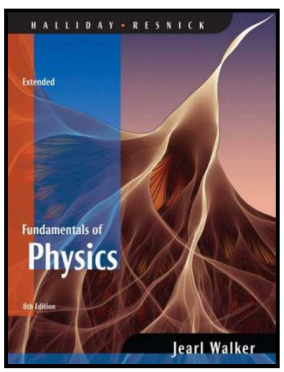
Workshop Physics 1017 - 311

University Physics I



Week 1 : Day 3

Kinematics

Kinematics is the part of mechanics that describes the motion of physical objects. We say that an object moves when its position as determined by an observer changes with time.

In this chapter we will study a restricted class of kinematics problems

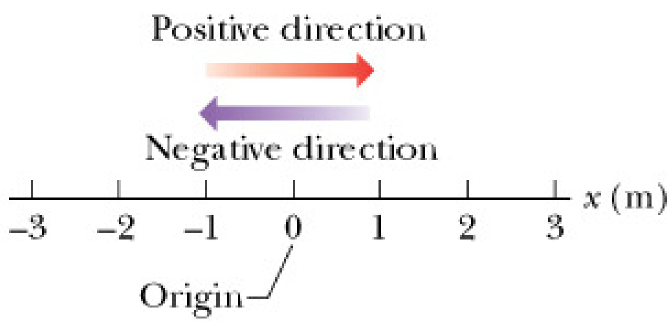
Motion will be along a straight line.

We will assume that the moving objects are “**particles,**” i.e., we restrict our discussion to the motion of objects for which all the points move in the same way.

The causes of the motion will not be investigated. This will be done later in the course.

Straight Line Motiion

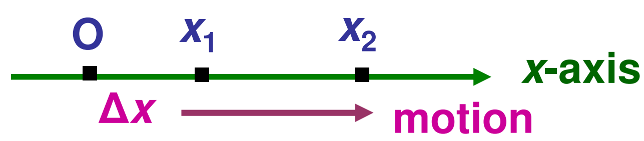
Consider an object moving along a straight line taken to be the *x*-axis. The object's position at any time *t* is described by its coordinate *x*(*t*) defined with respect to the origin *O*. The coordinate *x* can be positive or negative depending whether the object is located on the positive or the negative part of the *x*-axis.



Displacement

Displacement. If an object moves from position x_1 to position x_2, the change in position is described by the displacement

$$\Delta x = x_2 - x_1$$



For example if x_1 = 5 m and x_2 = 12 m then Δx = 12 – 5 = 7 m. The positive sign of Δx indicates that the motion is along the positive *x*-direction.

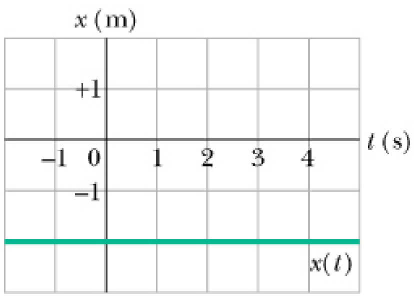
If instead the object moves from x_1 = 5 m and x_2 = 1 m then Δx = 1 – 5 = -4 m. The negative sign of Δx indicates that the motion is along the negative *x*-direction.

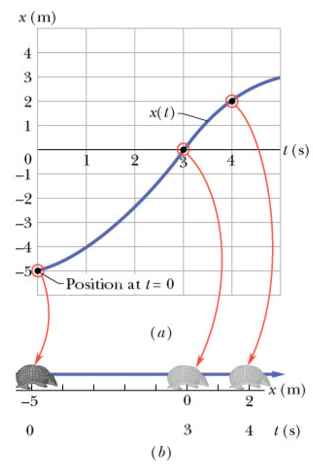
Consider as an example the motion of an object from an initial position x_1 = 5 m to x = 200 m and then back to x_2 = 5 m. Even though the total distance covered is 390 m the displacement then is Δx = 0.

Average Velocity

One method of describing the motion of an object is to plot its position x(t) as a function of time *t*. In the left picture we plot *x* versus *t* for an object that is stationary with respect to the chosen origin *O*. Notice that *x* is constant. In the picture to the right we plot *x* versus *t* for a moving armadillo. We can get an idea of "how fast" the armadillo moves from one position x_1 at time t_1 to a new position x_2 at time t_2 by determining the average velocity between t_1 and t_2.

$$v_{avg} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$



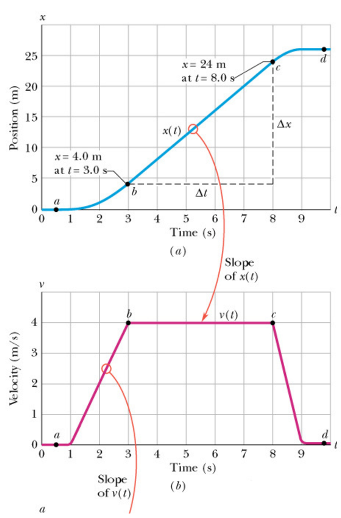


Here x_2 and x_1 are the positions $x(t_2)$ and $x(t_1)$, respectively.

The **time interval** Δt is defined as $\Delta t = t_2 - t_1$. The units of v_{avg} are m/s.

Instantaneous Velocity

The average velocity v_{avg} determined between times t_1 and t_2 provides a useful description of “how fast” an object is moving between these two times. It is in reality a “summary” of its motion. In order to describe how fast an object moves at any time t we introduce the notion of instantaneous velocity v (or simply velocity). Instantaneous velocity is defined as the limit of the average velocity determined for a time interval Δt as we let $\Delta t \to 0$.



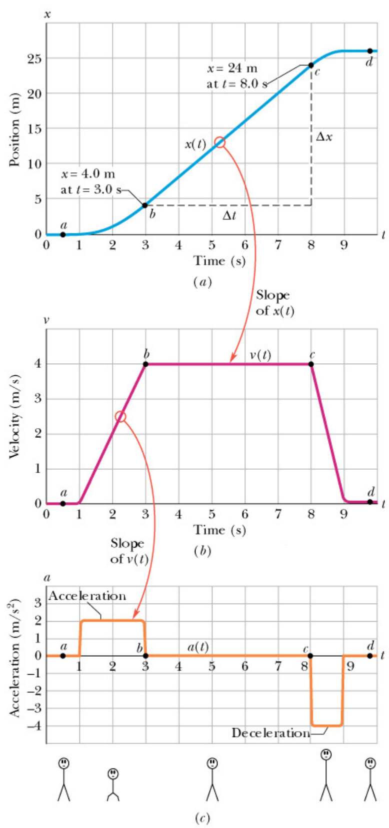
$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

From its definition instantaneous velocity is the first derivative of the position coordinate x with respect to time. It is thus equal to the slope of the x versus t plot.

Speed

We define speed as the magnitude of an object’s velocity vector.

Acceleration



Average Acceleration

We define the average acceleration a_{avg} between t_1 and t_2 as:

$$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

Units: m/s^2

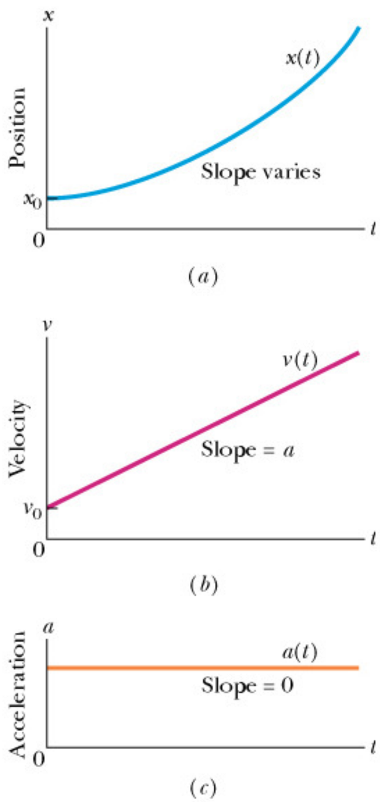
Instantaneous Acceleration

If we take the limit of a_{avg} as $\Delta t \rightarrow 0$ we get the instantaneous acceleration *a*, which describes how fast the velocity is changing at any time *t*.

$$a = \lim_{\Delta t \rightarrow 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}, \quad a = \frac{dv}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2 x}{dt^2}$$

The acceleration is the slope of the *v* versus *t* plot.

Constant Acceleration Equations



$$x = x_0 + v_0 t + \frac{at^2}{2}$$

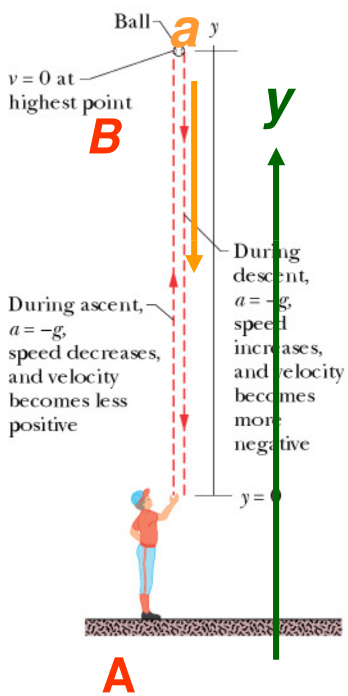
The $x(t)$ versus t plot is a parabola that intercepts the vertical axis at $x = x_0$.

$$v = v_0 + at$$

The $v(t)$ versus t plot is a straight line with slope = a and intercept = v_0.

The acceleration a is a constant.

Free Fall



If we take the *y*-axis to point upward then the acceleration of an object in free fall *a = -g* and the equations for free fall take the form:

$$v = v_0 - gt \qquad \text{(eq. 1)}$$

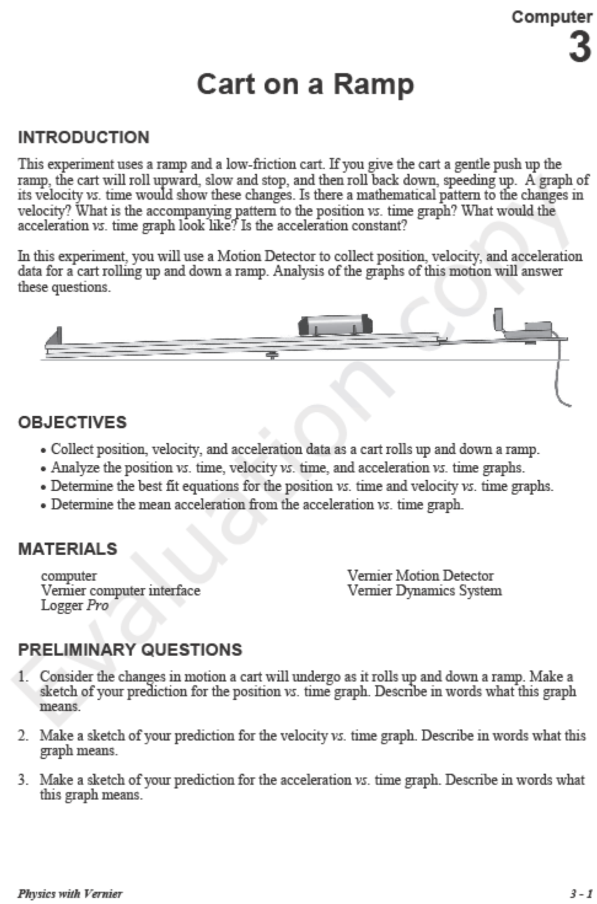
$$x = x_o + v_0 t - \frac{gt^2}{2} \qquad \text{(eq. 2)}$$

$$v^2 - v_0^2 = -2g\left(x - x_o\right) \qquad \text{(eq. 3)}$$

Note: Even though with this choice of axes $a < 0$, the velocity can be positive (upward motion from point *A* to point *B*). It is momentarily zero at point *B*. The velocity becomes negative on the downward motion from point *B* to point *A*.

Activity – Cart on a Ramp

- **Use Logger Pro**
  - Study basic motion
    - *Displacement – x(t)*
    - *Velocity – v(t)*
    - *Acceleration – a(t)*



Computer
3

Cart on a Ramp

INTRODUCTION

This experiment uses a ramp and a low-friction cart. If you give the cart a gentle push up the ramp, the cart will roll upward, slow and stop, and then roll back down, speeding up. A graph of its velocity *vs.* time would show these changes. Is there a mathematical pattern to the changes in velocity? What is the accompanying pattern to the position *vs.* time graph? What would the acceleration *vs.* time graph look like? Is the acceleration constant?

In this experiment, you will use a Motion Detector to collect position, velocity, and acceleration data for a cart rolling up and down a ramp. Analysis of the graphs of this motion will answer these questions.

OBJECTIVES

- Collect position, velocity, and acceleration data as a cart rolls up and down a ramp.
- Analyze the position *vs.* time, velocity *vs.* time, and acceleration *vs.* time graphs.
- Determine the best fit equations for the position *vs.* time and velocity *vs.* time graphs.
- Determine the mean acceleration from the acceleration *vs.* time graph.

MATERIALS

computer
Vernier computer interface
Logger *Pro*
Vernier Motion Detector
Vernier Dynamics System

PRELIMINARY QUESTIONS

1. Consider the changes in motion a cart will undergo as it rolls up and down a ramp. Make a sketch of your prediction for the position *vs.* time graph. Describe in words what this graph means.
2. Make a sketch of your prediction for the velocity *vs.* time graph. Describe in words what this graph means.
3. Make a sketch of your prediction for the acceleration *vs.* time graph. Describe in words what this graph means.

Physics with Vernier 3 - 1