1 The first meters of a 100-meter dash are covered in 2 seconds by a sprinter who starts from rest and accelerates with a constant acceleration. The remaining 90 meters are run with the same velocity the sprinter had after 2 seconds. (’82)

a. Determine the sprinter’s constant acceleration during the first 2 seconds.

For the first 2 seconds, while acceleration is constant, \( d = \frac{1}{2} at^2 \)
Substituting the given values \( d = 10 \) meters, \( t = 2 \) seconds gives \( a = 5 \) m/s\(^2\)

b. Determine the sprinters velocity after 2 seconds have elapsed.

The velocity after accelerating from rest for 2 seconds is given by \( v = at \), so \( v = 10 \) m/s

c. Determine the total time needed to run the full 100 meters.

The displacement, time, and constant velocity for the last 90 meters are related by \( d = vt \).
To cover this distance takes \( t = d/v = 9 \) s. The total time is therefore \( 9 + 2 = 11 \) seconds

d. On the axes provided below, draw the displacement vs time curve for the sprinter.
A world-class runner can complete a 100 m dash in about 10 s. Past studies have shown that runners in such a race accelerate uniformly for a time \( t \) and then run at constant speed for the remainder of the race. A world-class runner is visiting your physics class. You are to develop a procedure that will allow you to determine the uniform acceleration \( a \) and an approximate value of \( t \) for the runner in a 100 m dash. By necessity your experiment will be done on a straight track and include your whole class of eleven students. ('06)

Approach A: Spread the students out every 10 meters or so. The students each start their stopwatches as the runner starts and measure the time for the runner to reach their positions.

*Variant 1:* Make a position vs. time graph. Fit the parabolic and linear parts of the graph and establish the position and time at which the parabola makes the transition to the straight line.

*Variant 2:* Use the position and time measurements to determine a series of average velocities \( \bar{v} = \Delta x/\Delta t \) for the intervals. Graph these velocities vs. time to obtain a horizontal line and a line with positive slope. Establish the position and time at which the sloped and horizontal lines intersect.

*Variant 3:* Use the position and time measurements to determine a series of average accelerations \( \Delta x = v_0 t + \frac{1}{2} a t^2 \). Graph these accelerations vs. time to obtain two horizontal lines, one with a nonzero value and one at zero acceleration. Establish the position and time at which the acceleration drops to zero.

Approach B: Concentrate the students at intervals at the end of the run, in order to get a very precise value of the constant speed \( v_f \) or at the beginning in order to get a precise value for \( a \). The total distance \( D \) is given by \( a = \frac{1}{2} a t_u^2 + v_f (T - t_u) \), where \( T \) is the total measured run time. In addition \( v_f = a t_u \). These equations can be solved for \( a \) and \( t_u \) (if \( v_f \) is measured directly) or \( v_f \) and \( t_u \) (if \( a \) is measured directly). Students may have also defined and used distances, speeds, and times for the accelerated and constant-speed portions of the run in deriving these relationships.
A student stands in an elevator and records his acceleration as a function of time. The data are shown in the graph above. At time $t = 0$, the elevator is at displacement $x = 0$ with velocity $v = 0$. Assume that the positive directions for displacement, velocity, and acceleration are upward. 

a. Determine the velocity $v$ of the elevator at the end of each 5-second interval.

i. Indicate your results by completing the following table. Use the kinematic equation applicable for constant acceleration: $v = v_0 + at$. For each time interval, substitute the initial velocity for that interval, the appropriate acceleration from the graph and a time of 5 seconds.

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Velocity $v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 seconds</td>
<td>$0 + (0)(5 \text{ s}) = 0$</td>
</tr>
<tr>
<td>10 seconds</td>
<td>$0 + (4 \text{ m/s}^2)(5 \text{ s}) = 20 \text{ m/s}$</td>
</tr>
<tr>
<td>15 seconds</td>
<td>$20 \text{ m/s} + (0)(5 \text{ s}) = 20 \text{ m/s}$</td>
</tr>
<tr>
<td>20 seconds</td>
<td>$20 \text{ m/s} + (-4 \text{ m/s}^2)(5 \text{ s}) = 0$</td>
</tr>
</tbody>
</table>

ii. Plot the velocity as a function of time on the following graph.

b. Determine the displacement $x$ of the elevator above the starting point at the end of each 5-second interval.

i. Indicate your results by completing the following table.
i. Use the kinematic equation applicable for constant acceleration, \( x = x_0 + v_0t + \frac{1}{2}at^2 \). For each time interval, substitute the initial position for that interval, the initial velocity for that interval from part (a), the appropriate acceleration, and a time of 5 seconds.

- 5 seconds: \( x = 0 + (0)(5 \text{ s}) + \frac{1}{2} (0)(5 \text{ s})^2 = 0 \)
- 10 seconds: \( x = 0 + (0)(5 \text{ s}) + \frac{1}{2} (4 \text{ m/s}^2)(5 \text{ s})^2 = 50 \text{ m} \)
- 15 seconds: \( x = 50 \text{ m} + (20 \text{ m/s})(5 \text{ s}) + \frac{1}{2} (0)(5 \text{ s})^2 = 150 \text{ m} \)
- 20 seconds: \( x = 150 \text{ m} + (20 \text{ m/s})(5 \text{ s}) + \frac{1}{2} (-4 \text{ m/s}^2)(5 \text{ s})^2 = 200 \text{ m} \)

ii. Plot the displacement as a function of time on the following graph.

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4. A 0.50 kg cart moves on a straight horizontal track. The graph of velocity \( v \) versus time \( t \) for the cart is given below. ('00)

**Diagram of velocity versus time**

4. A 0.50 kg cart moves on a straight horizontal track. The graph of velocity \( v \) versus time \( t \) for the cart is given below. ('00)

a. Indicate every time \( t \) for which the cart is at rest.

The car is at rest where the line crosses the \( t \) axis. At \( t = 4 \) s and 18 s.
b. Indicate every time interval for which the speed (magnitude of velocity) of the cart is increasing.

The speed of the cart increases when the line moves away from the t axis (larger values of v, positive or negative). This occurs during the intervals t = 4 to 9 seconds and t = 18 to 20 seconds.

c. Determine the horizontal position x of the cart at t = 9.0 s if the cart is located at x = 2.0 m at t = 0 s.

The change in position is equal to the area under the graph. From 0 to 4 seconds the area is positive and from 4 to 9 seconds the area is negative. The total area is –0.9 m. Adding this to the initial position gives

\[ x = x_0 + \Delta x = 2.0 \text{ m} + (-0.9 \text{ m}) = 1.1 \text{ m} \]

d. On the axes below, sketch the acceleration a versus time t graph for the motion of the cart from t = 0 s to t = 25 s.

![Graph of acceleration vs. time]

e. From t = 25 s until the cart reaches the end of the track, the cart continues with constant horizontal velocity. The cart leaves the end of the track and hits the floor, which is 0.40 m below the track. Neglecting air resistance, determine each of the following:

i. The time from when the cart leaves the track until it first hits the floor

\[ y = \frac{1}{2} gt^2 \ (v_{oy} = 0 \text{ m/s}) \text{ gives } t = 0.28 \text{ seconds.} \]
ii. The horizontal distance from the end of the track to the point at which the cart first hits the floor

ii. \( x = v_x t = 0.22 \text{ m} \)

5. The vertical position of an elevator as a function of time is shown above. ('05)

a. On the grid below, graph the velocity of the elevator as a function of time.

\[ V (\text{m/s}) \]

\[ \begin{array}{c}
\text{Time (s)} \\
0 & 2 & 4 & 6 & 8 & 10 & 12 & 14 & 16 & 18 & 20 & 22 & 24 & 26 \\
\hline
0 & 2 & 4 & 6 & 8 & 10 & 12 & 14 & 16 & 18 & 20 & 22 & 24 & 26 \\
\end{array} \]

b. i. Calculate the average acceleration for the time period \( t = 8 \text{ s} \) to \( t = 10 \text{ s} \).

\[ a_{\text{avg}} = \frac{\Delta v}{\Delta t} = \frac{(0 - 1.5 \text{ m/s})}{(2 \text{ s})} = -0.75 \text{ m/s}^2 \]

ii. On the box below that represents the elevator, draw a vector to represent the direction of this average acceleration.