1: Describing Motion

Unit: 1: Motion and Forces
Standard: • NGSS: HS-PS2-1 — use data to relate net force, mass, and acceleration.
• TEKS: §112.45(c)(5)(C) [P.5.C] — analyze motion in one dimension using distance, displacement, speed, velocity, frames of reference, and acceleration; also (5)(A) motion graphs and (5)(B) scalar vs. vector.

Lesson Objective: You will analyze position-time and velocity-time graphs to describe how objects move, and compare scalar quantities like distance and speed to vector quantities like displacement and velocity. You will calculate average speed and average velocity using real motion data. This skill supports careers in automotive engineering, aerospace, and robotics.

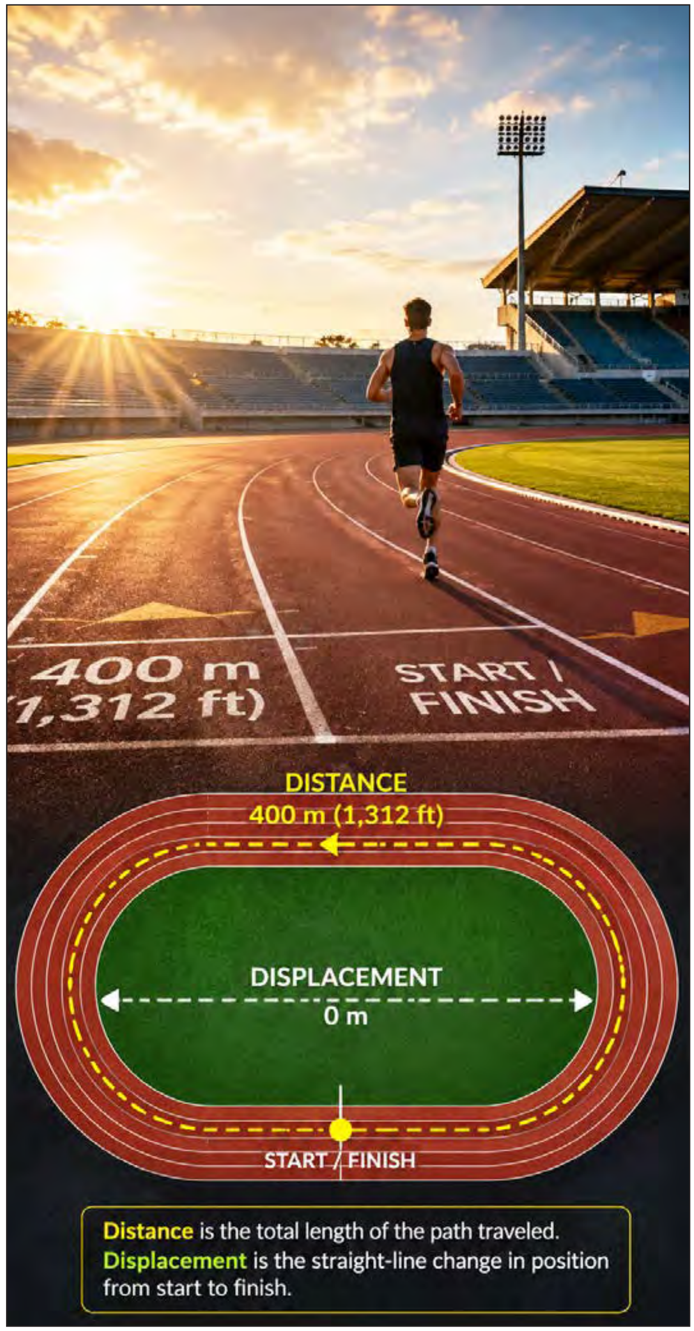
Unit 1, Lesson 1: Describing Motion
Top 3 Important Concepts

1. Scalars vs. Vectors
Scalars carry only a size, like distance and speed, while vectors carry both a size and a direction, like displacement and velocity. This distinction shows whether an object made real progress toward a destination, not just how much ground it covered.

2. Reading Position-Time and Velocity-Time Graphs
The slope of a position-time graph shows an object's velocity: steep means fast, flat means still, and a curve means the object is accelerating. This graph-reading skill lets you describe motion at a glance, without doing any math.

3. Calculating Average Speed and Velocity
Average speed and average velocity use simple, one-step equations that divide distance or displacement by time. Working through real numbers, like a runner's lap or a cart on a ramp, connects these formulas to real, measurable motion.

4. Why It Matters
Describing motion precisely is the foundation for vehicle safety systems, self-driving car sensors, and nearly any engineering decision that involves movement. Mastering scalars, vectors, and motion graphs turns raw data into real, actionable understanding of how things move.



One number can never capture the full story of how something moves.
Motion always has two sides: how far, and which way.

Beyond the Speedometer: How Physics Describes Motion

A speedometer needle can hold steady at 97 kilometers per hour (60 miles per hour) for an entire road trip, yet the car might finish only a short distance from where it started. That gap is why physicists never describe motion with a single measurement. How much ground an object covers, and where it actually ends up, are two different questions.

A vector arrow shows displacement: a straight line, far shorter than the winding path actually run.

Two Kinds of Answers: Scalars and Vectors

Physics divides quantities into two families, and motion is where the split matters most. A **scalar** is a quantity with only a size, or magnitude, such as distance or speed. A **vector** carries both a size and a direction, the way displacement and velocity do.

Distance is the total length of the path an object travels. **Displacement** is different. It is the straight-line change in position from start to finish, along with the direction of that change. Physicists often show that direction with a simple arrow, pointing from start to end.

A track athlete who runs one full lap around a 400-meter (1,312-foot) track ends up back at the starting line. The distance covered is a full 400 meters (1,312 feet), since every meter of the path counts. The displacement, however, is zero: the athlete's final position matches the starting position exactly.

The same split applies to **speed** and **velocity**. **Average speed** is calculated with:

$$v = d / t$$

where v is average speed, d is total distance, and t is total time. This equation only gives speed, because it uses distance rather than displacement.

Average velocity uses the same structure, but with displacement in place of distance, and the answer always includes a direction, such as north or back toward the start.

For the track athlete finishing that lap in 60 seconds, average speed comes out to 400 meters (1,312 feet) divided by 60 seconds, or about 6.7 meters per second (22 feet per second). Average velocity, though, is 0 meters divided by 60 seconds, which equals zero, since the runner never changed position.

Both numbers are correct; they answer different questions. Speed tells you how much ground got covered, while velocity tells you whether that effort moved the object anywhere at all.

A delivery driver circling the same block racks up real distance and speed, yet an average velocity near zero, since the truck ends up almost where it began. The same is true for a student biking to school and back: the round trip still ends with zero displacement.

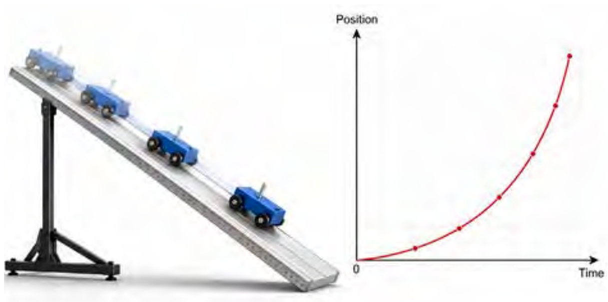
Engineers and route planners rely on this distinction: a vehicle can log distance without making progress toward a destination unless its velocity points the right way.

Sensor data lets a self-driving car track nearby vehicles many times each second.

Reading Motion Off a Graph

Position-time and **velocity-time graphs** turn raw numbers into a shape the eye reads instantly. On a position-time graph, position sits on the vertical axis and time on the horizontal axis.

The **slope** of that line, how steeply it rises or falls, represents the object's velocity. A flat, horizontal line means the object is not moving, since its position stays constant while time passes.



A curving position-time graph shows a cart accelerating down a ramp, its slope steepening over time.

A steep line means fast movement, and a gentler slope means slower movement. A line sloping downward means the object's position is decreasing, which represents motion in the negative direction, often the sign of heading back the way it came.

A simpler example: a student walking away from a classroom door, pausing, then walking back would produce three sections on a position-time graph: a rising line, a flat line, then a falling line, describing the whole trip without a stopwatch.

This idea, that slope equals velocity, lets a physicist glance at a graph and describe a trip without reading a single number. A cart released on a ramp does not move at constant speed, since gravity keeps pulling it forward and its velocity keeps increasing the whole way down. Its position-time graph is therefore not a straight line: it curves, starting shallow and bending upward more sharply as time passes.

A steep ramp bends sharply almost right away, showing rapid **acceleration**; a gentler incline bends upward more slowly. Testing several incline angles at equal time intervals turns this into real data, since each angle produces its own distinctly shaped curve.

Velocity-time graphs work on a related principle, though the axes change. The vertical axis shows velocity directly, and a flat horizontal line means the object is holding a constant velocity, neither speeding up nor slowing down.

A tilted line represents **acceleration**: the rate at which velocity changes. The steeper the tilt, the faster the velocity is changing.

Velocity can change even when speed stays the same, if the object reverses direction. A ball bouncing off a wall keeps the same speed but flips from positive to negative velocity, showing up as a sudden jump rather than a gradual tilt.

Graphs display change directly, letting scientists and engineers spot patterns and catch mistakes faster than raw data tables.

Why Precise Motion Data$_c$Keeps People Safe

Describing motion accurately forms the backbone of transportation engineering and safety design. Traffic engineers need reliable speed and reaction-time data, since a driver at highway speed covers real distance before a foot reaches the brake pedal.

A navigation app recalculates position constantly to estimate speed and direction.

Beyond the Speedometer: How Physics Describes Motion

A car moving at 30 meters per second (67 miles per hour) covers a full 30 meters (98 feet) in that first second of reaction time alone, before any braking begins. At a two-second reaction time in heavy traffic, that pre-braking distance can stretch past 60 meters (197 feet). Treating those numbers as a rough guess instead of a specific, direction-aware value could mean the difference between a safe stop and a collision.

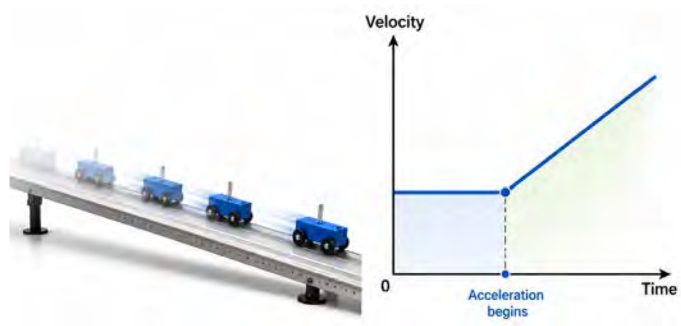
The same principles guide how modern vehicles track nearby traffic. Sensors inside a car measure the position of nearby vehicles at regular intervals, then use the change in position to calculate velocity.

Onboard software compares those velocities and directions to decide whether a lane change is safe or a following distance should increase.

None of that decision-making works without separating distance from displacement, or speed from velocity. A wrong direction reported as right could send a warning system into silence at exactly the wrong moment.

Beyond individual vehicles, transportation networks depend on this same foundation. Traffic signal timing and airport runway spacing rely on engineers who can read a position-time graph and translate its slope into safety decisions.

A small error in describing how fast something is moving, or in which direction, can create a missed safety margin. The physics is the same whether the moving object is a track athlete or an airplane on approach: direction-aware descriptions of motion keep fast-moving systems from colliding.



A tilted velocity-time line marks the moment an object begins accelerating.

A photo finish decided by hundredths of a second comes down to that same habit: separating how far a runner traveled from where she ended up, and clocking exactly how fast she got there.

How to Apply

- **Ask "how far" and "which way."** A direction means it's a vector (displacement, velocity); no direction means it's a scalar (distance, speed).
- **Look at the slope first.** A straight line on a position-time graph means constant velocity; a curve means acceleration.
- **Match the equation to the question.** Use v = d / t for speed. Swap in displacement, plus a direction, for velocity.
- **Check the tilt on a velocity-time graph.** Flat means constant velocity; tilted means acceleration.
- **Always attach a unit and, for vectors, a direction.** A number alone only tells half the story.

High-speed cameras tracked a sprinter's position at intervals, revealing exactly when she accelerated.

1: Describing Motion - Guided Notes

Three Most Important Concepts

As you read the article, jot down the three biggest ideas in your own words.

Concept 1: ____

Concept 2: ____

Concept 3: ____

Main Concept Overview

Fill in each blank using a word from the word bank below.

Word Bank: displacement, vector, distance, acceleration, slope

1. The total length of the path an object travels is called ____________________.
2. The straight-line change in an object's position, including direction, is called ____________________.
3. On a position-time graph, the ____________________ of the line represents the object's velocity.
4. A cart rolling down a ramp speeds up the whole way down because it is undergoing ____________________.
5. A quantity that includes both a magnitude and a direction, such as velocity, is called a ____________________.

Matching Section

Match each term to its correct description.

_____ Scalar	A. Represents an object's velocity on a position-time graph.
_____ Vector	B. A quantity that has only a magnitude, with no direction.
_____ Distance	C. The total length of the path an object travels.
_____ Displacement	D. A quantity that has both a magnitude and a direction.
_____ Slope of a Position-Time Graph	E. The straight-line change in position from start to finish, including direction.

1: Describing Motion - Guided Notes

True or False

Write T or F for each statement.

______ Distance and speed are examples of vectors.

______ Displacement can be zero even if the distance traveled is not zero.

______ A cart accelerating down a ramp produces a straight line on a position-time graph.

______ A steeper tilt on a velocity-time graph means a greater acceleration.

______ A car moving at 30 meters per second (67 miles per hour) covers about 30 meters (98 feet) in one second of reaction time.

Fill in the Table

Using what you learned in the article, label each quantity as a **Scalar** or a **Vector**.

Quantity/Concept	Scalar or Vector?
Distance	
Speed	
Displacement	
Velocity	
Slope of a Position-Time Graph	

Application Questions

1. A car travels 150 kilometers (93 miles) west, then turns around and drives 150 kilometers (93 miles) east back to its starting point, over a total time of 3 hours. Using the ideas from the article, explain why the car's average speed and average velocity for the trip are different, and calculate each value.

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2. Explain how an engineer could use a position-time graph, without doing any calculations, to determine whether a vehicle was speeding up, slowing down, or moving at a constant speed during a test drive.

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1: Describing Motion - Case Study

Usain Bolt's 100-Meter (328-Foot) World Record (Berlin, 2009)

When Usain Bolt ran 9.58 seconds at the 2009 World Championships, researchers tracked his position at fixed time intervals using cameras placed along the track. He did not run at one speed: he accelerated hard out of the blocks, reached a peak velocity of nearly 12 meters per second (27 miles per hour) between the 60-meter (197-foot) and 80-meter (262-foot) marks, then slightly slowed near the line. Because every camera measured position against the same starting line, the researchers shared a common frame of reference. Plotting position against time produced a curve whose steepening slope revealed his acceleration phase, while the nearly straight top-speed section showed almost constant velocity. A single average speed for the whole race would have erased all of that detail.

Applying the article: Use what the article explained about slope on a position-time graph: steeper means faster, flatter means steadier. Also recall why a shared reference point matters: it lets separate measurements be compared fairly, the same idea behind the researchers' cameras.

Analysis Questions

A. What quantities did researchers measure at fixed intervals, and why did a shared frame of reference matter?

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B. How does the slope of Bolt's position-time graph reveal where he was accelerating versus moving at nearly constant velocity?

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C. If you were given position-time data for a second sprinter, what features would you look for to predict who reached the higher peak velocity?

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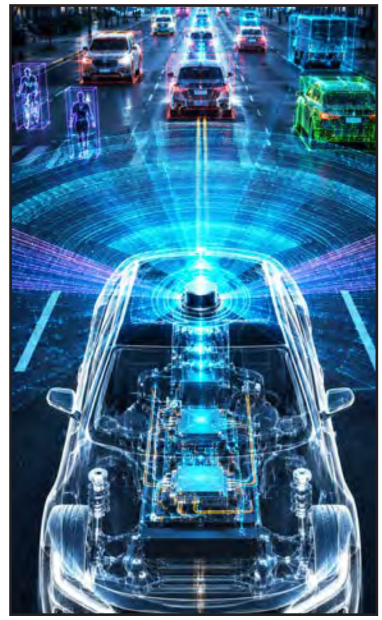
Frontier Application: Self-Driving Vehicle Perception



A self-driving car cannot move safely unless it continuously describes the motion of everything around it. Using radar, cameras, and LIDAR, the car's computer tracks the position, velocity, and acceleration of nearby vehicles many times per second, all measured relative to the car's own frame of reference. This constant stream of data lets the car predict where a nearby vehicle will be an instant later, not just where it is right now. Without that steady stream of updates, even a fast computer would end up reacting to old, outdated information.

Before you begin: Think back to how the article separated distance from displacement, and slope from acceleration. Apply those same distinctions here, to a car's sensors instead of a runner or a cart.

Analysis Questions

A. How does a self-driving car use position and velocity data to describe the motion of a car ahead of it?

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B. Why must the vehicle treat all measured motion relative to a consistent frame of reference to make safe decisions?

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C. Predict what could go wrong if the car measured another vehicle's position accurately but failed to track its acceleration.

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01

How does motion data, like stopping distances and reaction times, shape speed limits in your community?

Think about roads near schools or areas that get icy, and how officials might treat those differently.

02

How does the idea of a reference point in physics relate to how people describe the same event differently depending on their perspective?

Think about how your position or point of view might change the way you would describe something moving.

Bolt's 100-Meter (328-Foot) Race: Segment-by-Segment Velocity

Distance Segment	Segment Time (s)	Average Velocity, m/s (mph)	Cumulative Time at Segment End (s)
0 to 20 m (0 to 66 ft)	2.88	6.94 (15.5)	2.88
20 to 40 m (66 to 131 ft)	1.76	11.36 (25.4)	4.64
40 to 60 m (131 to 197 ft)	1.65	12.12 (27.1)	6.29
60 to 80 m (197 to 262 ft)	1.63	12.27 (27.4)	7.92
80 to 100 m (262 to 328 ft)	1.66	12.05 (27.0)	9.58

This table uses real interval data from Usain Bolt's 2009 World Championship 100-meter (328-foot) race, the same race described in the case study. Each row shows his average velocity over one 20-meter (66-foot) segment of the race, rather than a single average for the whole race.

Analysis Questions

1. **Basic Interpretation:** What was Bolt's average velocity between the 40-meter (131-foot) and 60-meter (197-foot) marks?

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2. **Pattern Identification:** Describe how Bolt's average velocity changed from the first 20-meter (66-foot) segment of the race to the last 20-meter (66-foot) segment.

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3. **Application:** A self-driving car's sensors, like the cameras tracking Bolt, measure position at repeated time intervals to calculate velocity. Using the pattern in this table, explain why a single average speed for an entire 100-meter (328-foot) stretch would not give a self-driving car's software enough information to detect that a nearby vehicle is still accelerating partway through a merge.

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1: Describing Motion - Hypotheticals

Scenario 1: Rideshare Route

Your rideshare app shows the trip covered 12 kilometers (7 miles) of winding streets, but the straight-line distance to your destination is only 6 kilometers (4 miles). The driver took the long way to avoid one-way streets. Your friend bikes straight there and arrives first.

a) Which number is the distance, and which is the displacement's size?
b) If the ride took 20 minutes, which would be larger, average speed or average velocity, and why?
c) How could a delivery company use this idea to give a better time estimate?

Scenario 2: Self-Driving Car Sensors

A self-driving car's computer measures the car ahead of it ten times every second. For one full second, the reported position does not change at all. Just before that second began, the other car had been moving steadily at a constant speed.

a) Why does the computer need more than one position reading to find the other car's velocity?
b) What would the flat position reading suggest about the car ahead?
c) Why might tracking only position, and not velocity, cause the self-driving car to react too late?

1: Describing Motion - Vocabulary

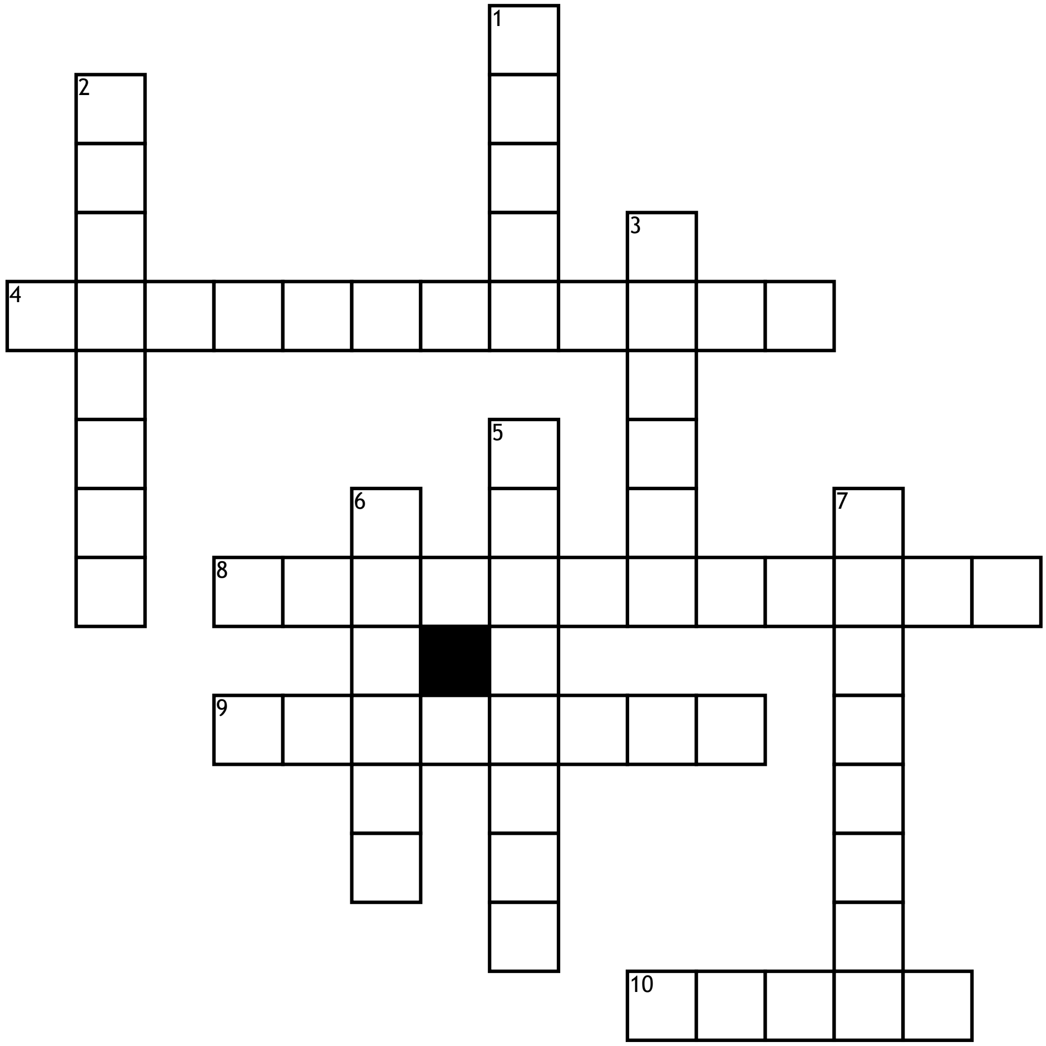
TERM	DEFINITION
Acceleration	
Average Speed	
Average Velocity	
Displacement	
Distance	
Position-Time Graph	
Scalar	
Slope	
Vector	
Velocity-Time Graph	

Describing Motion

Y	U	K	A	N	Y	E	U	F	A	P	R	W	L	U	U	O	Z	W	P	E	J	O	E
D	D	K	V	S	I	B	U	Z	V	V	Z	U	V	G	O	G	N	G	D	Z	E	Q	R
I	T	T	E	U	M	W	Z	T	V	J	C	X	V	A	R	A	Z	F	A	E	P	Y	R
S	D	U	R	R	M	I	K	W	Q	L	J	L	F	D	P	U	Y	Q	C	G	E	W	Z
P	H	C	A	N	V	V	J	G	T	E	N	T	U	A	P	E	P	V	C	K	U	V	U
L	M	W	G	N	Z	E	R	S	K	G	O	R	Q	X	I	C	W	O	E	H	C	N	N
A	M	J	E	T	X	L	W	A	O	I	R	W	O	X	M	F	W	N	L	R	Y	Q	B
C	P	F	V	S	J	O	Y	B	E	C	G	L	G	Z	Y	V	G	I	E	X	S	G	R
E	C	U	E	T	O	C	A	V	E	R	A	G	E	S	P	E	E	D	R	A	N	E	N
M	J	A	L	K	N	I	G	T	M	T	C	O	B	S	K	P	J	N	A	W	F	G	C
E	O	W	O	L	V	T	W	R	L	I	H	D	V	L	X	P	K	I	T	E	R	S	V
N	A	R	C	S	W	Y	F	W	D	U	D	H	V	D	U	C	S	B	I	C	M	W	C
T	T	M	I	Q	X	T	C	Q	O	S	A	M	R	E	K	B	A	X	O	Y	T	A	C
R	N	J	T	Q	V	I	F	U	S	E	P	E	L	H	C	C	E	K	N	S	P	E	V
F	M	Z	Y	T	X	M	S	O	F	J	O	V	P	A	T	T	M	O	X	R	C	W	J
H	S	N	V	L	E	E	X	D	D	T	U	T	V	Z	U	B	O	L	R	N	E	I	I
V	L	I	Z	T	T	G	K	F	T	U	C	B	N	N	H	R	X	R	S	R	U	R	U
B	D	Z	U	M	L	R	K	Y	W	H	P	C	J	P	S	E	M	J	O	M	P	R	I
S	L	Z	Z	K	U	A	W	A	T	D	R	Z	P	P	U	C	E	Z	Y	U	J	X	Y
L	E	O	K	Y	Y	P	U	Z	F	L	Q	I	G	U	U	W	A	O	G	N	M	G	Q
C	O	Y	H	T	P	H	S	L	O	P	E	J	B	Y	E	S	P	L	Z	C	K	X	D
U	U	Q	M	U	T	I	Y	S	Q	V	W	Z	R	D	P	A	C	Z	A	S	V	F	C
Q	C	N	Z	D	I	S	T	A	N	C	E	L	B	O	U	D	D	Q	K	R	H	V	P
K	B	E	P	I	Q	P	O	S	I	T	I	O	N	T	I	M	E	G	R	A	P	H	W

Velocity-Time Graph
Position-Time Graph
Average Velocity
Average Speed
Vector
Slope
Scalar
Distance
Displacement
Acceleration

Describing Motion



Across

4. The straight-line change in an object's position from start to finish, including direction.

8. The rate at which an object's velocity changes over time.

9. An object's total displacement divided by the total time, including the direction of that displacement. Average ____

10. The total distance an object travels divided by the total time it takes, without any direction included. Average ____

Down

1. How steeply a line on a graph rises or falls, used on a position-time graph to represent velocity.

2. A graph that shows an object's position on the vertical axis and time on the horizontal axis, with the slope of the line representing velocity. ____-Time Graph

3. A quantity that has both a magnitude and a direction.

5. A graph that shows an object's velocity on the vertical axis and time on the horizontal axis, with a tilted line representing acceleration. _____-Time Graph

6. A quantity that has only a magnitude, with no direction attached.

7. The total length of the path an object travels, regardless of direction.