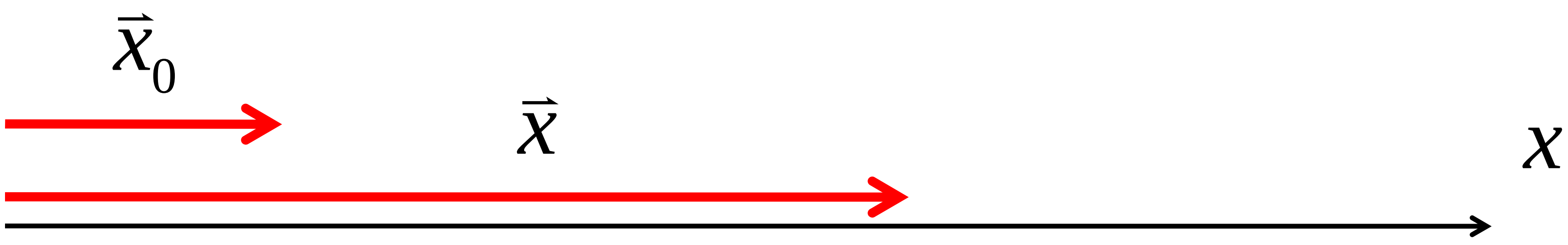
Chapter 2

Kinematics in One Dimension

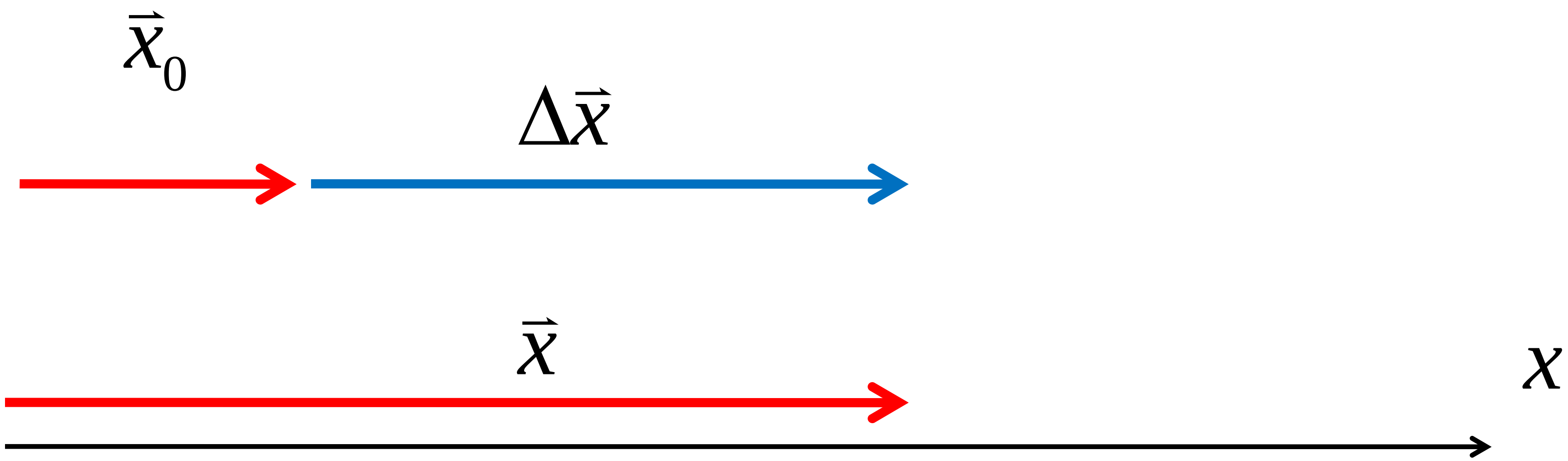
Displacement

- 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

Checkpoint	Time (hrs)	miles
1	0	0
2	0.50	20
3	1.25	35
4	1.50	55
5	2.00	60

40 miles/hr

20 miles/hr

80 miles/hr

10 miles/hr

Checkpoint	Time (hrs)	miles
1	0	0
2	0.50	20
3	1.25	35
4	1.50	55
5	2.00	60

40 miles/hr

20 miles/hr

80 miles/hr

10 miles/hr

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.

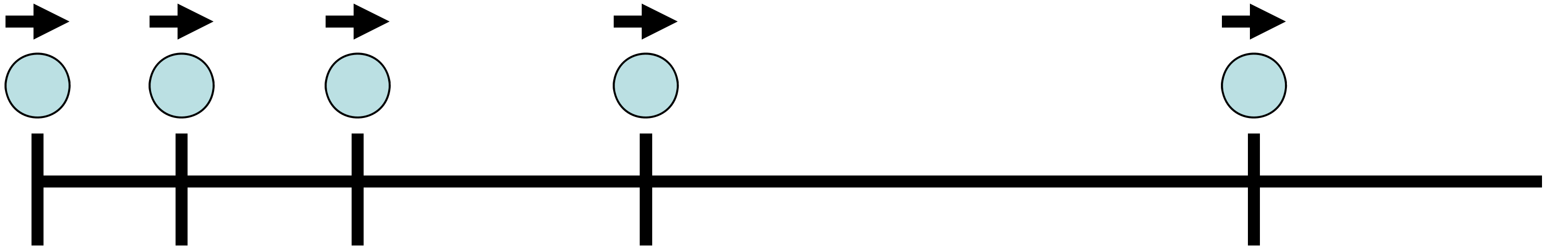
- Note: For most of the problems in this course the acceleration will be constant.

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 m/s - 5 m/s) = 15 m/s in 10 seconds.

The acceleration must be: a = (15 m/s) / (10 s) = <u>1.5 m/s^2</u>

Notice the units: m/s^2 (read meters per second, per second or meters per second squared)



Time:	0s	1s	2s	3s	4s
Position:	0m	5m	20m	45m	80m
Speed:	0m/s	10m/s	20m/s	30m/s	40 m/s

Calculate the acceleration in each time interval:

Answer: (10 m/s)/(1 s) = <u>10 m/s^2</u>

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 have four equations of motion that correspond to situations where the acceleration is constant.

$$\mathrm{v} = \mathrm{v}_0 + at$$

$$x = x_0 + \mathrm{v}_0 t + \frac{1}{2}at^2$$

$$x = x_0 + \frac{1}{2}\left(\mathrm{v}_0 + \mathrm{v}\right)t$$

$$\mathrm{v}^2 = \mathrm{v}_0^2 + 2a\left(x - x_0\right)$$

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 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.

$$x \qquad a \qquad \mathrm{v} \qquad \mathrm{v}_0 \qquad t$$

- We can organize the data that are given and the variable of which we are trying to determine into a table.

x	a	v	v_0	t
?	$7.50 m/s^2$	0	$40 m/s$	

- 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.

$$x = \frac{1}{2a}\left(\mathrm{v}^2 - \mathrm{v}_0^2\right)$$

- Now we substitute our values into this expression.

$$x = \frac{1}{2\left(7.50m/s^2\right)}\left(\left(40m/s\right)^2 - 0\right) = 106.7\,m$$

Galileo’s Law of Falling

Galileo performed many experiments with object 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.

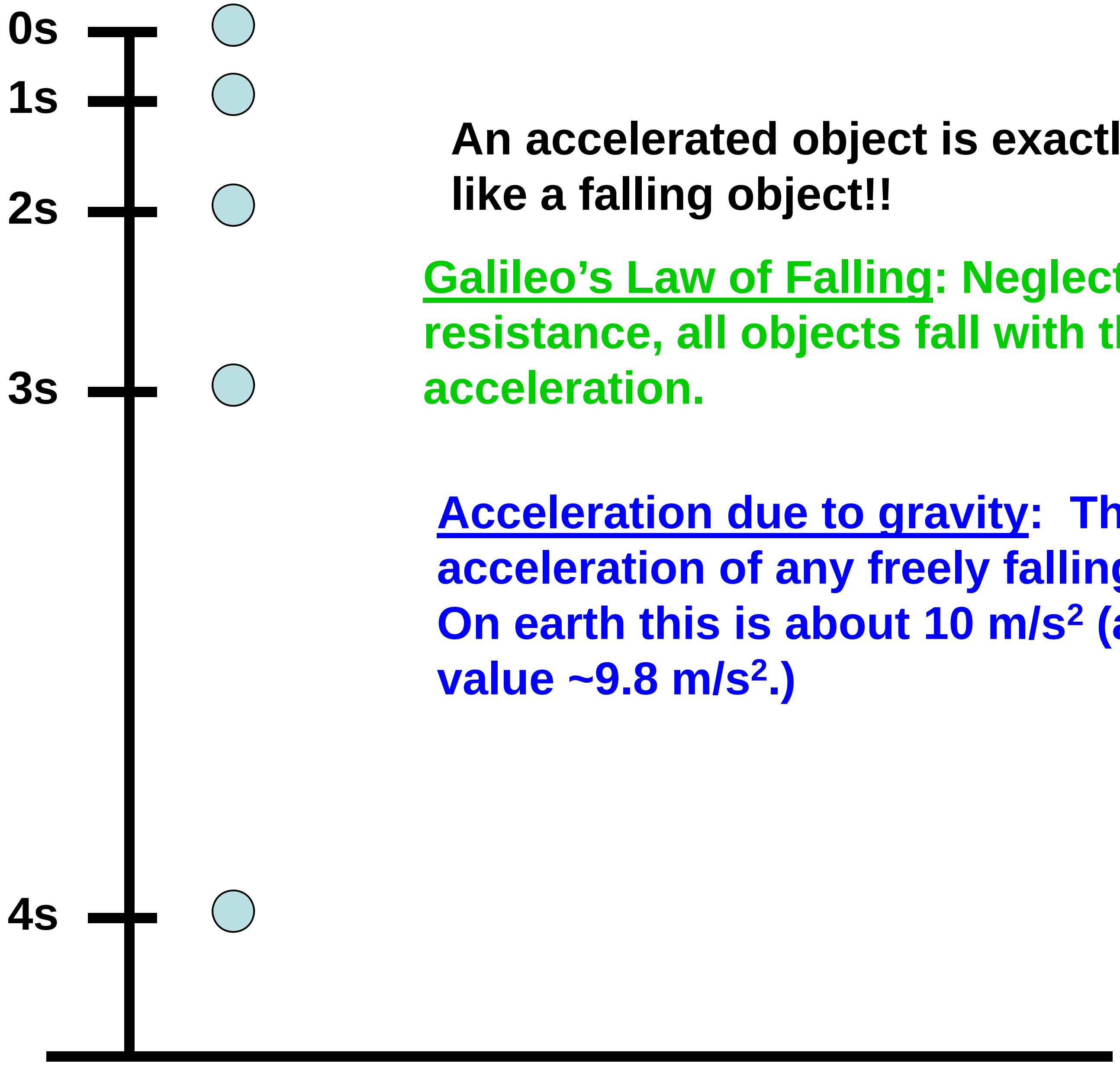
- This acceleration due to gravity is often expressed with the letter “*g*”.

- Hence:

$$g = 9.8\, m/s^2$$

Falling and Falling and Falling

- An object dropped from rest will fall 9.8 m/s, after the 1st second, about 19.6 m/s after the 2nd second, about 29.4 m/s after the 3rd and so on.



An accelerated object is exactly like a falling object!!

<u>Galileo's Law of Falling</u>: Neglecting Air resistance, all objects fall with the same acceleration.

<u>Acceleration due to gravity</u>: The acceleration of any freely falling object. On earth this is about 10 m/s^2 (actual value ~9.8 m/s^2.)

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: