Physics 1: Mechanics

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- No of credits: 02 (30 teaching hours)
- Textbook: Halliday/Resnick/Walker (2011) entitled Principles of Physics, 9th edition, John Willey & Sons, Inc.

Course Requirements

- Attendance + Discussion + Homework: 15%
- Assignment: 15%
- Mid-term exam: 30%
- Final: 40%

Preparation for each class

- Read text ahead of time
- Finish homework

Questions, Discussion

- Wednesday's morning and afternoon: see the secretary of the department (room A1.413) for appointments

Part A Dynamics of Mass Point

Chapter 1 Bases of Kinematics

Chapter 2 Force and Motion (Newton's Laws)

Part B Laws of Conservation

Chapter 3 Work and Mechanical Energy

✓Midterm exam after Lecture 6

Chapter 4 Linear Momentum and Collisions

Part C Dynamics and Statics of Rigid Body

Chapter 5 Rotation of a Rigid Body About a Fixed Axis

✓Assignment given in Lecture 11

Chapter 6 Equilibrium and Elasticity

Chapter 7 Gravitation

✓Final exam after Lecture 12

Part A Dynamics of Mass Point

Chapter 1 Bases of Kinematics

1. 1. Motion in One Dimension

1.1.1. Position, Velocity, and Acceleration

1.1.2. One-Dimensional Motion with Constant Acceleration

1.1.3. Freely Falling Objects

1. 2. Motion in Two Dimensions

1.2.1. The Position, Velocity, and Acceleration Vectors

1.2.2. Two-Dimensional Motion with Constant Acceleration. Projectile Motion

1.2.3. Circular Motion. Tangential and Radial Acceleration

1.2.4. Relative Velocity and Relative Acceleration

Measurements

- Use laws of Physics to describe our understanding of nature
- Test laws by experiments
- Need Units to measure physical quantities
- Three SI "Base Quantities":
  - Length – meter – [m]
  - Mass – kilogram – [kg]
  - Time – second – [s]

  Systems:
  - SI: Système International [m kg s]
  - CGS: [cm gram second]

1.1. Motion in one dimension

Kinematics

- **Kinematics – describes motion**
- **Dynamics – concerns causes of motion**

$$\vec{F} = m\vec{a}$$

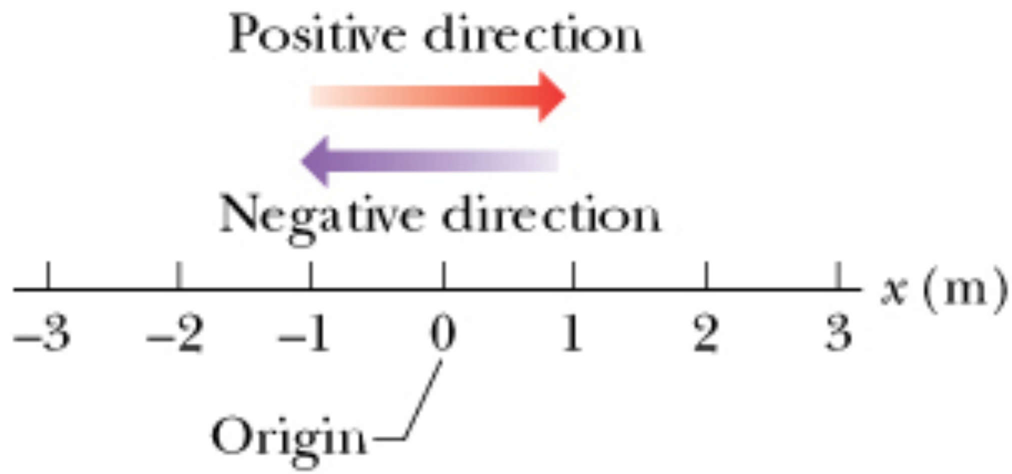
dynamics (→ $\vec{F}$) **kinematics** (→ $\vec{a}$)

To describe motion, we need to measure:

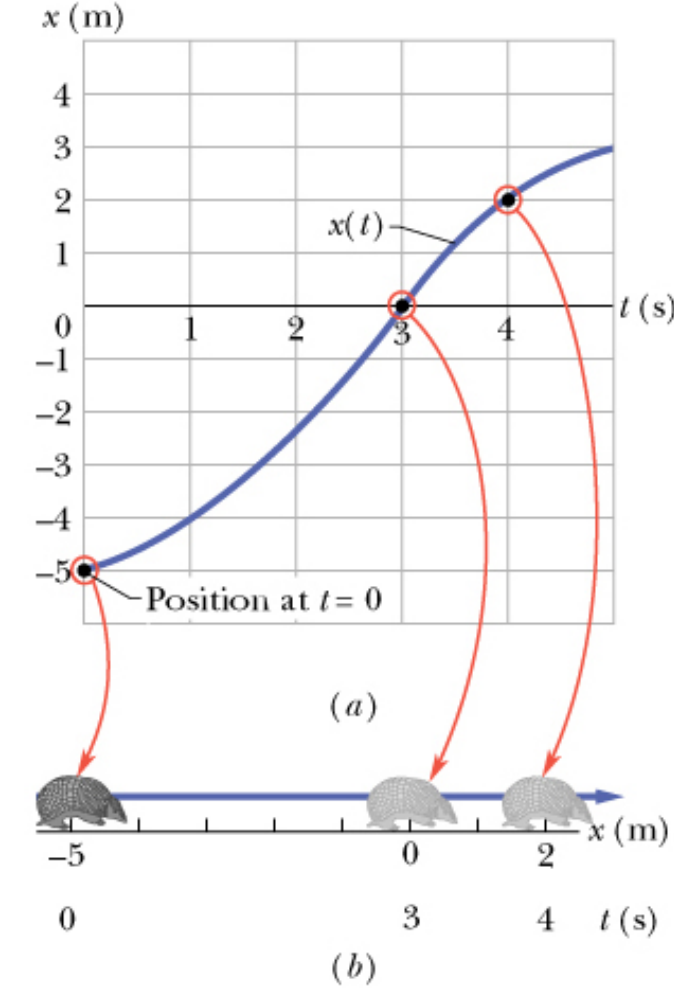
- Displacement: $\Delta x = x_t - x_0$ (measured in m or cm)
- Time interval: $\Delta t = t - t_0$ (measured in s)

1.1.1. Position, Velocity and Acceleration

A. Position: determined in a reference frame



Space vs. time graph



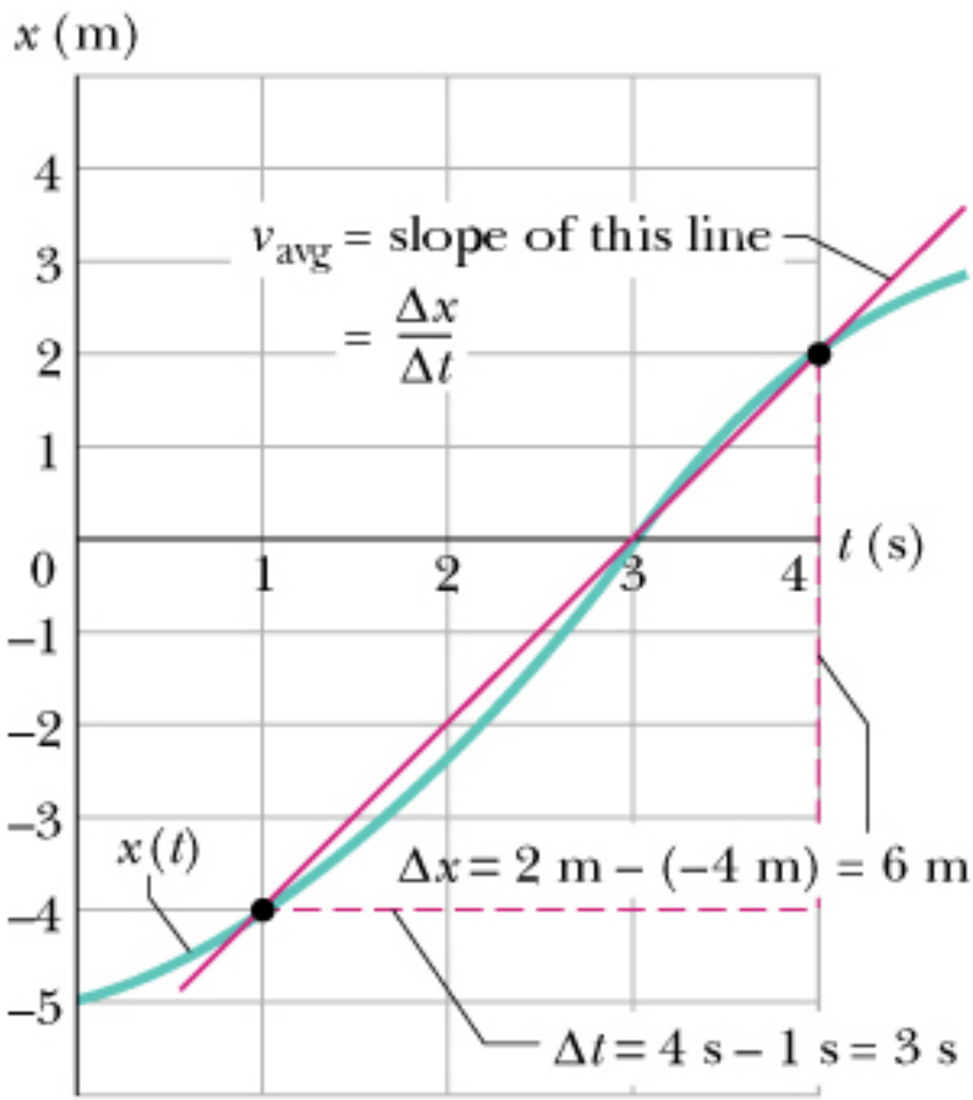
Motion of an armadillo

t=0 s: x=-5 m
t=3 s: x=0 m
$\Delta x=0-(-5)=5$ m

Two features of displacement:

- its direction (a vector)
- its magnitude

B. Velocity: (describing how fast an object moves)



B.1. Average velocity:

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

Unit: m/s or cm/s

The v_{avg} of the armadillo:

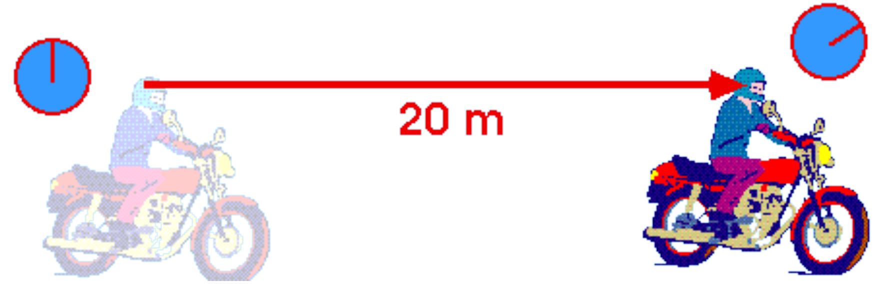
$$v_{avg} = \frac{6m}{3s} = 2m/s$$

B.2. Average speed:

$$s_{avg} = \frac{\text{total distance}}{\Delta t}$$

Note: average speed does not include direction

•If a motorcycle travels 20 m in 2 s, then its average velocity is:



$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{20\ \text{m}}{2\ \text{s}} = 10\ \frac{\text{m}}{\text{s}}$$

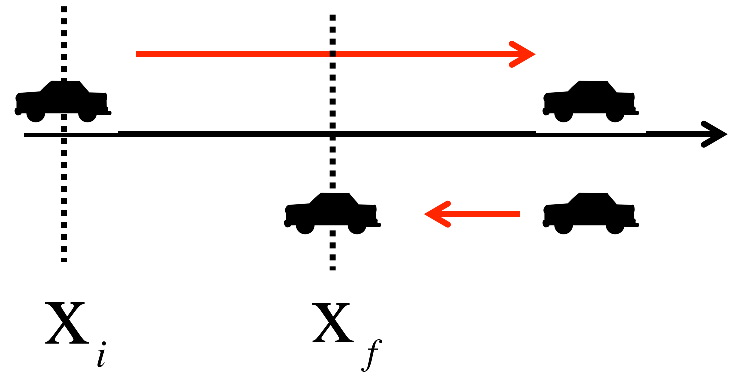
•If an antique car travels 45 km in 3 h, then its average velocity is:

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{45\ \text{km}}{3\ \text{h}} = 15\ \frac{\text{km}}{\text{h}}$$

Sample Problem (average velocity vs average speed):

A car travels on a straight road for 40 km at 40 km/h. It then continues in the opposite direction for another 20 km at 40 km/h.
(a) What is the average velocity of the car during this 60 km trip?

(b) What is the average speed? (Midterm Exam 2010)



(a)

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

$$x_f - x_i = 20 \text{ km}$$

$$t_f - t_i = \frac{40}{40} + \frac{20}{40} = 1.5 \text{ h}$$

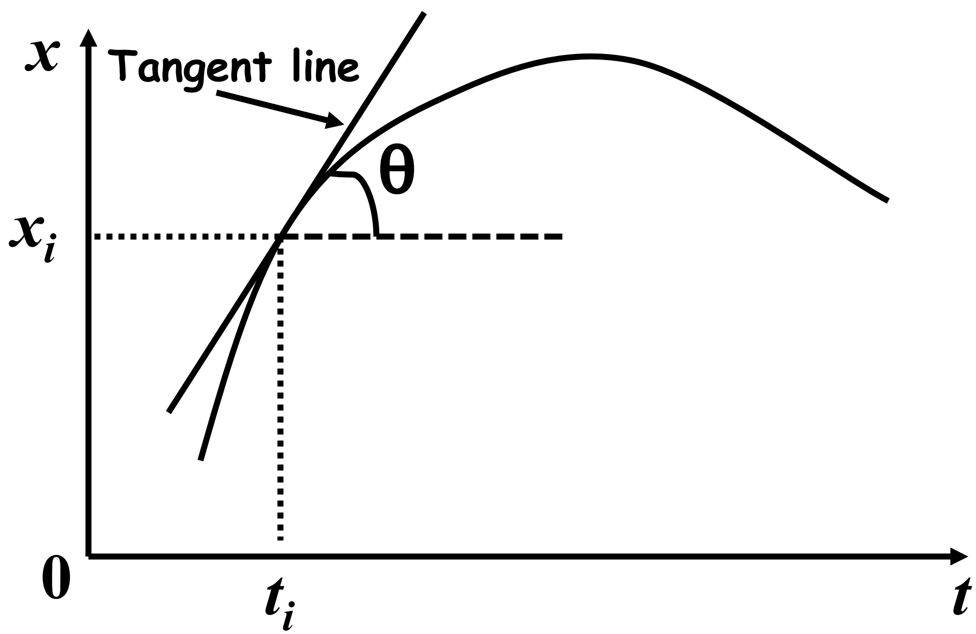
$$v_{avg} = \frac{20}{1.5} = 13.3 \text{ (km/h)}$$

(b) $$s_{avg} = \frac{\text{total distance}}{\Delta t} = \frac{40 + 20}{1.5} = 40 \text{ (km/h)}$$

B.3. Instantaneous Velocity and Speed

The average velocity at a given instant ($\Delta t \rightarrow 0$), which approaches a limiting value, is the velocity:

$$v(t) = \lim_{\Delta t \rightarrow 0} \frac{\Delta x(t)}{\Delta t} = \frac{dx(t)}{dt}$$



The slope (tanθ) of the tangent line gives v(t)

Speed is the magnitude of velocity, ex: v=±40 km/h, so s=40 km/h

Sample Problem :

The position of an object described by:

$x = 4-12t+3t^2$ (x: meters; t: seconds)

(1) What is its velocity at t =1 s? **v=dx/dt=-12+6t=-6 (m/s)**

(2) Is it moving in the positive or negative direction of x just then? **negative**

(3) What is its speed just then? **S=6 (m/s)**

(4) Is the speed increasing or decreasing just then?

0<t<2: decreasing; 2<t: increasing

(5) Is there ever an instant when the velocity is zero? If so, give the time t; if not answer no. **t=2 s**

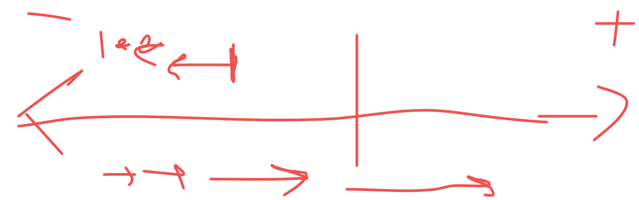
(6) Is there a time after t= 3 s when the object is moving in the negative direction of x? if so, give t; if not, answer no. **no**

C. Acceleration:

C1. Average acceleration:

The rate of change of velocity:

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



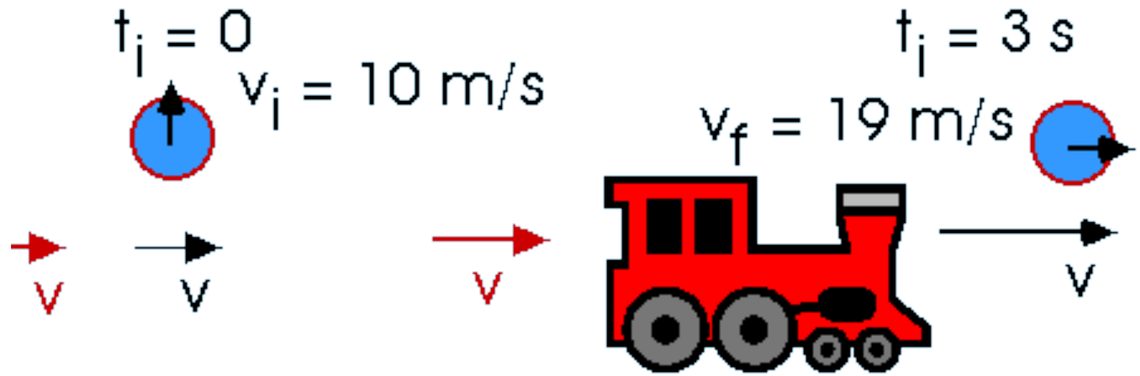
Unit: m/s^2 (SI) or cm/s^2 (CGS)

C2. Instantaneous acceleration:

At any instant:

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

→ The derivative of the velocity (or the second one of the position) with respect to time.



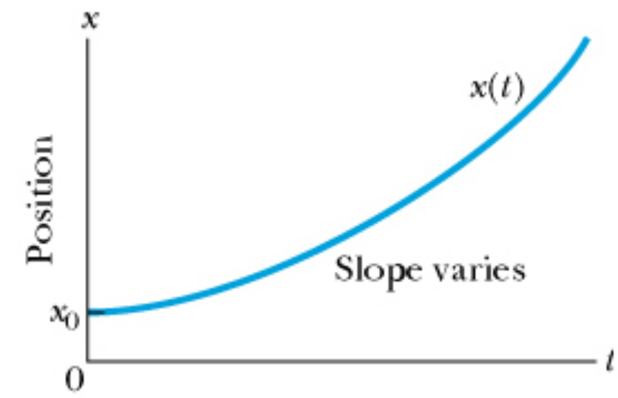
$$a = \frac{\Delta v}{\Delta t} = \frac{(19 - 10)\,m/s}{3\ s} = \frac{9\ m/s}{3\ s} = 3\ \frac{m/s}{s}$$

$$a = 3\ m/s/s = 3\ m/s^2$$

1.1.2. Constant acceleration:

$$a = \frac{dv}{dt} = a \ \text{const}$$

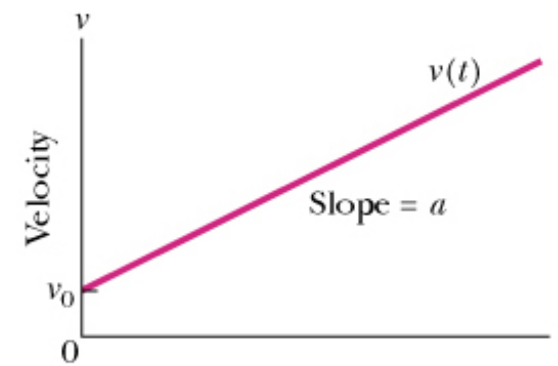
$$\Rightarrow v = v_0 + \int_{t_0}^{t} a\,dt \Rightarrow v = v_0 + a(t - t_0)$$



(a)

If t_0=0:

$$v = v_0 + at \quad \textbf{(1)}$$



(b)

$$v = \frac{dx}{dt} \Rightarrow x = x_0 + \int_{t_0}^{t} v\,dt = x_0 + \int_{t_0}^{t} [v_0 + a(t - t_0)]\,dt$$

$$x = x_0 + v_0(t - t_0) + \frac{a(t - t_0)^2}{2}$$

If t_0=0:

$$x = x_0 + v_0 t + \frac{1}{2} a t^2 \quad \textbf{(2)}$$

(c)

Specialized equations:

From Equations (1) & (2):

$$v^2 - v_0^2 = 2a(x - x_0)$$

$$x - x_0 = \frac{1}{2}(v_0 + v)t$$

$$x - x_0 = vt - \frac{1}{2}at^2$$

Problem 27:

An electron has $a=3.2\ m/s^2$

At t (s): $v=9.6\ m/s$

Question: v at $t_1=t-2.5$ (s) and $t_2=t+2.5$ (s)?

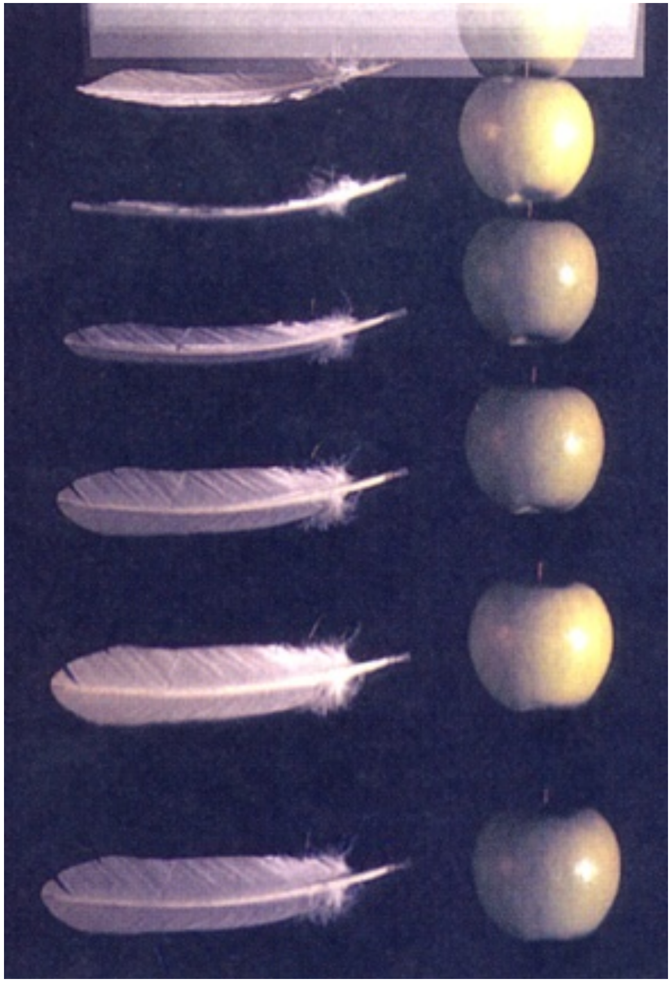
Key equation: $v = v_0+at$ (v_0 is the velocity at 0 s)

- At time t: $v = v_0+at$
- At t_1: $v_1=v_0+at_1 \rightarrow v_1=v+a(t_1-t)=9.6+3.2\times(-2.5) =1.6$ (m/s)
- At t_2: $v_2=v_0+at_2 \rightarrow v_2=v+a(t_2-t)=9.6+3.2(2.5)=17.6$ (m/s)

1.1.3. Freely falling objects:

- "Free-fall" is the state of an object moving solely under the influence of gravity.
- The acceleration of gravity near the Earth's surface is a constant, $g = 9.8\ m/s^2$ toward the center of the Earth.

Free-fall on the Moon



Free-fall in vacuum

Example (must do):

A ball is initially thrown upward along a y axis, with a velocity of 20.0 m/s at the edge of a 50-meters high building.

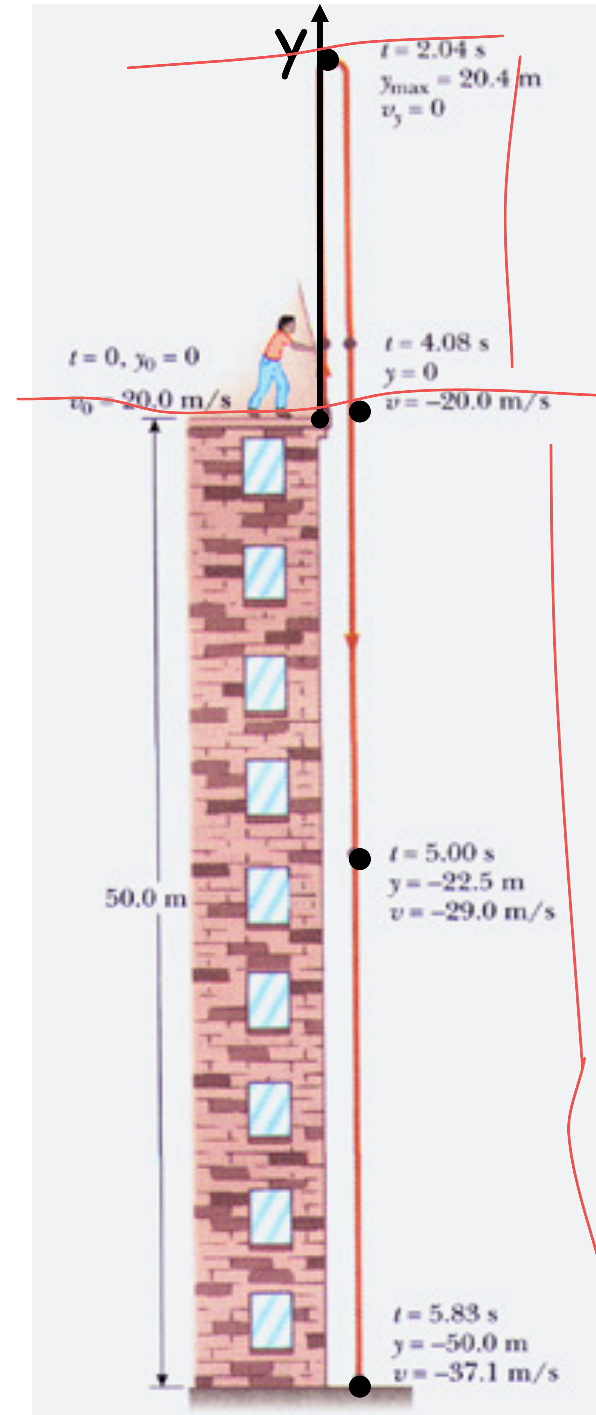
(1) How long does the ball reach its maximum height?

(2) What is the ball's maximum height?

(3) How long does the ball take to return to its release point? And its velocity at that point?

(4) What are the velocity and position of the ball at t=5 s?

(5) How long does the ball take to hit the ground? and what is its velocity when it strikes the ground?



Using two equations: $v = v_0 + at$

$$y = y_0 + v_0 t + \frac{1}{2}at^2$$

v_0 = 20.0 m/s, y_0 = 0, a = -9.8 m/s^2

We choose the positive direction is upward

(1) How long does the ball reach its maximum height?

$$v = v_0 + at = v_0 - gt$$

At its maximum height, v = 0:

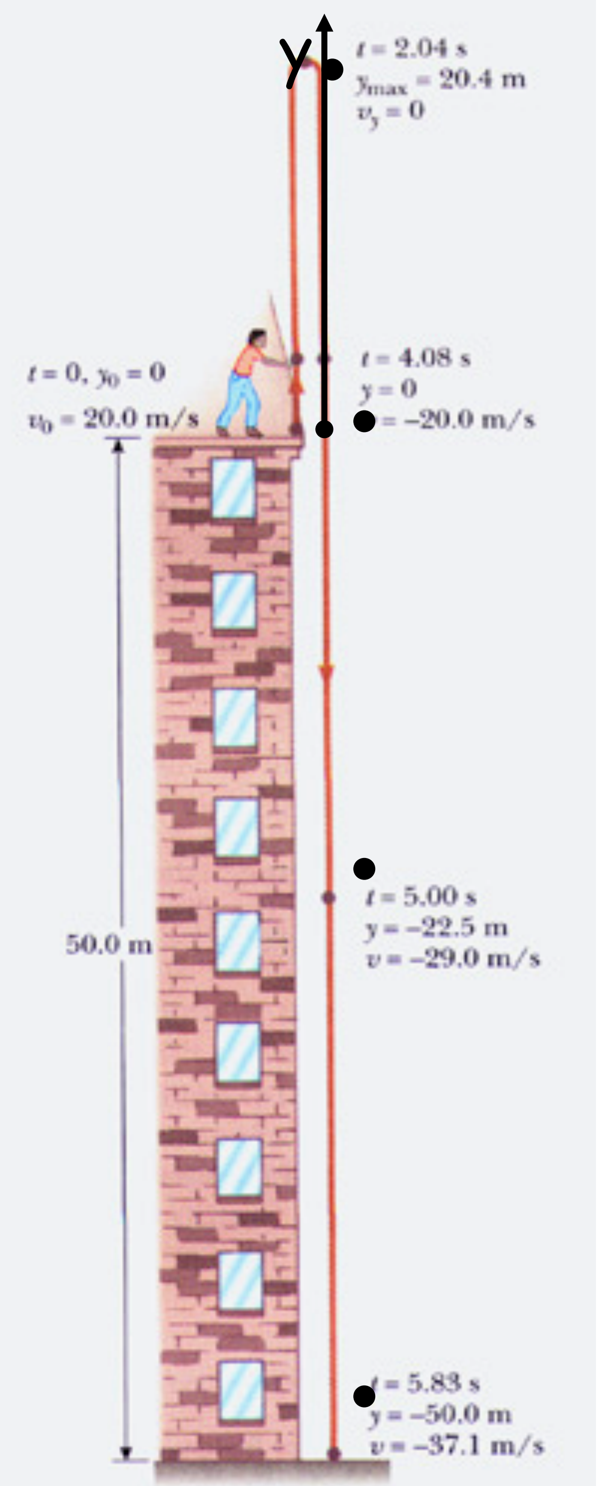
$$t = \frac{v_0}{g} = \frac{20}{9.8} = 2.04\,(s)$$

(2) What is the ball's maximum height?

$$y = y_0 + v_0 t + \frac{1}{2}at^2$$

$$y_{max} = 0 + 20 \times 2.04 + \frac{1}{2}(-9.8)(2.04)^2$$

$$y_{max} = 20.4\,(m)$$



We can use:

$$v^2 - v_0^2 = 2a(y - y_0)$$

At the ball's maximum height:

$$0 - 20^2 = -2 \times 9.8 \times y_{max}$$

$$y_{max} = 20.4\ (m)$$

(3) How long does the ball take to return to its release point? And its velocity at that point?

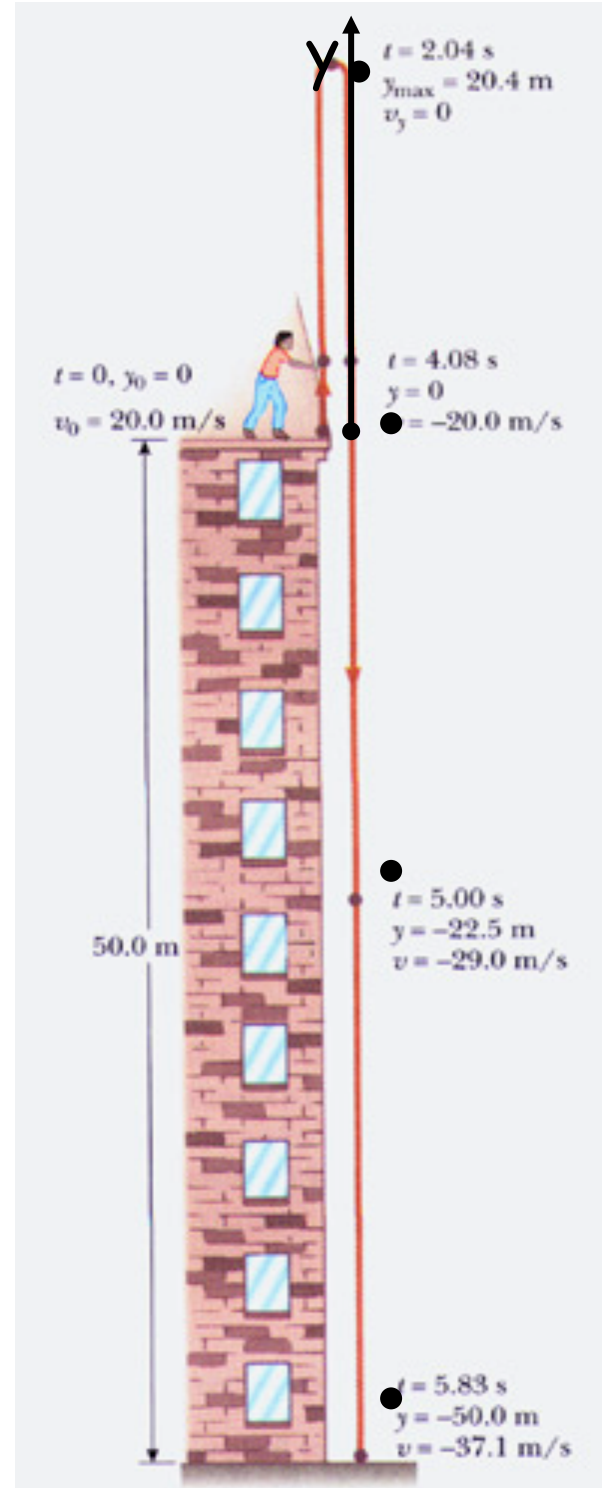
$$y = y_0 + v_0 t + \frac{1}{2} a t^2$$

At the release point: y = 0

$$0 = 0 + 20t - \frac{1}{2} 9.8 t^2$$

$$t = 0 \text{ or } t = 4.08\ (s)$$

So: $t = 4.08\ (s)$



$$v = v_0 + at = v_0 - gt$$

$$v = 20 - 9.8(4.08) = -20\ (m/s)$$

You can also use:

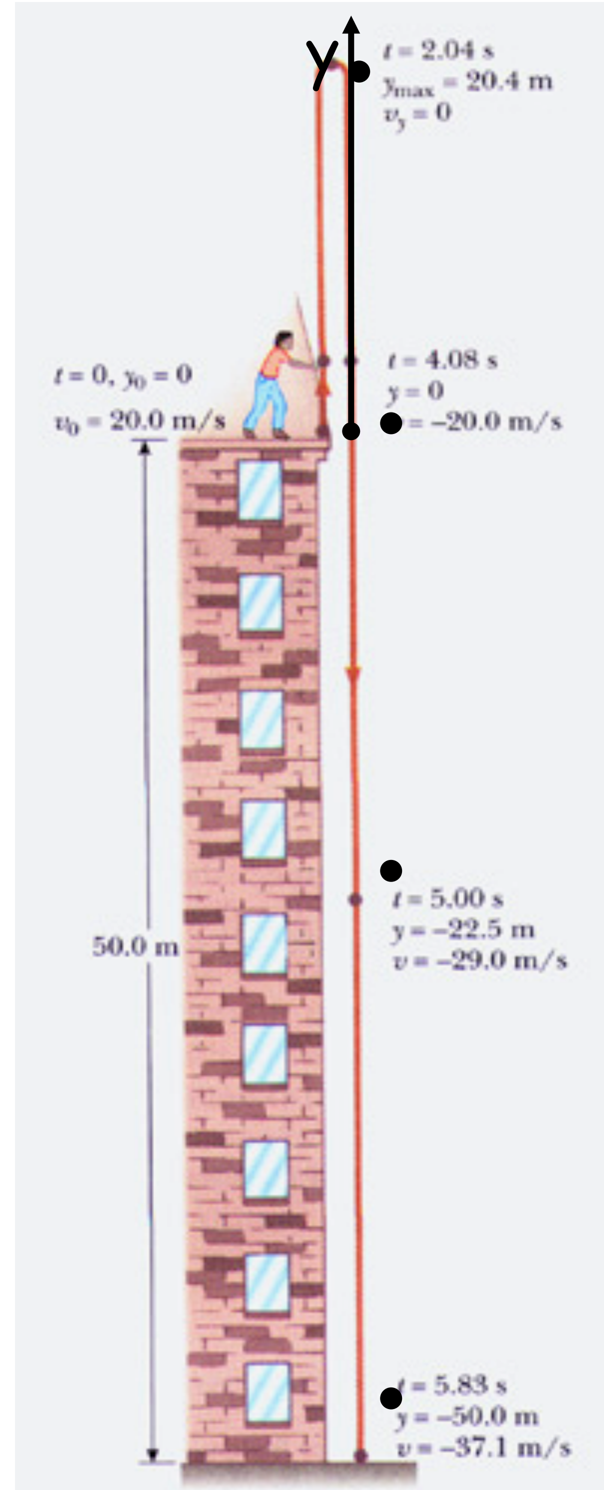
$$v^2 - v_0^2 = 2a(y - y_0)$$

$$v^2 = v_0^2 \Rightarrow v = -v_0 : \text{downward}$$

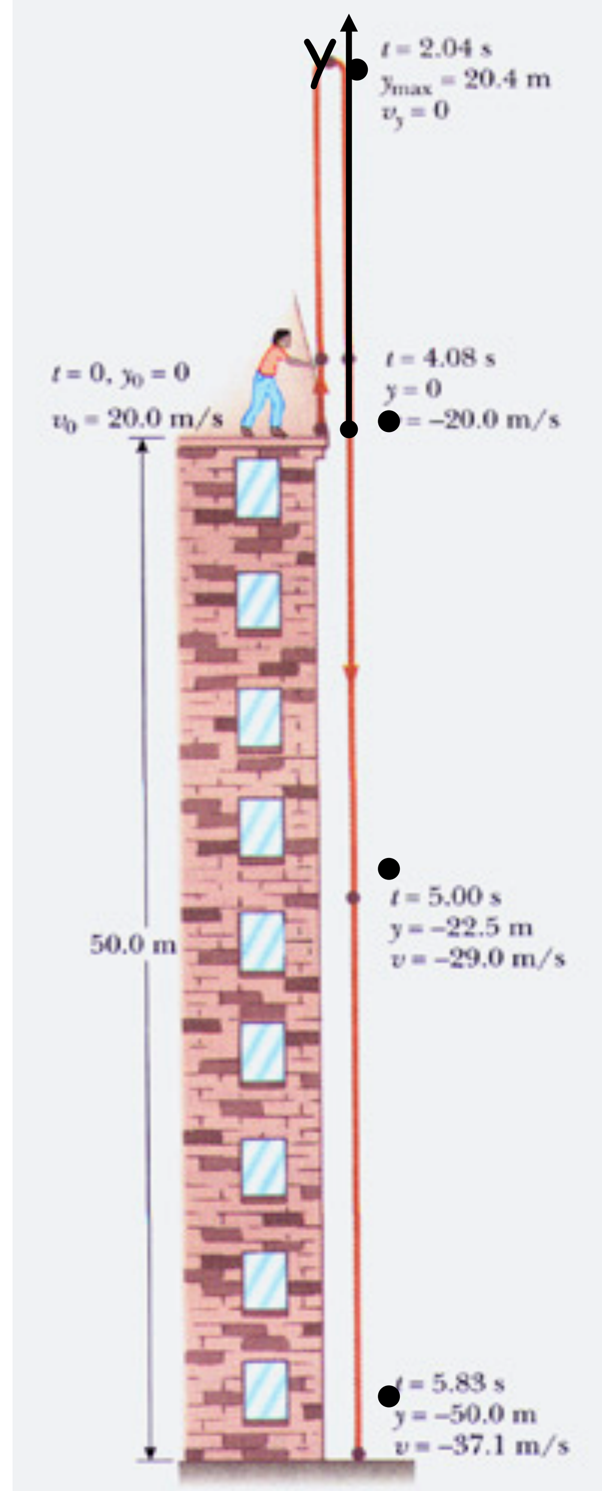
(4) What are the velocity and position of the ball at t=5 s?

$$v = v_0 - gt = 20 - 9.8 \times 5 = -29.0\ (m/s)$$

$$y = 20t - \frac{1}{2} 9.8t^2 = -22.5\ (m)$$



(5) How long does the ball take to hit the ground? and what is its velocity when it strikes the ground?



When the ball strikes the ground, y = -50 m

$$y = 20t - \frac{1}{2}9.8t^2 = -50$$

$$t = 5.83\,(s);\ t = -1.75\,(s)$$

<u>**so**</u>

$$t = 5.83\,(s)$$

$$v = v_0 - gt = 20 - 9.8 \times (5.83) = -37.1\,(m/s)$$

Keywords of the lecture:

1. *Displacement* (m): measuring the change in position of an object in a reference frame

$$\Delta x = x_t - x_0 \quad \text{(one dimension)}$$

2. *Velocity* (m/s): describing how fast an object moves

$$v = \Delta x / \Delta t$$

3. *Acceleration* (m/s^2): measuring the rate of change of velocity

$$a = \Delta v / \Delta t$$

Homework:

(1) Read Sec. 2-10.

(2) From page 30: Problems 1-6, 16, 20, 29-31, 33, 46, 48, 50