²
The increase in velocity is linear.
Frictional Effects

• If frictional effects (air resistance) are neglected, every freely falling object on earth accelerates at the same rate, regardless of mass. Galileo is credited with this idea/experiment.

• Astronaut David Scott demonstrated the principle on the moon, simultaneously dropping a feather and a hammer. Each fell at the same acceleration, due to no atmosphere & no air resistance.
• Galileo is also credited with using the Leaning Tower of Pisa as an experiment site.
What about the distance a dropped object will travel?

- $d = \frac{1}{2} gt^2$
- This equation will compute the distance ($d$) an object drops due to gravity (neglecting air resistance) in a given time ($t$).
Solving for distance dropped - Example

• A ball is dropped from a tall building. How far does the ball drop in 1.50 s?
• GIVEN: \( g = 9.80 \text{ m/s}^2, \ t = 1.5 \text{ s} \)
• SOLVE:

\[
d = \frac{1}{2} gt^2 = \frac{1}{2} (9.80 \text{ m/s}^2) (1.5 \text{ s})^2
\]
\[
= \frac{1}{2} (9.80 \text{ m/s}^2) (2.25 \text{ s}^2) = ?? \text{ m}
\]
Solving for distance dropped - Example

- A ball is dropped from a tall building. How far does the ball drop in 1.50 s?
- GIVEN: \( g = 9.80 \text{ m/s}^2 \), \( t = 1.5 \text{ s} \)
- SOLVE:
  \[
d = \frac{1}{2} gt^2 = \frac{1}{2} (9.80 \text{ m/s}^2) (1.5 \text{ s})^2
  = \frac{1}{2} (9.80 \text{ m/s}^2) (2.25 \text{ s}^2) = 11.0 \text{ m}
  \]
Solving for final speed – Confidence Exercise

• What is the speed of the ball in the previous example 1.50 s after it is dropped?
• GIVEN:  \( g = a = 9.80 \text{ m/s}^2 \),  \( t = 1.5 \text{ s} \)
• SOLVE:
  • \( v_f = at = (9.80 \text{ m/s}^2)(1.5 \text{ s}) \)
  • Speed of ball after 1.5 seconds = 14.7 m/s
Constant Acceleration = Gravity 9.8 m/s²

- Distance is proportional to $t^2$  
  – $(d = \frac{1}{2} gt^2)$
- Velocity is proportional to $t$  
  – $(v_f = at)$
v proportional to time (t)
d proportional to time squared (t^2)
Up and Down – Gravity slows the ball, then speeds it up

- Acceleration due to gravity occurs in BOTH directions.
  - Going up (-)
  - Coming down (+)
- The ball returns to its starting point with the same speed it had initially. \( v_0 = v_f \)
Acceleration In Uniform Circular Motion

• Although an object in uniform circular motion has a constant speed, it is constantly changing directions and therefore its velocity is constantly changing directions.
  – *Since there is a change in direction there is a change in acceleration.*

• What is the direction of this acceleration?

• It is at right angles to the velocity, and generally points toward the center of the circle.
Centripetal ("center-seeking") Acceleration

- Supplied by friction of the tires of a car
- The car remains in a circular path as long as there is enough centripetal acceleration.
Centripetal Acceleration

• $a_c = \frac{v^2}{r}$

• This equation holds true for an object moving in a circle with radius ($r$) and constant speed ($v$).

• From the equation we see that centripetal acceleration increases as the square of the speed.

• We also can see that as the radius decreases, the centripetal acceleration increases.
Finding Centripetal Acceleration

Example

• *Determine the magnitude of the centripetal acceleration of a car going 12 m/s on a circular cloverleaf with a radius of 50 m.*
Finding Centripetal Acceleration

Example

• Determine the magnitude of the centripetal acceleration of a car going 12 m/s on a circular cloverleaf with a radius of 50 m.
• GIVEN: \( v = 12 \text{ m/s}, \quad r = 50 \text{ m} \)
• SOLVE:
  \[
  a_c = \frac{v^2}{r} = \frac{(12 \text{ m/s})^2}{50 \text{ m}} = 2.9 \text{ m/s}^2
  \]
Finding Centripetal Acceleration
Confidence Exercise

• Compute the centripetal acceleration in m/s\(^2\) of the Earth in its nearly circular orbit about the Sun.

• GIVEN: \( r = 1.5 \times 10^{11} \) m, \( v = 3.0 \times 10^4 \) m/s

• SOLVE:

  \[
  a_c = \frac{v^2}{r} = \frac{(3.0 \times 10^4 \text{ m/s})^2}{1.5 \times 10^{11} \text{ m}} = \frac{9.0 \times 10^8 \text{ m}^2/\text{s}^2}{1.5 \times 10^{11} \text{ m}}
  \]

  \[
  a_c = 6 \times 10^{-3} \text{ m/s}^2
  \]
Figure 2.14

- An object thrown horizontally will fall at the same rate as an object that is dropped.
The velocity in the horizontal direction does not affect the velocity and acceleration in the vertical direction.
Projectile Motion

• An object thrown horizontally combines both straight-line and vertical motion each of which act independently.

• Neglecting air resistance, a horizontally projected object travels in a horizontal direction with a constant velocity while falling vertically due to gravity.
Projected at an angle (not horizontal)

Combined Horz/Vert. Components = Vertical Component + Horizontal Component
In throwing a football the horizontal velocity remains constant but the vertical velocity changes like that of an object thrown upward.
If air resistance is neglected, projectiles have symmetric paths and the maximum range is attained at 45°.
Under real-world conditions, air resistance causes the paths to be non-symmetric. Air resistance reduces the horizontal velocity.
Projectiles - Athletic considerations

- Angle of release
- Spin on the ball
- Size/shape of ball/projectile
- Speed of wind
- Direction of wind
- Weather conditions (humidity, rain, snow, etc)
- Field altitude (how much air is present)
- Initial horizontal velocity (in order to make it out of the park before gravity brings it down, it must leave the bat at a high velocity)
Important Equations – Chapter 2

- \( \overline{v} = \frac{d}{t} \) (average speed)
- \( d = \frac{1}{2}at^2 \) (distance traveled, starting from rest)
- \( d = \frac{1}{2}gt^2 \) (distance traveled, dropped object)
- \( g = 9.80 \text{ m/s}^2 = 32 \text{ ft/s}^2 \) (acceleration, gravity)
- \( a_c = \frac{v^2}{r} \) (centripetal acceleration)
- \( \Delta v = \frac{v_f - v_o}{t} \) (constant acceleration)
- \( v_f = v_o + at \) (final velocity with constant \( a \))
- \( a = \frac{\Delta v}{t} = \frac{v_f - v_o}{t} \) (constant acceleration)