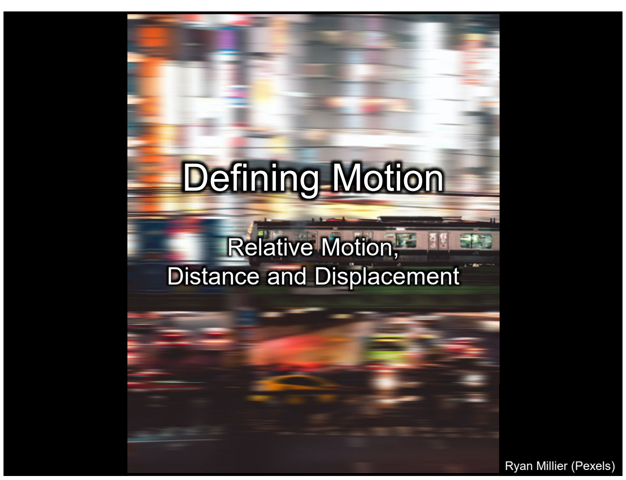
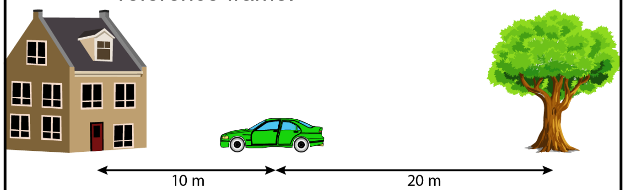
Motion in One Dimension



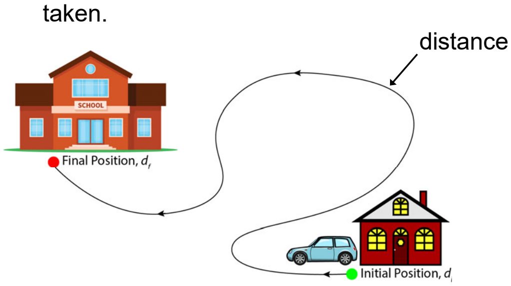
- The **position** of an object is its location at a particular time.
  - You need to specify its position relative to a convenient reference frame.
    - Earth is often used as a convenient reference frame.



- The car is 10 m to the right of the house.
- The car is 20 m to the left of the tree.

House – rdevries (public domain)
Car – Machovka (public domain)
Tree – GDJ (public domain)

- The **distance** an object moves is the length of the path between its initial position and its final position.
  - The distance traveled depends on the path taken.

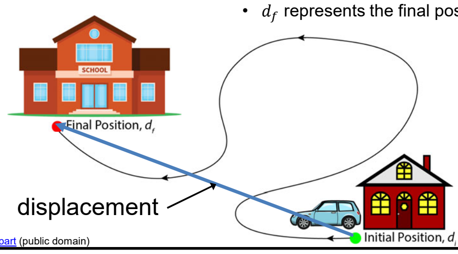


Images: Openclipart (public domain)

- The net change in position of an object is **displacement**.
  - The displacement is in a specific direction.

$$\Delta d = d_f - d_i$$

- d_i represents the initial position.
- d_f represents the final position.



Images: Openclipart (public domain)

- A quantity, such as distance, that has magnitude (i.e., how big or how much) but does not take into account direction is called a **scalar**.
- A quantity, such as displacement, that has both magnitude and direction is called a **vector**.
  - A vector quantity is symbolized by an arrow above the variable, $\vec{d}$.

Mario Aranda (Pixabay)

- Motion that is forward, to the right, or upward is usually considered to be positive (+).
- Motion that is backward, to the left, or downward is usually considered to be negative (−).
- Compass directions (North, South, East, West) can also be used to specify direction.

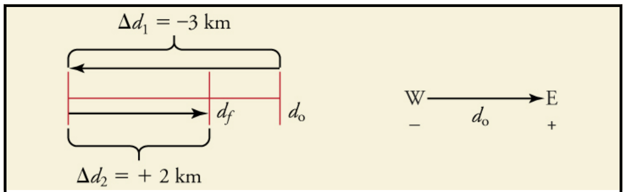
Example 1

A cyclist rides 3 km west and then turns around and rides 2 km east.

(a) What distance does she ride?

(b) What is her displacement?

(c) What is the magnitude of her displacement?



(a) distance

$d = 3 \text{ km} + 2 \text{ km}$
$d = 5 \text{ km}$

(b) displacement

The displacement can be calculated by adding the individual displacements together.

$\Delta \vec{d} = \Delta \vec{d}_1 + \Delta \vec{d}_2$
$\Delta \vec{d} = -3 \text{ km} + 2 \text{ km}$
$\Delta \vec{d} = -1 \text{ km}$

(c) magnitude of the displacement

1 km

Example 2

Tiana jogs 1.5 km along a straight path and then turns and jogs 2.4 km in the opposite direction. She then turns back and jogs 0.7 km in the original direction. Let Tiana's original direction be the positive direction. What are the displacement and distance she jogged?

Displacement

$\Delta \vec{d} = \Delta \vec{d}_1 + \Delta \vec{d}_2 + \Delta \vec{d}_3$
$\Delta \vec{d} = 1.5 \text{ km} - 2.4 \text{ km} + 0.7 \text{ km}$
$\Delta \vec{d} = -0.2 \text{ km}$

Distance

$d = 1.5 \text{ km} + 2.4 \text{ km} + 0.7 \text{ km}$
$d = 4.6 \text{ km}$

- A description of how fast or slow an object moves is its **speed**.
- Speed is the rate at which an object changes its location.
  - It depends on the time interval of the motion.
- Speed is a scalar because it has a magnitude but not a direction.
- Units: m/s

- When you describe an object's speed, you often describe the average over a time period.
- Average speed, v_{avg}, is the distance traveled divided by the time during which the motion occurs.

$$v_{avg} = \frac{distance}{time}$$

- A car's speed would likely increase and decrease many times over a trip.
- Its speed at a specific instant in time, however, is its **instantaneous speed**.
  - A car's speedometer describes its instantaneous speed.

Digital Buggu (Pexels)

- **Velocity** describes the speed and direction of an object.
- Velocity is the vector version of speed.
  - Speed and direction
- Units: m/s

- Average velocity is displacement divided by the time over which the displacement occurs.

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

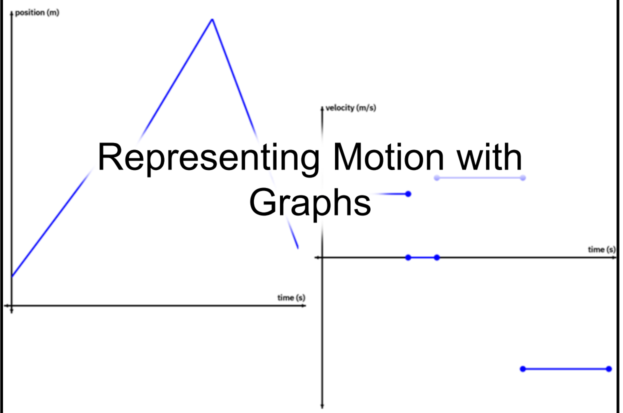
- The velocity at a specific instant in time. Is the **instantaneous velocity**.
  - Instantaneous velocity and average velocity are the same if the velocity is constant.

Example

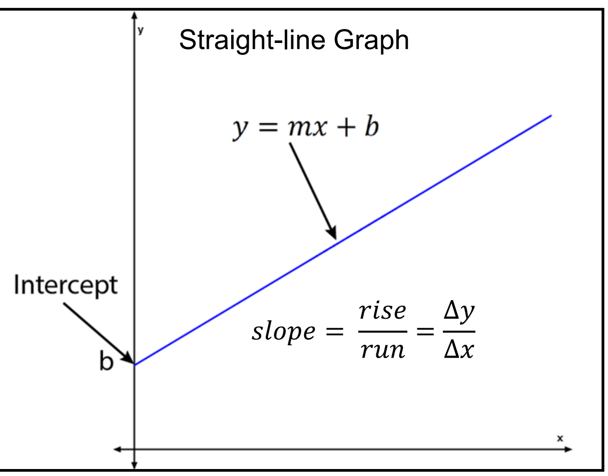
A student has a displacement of 304 m north in 180 s. Calculate the student's average velocity.

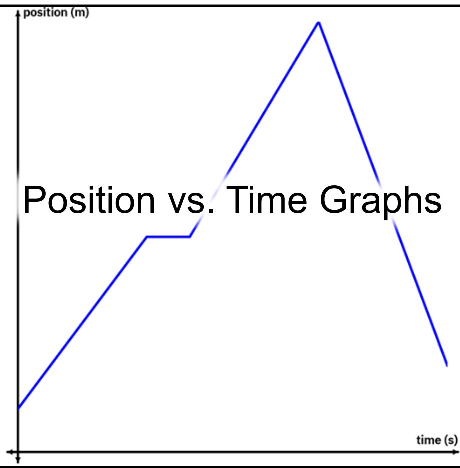
$$\vec{v}_{avg} = \frac{\Delta\vec{d}}{\Delta t}$$
$$\vec{v}_{avg} = \frac{304\text{ m}}{180\text{ s}}$$
$$\vec{v}_{avg} = 1.7\text{ m/s}$$

Representing Motion with Graphs



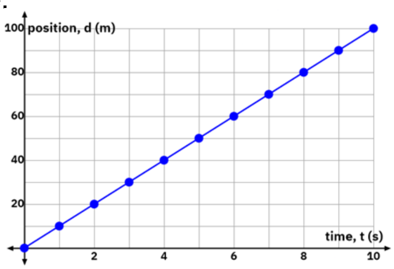
Straight-line Graph



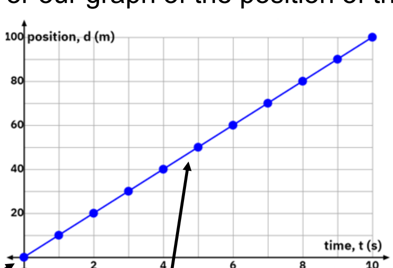


Position vs. Time Graphs

- Consider a car moving with a constant velocity of 10 m/s.
- The position of the car with respect to time can be shown on a graph of position vs time.



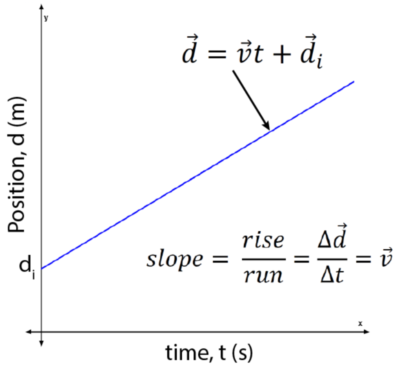
- For our graph of the position of the car…

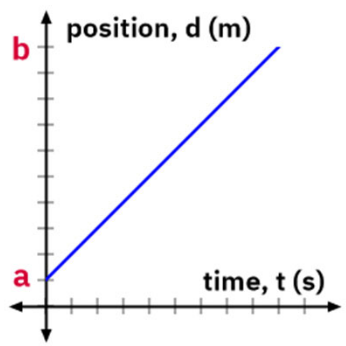


Initial position = 0

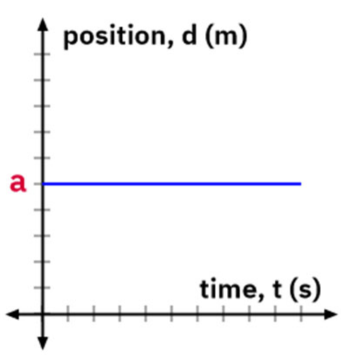
$$slope = \frac{rise}{run} = \frac{100-0}{10-0} = \frac{\Delta\vec{d}}{\Delta t} = velocity, \vec{v}$$

A graph of position versus time gives a general relationship among displacement, velocity, and time.

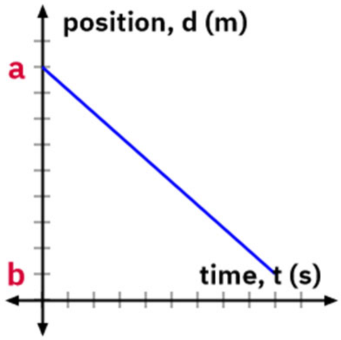




positive slope = positive velocity = moving forwards

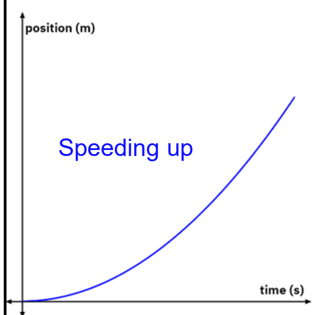


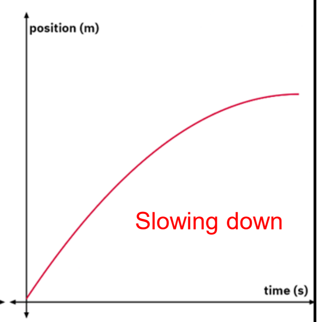
zero slope = zero velocity = stationary



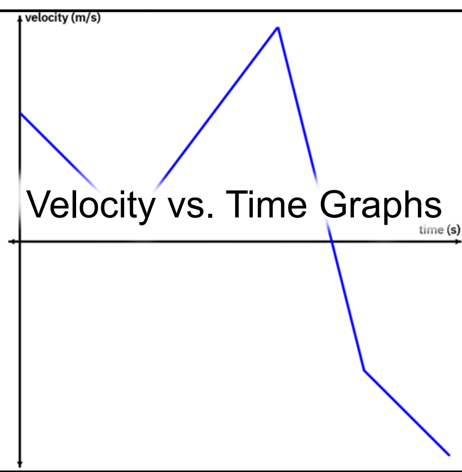
negative slope = negative velocity = moving backwards

- But what if an object is speeding up or slowing down?
  - The position-time graph will be curved.

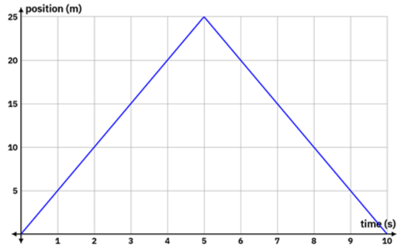




Velocity vs. Time Graphs

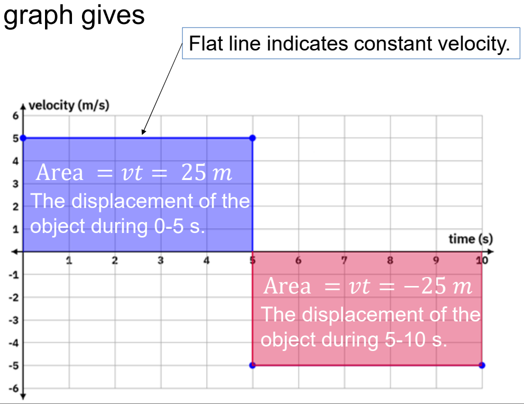


- Consider the following position-time graph.

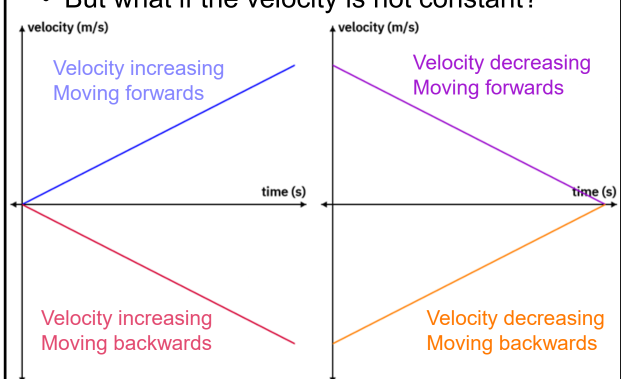


- The average velocity for the time 0 – 5 s is 5 m/s.
- The average velocity for the time 5 – 10 s is -5 m/s.

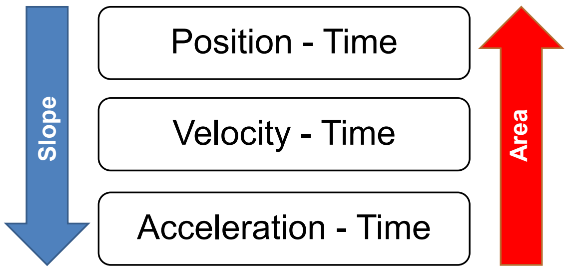
- Plotting these values on a velocity-time graph gives



- But what if the velocity is not constant?



The area under the curve is the displacement.



Acceleration

- **Acceleration** is the change in velocity divided by a period of time during which the change occurs.

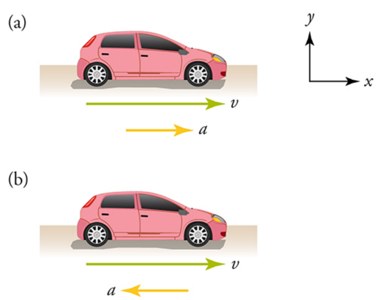
$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$$

The units for acceleration are m/s^2.

- It is important to remember that since velocity is speed plus direction, acceleration occurs whenever the speed **or** the direction of an object changes.

- The direction of the acceleration depends on
  - what direction the object is moving
  - how the speed is changing
- The general principle for determining the direction of acceleration is as follows:
  - **If an object is slowing down, then its acceleration is in the opposite direction of its motion.**

(a) Car is speeding up



(b) Car is slowing down

Image credit: Urone, Paul Peter, and Roger Hinrichs . "Defining Acceleration." In *Physics*. Houston, TX: OpenStax, 2020. https://openstax.org/books/physics/pages/3-1-acceleration (Creative Commons Attribution License 4.0)

Example 1

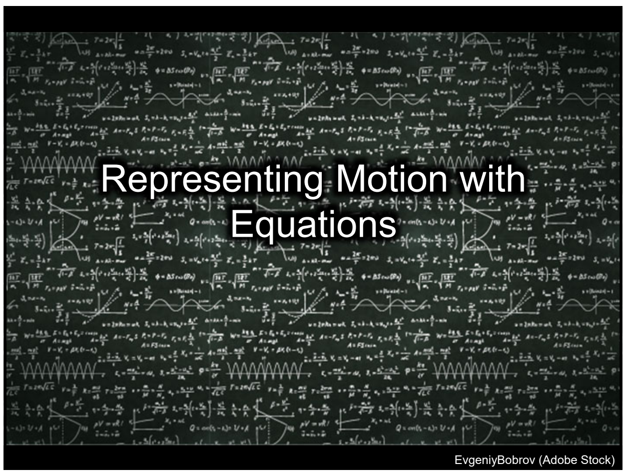
- A cheetah can accelerate from rest to a speed of 30.0 m/s in 7.00 s. What is its acceleration?

$$a = \frac{\Delta v}{\Delta t}$$
$$a = \frac{(30 - 0)}{7}$$
$$a = 4.29 \text{ m/s}^2$$

Example 2

- A women backs her car out of her garage with an acceleration of 1.40 m/s^2. How long does it take her to reach a speed of 2.00 m/s?

$$a = \frac{\Delta v}{\Delta t}$$
$$t = \frac{\Delta v}{a}$$
$$t = \frac{2 - 0}{1.4}$$
$$t = 1.43 \text{ s}$$



- The kinematic equations apply to conditions of **constant acceleration** and show how these concepts are related.
  - Constant acceleration is acceleration that does not change over time.
- We have defined (average) velocity as displacement divided by time.

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

- We can also define average velocity as

$$v_{avg} = \frac{v_i + v_f}{2}$$

Where: $v_i = \text{inital velocity}$
$v_f = \text{final velocity}$

- These two equations can be combined to give

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

- Acceleration is defined as the change in velocity over time.

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

- This equation can be rearranged to become

$$v_f = v_i + at$$

- Combing this equation with the previous equations relating displacement, velocity and time gives

$$d = v_i t + \frac{1}{2} a t^2$$

- The last equation allows for calculations when the time is not known.

$$v_f^2 = v_i^2 + 2ad$$

Kinematic Equations

$$v_f = v_i + at$$

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

$$d = v_i t + \tfrac{1}{2}at^2$$

$$v_f^2 = v_i^2 + 2ad$$

Example 1

- A race car accelerates uniformly from 18.5 m/s to 46.1 m/s in 2.47 seconds. Calculate distance traveled.

$v_i =$ 18.5
$v_f =$ 46.1
$t =$ 2.47
$d =$?

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

$$d = \left(\frac{18.5 + 46.1}{2}\right)2.47$$

$$d = 79.8 \text{ m}$$

Example 2

- A dragster accelerates from rest at a rate of 25 m/s² over 300 m. Calculate the final velocity of the dragster.

$v_i =$ 0
$v_f =$?
$a =$ 25
$d =$ 300

$$v_f^2 = v_i^2 + 2ad$$

$$v_f = \sqrt{v_i^2 + 2ad}$$

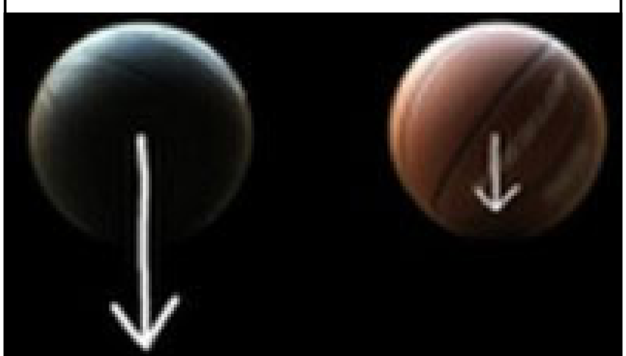
$$v_f = \sqrt{2(25)(300)}$$

$$v_f = 122 \text{ m/s}$$

Vertical Motion

OpenClipart - Vectors

Misconceptions About Falling Objects



https://youtu.be/_mCC-68LyZM

- When air resistance is not a factor, all objects near Earth's surface fall with an acceleration of about 9.8 m/s^2.
  - Although this value decreases slightly with increasing altitude, it may be assumed to be essentially constant.
- The value of 9.8 m/s^2 is labeled **g** and is referred to as the **acceleration due to gravity**.
- Since gravity pulls objects towards the earth's surface, this acceleration is **always** down (negative).

Example

- A ball is dropped from a height of 10 m. What is its velocity just before it hits the ground?

$v_i = 0$
$d = -10 \text{ m}$
$a = -9.8 \text{ m/s}^2$
$v_f = ?$

$v_f^2 = v_i^2 + 2ad$

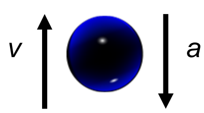
$v_f = \sqrt{2ad}$

$v_f = \sqrt{2(-9.8)(-10)}$

$v_f = 14 \text{ m/s}$

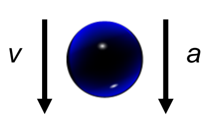
What happens when a ball is thrown straight up in the air?

- On its way up, the ball slows down
  - The acceleration due to gravity is in the opposite direction of the velocity of the ball



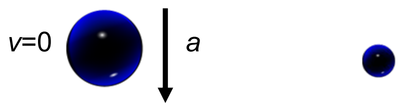
Credit: Sabrog (public domain)

- On its way down, the ball speeds up
  - The acceleration due to gravity is in the same direction as the velocity of the ball



Credit: Sabrog (public domain)

- What happens to the ball at the very top of its path?
  - It stops
- What is the acceleration at that point?
  - It is still the acceleration due to gravity and it is still down
  - The **direction** of the ball is changing instead of the speed.



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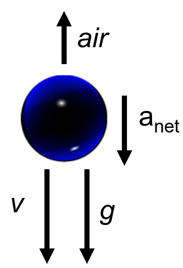
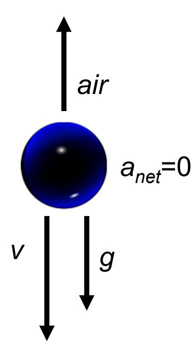
Air Resistance

- When objects fall through the air, gravity pulls down and the air pushes up on the falling object.
- This reduces the net (total) acceleration of the object.



Credit: Sabrog (public domain)

- The force due to the air will increase the longer the object falls.
- Eventually, the force from the air will equal the force of gravity resulting in a net acceleration of zero.
- The object will continue to fall but will no longer accelerate.



Credit: Sabrog (public domain)

- This maximum velocity is referred to as the **terminal velocity**.
- Terminal velocity is related to the surface area and mass of the falling object.

Kevin Phillips (Pixabay)

Brian Cox visits the world's biggest vacuum (Human Universe – BBC)

https://youtu.be/E43-CfukEgs

Apollo 15 Proves Galileo Correct

https://youtu.be/ZVfhztmK9zI