WHAT IS KINEMATICS?

Kinematics is the study of how things move. Engineers need to understand the relationships among the important variables of distance, speed, acceleration, and time. These relationships are collectively called kinematics when they do not also involve the forces on objects or the inertia of the objects.

Engineers are concerned with the kinematics variables because they are the basic variables used to understand the motion of objects, such as the motion of cars in traffic. In the simplest cases, they are related to each other by geometric methods or in more complicated situations by the methods of calculus.

الكينماتيك (علم الحركة)، جزء من علم الميكانيك يهتم بوصف حركة الأجسام دون البحث في أسبابها.
يحتاجه **المهندسون** لفهم العلاقات التي تصف تحول المسافة (Distance)، السرعة (Speed)، والتسارع (Acceleration) مع الزمن (Time).

WHAT IS KINEMATICS?

DISTANCE, SPEED, AND ACCELERATION

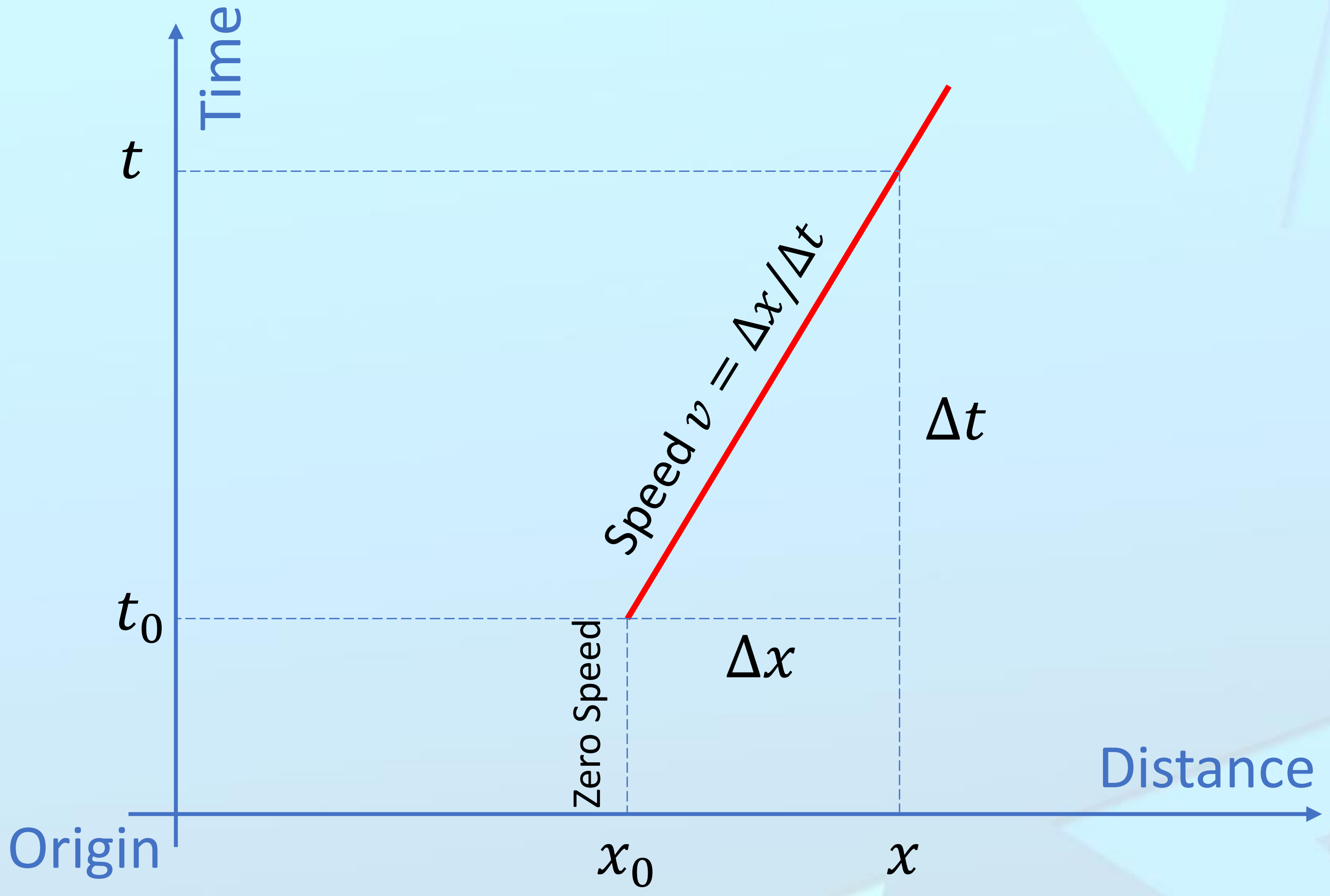
Here, only motion in a single direction (often called one-dimensional) is considered. For convenience, think of positive **distance** as from left to right, and negative distance as from right to left, just as in Cartesian geometry. **Speed** is a variable commonly measured in miles per hour (mph) in the United States but in kilometers per hour (kmph) in most of the rest of the world. But, for engineering design, the SI units of m/s are often more convenient.

سينحصر اهتمامنا بالحركة في اتجاه واحد على خط مستقيم موجه من اليسار إلى اليمين. نعتبر المسافات موجبة في اتجاه المحور وسالبة في الاتجاه المعاكس. تقاس السرعة في النظام الدولي بالمتر على الثانية وتستخدم واحدة الكيلومتر في الساعة في الحياة العملية وفي أمريكا والدول التي تتبعها بالميل في الساعة.

Speed is calculated by dividing the distance traveled (Δx) by the spent time (Δt). Then the speed $v = \Delta x/\Delta t$ (the uppercase Greek "delta" Δ symbol means "difference").

تحسب السرعة من حاصل تقسيم المسافة المقطوعة على الزمن اللازم لقطعها.

In Cartesian geometry, this is the average *slope of the x - t* line. In this case, speed means the final position minus the initial position divided by the final time minus the initial time, Fig.



Constant speed occurs when $v = \Delta x/\Delta t = constant.$

We use the symbol *v* (as in velocity) for speed. But, there is an important difference between the concepts of *speed* and *velocity.* Speed is the *magnitude* of the velocity.

السرعة مقدار شعاعي له اتجاه وقياس. في الحركة على المستقيم يمكننا التساهل والاكتفاء بالقياس الجبري.

Adding a word to *speed* gets us to the phrase *speed up.* We have already met the speed up variable, **acceleration.** It is defined as change of speed divided by the change in time or, more mathematically precise, as the rate of change of speed, and is commonly measured in m/s^2, or ft/s^2.

يعرف التسارع كحاصل قسمة تغيّر السرعة مع الزمن اللازم لذلك ويقاس بالمتر (أو قدم) على مربع الثانية.

Acceleration also has a magnitude and direction, it is a vector. For it we use *a,* except for that due to gravity where we use *g.*

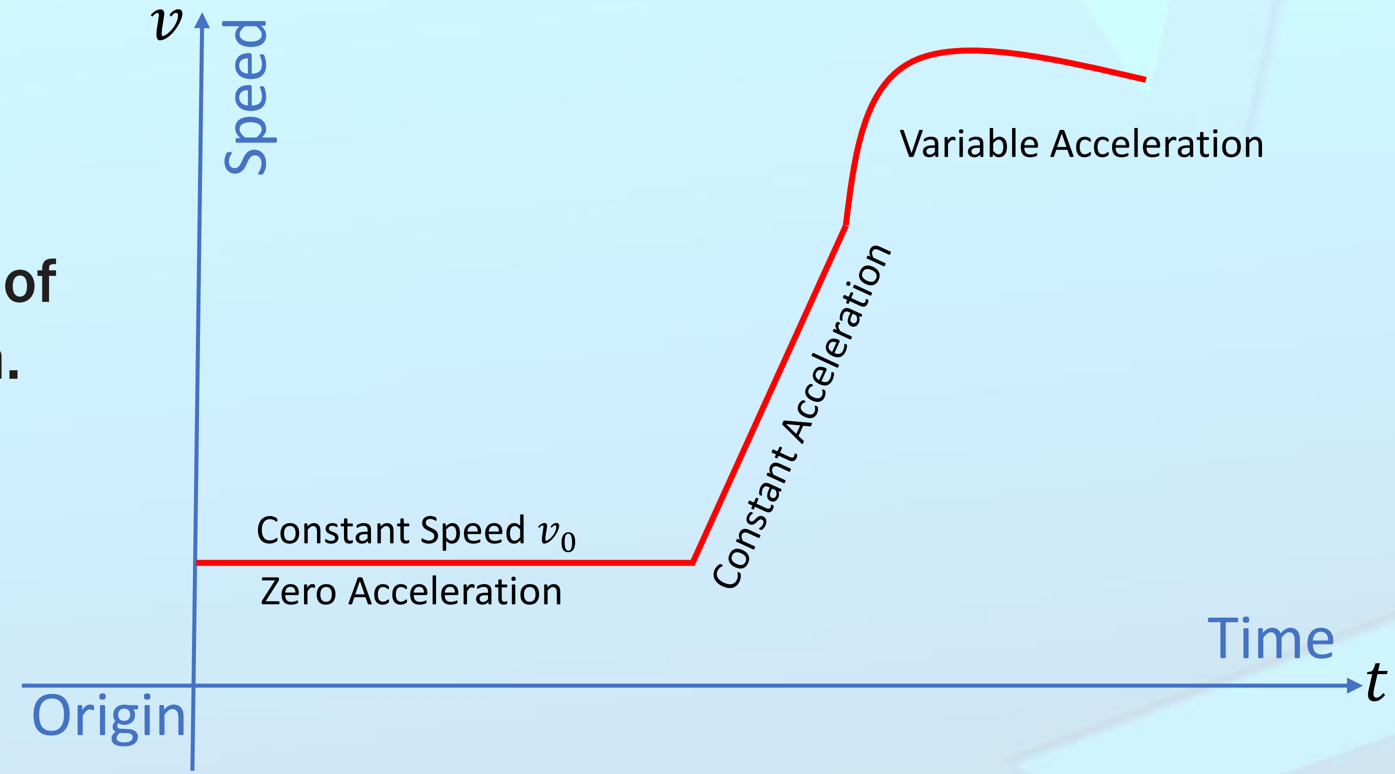
التسارع كالسرعة وكالقوة مقدار شعاعي له اتجاه وقياس.

Strictly speaking, two of the preceding variables should be defined in two ways: in terms of *instantaneous* speed and acceleration, and in terms of *average* speed and acceleration. In this textbook, we will work with constant or “average” accelerations. An average acceleration *a* is defined as:

THE SPEED VERSUS TIME DIAGRAM

One could deal with problems of distance, speed, acceleration, & time just using words and equations, but a much more useful tool makes possible an insightful description of motion problems. This versatile tool is the **speed versus time diagram** shown in Fig.

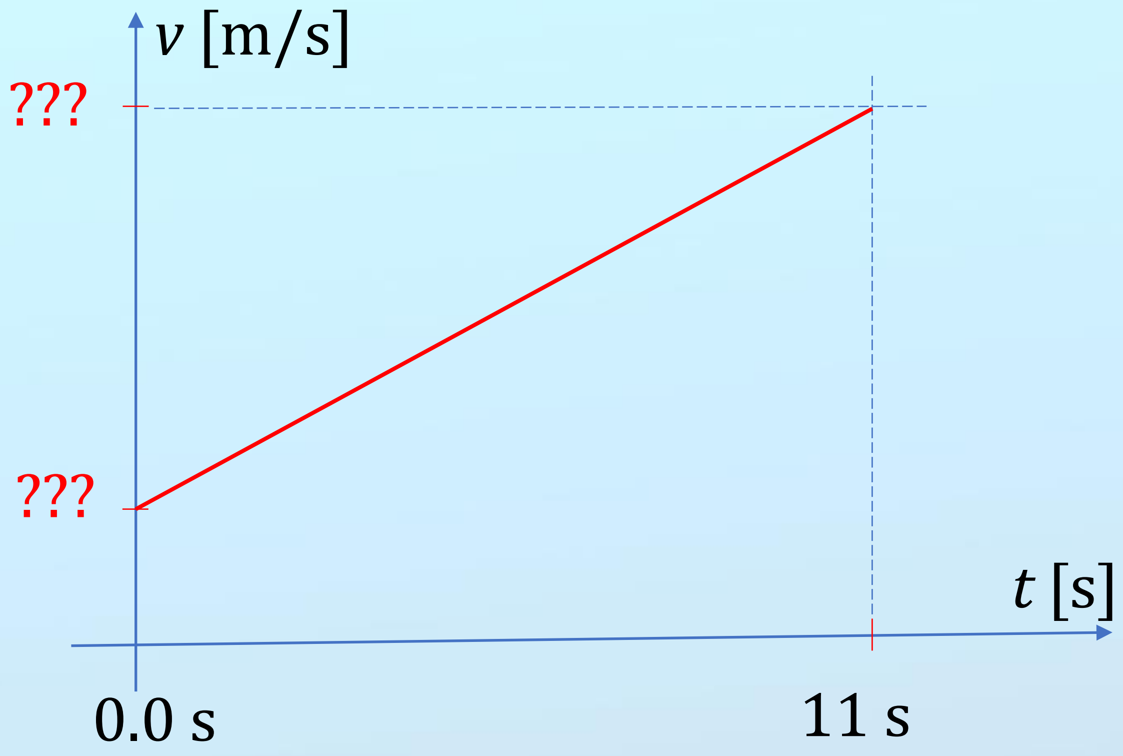
Acceleration is the slope of the speed - time diagram.



For brevity, we call this diagram the v–t diagram. The horizontal axis represents time, with zero being the instant the situation being considered began. For each instant of time, the speed is plotted in the vertical direction.

EXAMPLE

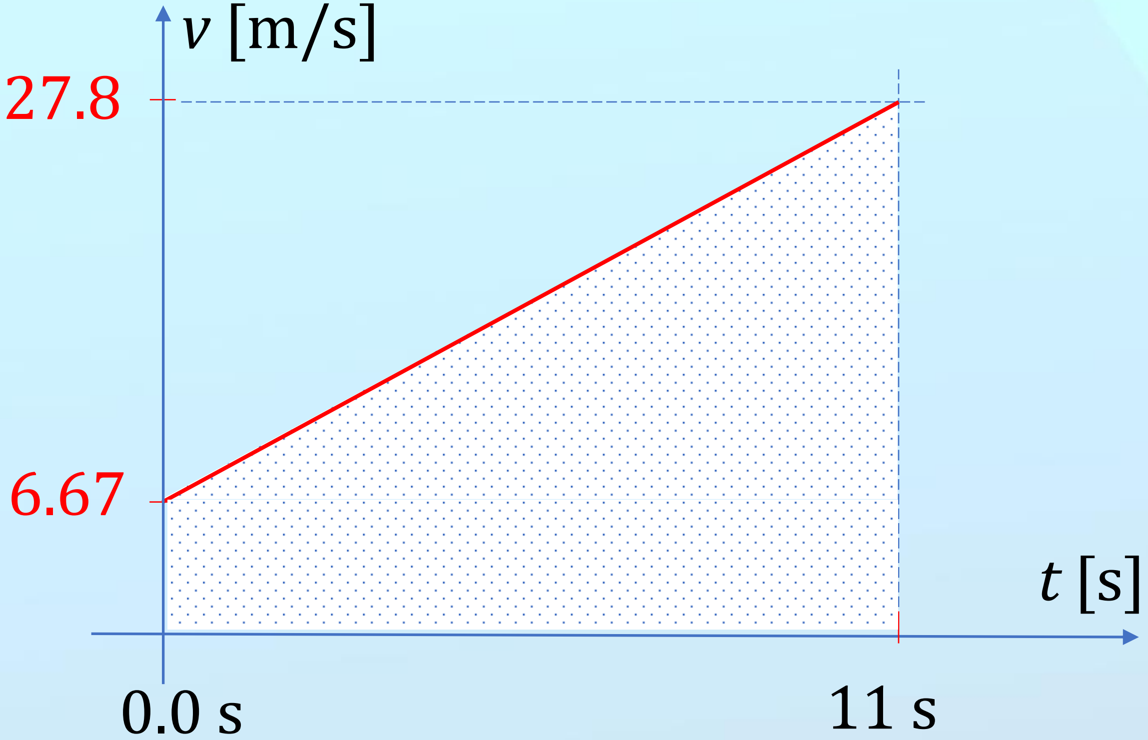
A car enters an on-ramp traveling 24 kilometers per hour. It accelerates for 11 seconds. At the end of that time interval, it is traveling at 100 kilometers per hour. What is its average acceleration? Plot the $v\text{–}t$ diagram in SI units



Why is this particular graph so important? There are two reasons.

1. **The slope of the $v\text{–}t$ graph is the acceleration.**
2. **The area under the $v\text{–}t$ graph is the distance traveled.**

No other graph involving these four variables summarizes so much information in so intuitive a manner. The slope of a line is its vertical *"rise"* divided by its horizontal "*run*." The "rise" of the graph has units of speed, m/s. The "run" of the graph has units of time, s. So, slope = rise/run = $\Delta v/\Delta t$ in units of [m/s]/[s] or m/s^2, the dimensions of acceleration. $a = (27.8 - 6.67)/11 = 1.92\ \mathrm{m/s^2}$



The second statement relating area under the curve to distance traveled is less obvious. The *average speed over the* (11 s) *period of acceleration* is [(27.8 + 6.67)/2 = 17.2 m/s], and so the vehicle will have covered [17.2 m/s] × [11 s] = 189 m (to two significant figures). It also can be approached dimensionally. The "height" or ordinate has units of [m/s]. The horizontal axis has units of seconds. So, length × height has units of [s] × [m/s] = [m], a unit of distance.

Ex. 1. Acceleration is sometimes measured in *g*, where 1.0 g = 9.8 m/s^2. How many *g*'s correspond to the steady acceleration of a car going from exactly 0 to 100 km/h in 10 s?

Ex. 2. A person pushes a crate on a frictionless surface with a force of 450 N. The crate accelerates at a rate of 1.00 m/s^2. What is the mass of the crate in kg?

Ex. 3. The force of gravity on the moon is exactly one-sixth as strong as the force of gravity on Earth. An apple weighs 1.00 N on Earth. (a) What is the mass of the apple on the Moon in kg? (b) What is the weight of the apple on the Moon, in N?

Ex. 4. A rocket sled exerts 3.00×10^4 N of thrust and has a mass of 2.00×10^3 kg. How much time does it take to go from exactly 0 to 100 km/h? How many *g*'s does it achieve?

Ex. 5. A car is at a red light. When the light turns green, it starts at constant acceleration. After traveling 100. m, it is traveling at 15 m/s. What is its acceleration?

Ex. 6. A car is at a red light. When the light turns green, it starts at constant acceleration. After traveling exactly 200, it is traveling at 50. km/h. What is its acceleration in m/s^2?

Ex. 7. A car starts from a stop at a traffic light and accelerates at a rate of 4.0 m/s^2. Immediately on reaching a speed of 32 m/s, the driver sees that the next light ahead is red and instantly applies the brakes (reaction time = 0.00 seconds). The car decelerates at a constant rate and comes safely to a stop at the next light. The whole episode takes 15 seconds. How far does the car travel?

Ex. 8. A car leaves a parking space from a standing stop to travel to a fast-food restaurant 950 m away. Along the journey, it has to stop after 325 m at a stop sign.

The car has a maximum acceleration of 3.0 m/s^2 and a "maximum" deceleration of 10 m/s^2.

The driver never exceeds the legal speed limit of 15 m/s.

What is the least possible time it can take until the car comes to a full stop in front of the fast-food restaurant?

Ex. 9. You are an engineer designing a traffic light. Assume a person can see a traffic light change color from red to yellow, and it takes 1 second to respond to a change in color. Suppose the speed limit is 15 m/s. Your goal is to enable drivers always to stop after seeing and responding to the yellow light with a "maximum" deceleration of 5.0 m/s^2. How long should the yellow light last?

Ex. 10. You are a driver responding to the traffic light in the previous exercise. If it was correctly designed according to that problem, at what distance from the light should you be prepared to make your "to stop or not to stop" decision? Assume you are a safe driver who neither speeds up to get through the yellow light nor stops more suddenly than the deceleration rate of 5.0 m/s^2.

Ex. 11. Suppose the deceleration of a car on a level off-ramp is 3.0 m/s^2. How long would the off-ramp have to be to allow a car to decelerate from 100 km/h to 25 km/h?